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# Autonomous Vehicles

Sarah Flis
saf75@zips.uakron.edu

University of Akron

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Sarah Flis

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The topic of autonomous vehicles is becoming more and more relevant in the field of transportation. A fully autonomous vehicle is one that drives on its own without a human controlling it. There are various levels of human involvement in autonomous vehicles. Production vehicles out on the road today still depend on a human operator while the vision for them in the future is to have no human responsibility in the operation of the vehicle. This vision, however, still requires a lot of work and research until it can become a reality. There are so many aspects that need to be studied and perfected in order to allow for a fully autonomous transportation system.

Some research objectives to be considered in this paper will include: What are the general advantages and disadvantages of having fully autonomous vehicles? What research has been done on the safety of them and what needs to be done to improve that safety? In order to have the safest and most efficient system for autonomous vehicles, will there be a place for older vehicles that require a human to operate in this new transportation system? Where does Ohio stand in the development of autonomous vehicles and what steps are they taking to prepare for such technology?

Another important research objective to be discussed is: How would these vehicles be distributed and how would ownership work? Will there be a general government owned fleet that consumers can pay to use? Will people be able to purchase their own autonomous vehicles? If this is the case, how would allowing individuals to each own their own autonomous vehicle help improve the efficiency of our transportation system? If it was owned by the government or a large private company and was a pay-per-ride system, it would be a more efficient system.

## Levels of Automation

The Society of Automotive Engineers (SAE) has set five levels of Automation (Automated Vehicles for Safety). No automation would be where the driver is to perform all driving procedures and tasks. Levels one and two are considered an advanced driver assistance system (ADAS). The first level of automation is Driver Assistance. This is where the driver is still basically in full control of the vehicle; however the vehicle will be designed to include a few driving assist features. These features could include either assistance with steering or assistance with breaking and accelerating. However it cannot include both of these at the same moment. The second level of automation is Partial Automation. This is where the driver still must be engaged in driving procedures and must stay aware of the environment at all times but the vehicle can offer combined automated features including braking/acceleration and steering. In this level those features can be performed at the same time in certain situations (Automated Vehicles for Safety).

Levels three through five are classified as an automated driving system (ADS) (Automated Vehicles for Safety). The third level of automation is Conditional Automation. This is where a driver is still needed but they are not required to stay aware of the environment. However, the driver must be ready to take control of the vehicle if needed. In this level the vehicle is able to perform all driving procedures in some situations but this is when the driver should be ready to take control if needed. Outside of these certain circumstances the driver is to perform driving procedures. The fourth level of automation is High Automation. This is where the vehicle can perform all driving procedures under certain conditions, including monitoring the environment, but the driver still has the option to take control of the vehicle. The fifth and final level of automation is Full Automation. This is where the vehicle is able to perform all driving

procedures under all conditions. However, the driver may still have the option to take control of the vehicle but there is no point where they would be required to do so (Automated Vehicles for Safety).

The companies of Tesla, Google, Uber, and Nissan are already developing relatively high level autonomous vehicles. Most of these vehicles start by creating an internal map of the nearby surroundings (Self-Driving Cars Explained). Different technologies used to help with creating and maintaining these maps are lasers, radar, high-powered cameras, and sonar. The software inside the vehicles then takes this information and chooses a path for the vehicle to take and put this path into motion by initiating acceleration, deceleration, and steering (Self-Driving Cars Explained). They are also programmed to do various things including avoiding obstacles and being able to identify various objects.

Fully autonomous vehicles appear to be inevitable at this point. Nobody can say for sure when they will be in full effect, however the National Highway Traffic Safety Administration (NHTSA) has set up an approximate timeline representing when different levels of automation have been and will be put into place. Between the years of 1950-2000 they list the addition of safety/convenience features including cruise control, seat belts, and antilock brakes. Between the years of 2000-2010 they list the addition of advanced safety features including electronic stability control, blind spot detection, forward collision warning, and lane departure warning. Between the years 2010-2016 they list the addition of advanced driver assistance features including rearview video systems, automatic emergency braking, pedestrian automatic emergency braking, rear automatic emergency braking, rear cross traffic alert, and lane centering assist. Between the years of 2016-2025 they list the addition of partially automated safety features including lane keeping assist, adaptive cruise control, traffic jam assist, and self-park.

For the year 2025 and beyond they expect fully automated safety features including highway autopilot (Automated Vehicles for Safety). Although not something to expect within the next few years, autonomous vehicles are definitely approaching quicker than some realize. Some automakers and technology companies see fourth level automation being made available in some vehicles within the upcoming years (Self-Driving Cars Explained).

## Advantages

This timeline puts into perspective how soon many of these changes can occur and that what seemed like something of the far future is quickly becoming a reality. This brings up the matter of safety because having such a complex idea become a real thing brings up many real issues with functionality and safety. There are many safety benefits that would come along with autonomous vehicles. One of the biggest issues with the transportation system today is human error. This is what causes majority of serious crashes. The goal of automated vehicles is to reduce, and in the future remove, human error which would help decrease crashes and the injuries/fatalities they cause. It will benefit the passengers in the vehicle as well as people the vehicle would interact with including bicyclists and pedestrians.

Aside from the safety benefits there are many more pros to autonomous vehicles. Some economic and societal benefits include the fact that car crashes, injuries, and fatalities are all very expensive so helping to eliminate all those things will greatly lower costs. According to a 2010 NHTSA study, motor vehicle crashes cost $242 billion in economic activity (including lost workplace productivity at $57.6 billion). Loss of life and lower quality of life because of injuries as the result of these crashes also cost $594 billion (Automated Vehicles for Safety).

Some efficiency and convenience benefits come from the fact that people spend a lot of time sitting in traffic which wastes time and also ends up wasting fuel and increases harmful emissions. Autonomous vehicles would allow for a decrease in traffic and for a more efficient transportation system (Automated Vehicles for Safety). This time and money could then be put to much better use.

Another benefit of autonomous vehicles is mobility. Many people depend on their ability to drive in order to have a job or live independently (Automated Vehicles for Safety). For many people it is either not financially or physically possible for them to own or drive their own vehicle. Autonomous vehicles would especially help those who are elderly or disabled. Many elderly people are unable to drive due to many worsening health issues or just from their generally slower reaction times and impaired vision. This would allow many elderly people to keep their independence much longer than they are able to today. Rather than having to move to assisted living or a nursing home they could continue to live in their homes and have transportation to various stores and appointments. This in turn would save them and their families' money. Those individuals who are disabled also sometimes face great challenges with mobility and being able to get around. Today, there are a variety of vehicle modifications that allow many of these individuals to be able to have the independence of driving their own vehicle, but there are still many individuals whose mental or physical disability still prevents them from being able to drive. Autonomous vehicles would allow for these individuals to also have more independence and freedom by allowing them to have a source of transportation.

Another benefit, which in a sense plays off a one of the cons of autonomous vehicles, is that having an interconnected system allows for changes to be implemented at a very quick rate. When a human is driving a car and they come across a situation that they have never seen before

they are forced to react to it quickly and learn for future instances how to properly handle the situation. This occurs only on an individual basis so each human would have to go through this to learn that new skill for themselves (Oliver et al). An autonomous vehicle on the other hand going through the same situation would learn what should be done in that particular situation then that knowledge can be transferred to all vehicles almost immediately to help avoid it happening to any vehicle in the future. So in the end, autonomous vehicles are theoretically able to learn and adapt to new situations very quickly (Oliver et al).

## Disadvantages

Some negative aspects of autonomous vehicles include the challenges the technology still faces that could lead to fatal mistakes. Although the technology in many situations can surpass the performance of a human driver, there are still many obstacles and situations where it could misinterpret or miss something completely. For example, sunlight as well as fog or other weather conditions cause for some difficulty for lasers and cameras to be able to read different cues in the environment whereas humans are better able to perform in these situations (Oliver et al). The Harvard Business Review brought up an interesting point that it is not necessarily dependent on when the technology will be ready for full autonomy but more so the environment that it will be in. Many of the issues that are faced with the advancing technology of vehicle autonomy have to do with various aspects of the environment preventing the technology to fully interpret a situation. The current environment will still allow for some degree of "human error" even if it has nothing to do with the vehicles themselves (Oliver et al). There are so many human factors that play a role in driving including pedestrians and bicyclists who can be extremely unpredictable. An ideal environment would be one that is clean and unambiguous (Oliver et al).

In today's environment, unfortunately there are still so many combinations of situations that the technology is just unable to account for.

An economic disadvantage is that any humans who are currently employed as drivers will be out of a job, increasing the unemployment rate. It will also be a very expensive transition to autonomous vehicles considering that currently the higher level autonomous vehicles out today range in prices of $300,000 to $400,000 however this price will most likely go down as the technology advances (Self-Driving Cars Explained). It will also be extremely costly to prepare the infrastructure for changes this big and this will have to be paid for by someone so more than likely taxes will increase significantly to cover this.

An environmental concern could be if these vehicles are still to be powered by gasoline, there could be an even bigger carbon footprint created by autonomous vehicles (Self-Driving Cars Explained). This is because with the convenience of the system and the likelihood that many people who did not previously drive would also utilize the system, there will be even more vehicles on the road than there were before resulting in even more emissions released into the atmosphere. On the other end of this topic could be a positive impact if the system were to be implemented as electric cars on a clean electricity grid (Self-Driving Cars Explained).

Another drawback is the fact that for the best research to be done there needs to be real world experience which is not easy to obtain because the technology is new and there are risks of performing real world experiments. Since this is a developing technology it creates a large amount of risk when running in our current transportation system but without doing so we cannot obtain adequate research on the technology and how it performs in the real world. It can be tested on isolated tracks and real world experiences can be simulated which is still a pretty good start

(Self-Driving Cars Explained). Because of this lack of experience, in the early stages of this technology being released there will likely be many situations that the technology will not know exactly how to handle. Since the plan is obviously not to jump straight into the fifth level of automation, there will still be a human with the power to take control of the vehicle.

The issue with this is that for the lower levels of automation where the driver must be ready to take control of the car in situations the vehicle is not capable of reacting to, there is a bit of a disconnect between driver and vehicle (Oliver et al). People will not be as alert as they need to be to fully process these situations if they are not continuously engaged in the driving experience and paying attention to the environment around them. The human in the vehicle will not be paying their full attention to what is going on if they are convinced the car can do the work so therefore transitioning from day dreaming to all of a sudden having to handle a certain situation will prove quite difficult (Oliver et al). Because these vehicles will be able to handle most easy situations, the ones it struggles with will definitely be far from common and easy to adjust to. Humans may not be able to reengage and respond as well as needed for these situations. According to the Harvard Business Review, Tesla has had issues with this being the case with some of their models that offer autopilot systems. There were two instances of crashes with these specific vehicles. It shows the human present in the vehicle was not attentive or touching the wheel during majority of their drive and especially in the moments immediately preceding the crash (Oliver et al).

Another concern many people have about autonomous vehicles is that they depend on the communication and proper functioning of the computer systems. This opens up the possibility of hacking. Many aspects of our lives depend on or coincide with information technology. This technology is constantly improving which means that even though there the issues with hacking

are constantly being mitigated, the speed at which technology increases allows for there to constantly be new ways for hacking to occur. When the application of cyber security is toward vehicles it must be taken very seriously. This is because autonomous vehicles communication and technology are vital to the safety of the occupant, other roadway users and nearby environment so any harmful attacks, unauthorized access, or damage must be prevented (Vehicle Cybersecurity).

As the technologies and levels of autonomy are improving, so are the efforts to better the cyber security to accompany it. NHTSA is constantly exploring all of its tools and resources to make sure that as these technologies develop it is done safely and effectively, ensuring that all challenges that may come about are handled including cyber security (Vehicle Cybersecurity). NHTSA has also taken on a multi-faceted research approach that goes along with the National Institute of Standards and Technology Cybersecurity Framework (Vehicle Cybersecurity).

## Plans for the Future

As for the issue of what to do with all the vehicles that exist today which may not interact well with fully autonomous vehicles, there is no definitive plan at this time. Since the plan for autonomous vehicles is that of slowly introducing the technology into the system the vehicles will be able to interact together initially. As the technology surpasses a point of interacting well with the level of autonomy in vehicles today, guidelines will likely be put into place as to how to handle this issue. As for now the focus is to be able to, as effortlessly as possible, combine the vehicles already out today and those that are at a higher level of autonomy.

There are many different entities in charge of various aspects of the environment of our transportation system today and it is unclear who will have control of regulations and

maintaining infrastructure when autonomous vehicles stop becoming a thing of the future and instead become the present.

Ohio is already ahead of the game when it comes to automotives, engineering and manufacturing. This being said, the Ohio Department of Transportation (ODOT) has started an initiative to help encourage collaboration between the public and private sectors called DriveOhio (The Future of Smart Mobility). The purpose of DriveOhio is to act as one single point of contact for autonomous and connected technologies in Ohio. There are many private and public entities in Ohio that are involved in the design, development, testing, use and regulation of these technologies and the intent of DriveOhio is to help bring them together and encourage collaboration (The Future of Smart Mobility). DriveOhio also helps break down government barriers and increases efficiency for companies that would like to become a part of the autonomous industry. They push for the construction of infrastructure for smart mobility and have already been involved in a large number of smart mobility projects (The Future of Smart Mobility).

DriveOhio believes Ohio is a great place to start with the research for autonomy because of its vast amount of existing resources and testing facilities as well as the fact that Ohio has four season climate allowing for many weather conditions to be taken into account (The Future of Smart Mobility). Ohio also offers a good mix or rural and urban areas to give variety in the testing (Drive Ohio Fact Sheet).

Some examples of smart mobility projects already in Ohio according to DriveOhio would include the U.S. 33 Smart Mobility Corridor and the Ohio Turnpike which are both equipped with fiber optic cables. The U.S. 33 Smart Mobility Corridor also is equipped with wireless

roadside sensors. The I-90 Lake Effect Corridor is equipped with short-range digital communications units and will also test wireless technologies that will send and receive data from various units located on public transportation. Another smart mobility project is the I-670 Smart Lane which will be Ohio's first "smart lane" and will involve converting the shoulder into a smart lane equipped with high-resolution cameras that will monitor conditions. Connected Marysville is another project where short-range communications units will be installed into traffic signals that will communicate with devices located in various public and private vehicles. Lastly, Smart Columbus is a project in which Columbus was selected by the U.S. Department of Transportation as the winner of the "Smart City Challenge" where a brand new smart mobility system will be put in place to improve safety, mobility, opportunities, and an improved quality of life (Drive Ohio Fact Sheet).

Another asset that sets Ohio apart from other states is the fact that the largest independent automotive proving ground in North America is located in East Liberty Ohio. This testing facility is The Transportation Research Center, or TRC, and is a great location to test and validate vehicles with a great controlled environment (Drive Ohio Fact Sheet). Within the TRC, there is the start of the Smart Mobility Advanced Research and Test Center, or SMART, which will be a hub at the TRC dedicated to automated and autonomous testing (Drive Ohio Fact Sheet). Another perk of the TRC is that it is home to NHTSA's Vehicle Research and Test Center. This is the only federal level vehicle testing lab in the nation (Drive Ohio Fact Sheet).

The U.S. Department of Transportation (U.S. DOT) has collaborated with NHTSA to release a Federal Automated Vehicle Policy in 2016 and released an updated version called Automated Driving Systems: A Vision for Safety 2.0 in 2017. The purpose of this document is to provide guidance for the industry to assist in developing best practices in design, development,

testing, and deployment of the technologies involved in autonomous vehicles (Automated Driving Systems: A Vision for Safety 2.0). This document is voluntary guidance but is suggested to ensure there is some degree of uniformity in the development of these technologies. The plan seems to be that private companies will be in charge of producing the autonomous vehicles and selling them to the general public. This collaboration between NHTSA and the U.S. DOT will be the beginning of guidelines and regulations that will be put into place as this technology advances.

The Automated Driving Systems: A Vision for Safety 2.0 document addresses many aspects of the development of the technology for autonomous vehicles. The twelve main topics covered include system safety, operational design domain, object and event detection and response, fallback (minimal risk condition), validation methods, human machine interface, vehicle cybersecurity, crashworthiness, post-crash ADS behavior, data recording, consumer education and training, and lastly federal, state, and local laws(Automated Driving Systems: A Vision for Safety 2.0).

The section of system safety addresses a design free of unreasonable safety risks. It also suggests for entities involved in the upcoming technology of autonomous vehicles to use accredited standards-developing organizations such as SAE or the International Standards Organization (ISO) for guidance. It also encourages entities to keep records of any actions, design choices, changes, analyses, associated testing, and data for future use (Automated Driving Systems: A Vision for Safety 2.0).

The section of operational design domain (ODD) ensures that the ODD is well defined and documented including the specific conditions in which a certain feature of ADS is meant to

operate under. Some conditions that should be included are roadway types, geographic area, speed range, and environmental conditions. An ADS must be able to safely operate under these conditions and there must be a minimal risk condition set up for when conditions fall outside of the set ODD (Automated Driving Systems: A Vision for Safety 2.0).

The section covering object and event detection response (OEDR) discusses situations where an ADS is expected to be able to detect circumstances relevant to the driving task. Some examples include being able to detect other vehicles in its path, bicyclists, pedestrians, animals, and objects that pose a threat to the vehicle's safety. The OEDR should also be able to address situations involving emergency vehicles, temporary work zones, construction workers, as well as other unusual roadway situations (Automated Driving Systems: A Vision for Safety 2.0).

The section that addresses fallback (minimal risk condition) discusses what should be done when an ADS is either operating outside of its determined ODD or is operating in a degraded state. In the lower levels of automation this could include a warning that would alert the human driver to regain control but must do so in a manner that accounts for human inattentiveness. For higher levels of automation there may be no human driver available so a fallback must be predetermined to remove the ADS from the ODD it cannot operate within and potentially bring the vehicle to a stop outside of a busy lane (Automated Driving Systems: A Vision for Safety 2.0).

The section of validation methods covers appropriate guidelines to be met when validating the operations of the ADS. These should include any behaviors the ADS would be expected to perform in its ODD and how it would perform when handling a fallback as well (Automated Driving Systems: A Vision for Safety 2.0).

The section on human machine interface (HMI) discusses what entities should consider when setting up an HMI and what processes they should be measuring. An example is whether or not the need to monitor human interaction in lower level autonomous vehicles where a human driver must be ready to take control of the vehicle. They could measure the time and how attentive the human driver seemed at given moments when the vehicle could no longer function on its own. They also need to determine ways to keep human drivers and/or passengers informed on the environment surrounding them, including passengers who may have certain disabilities or limitations (Automated Driving Systems: A Vision for Safety 2.0).

The section covering vehicle cybersecurity stresses that the product development approach entities may choose to use must minimize risks to safety including those on the cybersecurity level. It is encouraged that there be thorough documentation of the testing performed on various aspects of the ADS as well as the system as a whole. It is also encouraged that information obtained from these tests be shared through the Automotive Information Sharing and Analysis Center (Auto-ISAC) so that other entities can prevent similar problems (Automated Driving Systems: A Vision for Safety 2.0).

The section on crashworthiness discusses safety measures that need to be taken in the event of a crash. Since there will be a mixture of vehicles of different levels of autonomy on the road, even ADSs must be properly equipped to keep passengers safe if a crash is to occur. This could include the seating arrangement as well as other measures to ensure the passengers remain safe. Another aspect discussed was that of unoccupied ADSs such as those that deliver products. In the event of a crash these specific vehicles need to provide energy absorption and other aspects that minimize damage to the other ADS potentially occupied by humans (Automated Driving Systems: A Vision for Safety 2.0).

The section discussing post-crash ADS behavior covers what should be done after a crash has occurred. Some possible options, depending on the severity of the crash, include shutting off any sources of power, shutting off the fuel pump, or relocating the vehicle off the road or to a safer place if the damage is not too severe. It also discusses steps that should be taken afterwards to ensure the vehicle is maintained in operational form (Automated Driving Systems: A Vision for Safety 2.0).

The section on data recording discusses how important data collection is for the improvement of the technology for autonomous vehicles. Taking data after a crash can help prevent similar events from occurring with other ADSs. The constant collection of data also allows for a cause of the crash to be determined (Automated Driving Systems: A Vision for Safety 2.0).

The section on consumer education and training covers the importance for entities to keep employees, dealers, distributors, as well as consumers educated on the coming technology and how it differs from the technology today. It is especially important that people are educated on what exactly an ADS can and cannot do to ensure the safest use (Automated Driving Systems: A Vision for Safety 2.0).

The section on Federal, State, and local laws discusses the fact that entities must always be aware of Federal, State, and local laws that would apply to autonomous vehicles. The vehicles must be able to abide by all traffic laws. This brings up the need for human drivers to have the power to override certain rules programmed into the vehicle for situations that may require violating a traffic law such as passing a broken down vehicle which requires crossing over a solid line. Since laws are constantly being updated, so must the systems that the ADS runs on.

Entities must set up processes to update and adapt to these new requirements (Automated Driving Systems: A Vision for Safety 2.0).

NHTSA is commanded by Congress to "protect the safety of the driving public against unreasonable risks of harm that may arise because of the design, construction, or performance of a motor vehicle or motor vehicle equipment, and to mitigate risks of harm, including risks that may arise in connection with ADSs (Automated Driving Systems: A Vision for Safety 2.0)." Because of this, NHTSA will handle this up and coming technology with guidance from its statutory mission while enforcing obligatory laws. NHTSA is encouraging States not to incorporate this document into any state laws or legislation because they would prefer to keep the regulation of safety design and performance aspects of automated driving systems at their Federal level in order to avoid any conflicts between Federal and State laws (Automated Driving Systems: A Vision for Safety 2.0).

Overall the advantages of autonomous vehicles seem to outweigh the disadvantages. This is a technology that appears inevitable and agencies such as NHTSA and the U.S. DOT are doing everything in their power to ensure a smooth transition into fully autonomous vehicles. The vehicles on the road today are already to some degree autonomous and the purpose of vehicle autonomy is the better the environment of our transportation system today. It will help reduce injuries and deaths due to vehicle crashes by working to eliminate human error. It will also allow people to save time on commutes and offer transportation to individuals who did not have access to it before. There is still a lot that needs to be figured out along the way but for now the goal is to start educating people on the technology and on what to expect for the future of transportation.

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