A few years ago, driverless cars might have seemed like unrealistic inventions, but as automotive technology continues to advance, a future where autonomous vehicles are commonplace may not be so far away. In recent years, major motor companies have been advertising autonomous features, such as automatic emergency braking and parking assistance (1), while corporations like Google and Uber, among others, already have completely autonomous test models in the streets of major cities (2). As seen on the next page in Figure 1, there are various levels of autonomy in vehicles, ranging from total driver control to completely self-operating. Even though Business Insider Intelligence estimates that there will be around ten million cars with self-driving features by 2020 (3), there is some debate surrounding the extent to which cars should be autonomous, with critics raising safety concerns such as hacking in computer-controlled cars. One response to these concerns would be to prohibit the use of fully
autonomous vehicles, requiring that there always be a human driver behind the wheel. Other possibilities include utilizing a public transit or commercial rideshare system consisting only of autonomous vehicles, or allowing individuals to personally own autonomous vehicles. There are benefits and drawbacks to each approach, and each will require some level of government legislation to ensure a smooth transition, as well as to address concerns surrounding the operation and safety of these vehicles.

**Key Terms:**

**Autonomy** is defined as being independent from external control (4).

**Ridesharing** is becoming more common today, and is best exemplified in services like Uber, where individuals pay a fee to travel in a personal car driven by its owner.

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**Figure 1**

The various levels of autonomy, ranging from complete human control to a driverless system (5).
The Three Approaches

**APPROACH ONE: HUMAN DRIVER WITH AUTONOMOUS ASSISTANCE**

While it is impractical to suggest that there be no form of autonomy in cars whatsoever, it is feasible to stop any further development of autonomous cars. By maintaining our current level of autonomy, we could ensure that all cars have a human driver. This driver could benefit from autonomous features currently implemented in many cars, including parking assist, automatic braking, and blind-spot warning systems.

**APPROACH TWO: NON-PERSONAL USE FOR RIDE-SHARE AND PUBLIC TRANSIT**

Another potential option is to implement fully autonomous vehicles for ride-share, public transit, and commercial use. Manual vehicles would be obsolete. This option allows for increased efficiency in the commercial and public sectors, yet faces challenges from job losses and the major cultural shift required for this option to be implemented.

**APPROACH THREE: FULL-SCALE IMPLEMENTATION OF PERSONAL, AUTONOMOUS VEHICLES**

This option proposes autonomous vehicles for personal use. Every car on the road would be completely autonomous. Despite seeming hard to imagine, fully autonomous personal cars are not necessarily that far off, and they require surprisingly limited regulation. These autonomous personal cars present the opportunity to decrease the environmental impact of cars, but they also come with concerns over the safety of a world filled with all autonomous vehicles.
OPTION 1: HUMAN DRIVER WITH AUTONOMOUS FEATURES

Approach by Alex Ellis and Chris Rosendale

What the Future Might Look Like

This level of implementation is very similar to what we have today, but it would require phasing out older cars as part of a transition to cars with autonomous features like blind spot detection, parking assistance, and automatic stopping. It is important to note that these features in no way resemble a “self-driving” car, but one that has useful tools to help prevent accidents and aid the driver. This is level one out of five on the scale of autonomy.

Ease of Implementation

This approach does not require much work to implement, because we already have numerous vehicles on the market with these features. As time progresses, these types of vehicles will likely become the most common, as older cars are naturally phased out. Perhaps we could see government incentive programs to trade in traditional cars for deals on newer cars, similar to the 2009 “Cash for Clunkers” program, which was intended to encourage people to trade their old cars for more modern, fuel efficient vehicles.

To ensure that fully autonomous vehicles are not widely adopted, the government has a couple of options. First, it could either place an outright ban on either the sale of fully autonomous vehicles or require that a human always be responsible for driving. That would essentially eliminate the benefits of autonomous vehicles and stop their development, as long as the government policy remains consistent. Second, the government could simply let the market decide, without subsidizing cars with new autonomous features, but with regulation of the technology and safety equipment of those cars. If concerns about the downsides of autonomous vehicles are warranted, most people will decide against buying them and most cars on the road will have only limited autonomy.

Road Space and Congestion

Keeping our current level of vehicle autonomy will mean also keeping our current traffic issues. For example, Americans spend a combined 14.5 million hours waiting in traffic each day due to congestion; according to the Texas Transportation Institute’s Annual Mobility Report, congestion in urban areas equates to each driver losing $755 per year on wasted time and fuel. Because new safety features will not affect people’s driving habits, traffic congestion and pollution will remain large problems.

Safety

Motor vehicle crashes are the 13th-leading cause of death in the U.S. and the leading cause of death among teenagers. In 2015, over 38,000 people were killed and 4.4 million people were seriously injured on U.S. roads. New technological and structural safety features are being added to cars in response to this, and they are expected to decrease the frequency and severity of crashes, which will reduce driving injuries and deaths in turn. We have not seen the benefits of many new developments yet, because they simply do not comprise a large proportion of cars on the road. In fact, the average age of cars on U.S. roads is a staggering 11.6 years, meaning that many cars currently being driven were made in 2005 or before. With the expediency of time and small government incentives, more vehicles with new safety features - such as electronic stability control (ESC), adaptive cruise control, and automatic emergency braking - will appear on the roads in the next few years and make driving safer.
Though these features cannot make driving as safe as fully autonomous vehicles, this approach does have the advantage of integrating more smoothly with our existing system, since fully autonomous vehicles would face a number of challenges along their path to full integration. For example, automated cars have a different driving style than humans, which could initially cause many minor accidents due to unpredictable driving. This has been demonstrated by Google’s fleet of automated cars; though its accidents have technically been the fault of other drivers, the automated cars’ overly cautious behaviors are thought to have contributed to many of the accidents (6). This and other concerns, such as how autonomous vehicles would react to a policeman directing traffic, can be avoided by remaining at our present level of vehicle autonomy.

Vehicles with low-level autonomy also have the potential to face a lower risk from hacking than their autonomous counterparts, but there is more work to be done on that front. Even with limited autonomous features in these vehicles, there is an incredible amount of code that goes into the on-board computers. According to Chris King, a researcher with Carnegie Mellon University’s Cert team, a group that researches and provides cybersecurity solutions, these modern cars still have vulnerabilities which could be used by someone attempting to disrupt the car’s functions and cause an accident. Many cars now come with on-board entertainment systems such as built-in wifi and bluetooth.

Costs: Capital and Operating

New safety features will not contribute significantly to new cars’ prices. Toyota is currently offering advanced safety features for an extra $300 to $500 on most new Toyota vehicles sold in the United States. Prior to Toyota’s announcement, most of these features had only been offered on high-end luxury brands. Toyota’s move brings important safety features to a market of more affordable cars, and other carmakers will likely follow suit. For example, Subaru is already offering similar features on its Legacy sedan for about $1000 (7). Because these features will not place a tremendous burden on consumers, government subsidies will probably not be necessary to encourage consumers to transition to cars with these features. However, a trade-in program for old cars without modern safety features may help to speed along the transition.

Jobs

Remaining at the current level of vehicle autonomy will preserve millions of driving jobs for truckers, bus drivers, mail carriers, and so on. New technological safety features will also make those jobs slightly safer. However, the cutting-edge research by technology firms and auto manufacturers for fully autonomous vehicles will likely stop, jeopardizing research jobs and funding in that field.

Environment

This approach will perpetuate much of the current environmental damage caused by personal driving because it does nothing to encourage people to use public transportation or to reduce fuel consumption. Indeed, the important structural safety features of modern cars contribute significantly to their weight, which reduces their fuel economy compared to autonomous vehicles. Because autonomous vehicles would have safe robotic navigation, they could get rid of several safety and driver-assist features to become considerably lighter, which would in turn save fuel.

The environmental liability of this approach is a large concern. As the largest source of air pollution in the U.S., vehicle use significantly decreases air quality and contributes to global warming via the greenhouse effect (8). Therefore, other environmentally friendly policies should be considered along with this approach. Such policies currently in effect or
being considered at the national level are a carbon tax and ambitious fuel efficiency standards, each of which aim to reduce carbon dioxide emissions (9, 10).

This approach does have a potential advantage over fully autonomous vehicles, though, in that people will not face new temptations to overuse their cars. With fully autonomous vehicles, people would be tempted to send their cars on unnecessary errands or have them drive in circles to avoid paying for expensive parking spaces. With cars that have low levels of autonomy, people will have to remain engaged in driving and therefore fully aware of the time the cars spend on the road.

**Experience Factor**

There is a certain feeling that accompanies driving yourself somewhere. It depends on the person and the situation, but that feeling often includes some degree of responsibility, control, and exhilaration. This approach preserves that experience. If fully autonomous vehicles are developed and sold, they will slowly be adapted everywhere for their safety and efficiency. Those are laudable goals, but they come at the expense of personal control and the traditional experience of driving. This approach to autonomous vehicles allows us to maintain our personal agency in driving.

Though the current driving experience is worthy of being preserved, it does have some downsides. The driver must maintain a high level of focus at all times, even when driving becomes tiring or when distractions are present (e.g. children fighting in the back seat). Also, the driver could be doing something else during time spent driving. In a fully autonomous vehicle, it would be possible to get work done, eat, drink, watch a movie, or sleep while the car does the driving.
## Pros

- There is no need to deal with the complicated logistics of implementing fully autonomous vehicles.
- New safety features will not place a large financial burden on car buyers, so only small government subsidies will be necessary to aid the transition.
- Millions of driving jobs will be preserved and made safer, especially in the trucking industry.
- The traditional driving experience will be largely preserved and people will retain control.
- There will be no new temptations to have cars drive unnecessary errands.

## Cons

- Research regarding autonomous vehicles will lose funding and relevancy (because the sale of fully autonomous vehicles will be banned) and we will miss out on potential breakthroughs in that area, at least in the United States.
- Traffic issues such as congestion and pollution will persist at current levels.
- People will continue to spend a lot of time driving (without being able to relax or be otherwise productive).
- Though new technological features will slightly improve safety, thousands of people will continue to die on the roads each year.

## Policies

Options regarding autonomous vehicle development:

- Pass a federal regulation requiring that human drivers be responsible for driving all vehicles on the road, essentially banning autonomy higher than level two.
- Allow private companies to continue research and testing for autonomous vehicles, but provide no funding for their research or subsidies for their cars, and maintain strict safety regulations. If fully autonomous vehicles succeed in the free market, it will be because consumers are willing to give up personal control (which is their right).

Ways to facilitate this approach and address its weaknesses:

- Initiate federal program to buy back old cars that lack modern safety features.
- Address environmental concerns through other means, such as implementing a carbon tax and maintaining ambitious national fuel efficiency standards.
- Ban unnecessary technology in vehicles that makes them vulnerable to remote hacking (e.g. Bluetooth, built-in WiFi).
What the Future Might Look Like

Imagine a world where computers controlled the vehicles on the road. Delivery trucks, commercial vehicles, and buses would run without a human in the driver seat. Manually driven cars would be obsolete. In order to travel individually, you would hail an autonomous vehicle with your phone. You would program the car to tell it where you want to go. Then, during your commute you would not be the one driving. This scenario could be our future reality if our public transit turned to autonomous vehicles.

Ease of Implementation

Compared to autonomous person cars, autonomous public transit vehicles will be far easier to implement. In fact, people were already implementing autonomous transit vehicles back in the 1970s in the form of subways like the Washington Metro (1). Also, transit has set repetitive paths to travel and designated spaces drive on. As such, since there are fewer roads that need to be analyzed, autonomous public transit are easy to implement and start fully operating. they will be easier to implement than autonomous personal cars because they have to analyze fewer roads to start operating (2).

In fact, experts predict that trucking will be the first type of driving to be fully automated. Experts predict trucks without human hands at the wheel on American roads easily within the decade, maybe even in the next few years. Otto, a self-driving truck company started by former Google engineers, has already been test driving with autonomous technology on Interstate 280 and 101 Freeway (3). The transition to autonomous transit vehicles will have countless added conveniences: trucks could drive 24/7, doubling their time on the road and hence shortening delivery time and costs. Traveling in general would become easier, more convenient, and cheaper.

Should the country chose to eliminate personal vehicles altogether, it would not be as substantial a leap for the government to restrict the automotive industry exclusively to shared and commercial vehicles. Due to the expense of the new technology of autonomous vehicles, the transition is predicted to lessen the number of cars each family owns, if they own them at all. Experts predict autonomous vehicles are already going to decrease vehicle ownership up to 43% and increase travel per vehicle by up to 75% (4). The government could use these studies to promote this shift in our culture’s future. Hence, in the future, realistically our country could possible get rid of all personal vehicles, leaving behind a fully autonomous commercial and public transit system.

Road Space and Congestion

People have used the idea of extra road space reducing congestion since the boom of the automobile, claiming congestion would increase indefinitely unless a road was expanded. However, it's been proven time and again that road space only increases congestion. The phenomenon is called induced demand (5). In a congested area, when there is more supply in road space, cars will fill it up until congestion is at the same level it was before, even while using more lanes. This happens in two phases: right away, people run more errands on the road, go to different, farther away stores, ride transit or bikes less, and don't trip chain (go on multiple errands at a time to save driving distance and time) as much; and later, more people move to
areas where they drive on the road to access work or shops.

This could partially be solved by only allowing autonomous rideshare vehicles on roads because a central command unit could oversee all traffic and route cars to certain areas to keep congestion down, but there would still be the problem that less congestion means people can move farther away from their work and have the same commute time, meaning congestion could return once again.

Transit, on the other hand, basically solves the problem of induced demand. It is true induced demand impacts transit like it does personal cars, but because transit vehicles can fit so many more people than cars in the same space, the impacts are felt at a far higher threshold. As illustrated in figure 2, compared to 100% Connected Autonomous Vehicles (CAV), human-driven buses (in human-driven mixed traffic) are 2.5 times more efficient, and this only improves without other personal cars (6). In fact, a single lane of human-driven Bus Rapid Transit (buses in dedicated lanes) is 5.56 times more efficient than 100% CAV and human-driven Heavy Rail (Subways) are 22.22 times more efficient. Efficiencies will only improve with more connected and autonomous transit vehicles. When many more people are able to be transported in the same amount of space, congestion could truly be a thing of the past.

Figure 2
CAV: Connected Autonomous Vehicle
BRT: Bus Rapid Transit (dedicated lanes, etc.)
Chart comparing different forms of transportation with their respective hourly capacities per 3.5 miles
Safety

But regardless of congestion levels, autonomous public transit could potentially save tens of thousands of lives every year, or the mixture of autonomous and human driven cars could cause more car crashes.

Even in the current structure of transportation, compared to driving, transit by rail and bus are far safer. There are 0.24 and 0.11 deaths per billion miles traveled by transit rail and bus respectively compared to 7.28 in cars, according to a survey by Northwest University from 2000 to 2009 (7). Even though cars will be far safer when autonomous, transit safety will also improve, meaning transit would remain a safer option. Transit is also safer for pedestrians and bikes because fewer vehicles are required to transport the same amount of people, leading to far fewer possibilities for conflicts.

However, the mixture of autonomous vehicles and non-fully autonomous vehicles proves to be one of the most risky approaches regarding safety. If passengers feel safer, occupants may reduce seatbelt use, other road users (i.e. pedestrians, bikers) may become less cautious, and vehicles may operate faster and closer together. Researchers with the University of Michigan Transportation Research Institute, Michael Sivak and Brandon Schoettle, concluded in 2015 that “autonomous vehicles may be no safer than an average driver and may increase total crashes when self- and human-driven vehicles mix” (8).

Regarding the commercial vehicles, if a company’s fully autonomous delivery truck is hacked and their course is altered, hackers could easily steal merchandise and money. This concern would not only cost the company a lot of money in order to replace the lost goods, but it could also promote the frequency of attempted theft.

Costs: Capital and Operating

Not only are safety concerns worthy of consideration, but let’s look into how this transition will affect costs.

For one, autonomous commercial vehicles will be cheaper to run. For instance, take the public transit industry. At CATA, about 50% of expenses are from driver salaries and wages. Given the current expenses for public transit, even if a conservative estimate of 50% of expenses can be saved with autonomous buses, transit services could transition in 3 possible ways (9). For one, transit service could double their times of operation. Since adding more transit service leads to an exponential growth in ridership, the popularity of public transit could skyrocket (10). Secondly, public transit service could become free for everyone leading to more ridership because the service is cheaper. A third option would be to leave transit operations as they are, and because over 50% of CATA’s funding comes from passenger fares, the transit agency could become profitable.

Let’s also consider the ridesharing industry. Rideshare would have lower costs with autonomous vehicles than with human drivers; however, the costs would not be as drastic as transit cost changes because drivers are paid far lower wages (11, 12). However, in the long run, cost for the passenger would greatly diminish, compared to our current human-driven taxi system. Autonomous ridesharing would cost $0.60 - $1.00 per vehicle-mile. Currently, human-operated taxis cost $2.00 - $3.00 per vehicle-mile. These costs would entice more people to utilize ridesharing, such as taxis or Ubers, and as more people utilize rideshare, costs could continue to decrease.

Jobs

There are more fiscal concerns than just the cost of commercial autonomous vehicles; for instance, what is going to happen to all the
Americans who are employed in this industry? Everyone from taxi and truck drivers to supporting transit management would be affected. The transition away from manually driven trucks, taxis, and buses could result in the disappearance of 4+ million driver jobs (13). There are an additional 5.4 million Americans employed in related industries (e.g., warehousing and management of the trucking industry). The elimination of human drivers effectively means 10 million Americans may lose their jobs and means of supporting their families.

Trucking is one of the last remaining careers that offer middle-class pay (average of $42,500 annual salary) to those without a college degree (13). While factory jobs have diminished, trucking has grown, allowing for these Americans to be able to earn a living.

Experience Factor

Now let’s consider the effect of this transition on the general public and the experience of transportation.

For one, consider the people with medical or economic restrictions preventing them from owning a car or earning a driver’s licence. With public, ride-sharing vehicles, everyone would have equal access to transportation.

On the commercial side of deliveries, ordering merchandise online and choosing delivery would become cheaper and arrive faster. Furthermore, you could hail a car to go pick up the groceries for you. No longer would it be required that you go to the store yourself. Also, without a personal vehicle, the passenger does not need to worry about filling up the gas tank or maintaining a car.

On the flip side, the passenger could no longer own their own car, which would shift the American culture surrounding vehicles. A car is a symbol of one’s occupation or wealth. It’s also an expression of one’s personality – either through choices in car model or how the owner chooses to decorate it through bumper stickers and paint jobs. Also, a personal car is a place to store extra essentials in case of emergency or an unexpected situation that may arise.

Environment

The minimization of congestion and limiting of personal vehicles as a result of autonomous public transit is what would make this system environmentally friendly.
<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheaper delivery, travel, and ride-sharing costs</td>
<td>Loss of up to 10 million jobs</td>
</tr>
<tr>
<td>Everyone, regardless of medical or economic restrictions, could have equal access to transportation</td>
<td>Cultural shift of no longer owning a personal vehicle – this would require substantial, transformative legislation, and lots of government compensation on behalf of people whose cars would effectively become antiques.</td>
</tr>
<tr>
<td>Could reduce congestions on roads</td>
<td>Possibility for easier &amp; more frequent theft of delivery vehicles</td>
</tr>
<tr>
<td>Autonomous commercial vehicles already being test-driven and could be on the roads in a few years</td>
<td>Feeling of safety could cause pedestrians, bikers, human driven vehicles to become more confident or reckless, leading to more vehicle related fatalities each year.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Policies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Government restricts vehicles to only commercial company use and public transit. As such, the average American will rely on ridesharing and public transit in order to travel.</td>
</tr>
<tr>
<td>Government mandates roads be autonomous vehicle-only. Manually driven vehicles could become illegal.</td>
</tr>
<tr>
<td>All cars (except for commercial use) become identical to be used to rideshare purposes</td>
</tr>
<tr>
<td>Without paying driver wages, public transit could use the extra money to:</td>
</tr>
<tr>
<td>1. Double their times of operation</td>
</tr>
<tr>
<td>2. Become free for passengers</td>
</tr>
<tr>
<td>3. Increase their profit margins</td>
</tr>
<tr>
<td>Consider how to implement into rural areas? Should autonomous public transit be implemented in rural areas? If not, consider how to legislate what constitutes a rural area. (population, number of cars, etc), and how those living in rural areas would travel to cities or visa versa.</td>
</tr>
</tbody>
</table>
OPTION 3: FULL-SCALE IMPLEMENTATION OF PERSONAL, AUTONOMOUS VEHICLES

What The Future Might Look Like

Imagine a future that, to the casual observer, doesn’t look too different from what we see today. Myriads of homes have cars parked in their garages or on the curb. People are, in general, more well-rested and less stressed than they were in the past. This is a future where the human-controlled personal cars of today have been gradually phased out until everyone who owns a car owns one that is completely autonomous. The morning commute becomes an opportunity to sleep a little longer or catch up on work. If the kids have an evening activity to get to, it might be possible to send them on their way alone in the car. Long car trips become time for family bonding. All this happens in a personal car, one that is the right fit for its owner, who takes care of it.

Ease of Implementation

This approach requires far less government regulation (1) than an approach which bans private autonomous vehicles in cities. Instead of the government getting involved in which types of vehicles can be sold and to whom, the invisible hand of the market can decide how many people want to save money and take transit or rideshare, how many want the convenience and comfort of their own car, and how many would rather use multiple modes for different occasions. There would probably be less public backlash because, instead of prescribing rules, the government is taking no action. The government wouldn’t have to stop technology companies from developing new technology. This approach would involve the continuation of current practices as technology improves until we have full autonomous vehicles. Regulation, to a certain degree, would still be necessary, though it might not come from the government. When the roads are full of autonomous vehicles, the vehicles not only need to be able to sense and respond to their environment individually, but communication between vehicles and sensors and traffic signals will be necessary to realize the full benefits of autonomy. The industries and companies involved with making vehicles and their peripheral equipment, both in hardware and software form, will need to organize themselves to create agreed-upon standards through an organization such as the International Standards Organization to make this possible and as efficient as possible.

Road Space and Congestion

It's common to hear autonomous vehicles will be able to drive closer to one another and so congestion will go away because of the added road space no longer between vehicles (See Figure 2). Unfortunately, the phenomenon of induced demand (4) is almost guaranteed to make congestion worse when individuals own personal cars (See Figure 3). People will go on far more trips in cars because they no longer need to waste their time driving, especially if they can send their car to pick up pizza or dry cleaning and have it come back without a person inside. Even worse, owners will send their cars home to park when they go somewhere with few parking spaces or high prices and make it drive back to them to pick it up. This would double the vehicle miles travelled for a personal car because each trip would be composed of two round trips instead of one.
Safety

The National Safety Council estimates that, in 2015, over 38,000 people were killed and 4.4 million people were seriously injured on U.S. roads; preliminary data from 2016 indicates that these numbers are continuing to increase (5). Ideally, these numbers should be as close to zero as possible. Since more than 90 percent of these accidents were due to human error, a large proportion of the total could theoretically be eliminated by switching to autonomous vehicles.

Google’s autonomous vehicles have logged more miles than any other company’s; over the course of two million miles, its cars have been involved in 14 minor accidents that resulted in two injuries. Of the 14 accidents, 13 were caused by the other driver and one occurred when the car’s operator had it under manual control (6). This means that for two million miles, the car’s software did not directly cause any accidents and there were no fatalities at all. By comparison, the average for manually driven cars is 77 injuries and 1.09 fatalities per 100 million miles. It is a good sign that Google’s cars have not caused any injuries or deaths in a combined two million miles, but it is hardly statistically significant. Indeed, an analysis by the RAND (7) Corporation found that autonomous vehicles would need to drive 275 million miles without a fatality to determine,

Figure 3
Chart showing how expanded capacity creates more demand on the road and use of the road increases:
with 95 percent confidence, that they are safer than manually driven cars.

When automated cars are integrated with manually driven cars on the roads, they face certain challenges that could theoretically be eliminated if they became adopted exclusively (or nearly exclusively). Whatever their ultimate benefits, though, autonomous vehicles first have to prove themselves by operating safely on roads dominated by manually driven vehicles.

Because automated cars have a different driving style than humans, there will be many minor accidents due to unpredictable driving while manually driven cars are still on the roads. This has been demonstrated (8) by Google’s fleet of automated cars; though its accidents have technically been the fault of other drivers, the automated cars’ overly cautious behaviors are thought to have contributed to many of the accidents. For example, Google’s cars were programmed to not drive through yellow lights and to wait a full second and a half to go when a light changed from red to green.

Also, people are inclined to drive like other drivers around them and will follow the habits of the autonomous vehicles. Because autonomous vehicles can react much more quickly than humans, they can drive closer to cars in front of them. If it becomes necessary to come to a quick stop, then the human drivers will likely cause accidents being too close to the car in front of them.

These factors will cause the rate of injuries and fatalities to increase while autonomous vehicles are partially integrated. Automated cars will also face other challenges, such as being expected to react to hand signals from cyclists or from people directing traffic. Even if autonomous vehicles are fully implemented, they will have to face challenges such as driving in bad weather and turning left across traffic that they currently have trouble with. These are problems that companies like Google (actually Alphabet, Inc.) will have to overcome in order to reach level four or five autonomous vehicles (see Figure 1, page 2).

In addition to abstract injury and fatality statistics, many people worry about ceding control to opaque computer algorithms and are especially concerned about how those algorithms would respond to moral dilemmas that may present themselves on the road. However, those situations are not really a concern, according to Ryan Hagemann, a civil liberties policy analyst at the Niskanen Center and fellow on robotics at TechFreedom. An oft-cited moral dilemma is when an automated car has to swerve one way or another to avoid an accident and essentially decides who lives.

Hagemann argues that this is an incredibly rare occurrence: “Most of those circumstances would probably just be resolved by the computer telling the car to brake instead of swerving one way or another.” In a case where the car’s computer actually had to “decide” who lived, it would be a split-second decision that wouldn’t leave a human time to think about moral complexity. “Whether a human driver is making the decision or the algorithms in the car are, it's never going to be a perfect scenario,” Hagemann says.

Certainly there will be intense and strict government regulation on the computers in autonomous vehicles to avoid hacking. Anything has the potential to be hacked, but if autonomous vehicles are shown to be more vulnerable to cyber attack and there is some sort of attack resulting in fatalities, public trust of these cars would likely be irreparably damaged. Just think, if you saw on the news that an autonomous vehicle had been hacked and driven into a building, how comfortable would you feel hopping into yours for a trip to the grocery store? It is important to note, however, that cars sold today have many computers already. Even without autonomous features, some cars have been shown to be hacked to the point where attackers of a vehicle on the highway could (9) “turn the wheel 180 degrees.”
Costs: Capital and Operating

Autonomous vehicles will probably be more expensive to buy than current cars because of the amount of technology included. This will mean fewer people will be able to afford having their own personal autonomous vehicle, which might lead to a boom in ridership for transit, rideshare, and alternate modes of transportation.

However, approximately 40% (10) of the cost of owning a vehicle over five years comes from insurance (11), maintenance, and fuel, with nearly an additional 50% coming from depreciation. Since nearly all crashes that occur today are due to human error, which would be eliminated by self-driven machines, insurance claims, and therefore the cost of insurance overall, are likely to go down. Self-driving cars will be able to travel more efficiently, at speeds best for the engine and without sudden accelerations. This will decrease fuel and maintenance costs per mile driven, which is also likely to decrease the rate of depreciation. Whether the reduction in ownership costs for autonomous, and likely electric, vehicles will offset the undoubtable increase in cost due to the high technology in them remains to be seen.

Jobs

A full implementation of autonomous vehicles will make some jobs obsolete as was discussed in other approaches; however, in a report published last year, the Conference Board of Canada (12) estimated that the economic benefits from automated vehicles could be more than $65 billion annually, the result of a significant decline in collisions, congestion and fuel consumption, plus more free time for commuters”.

Environment

Individual autonomous vehicles will provide significant user fuel saving, and pollution reduction benefits as discussed before. However, because congestion will most likely get worse, the environment might actually suffer from the switch to autonomous vehicles, especially if new roads are built to reduce congestion, leading to new induced demand.

Experience Factor

For some, a personal car might be the most convenient and comfortable way to get around. For others, transit might allow them to avoid congestion. If private autonomous vehicles were allowed, there are two possibilities for other modes of transport. The government could choose to let transit and rideshare die because they don’t attract the necessary ridership, or subsidize those modes more than current levels so each person would be able to choose which experience they wanted based on which fit themselves the best. However, people in private autonomous vehicles might negatively impact others because they slow transit down with their congestion and scare away street life with high speeds.
<table>
<thead>
<tr>
<th><strong>Pros</strong></th>
<th><strong>Cons</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Easiest to implement because no controversial laws are required, market will decide</td>
<td>Congestion will not go down and will probably increase</td>
</tr>
<tr>
<td>Autonomous vehicles are showing to be relatively safe so far</td>
<td>More testing is required to make sure autonomous vehicles are safe</td>
</tr>
<tr>
<td>Hacking is not exclusive to personal autonomous vehicles or even autonomous vehicles in general</td>
<td>Hacking could become a bigger issue</td>
</tr>
<tr>
<td>Autonomous vehicles might be more environmentally friendly individually</td>
<td>Cars would probably cost more, meaning less people could buy them</td>
</tr>
<tr>
<td>Private cars might be the most comfortable and convenient option for some people, who would have the choice to buy one</td>
<td>Without personal vehicles in cities, job loss will occur</td>
</tr>
<tr>
<td>Cars can be personalized because they are owned</td>
<td>With more congestion, personal autonomous vehicles might make pollution worse</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Policies</strong></th>
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</thead>
<tbody>
<tr>
<td>Government doesn’t interfere with who buys and uses autonomous vehicles and for what purpose.</td>
</tr>
<tr>
<td>Government mandates roads be autonomous vehicle-only. Manually driven vehicles could become illegal.</td>
</tr>
<tr>
<td>Government may have to subsidize rideshare and transit more than current levels to keep lifeline service for those who can’t afford private cars if owning a personal car becomes almost mandatory.</td>
</tr>
<tr>
<td>Government may push aggressive congestion charges or not allow for use of autonomous vehicles without passengers to reduce congestion.</td>
</tr>
</tbody>
</table>
References:

Introduction:

Option 1:

Option 2:


