Autonomous Vehicles: State of the art, Challenges, Future Trends and Opportunities

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Abstract*—Autonomous vehicle systems are quickly becoming a viable alternative to traditional human operation. Current commercially available vehicles remain constricted to SAE Level 2, although some fully autonomous vehicles will be available as early as Fall 2020. These autonomous vehicles will provide numerous advantages over traditional transportation methods due to their lack of human involvement, better SHRP 2 NDS accident rate, and improved energy efficiency. Some fully autonomous systems are already active in closed environments, and sensor and processing system improvements seem keen to make their way into commercial products. Some existing autonomous vehicles such as Tesla cars and Boeing 737 Max 8 aircraft have evoked controversy due to inadequate system redundancies and safety mechanisms, resulting in unexpected crashes and fatalities. It is apparent that regulations and laws must be implemented in order to ensure safe system design and protect the future of autonomous vehicles. In the future, autonomous systems will expand to include advanced communication systems such as V2X and Cellular V2X. These high-speed communication technologies will allow autonomous vehicles to interact with both traditional vehicles and other autonomous vehicles to coordinate movements and share other data.

***Keywords*—Autonomous vehicle; SAE Level; V2X Communication; MCAS; Tesla Autopilot; Driver Assistance**

I. Background

In recent years, large technological leaps have been taken towards creating a future with autonomous driving. Entities designing for private use and commercially available options have both arose on the market, with companies like Google, Tesla, and Ford leading the charge towards an automated future.

Prototype cars from these companies aim to improve the safety and reliability of the transportation systems worldwide, while reducing human interaction and improving vehicle energy efficiency. By eliminating human error on the road and incorporating advanced power systems into autonomous vehicles, large leaps in vehicle efficiency are possible without fundamentally altering the road system itself. Autonomous vehicles will be able to communicate with one another to optimize the route to a certain location, avoid traffic buildup, and reduce idle time. These goals will all combine to save fuel and money for the global economy and allow humans to focus efforts on other goals that machines cannot yet complete.

This research will provide an insight into what the future may hold for autonomous vehicles, and what we might learn from recent misgivings in autonomous technology. In the past, negligence and improper design have resulted in a loss of human life from autonomous vehicle systems. There is much that can be learned from these accidents, and that can be incorporated into future designs so that the systems can prevent accidents like them. As technology advances, sensors available to engineers will become more accurate and the computer systems driving the vehicle more complex, allowing for greater precision and smarter reaction to real world situations. This will cause autonomous driving systems to surpass the abilities of humans to respond and react to driving environments, giving autonomous systems a distinct edge over any human driving a vehicle.

However, I believe that in order to be successful, these systems must have the ability to remain isolated from communication networks. Currently, if a hacker is able to take down a communication network, such as GPS or cellular networks, they would wreak havoc on the present autonomous systems. It is not hard to imagine a scenario in the future where cyberattacks are a regular occurrence, and in these situations, autonomous vehicles should be able to drive independent of outside assistance if they are to become widespread.

I believe that there are distinct advantages for autonomous vehicles to be able to communicate with external devices. These vehicles will be able to provide accurate data about traffic and road conditions while receiving external data to find a faster route and react instantaneously to conditions not directly in the vehicles line of sight.

II. Literature Review and Independent Analysis

A. What are autonomous vehicles? How are they different from conventional vehicles?

Autonomous vehicles are vehicles that are designed to operate without a human driver [1]. To accomplish this, autonomous vehicles utilize a variety of hardware and software solutions that are implemented in the vehicle's body. This may include GPS receivers, cameras, sound sensors, Light Detection and Ranging (LIDAR) sensors, and Radio Detection and Ranging (RADAR) sensors. Autonomous vehicles utilize these sensors to receive data about the environment and "see" their surroundings. Many autonomous vehicle solutions include a variety of these sensors in tandem to allow for a more comprehensive view of the environment. Integrated computer processing allows the vehicle to interpret the data received and make intelligent decisions to drive the vehicle around in the environment.

Autonomous vehicles differ from conventional vehicles based primarily on the driving assistance they provide compared to the fully manual driving systems of conventional vehicles [1]. For example, a partially autonomous car would allow for driving lane detection, and warn a human that they are close to the edge of their lane, while a conventional car would allow the human to drift from their lane, potentially causing an accident [1].

Conventional vehicles also have limited computing systems on board compared to autonomous vehicles. For example, in a conventional car, there might be a "smart" entertainment system with a touchscreen display that can access the internet, but this system is not integrated with the driving capabilities of the car. In an autonomous car, the processing power of the onboard computing system is directly used to assist in the driving of the car.

Autonomous vehicles are not limited to the automotive industry. They can be found in a variety of different sectors, including aerospace, warehouse operations, and home appliances.

B. What are the building blocks of an autonomous vehicle system? What are the challenges?

There are several independent blocks of an autonomous vehicle system, including sensors, a processing system, and the vehicle drive chain.

The type of sensors implemented in an autonomous vehicle can vary greatly. One of the more common solutions for land vehicles is the implementation of several video cameras throughout the car body. These cameras generally have a wide range of view and take in their surroundings in full color, allowing for detection of traffic signals, street signs, and other color distinguished items on the road [1]. Additionally, these cameras can be designed to work in high or low light conditions and at varying ranges, making this type of sensor system very versatile [1].

Another common sensor solution is LIDAR. This system utilizes lasers to detect objects in its surroundings. The LIDAR sensor rests on top of the vehicle and emits millions of laser pulses per second in all directions in order to get a more complete view of the environment. This sensor "sees" based on how long it takes for the laser pulses to bounce back [1]

Autonomous vehicles can utilize other supplementary sensors such as GPS and audio detection to provide more complete data of the vehicle's surroundings.

A complex processing system is required for a given vehicle to understand the data being received from all the available sensors. Toyota's approach is to use the processing system to build a specialized map of the surrounding area based on sensor or previous knowledge about the given area [2]. This map will be used with computer processing algorithms to predict future events and how surrounding objects, such as pedestrians and other vehicles will move in the near future [2]. This will allow the vehicle to plan how the vehicle should respond and move once conditions change and help create a "movement plan" for the car. If conditions change, the vehicle must react quickly, such as to prevent an accident [2]. This means that the latency of the processing system must be very small. After the movement plan is created, the vehicle must be controlled correspondingly.

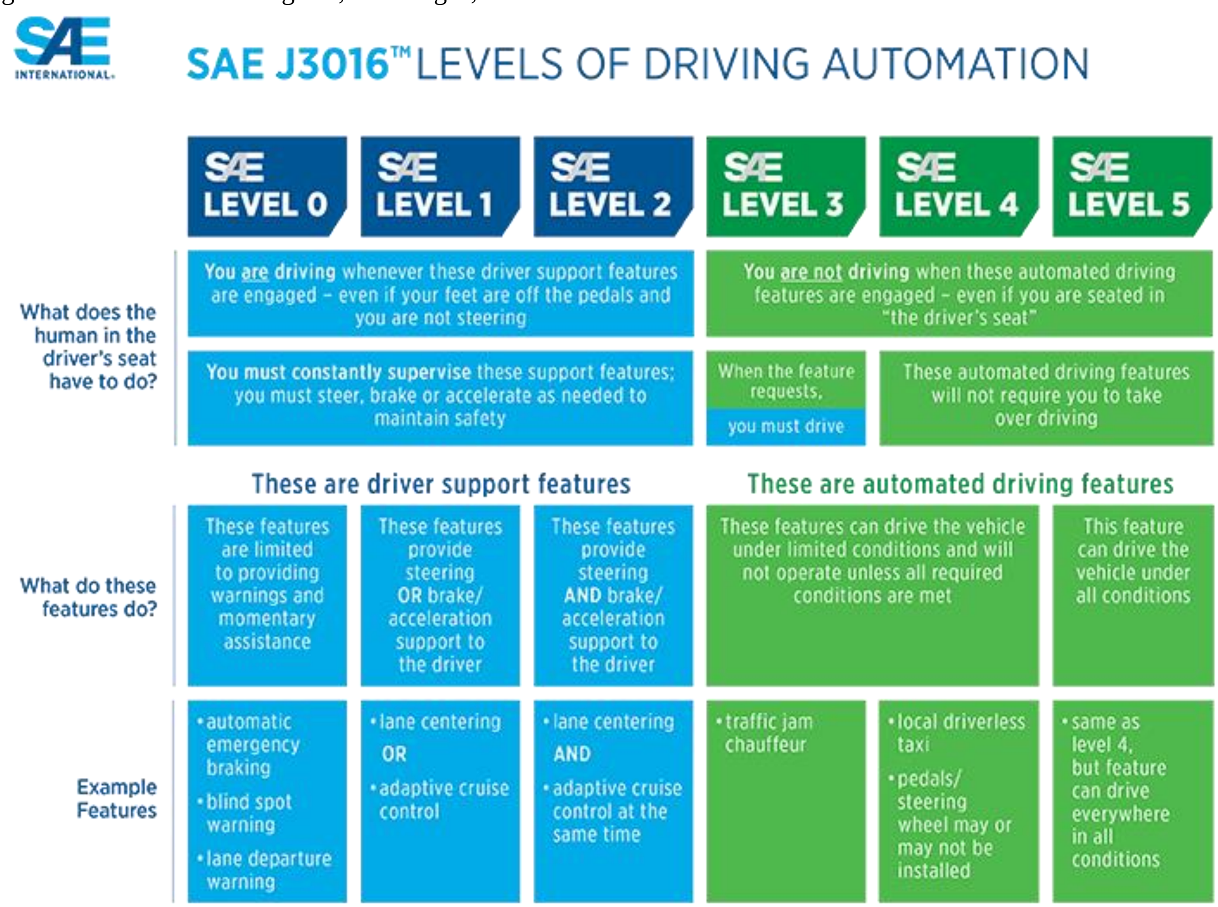

Figure 1: SAE International Car Autonomy Levels [3]

To control the car's movement, modifications to a traditional vehicle's drive chain is necessary. Toyota states that their automated driving systems plan the course and then utilize a control system to execute commands from the planned course of action [2]. This is done by utilizing "actuators that direct vehicle drive functions" [2]. This acts essentially as a second steering wheel for the vehicle that is controlled entirely by the automated system.

It is important to note that there are different levels of vehicle autonomy. The Society of Automotive Engineers International (SAE International) defines the degree of autonomy of a vehicle in 6 distinct categories based on the level of sensing and processing in a vehicle [3]. These levels are a part of the SAE J3016 standard [3]. The first three levels (0-2) are designated as "driver support" levels [3]. This means that the autonomy features available in the car are limited, and a human is required to drive constantly, although the car may issue warnings or automatically steer or brake if imminent danger is seen [3]. The higher 3 levels (3-5) are designated as "automated driving" levels. In these levels, a human is not required to drive except in specific, restricted situations [3]. These situations only occur in SAE autonomy level 3, where if the automated system is unclear in what to do, it will direct control over to the human driver in the car. SAE Levels 4 and 5 will never require a human to assume control of the vehicle and have additional automated features that will be implemented in a scenario where the vehicle is unclear what action to take [3]. This may include pulling over and stopping or slowing down drastically until the processing system has a clear understanding of what action to take [3].

The challenge with autonomous vehicles is their complexity. In order to be fully autonomous (and safe while being autonomous), vehicles must be able to adapt to a variety of different situations and be capable of functioning even during system failure. The SAE Autonomy levels depict this complexity by breaking down the level of autonomy into distinct segments. It is much easier to say that a car has "driver assistance" features then to say a car can drive itself. The leap taken here is that once the car is driving itself, there are going to be lives at risk. Any mistake made by the autonomous system could result in an accident, or even death, so the system must have redundancies and a plethora of different sensors available to create an accurate picture of the environment. In the future, sensor and computing technology will advance to the point where designers are confident that the vehicles will function and react better than a normal human would, and this would be the point where autonomous vehicles could drastically increase in popularity.

Even at this early stage in autonomous technology, reports have shown that autonomous cars show reduced accidents when compared to the crash rate of humans, although it remains to see how these numbers change as the number of autonomous cars on the road increases [10]. This data is shown in figure 2 where self-driving cars have a defined reduction in crashes per million miles.

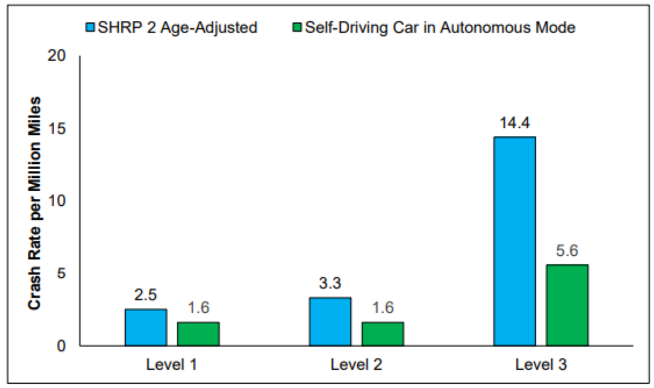

Figure 2: SHRP 2 NDS and Self-Driving Car Crash Rates per Million Miles [10]

In figure 2, the levels 1 through 3 correlates to the SHRP 2 NDS Crash Severity Classifications, not the SAE Autonomy level [10]. Specifically, level 3 crashes are crashes that involves physical contact with another object, but with minimum damage This includes most instances where a car "jumps the curb", strikes a small animal, and other minor incidents like scraping a guardrail [10]. Level 2 crashes are crashes involving property damage needing to be reported and crashes that reach an acceleration of greater than 1.3g's of acceleration in any direction [10]. Level 1 crashes involves any crash with airbag deployment, bodily injury, rollover, incidents require towing, or any other incident that results with an acceleration of over 2g's in any direction [10].

C. What have researchers/companies done? Which parts are done in the lab and how much of that has been implemented in commercially available vehicles?

Currently, most of the research being conducted into autonomous car driving has been conducted privately by companies for use in their products. For example, Tesla, a company that has implements self-driving features on several car models, has conducted "billions" of miles of testing for features currently implemented in their cars [4]. This means that the overwhelming majority of testing for Tesla's autonomous systems has taken place on actual roads and not in a laboratory. Currently available on Tesla's cars is level 2 autonomy, meaning that Tesla's autonomous driving systems are currently limited to "driver support" features and are not expected to drive the car completely [3][5]. In the future, Tesla aims to make their cars fully autonomous and implement features such as "traffic signal recognition" and "autonomous driving on city streets" as soon as the end of this year [4].

Much of the research being completed in the lab is research on advanced sensors and processing system upgrades. Tesla has gone so far as to design its own processing system from scratch for increased control over processing power, I/O features, and power consumption. This processor will allow Tesla to better pursue complete self-driving car capabilities without relying on an external company for hardware [5].

Other companies, such as Amazon, intend for their autonomous vehicles for remain privately operated, and not utilized in a commercial product [6]. Amazon has research into smaller autonomous vehicles for use in warehouses. These robots can navigate a maze of different chutes used to sort packages without running into obstacles or other robots

[6]. The new autonomous robots will eliminate the need for human sorting and has the end goal of improving warehouse efficiency to reduce shipment times.

The fact that much of the current autonomous driving technology is unavailable in commercial products is a testament to how far the technology still has to develop. It is much easier to design robots for use in a contained environment, but if they are to be used on an ever-changing environment like the U.S. road system, much more processing power and redundancies are required. This will come at an obscene price, preventing smaller companies from tackling autonomous driving. For this reason, companies with large research budgets like Google, Tesla, and Amazon have been at the forefront of this developing technology.

D. What concepts are being explored

The increased use of autonomous vehicles is of high priority to the U.S. Department of Transportation (DOT). In a report on American leadership in the sector, they state that the Dept. of Agriculture (USDA) is researching unmanned ground vehicles (UGV) and autosteering methods for other farm equipment [7]. Furthermore, the USDA intends to develop automatic systems for feeding ranch animals, utilizing robotics to deploy herbicide, pick fruit from trees, and increase pollination of plants [7]. These are all aimed to increase farm productivity while reducing labor required. This will allow farmers to cover more land with the same number of workers, increasing overall efficiency and food produced [7].

The Dept. of Defense (DoD) is researching further into autonomous devices, but for different reasons. Rather than replace soldiers entirely, the autonomous vehicles being researched would supplement soldiers, allowing them to extend their capabilities and improve speed of reaction [7]. Additionally, the DoD is researching advanced sensor technologies, such as more accurate GPS and LIDAR sensors. These sensor improvements will eventually make their way to the private sector, allowing for greater energy efficiency or more precise tracking for autonomous systems [7].

In addition, the National Science Foundation (NSF) continues to facilitate research in advanced sensor design, computer vision improvements, Communication between vehicles and other devices, autonomous vehicle security, and perception/peripheral vision advancements for autonomous vehicles [7].

III. Case Study

A. Discuss the two specific issues that happened with the Tesla cars and Boeing 737 Max 8. What went wrong?

1) Tesla Car Accidents

In 2018, a Tesla model X car crashed in California, killing the driver, while the Tesla “Autopilot” mode was engaged [11]. Recently, the National Highway Traffic Safety Administration (NHTSA) found that the Autopilot feature “failed to keep the driver’s vehicle in the lane” and “failed to detect a highway barrier” [11]. These findings, coupled with the fact that the driver was on his phone and unable to assume control of the vehicle in time, resulted with the car crashing into a highway barrier [11].

For context, the Tesla Autopilot system is not marketed as a “self-driving” feature, but rather a “driver assistance” feature. This is shown by the rating given to the feature by SAE International, a “level 2” autonomy rating [11]. Tesla markets this autopilot feature on its website as allowing for “Traffic-Aware cruise control” and “Autosteering” to assist in steering within a clearly marked lane [4]. This means that on most highways, autopilot can assume control of the car and keep the car oriented inside its lane, although the driver is expected to remain alert [4]. Tesla attempts to make you stay alert by requiring you to touch the wheel intermittently during Autopilot operation but falling short of requiring a constant hand on the wheel [4].

In this crash, the driver had autopilot engaged for 19 minutes, but did not have his hands on the wheel at the instant the car crashed [11]. The car logged that the driver had touched the wheel three times in the minute before the crash, but not in the 6 seconds preceding the accident [11]. This leads investigators to believe that the driver was playing a game on his phone while driving [11].

It was found that the car was travelling at 71 miles per hour when it veered into the median highway barrier, causing the car to flip and strike two other cars before catching fire [11].

Shortcomings in sensor design resulted in the Autopilot system believing that it was remaining in its highway lane when it drove into the median barrier. This accident may have been prevented had Tesla always required a hand to remain on the wheel, or if Tesla had more warnings when the system was unsure about its surroundings. Additionally, the term “Autopilot” gives users the sense that the car can drive itself, when it was dictated by SAE International that it is only a “driver assistance” feature [11].

It is also important to note that this crash was not an isolated incident, as there are other crashes resulting from Autopilot use from as early as May 2016 [11].

2) Boeing 737 Max 8 Accidents

The Boeing 737 Max 8 erroneously caused planes to go into sudden nose-dives, causing the pilots to lose complete control of the aircraft (and crash). The first instance of this behavior occurred two minutes into a Lion Air flight out of Jakarta, Indonesia. The plane was at an altitude of 2175 feet, already very low in the sky, and suddenly automatically went into a 700-foot dive, dangerously close to the ground [8]. The crew would struggle with the autopilot for another 10 minutes, at which point the plane disappeared from radar and crashed, killing all 189 aboard [8].

Four months after the Lion Air crash, similar behavior would be seen in another 737 Max 8 from Ethiopian Airlines, again resulting with the death of all on board [8]. This would prompt the grounding of all 737 Max aircraft globally as the issue was investigated further by Boeing.

The Boeing 737 Max 8 was intended to be a refresh to the 737 series, Boeing’s bestselling plane of all time [9]. Due to the large fleet of 737s already in the air, it was in Boeing’s interests to ensure that transitioning to the new plane would require minimal training and no “new plane recertification” for current 737 pilots. In other words, Boeing wanted the 737 Max 8 to act and feel the same as previous aircraft to avoid being labeled as an entirely different aircraft [9]. The issue with this lies in the fact that had Boeing fundamentally altered the flight characteristics of the 737 Max 8 because of certain modifications.

To stay competitive with the competition, Boeing wanted to introduce larger, more efficient engines [9]. This required positioning the engines closer to the front of the aircraft, which drastically altered the lift characteristics of the plane compared to previous 737s [9]. To compensate for this (and to reduce the learning curve for 737 pilots), Boeing introduced a new autopilot subsystem that would counteract the change in lift. The Maneuvering Characteristics Augmentation System (MCAS) was this new subsystem. Because the new engine placement caused the plane to lift upward more easily, the MCAS was designed to "push the nose of a climbing aircraft down if it calculates the plane is in danger of stalling" [9]. This would happen automatically, and without the pilot's knowledge. There were three criteria for activating MCAS: the flaps of the aircraft must be up, the autopilot must be turned off, and the angle of attack sensor must indicate a stall warning (high angle of attack).

The most critical issue with the MCAS subsystem was that the pilots had no knowledge of the system or how it functioned. Pilots were not trained on what the MCAS was or how it operated and did not know there were MCAS override controls available [9]. Boeing's objective here was again to simplify pilot training for the new aircraft and reasoned, along with the Federal Aviation Administration (FAA), that it was acceptable to omit the MCAS system in documentation entirely because it would only be activated when the plane appeared to be stalling, and would rectify the situation without intervention of any kind.

What Boeing had not planned for was faulty sensors on an airplane. This was the case in Lion Air flight 610, as found with the replacement of the angle of attack vane a day prior to the fatal flight [8]. This replacement was found to be "older than the airplane itself" and sourced from an unreputable seller [8]. It was this faulty sensor, that showed erroneously that the airplane was stalling, that fulfilled the conditions required for MCAS interference.

After takeoff on Lion Air flight 610, the autopilot was disengaged, the flaps were brought up, and the angle of attack sensor was reading that the plane was stalling despite the angle of attack being perfectly normal. This resulted with the MCAS attempting to reduce the angle of attack by banking the airplane sharply downward, but this sent the airplane into a nose-dive. The pilots, not knowing that the MCAS system or its overrides exist due to its omission in training and documentation, struggled to regain control over the aircraft and eventually crashed. The sensor failure in this flight was confirmed using data from the plane's black box.

IV. Discussion

A. What do you think of each building block? Are there any topics you feel are missing?

In the Independent Analysis section, I expressed how the main building blocks of an autonomous vehicle are the sensors, processing system, and vehicle drive chain. Of these building blocks, I believe that the processing system is the most interesting. This is for a few reasons.

The processing system's ability to map its surroundings is limited by the sensors included on the autonomous vehicle. However, the vehicle is strictly reliant on the processing system for sensor data interpretation and to determine the course of action and how the vehicle should react to the sensor data. The processing system will limit how fast or accurately the autonomous vehicle can react to the sensors but is itself constricted in abilities by the amount of sensor data received. More sensor data and more processing power means the system will have a better understanding of the environment around the autonomous vehicle

Additionally, I believe that sensors will continue to be innovated upon in the next few years in order to provide more robust and precise tracking of objects. Current Tesla cars have 8 tracking cameras, a radar module, and 12 ultrasonic sensors to feed the processing system, and I expect that in the future the sensors will be come more precise or increase in number [4]. These advanced sensor arrays will feed the processing systems with more complete data. Emerging sensor systems, like LIDAR, will become more viable for everyday use as they are miniaturized and proven in test autonomous systems.

Least important, in my opinion, is the vehicle drive chain. This is the system that allows the computer to steer and move an autonomous system, and I do not see any important advancements being made on this technology anytime soon. It is unclear how the drive chain could be optimized to improve reliability and functionality, as they already perform as expected in available autonomous systems. Also, I was unable to find any reports of accidents where the autonomous drive chain or steering system was specifically was at fault.

One topic I feel was missing from the list of "building blocks" was external connectivity and interactions. I believe that in the future, autonomous systems should be able to interact and relay data between devices. This may include other autonomous systems relatively close to one another, or in the cloud. V2X communication appears to be this system. V2X stands for "vehicle to everything" and represents what the future may hold for autonomous systems [14]. This emerging technology currently utilizes a standard based on WIFI called IEEE 802.11p, which can transmit data between devices at a range of up to 1km with a latency as small as 2ms [14]. In cars, this type of communication could allow vehicles to automatically get out of the way of ambulances or police cars and could signal other vehicles when it is about to change lanes [14].

Furthermore, a competing standard for V2X is being formed, and is called "cellular V2X". This standard would utilize future 5G wireless communication to transmit data over longer distances and at a high speed compared to current cellular technology [14]. This cellular connectivity would allow for vehicles to transmit data about traffic and weather conditions to the cloud to assist other autonomous vehicles, while also receiving data such as parking and charger locations from the cloud [14].

It is easy to see how these two technologies could work together to form an additional, important part of autonomous vehicle systems and revolutionize the driving system. With short range communication, cars would be able to coordinate lane changes, speed data, and other vital information [14]. At the same time, long range communication would allow for robust map data and more complex cloud processing that would be impractical to implement in a power-limited system like the processor in a car [14].

B. What are the future trends you see on the horizon? What obstacles do you notice? How can they be overcome?

I believe that in the future, high speed communication between autonomous vehicle systems will become more prevalent and allow for greater efficiency in transit systems. With V2X communications, road vehicles will be able to talk to one another to change lanes and prevent collisions, and cellular V2X will allow for cars to receive information from the cloud to alleviate congestion and automatically choose different routes [14].

Furthermore, this system could be implemented in conventional vehicles as well. For example, this may allow non-automated cars to inform automated vehicles that they are performing a lane change before the automated vehicle “sees” them through proximity and camera sensors.

Cellular V2X could even be utilized as a high-data analog for AM/FM radio. Cellular V2X would have the capacity to provide “free” data to conventional and automated vehicles alike. This system could be ad-supported, like traditional radio, and allow complete access to the internet from a vehicle’s processing system. We may see this technology appear in cars very soon if 5G rollouts continue as expected in the United States.

The primary obstacle I see in allowing high-speed communications between vehicles is outage vulnerabilities. If autonomous vehicles are, for some reason, unable to access the V2X communication network, they should be able to continue driving autonomously on their own. This would be especially important in situations where the latency is very high and the delay in information might cause an accident. In situations like these, the vehicles should still have processing systems onboard to allow for quick decision-making. Ideally, this transition between cloud processing and internal processing would be seamless.

C. Opinion on the Tesla Car Accidents

I believe that, while the autopilot system surely failed, resulting in multiple accidents, a portion of the blame lies with the driver of the car. In the 2018 incident, the driver was on his phone with both hands off the wheel [11]. While it is Tesla’s fault for not implementing strict enough engagement requirements for the driver, any person would know that being on the phone and completely distracted in the driver’s seat is a recipe for disaster. Despite not having adequate engagement requirements, upon the first use of the Autopilot system an agreement is shown requiring the user to “keep your hands on the steering wheel at all times” and “maintain control and responsibility for your vehicle” [4]. Upon each activation of the autopilot system a prominent reminder to “keep hands on the wheel at all times” is shown [4]. This means that the driver was knowingly not paying attention and knew that his behavior was not in line with how Tesla intended for the system to be utilized.

Later this year, Tesla plans to roll out “full self-driving capabilities”, and this will have a strong impact on whether they are viewed as a safe option for autonomous driving [4]. Given that accidents involving Tesla’s Autopilot have continued to occur, Tesla needs to be very thorough with testing to ensure that accident rates continue to fall [12].

Even so, I believe that the intermittent nature of high-profile Tesla Autopilot accidents should be a testament to how far the technology has come. Fatal car crashes occur daily, but crashes involving Tesla’s Autopilot have been sparse. This is obviously a legal gray area, as the NHTSA has yet to release any regulations on how autonomous driving systems operate, and any accidents that occur using the feature will shine a bad light on it [12].

Rather, I believe that Tesla’s autopilot system has saved lives due to removing human error. As previously shown from the data in figure 2, autonomous cars do statistically have less crashes than conventional cars [10]. Although this is not directly comparable because the Tesla system is only a SAE Level 2 autonomy system, one would expect that the system would prevent some crashes due to drifting lanes, etc. This expectation is upheld by Tesla and the NHTSA’s data. Tesla reports that in Q4 2019, there was one accident for every 3.07 million miles driven for which Autopilot was enabled [13]. The NHTSA’s most recent data designates that on average there was one automobile crash every 479,000 miles driven [13]. This means that for every accident reported by Tesla when autopilot was enabled, there were approximately 6.4 accidents reported by NHTSA across all sectors [13]. This is a phenomenal crash reduction but is covered less by news sources because any accident occurring is seen as bad.

D. Opinion on the Boeing 737 Max 8 Accidents

It is clear to me that the Boeing aircraft accidents were almost entirely due to the autonomous operation functionality of the Boeing 737 Max 8 not being implemented properly. The market circumstances (pressure from rival Airbus for the release of a competitive plane) resulted with the rushing of the Max 8 to market with corners being cut. Instead of redesigning the plane due to the different lift characteristics caused by the shifting of the engines, or accepting that the plane would require additional pilot training due to the different characteristics, Boeing opted to haphazardly implement a system to “fake” the lift characteristics of the aircraft [9]. It is clear that the MCAS system was viewed as an afterthought to Boeing based on the lack of safety measures used in its implementation. Despite there being multiple angle of attack sensors (one for the captain and one for the co-pilot), Boeing did not require agreement between these sensors for the MCAS to activate, instead only taking input from the captain’s sensor in determining if a stall was occurring[8].

Furthermore, the lack of communication between Boeing and pilots about the implementation of this system carries a portion of the blame for these accidents. If the system had been mentioned during checklists for stalling, or other emergency documentation, the emergency bypass switches would have been utilized, and these accidents may have been prevented.

Lastly, a bit of the blame for these accidents lies on the engineers who replaced the angle of attack sensors on the aircraft. If testing had been done completely on the newly installed instruments, the engineers clearly would have noticed the malfunctioning sensor. Instead, to get the aircraft back in “working order” they reset the warnings and gave the aircraft the “all clear”. This clear negligence is what started this catastrophe. One may argue that if the engineers installed a certified/new part from Boeing instead of a black-market part this would not have been an issue, but this is not the point. Instead, I argue that if the proper precautions and testing were used when implementing the MCAS automatic system, there would be no need for a ‘faulty sensor’ to be an issue, because the MCAS would disable itself upon realizing that a sensor is faulty.

E. General Reflections

As a whole, I believe that autonomous driving will do more good than bad for society. When designed and implemented with appropriate safety measures and regulations, it will take human error entirely out of the equation, meaning that vehicles can move seemingly without intervention. Extra scrutiny must be taken to ensure that “bumps” along the progression of autonomous technology do not become larger issues. The issue with the Boeing 737 Max 8 was that the autonomous system did not go through the scrutiny and complete analysis that it should have. Ideally, all autonomous systems would be required to go through the same rigorous testing to ensure that even during a catastrophic failure, control can be safely returned to a human, or that a more rudimentary backup system to control the vehicle can be used.

To increase public confidence in autonomous driving, the technology must be proven through successful implementations, and regulations must be set in place to ensure safety measures are in place. It is unreasonable to expect that accidents will never occur from autonomous driving, but it is necessary that these accidents be minimized and incremental improvements to the systems be implemented to ensure that autonomous driving remains viable as a technology.

V. Conclusion

A. Based on your research, what do you think of the viability of autonomous vehicles?

I believe that autonomous vehicles have very strong potential to disrupt transportation and industrial systems due primarily to their lack of human involvement. The fact that humans will not be required to operate these systems means that humans will be able to focus on tasks that require more critical thinking and are currently unable to be done by a machine. Furthermore, removing human error from transportation systems will result in a dramatic reduction in the number of accidents, as when implemented correctly, autonomous vehicles have been proven to have a lower crash rate [10]. This is because humans sometimes get distracted or have slow reaction times, while autonomous systems will provide consistent results all the time.

Additionally, autonomous vehicles will severely reduce traffic congestion, increasing the fuel efficiency of all types of vehicles. V2X communication will become an important connection between all types of vehicles that will allow for better vehicle movement coordination, accident prevention, and improve the experience for humans still driving vehicles. This communication between vehicles may allow for the increasing of speed limits on transportation systems as vehicles become more aware of their surroundings.

I believe that in order to successfully implement autonomous driving, numerous stringent guidelines should be enacted to ensure that systems will function adequately even during catastrophic sensor failure. Additionally, I believe that requiring thorough testing will improve public reception of the technology, as the autonomous vehicles will have a proven track record by the time they are introduced commercially.

B. What is a reasonable timeline?

Autonomous vehicles may begin showing up as soon as this year, although at a restricted scope. Tesla plans for “full self-driving capability” to be rolled out on several models by the end of this year [4]. This means that if all continues well, Tesla cars will be able to drive automatically on most normal streets without user intervention [4]. It remains unclear what SAE Autonomy level Tesla’s system will support, and this system will still be a purchased upgrade for the foreseeable future [4].

Other companies have already rolled out autonomous systems. Amazon, for example, is actively using autonomous robots in warehouses for sorting packages [6]. Additionally, Waymo, a Google subsidiary, has been utilizing self-driving cars as a taxi service in the Phoenix, Arizona Area since April 2017 [1].

Other companies are less far along. Ford, for example, intends to launch an SAE Level 4 autonomous vehicle sometime in 2021, but will restrict the vehicle to a certain region [15]. Honda and Toyota intend to have only highway autonomy (like Tesla’s SAE Level 2 Autopilot system) by the end of 2020 [15].

All this means that while autonomous vehicles have made great advancements in sensor and processing technology, it might be 5-10 years before autonomous vehicles become commonplace on the road. This is partly due to the wide range of conditions seen on the open road. Pedestrians, other cars, objects like trash cans, and even weather conditions need to be accurately seen and recognized by autonomous vehicles, and this must be done in a safe and time-sensitive manner.

This is all not to mention the costs associated with autonomous vehicles. Tesla’s “full self-driving” feature costs an additional $5,000 across their product line [5]. Consumers will need to see value commensurate with this cost for autonomous systems to be adopted widely.

C. What challenges should we prepare for?

A major challenge that may be faced by autonomous vehicles is vehicle response in dire circumstances. A dilemma may be faced in an accident where an autonomous vehicle knows that it has a high probability of crashing, and there is a pedestrian in the crash zone. The car may be able to prevent this crash by swerving into another car, injuring the occupants. Which action should the car take? And who is liable for the accident. This is a morally gray area, and regulations and law must be written on topics pertaining to autonomous vehicles to resolve these debates.

Furthermore, autonomous vehicles may lead to a net loss in the number of jobs, as self-driving vehicles replace truckers and taxis. Autonomous vehicles seem poised to replace these roles in society, and it is unclear whether the economic benefits of automation will make up for these lost jobs.

Another large obstacle revolves around the cybersecurity of autonomous vehicles. Where there is communication between cars, whether it be V2X communications or otherwise, there is a potential for hacking and exploitation of the system. Adequate security measures must be taken to ensure that autonomous vehicles are not susceptible to hacking, as this could have dangerous consequences for occupants and other persons on the road. If an autonomous system is hacked, the hacker could conceivably assume control of the vehicle and crash it or steer the car to crash another vehicle on the road. For this reason, I believe that encryption and wireless security should be greatly increased on connected autonomous driving systems.

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