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An Examination of Autonomous Vehicle Technology

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Autonomous Vehicle technology has evolved and developed over time. This article will explore the origins of the technology and follow the progress of its rapid advancement up to the present day. Autonomous Vehicle technology consists of six levels which were created by the Society of Automotive Engineers in 2014, and subsequently adopted by the National Highway Traffic Safety Administration. Level Zero consists of no automation as the driver completes all of the driving tasks. Level One Thru Level Five (Fig. 1) consist of ever increasing levels of autonomy where Level Five is complete autonomy requiring no intervention from the driver.

Numerous companies have received government approval for testing and trials not only throughout the United States but world-wide. This article is concerned with the development of this technology within the scope of the United States. This article will explore the variety of technologies utilized such as AI, Machine Learning, radar, LIDAR, laser light, GPS, Odometry, telemetry, sensor fusion, Deep Neural Networks, IMU's, and computer vision.

Although Autonomous Vehicle (A/V) technology has been advancing at a rapid pace, the prospect of mass deployment has not yet been achieved.

Prominent players within the industry are utilizing a variety of technology platforms with no industry technology standard, instead utilizing a free-style mix of different technology components. This article will endeavor to explore, as well as compare and contrast, the divergent technology platforms each of the prominent players have adopted.

With the rapid advances in Autonomous Vehicle technology, automobile manufacturers have provided consumers optional products with increasing levels of autonomy rolling out such features as adaptive cruise control, parking assistance, lane keeping assistance, and automatic emergency breaking. These features have introduced American drivers to the lower levels of autonomous vehicle technology providing added safety benefits. The bifurcation of Autonomous Vehicles and Connected Vehicles (vehicle to infrastructure- V2I, Vehicle to Pedestrian-V2P and Vehicle to Vehicle- V2V) will be explored as there does not exist a melding of these two types of technology platforms that are currently being tested. These two separate stand-alone technologies are in their beta phase.

Keywords: A/V technology, Driverless, Lidar, Cloud-based computing, Artificial Intelligence, Radar, Mapping, Self-driving, Robotic, Data Analytics, Connected Vehicles (CV's), Smart Cities, DSRC, C-V2X, ADASs

In May 2016, the first US death involving a semi-autonomous vehicle was reported (Vlasic & Boudette, 2016). The Tesla Model S, while being operated in autopilot mode failed to detect a white 18- wheeler crossing the highway in the bright sunshine. The Model S crashed under the trailer at full speed killing the driver. While over 100 traffic fatalities occur each day in the United States (Bomey, 2018), this was not supposed to happen with an autonomous vehicle. Also widely reported nationally, a second sensational accident occurred in Tempe, Arizona in 2018 with a Waymo Autonomous Vehicle killing a pedestrian (Wakabayashi, 2018). According to a preliminary report released by the National Transportation Safety Board (NTSB), the vehicle did not have emergency braking enabled so as to prevent erratic behavior (Laris, 2018). It is no wonder that in a recent automotive study (PR Newswire 2018), the percentage of American drivers who believed roads would be safer if all vehicles were fully autonomous dropped from 63% in 2016 to 49% in 2018. Two years ago, a Cox automotive study showed that 30% of respondents stated they would never own an autonomous vehicle. In the 2018 study that figure increased to 49%. Karl Brauer, executive publisher of Autotrader and Kelley Blue Book stated, “As awareness around the development of autonomous technology increases, we’re seeing some dramatic shifts in consumer sentiment” (PR Newswire 2018).

In addition to the technological hurdles Autonomous Vehicles have still to overcome, there is also the issue of the decline in public acceptance and increased apprehension. The benefits of this technology are expected to reduce traffic fatalities by 90% (McKinsey & Co. 2015), as well as prevent $190 billion in damages. A market research study (Allied Market Research, 2018) predicts that the Autonomous Vehicle car market will be worth $57 billion in 2019, expects it to grow to $557 billion worldwide by 2026, representing a ten-fold increase. The stakes are extremely high with such significant sums of capital and human lives at stake. Autonomous Vehicles are coming, albeit slowly, as the lower levels of automation have been embraced by consumers. Levels 1-3 which offer consumers driver assistance, partial automation, and conditional automation will comprise the bulk of the expected Autonomous Vehicle car market in 2019 according to the Allied Market Research study.

Autonomous Vehicles represent a technological leap forward that can influence how individuals view mobility (Howard & Dai, 2014). The disruptive aspects of new technology cannot be underestimated. Expected shifts in business models, insurance, land use, safety and security may very well contribute to disruptive effects. Numerous companies have invested billions in this technology as they test their proprietary technology platforms in the pursuit of a break through that will be widely accepted and deployed. Clayton Christensen (2011) postulates that disruptive innovation causes great firms to fail, but they do so unwillingly. If this industry fails to convince consumers of the efficacy and safety of fully (Level 5) autonomous vehicles, it may very well lead to the demise of the companies invested in it.

The Industry

The Autonomous Vehicle technology environment has progressed tremendously in the last few years with numerous competing industries vying for the pre-eminent technology platform. Worldwide competition has been keen, but this article will explore Autonomous Vehicle technology within the United States. Beginning with a history of Autonomous Vehicle technology and a review of the progress, the article will then pivot towards the analysis of the key technology platforms of the major players within the industry. Unlike the automobile industry, where that market is dominated by the automotive manu-

Methodology

An Industry Analysis of the Autonomous Vehicle technology will be the first in a series of three articles in the fulfillment of the requirements for the DBA degree at the Muma College of Business at the University of South Florida. The second article will present and review interviews conducted with industry thought leaders. Their views on the expected and perceived benefits to American society will be explored and compared. The pool of Interviewees will include experts from Government, Academia, Media, and Autonomous Vehicle industry. The third and final article will synthesize all of the information contained within the first two articles and highlight the gaps and summarize the conclusions of the industry thought leaders on the expected changes and benefits of Autonomous Vehicle technology.

The Autonomous Vehicle technology industry has undergone rapid advancement within the past few years. While no “industry technology standard” exists, numerous companies are competing to develop fully autonomous vehicles with their own proprietary solutions to the complex technology. Primary sources of information on this industry include numerous articles, peer reviewed journals, books, news reports, Autonomous Vehicle conferences as well as information supplied by many of the companies involved in the development of this technology. A literature review of the industry revealed gaps which included the types of technology platforms utilized. It appears there are two primary tracks of development within the industry, autonomous vehicles, and connected vehicles.

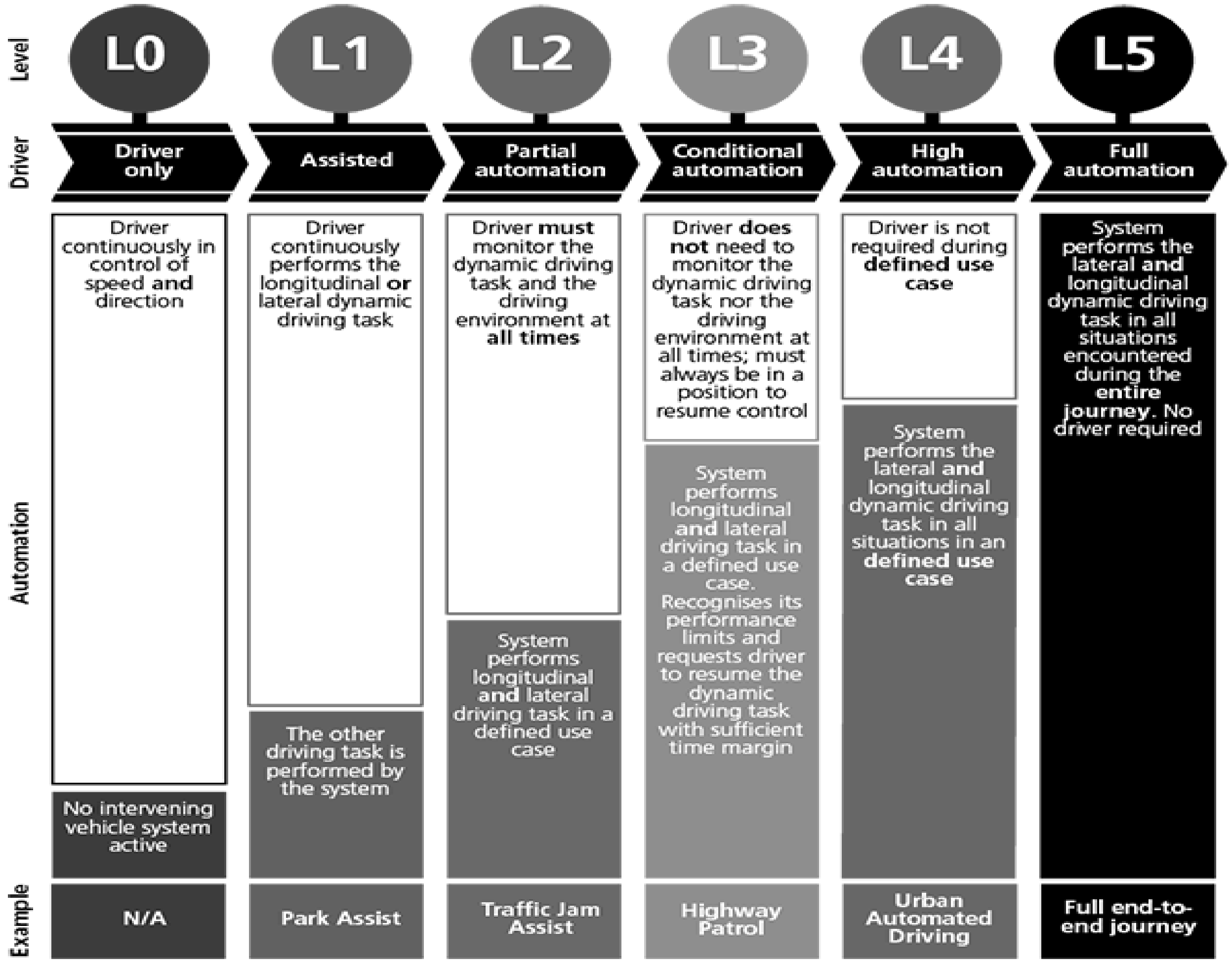

Figure 1: Society of Automobile Engineers, Levels of Automation 2014(Adopted by DOT)

facturers themselves, the Autonomous Vehicle "industry" not only includes automotive manufacturers, but technology companies, software companies, search engine companies, and book sellers. With an emphasis of the specific technology platforms and the benefits, features, and drawbacks of each of the technologies, this article will endeavor to review the perceived benefits of each.

Connected Vehicles and Smart Cities also play a crucial role as an aspect of Autonomous Vehicles. However, at this point they remain separate and distinct from Autonomous Vehicles technology. This is somewhat surprising given that connected vehicles appear to be closer to mass deployment on a much earlier timeline than Level 5 Autonomous vehicles (Fig. 1). Connected Vehicles send and receive information from their environment through a variety of sensors providing drivers with real time information so better and safer traffic decisions can be made.

Background

In general, all autonomous vehicles have technology that read their surroundings. This technology differs with manufacturers, but all vehicles utilize sensors, cameras, and some type of radar and/or LIDAR. Terms such as GPS (Global Positioning System), Lidar (survey method of distance measurement using pulsed laser light), software, Radar (object detecting system utilizing radio waves), Sensors (devices utilized to detect environmental change and send findings to other devices) are used when describing the technology contained within A/V's. Software coordinates all of these disparate parts through the use of Artificial Intelligence and Machine Learning. NVIDIA and CAGR are considered the datacenters of Autonomous Vehicles and are utilized by the major players in the Autonomous Vehicle technology field such as Tesla, Google, Delphi, and Intel.

Other terms such as V2V (Vehicle to Vehicle), V2P (Vehicle to Pedestrian) and V2I (Vehicle to Infrastructure) are used frequently as well in the context of connected vehicles. These three terms refer to direct communication between A/V's as well as direct communication with other devices sharing telemetry data. Connected Vehicles receive their information from other vehicles as well as infrastructure such as Smart Cities, areas outfitted with sensors that provide traffic conditions and safety information directly to vehicles and pedestrians. The technology contained within connected vehicles includes a short range radio, antennas, and a rear-view mirror specially modified to provide the driver with updated information on traffic conditions (Fig. 3).

Crash reduction rates of Connected Vehicles and Driver Assist technologies are expected to be between 15%-70% according to an analysis of crash data from 2005-2008 (Yue & Abdel-Aty, 2018). Combined with Active Traffic Management, these strategies could increase safety and efficiency.

In 2016, the U.S. Department of Transportation (USDOT) awarded New York City, Tampa, Florida and Wyoming $45 million to create a Connected Vehicle (CV) Pilot Deployment Program (Figure 4- CV Pilot Tampa). Sponsored by the USDOT Intelligent Transportation Systems Joint Program Office (ITS JPO), the CV Pilot Deployment Program is a federal effort to deploy cutting edge mobile technologies nationally in an effort to improve driver safety.

The Federal government has provided additional assistance to the Autonomous Vehicle technology industry by designating ten Autonomous Vehicle proving grounds on January 25, 2017. This is illustrated in Table 1 and Figure 2. The purpose of the proving grounds is to assist in the testing and development of autonomous vehicle technology using big data and complying with federal regulations. Out of 60 applicants, the following locations were selected:

Table 1: Listing of Autonomous Vehicle Proving Ground Designees

Designee	Location
1.	City of Pittsburgh and the Thomas D. Larson Pennsylvania Transportation Institute
2.	Texas AV Proving Grounds Partnership
3.	U.S. Army Aberdeen Test Center
4.	American Center for Mobility (ACM) at Willow Run
5.	Contra Costa Transportation Authority (CCTA) & GoMentum Station
6.	San Diego Association of Governments
7.	Iowa City Area Development Group
8.	University of Wisconsin-Madison
9.	Central Florida Automated Vehicle Partners
10.	North Carolina Turnpike Authority

History of Autonomous Vehicle Technology

One could argue that the horse was the first autonomous vehicle. But for the purposes of this paper

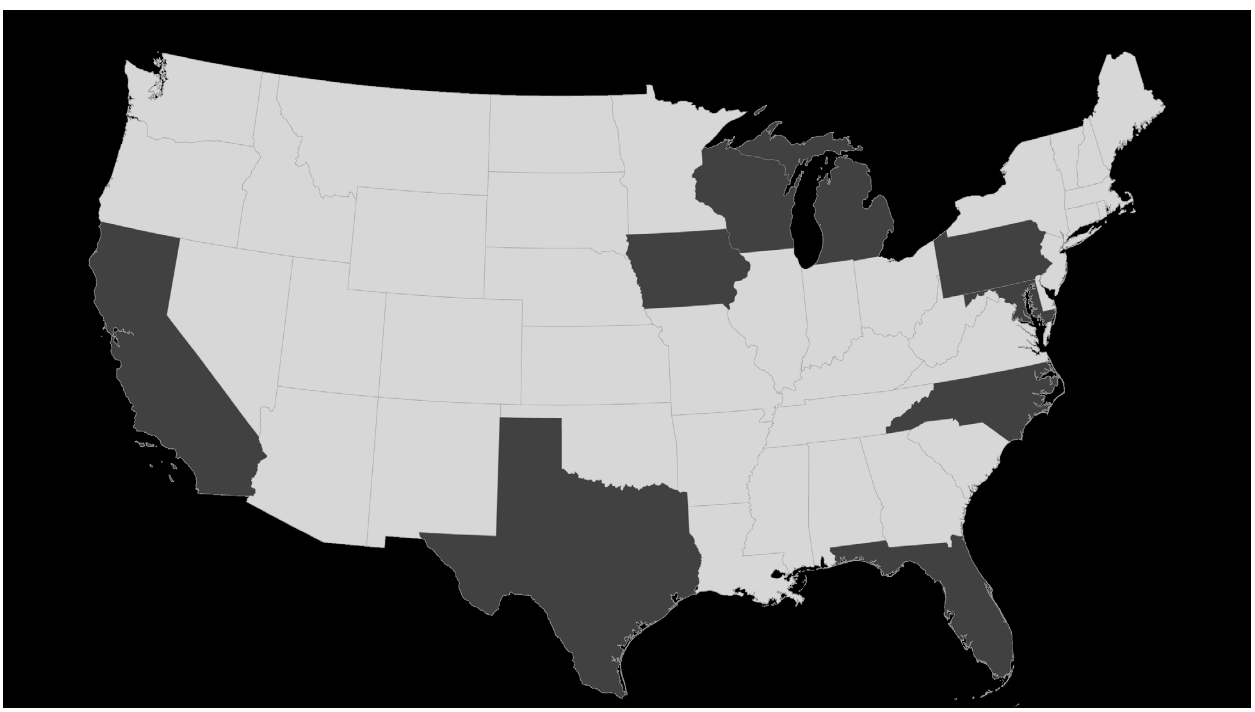

Figure 2: USDOT 10 Autonomous Vehicle Proving Ground Designees

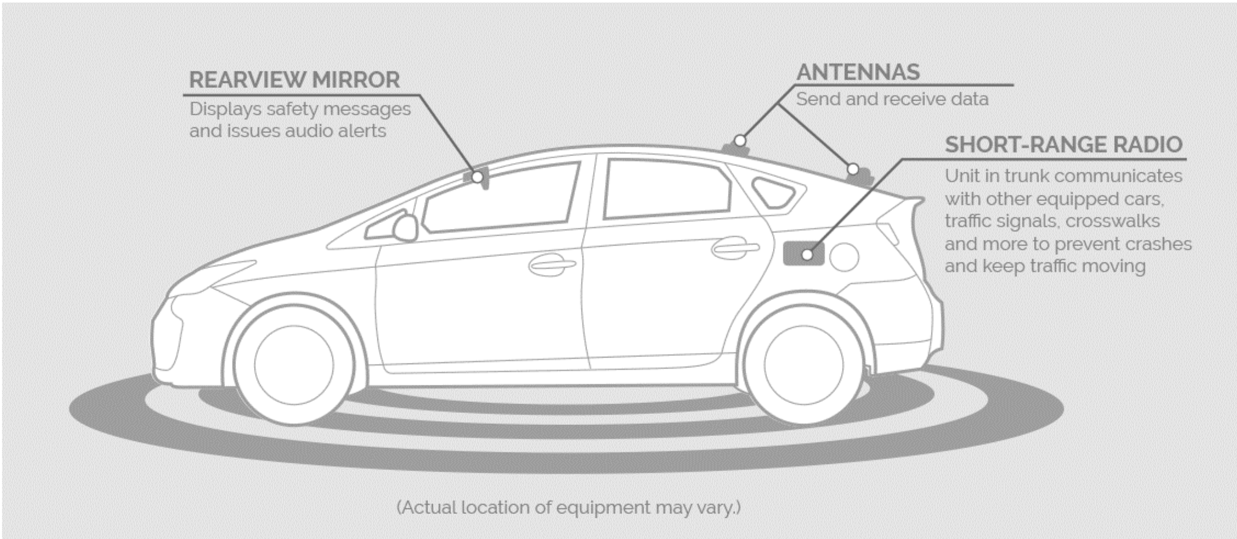

Figure 3: Connected Vehicles- CV Pilot Tampa (Image Supplied by Tampa Hillsborough Expressway Authority(THEA)

man-made inventions are the qualifying characteristic for inclusion on the list. The accompanying table (Table 2) and graphic (Figure 5) illustrate some important milestones in the evolution of autonomous vehicle technology:

Stakeholders

The stakeholders within the Autonomous Vehicle industry run the gamut from automobile manufacturers looking to continue their domination of the industry they created to software and hardware technology companies. Software companies play a major role in tying all of the divergent technologies together and forcing cohesion while still utilizing automobile platforms. The major players in the U.S. Autonomous Vehicle technology sector include Tesla, Waymo, GM, Ford, Voyage, Toyota, Ford, Uber, and Lyft.

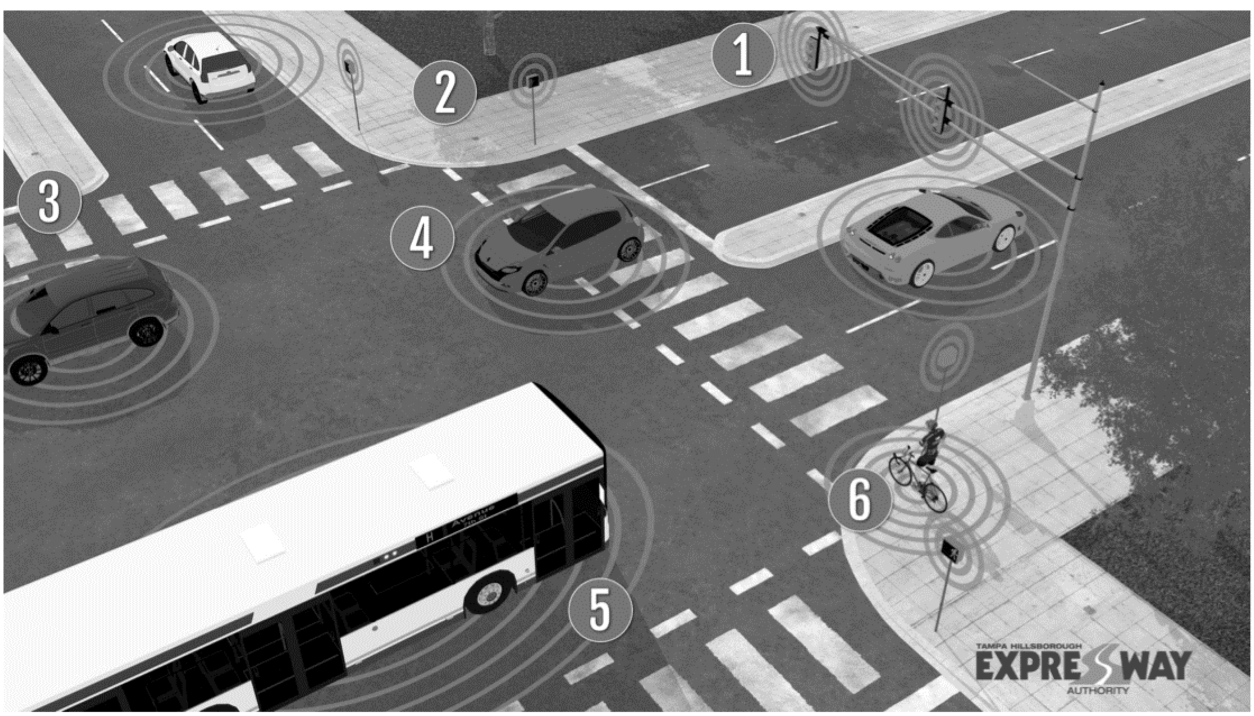

Figure. 4: Schematic of sensors deployed in vehicles and infrastructure (Image supplied by THEA)

Table 2: Important milestones in the history of Autonomous Vehicle technology

Year	Technology
1478	In 1478 the Italian inventor, Leonardo DaVinci sketched a pre-programmed clockwork cart. The invention was powered by coiled clockwork springs and was capable of propelling the vehicle over 130 feet. Had it been built it would have been capable of tackling a predetermined course.
1868	In 1868 Robert Whitehead was credited with developing the self-propelled torpedo containing rudimentary guidance systems that allowed it to maintain a constant course and depth.
1933	Sperry Gyroscope Co. invented autopilot systems for long-range aircraft. Called Mechanical Mike, gyroscopes were an integral part of the system and remain so in today's technology.
1945	Ralph Teetor did not like how his attorney drove, so he invented cruise control in 1945 to combat poor driving from his attorney. His invention smoothed out automobile rides and became commercialized in 1958.
1961	At the height of the space race scientists pondered how autonomous vehicles would operate on the moon. James Adams, a Stanford engineering student, came up with the idea for a remote controlled lunar rover called The Cart. It was outfitted with cameras, which still play a large role in today's autonomous vehicle technology.
1977	Tsukuba Mechanical, a Japanese company, developed an A/V passenger vehicle that was capable of traveling 20 miles per hour, and could identify street markings with its two cameras.
1987	After 8 years of development, Ernst Dickmann's VaMors (German language acronym) Mercedes Van was introduced. Computers controlled the gas pedal, braking, cameras and steering. Computers controlled the cameras which could move, thus providing greater visibility. The van was completely autonomous, and achieved speeds of 97 kilometers per hour on an empty autobahn.
1995	General Dynamics created the MQ-1 Predator drone in 1995, another type of autonomous vehicles. The drone contained technologies that are now being adapted for cars such as radar and thermal imaging cameras.
2004-13	The U.S. Department of Defense DARPA division challenged inventors of autonomous vehicle technology by offering prize money for vehicles that could self-navigate a 150-mile desert trip. Although no entrants won the challenge, subsequent challenges in later years produced entrants that completed the course.
2015	In 2015, Tesla introduced Autopilot which was an advanced driver-assistance program capable of handling lane centering, adaptive cruise control, change lanes without driver assistance, self-parking, and car summoning. This feature was delivered to Tesla Model S owners by way of a software update.
2015	The University of Michigan launched MCity, a testing facility for autonomous vehicle technology utilized by the Ford Motor Company.

The media plays an important role in this industry, providing information to interested parties about the latest advances, deployments, and failures. They watch this industry closely, and are quick to exploit and highlight failures, communicating this information to a thirsty public eager for any tidbits of information about this new technology.

Lastly, the most important stakeholder is the general public. They are the ultimate customers of Autonomous Vehicle Technology and will be the ones utilizing the product. With the expected benefits in terms of the modification of business models, land use, safety, security, and productivity improvements, an eager public awaits the continued testing and improvements to the technology.

Tesla

Tesla is an automotive and energy company best known for its electric automobiles. Tesla has been a leading company in the development of autonomous

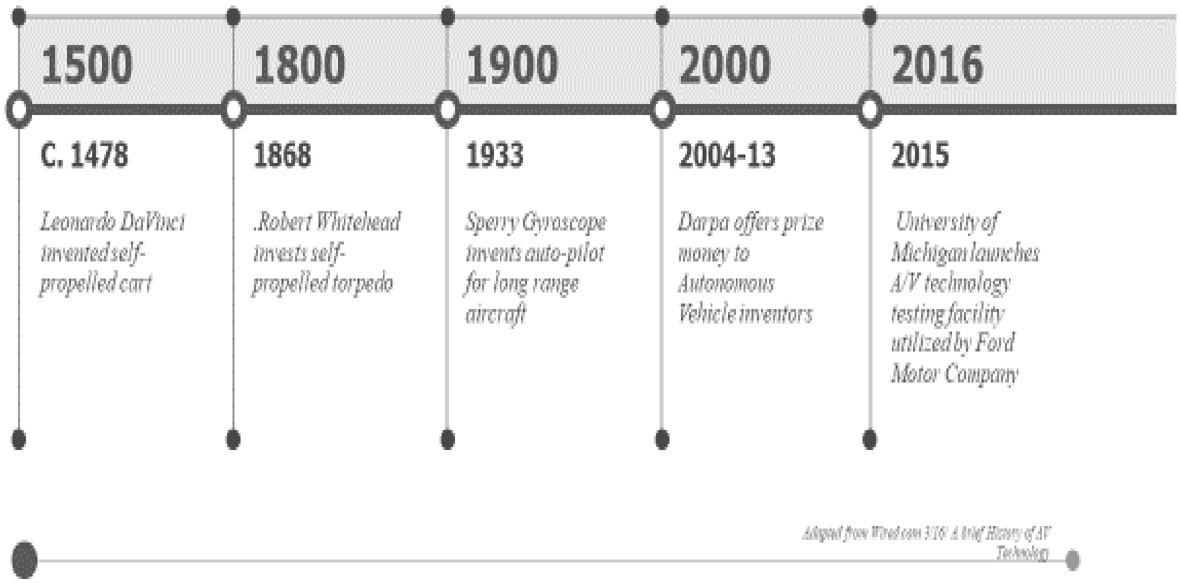

Figure 5: History of Autonomous Vehicle Technology (http://www.wired.com/brandlab/2016/03/A-brief-history-of-autonomous-vehicle-technology/)

vehicles, having delivered its autopilot program to its Model S customers via a software update. Autopilot is an advanced driver-assistance system providing Level 3 automation to its owners. Tesla has now provided Enhanced Autopilot, which is the second release of its software product. Tesla's technology platform does not include Lidar. Often referred to as computers that can drive, Tesla models (Model 3, Model S, Model X) are electric vehicles with enhanced software (Artificial Intelligence) where computers can do all of the work through the Vehicle Management System. Tesla announced they had overcome production issues with their new Model 3 IN Q3 of 2018, claiming they outsold Mercedes Benz in the U.S. The FBI announced shortly thereafter that they would investigate Tesla production claims.

Waymo

Waymo is Alphabet's (Google) autonomous vehicle subsidiary. Waymo utilizes Chrysler Pacifica vans outfitted with their own proprietary technology platform developed in conjunction with their software and technology partners. With over 10,000,000 self-driven miles and six billion in simulation they have the most experience in the A/V industry. Their Artificial intelligence (AI), and machine learning (ML) have been enhanced with both the actual and the simulation driving, enabling their vehicles to navigate through many hazards, as every vehicle in their fleet shares its information with the rest of the fleet. With over 400 vehicles in use in Chandler, Arizona, they have launched the first autonomous vehicle taxis in the area. Thus far, Waymo has filed 338 patents between 2010 and July 2017 for autonomous vehicle technology.

According to a UBS Warburg report, Waymo may deliver $114 billion in revenue by 2030. This would have a bigger impact on Alphabet's stock than You Tube or cloud computing (Krause, 2018). Waymo sued Uber in 2017 for stealing self-driving sensor designs. In early 2018, they settled the lawsuit and Waymo received $245 million in Uber stock.

Waymo is ordering 62,000 Chrysler Pacifica' hybrids as well as 20,000 ($1.4 billion) Jaguar Land Rover I-Pace electric vehicles (Higgins & Dawson, 2018). The delivery of the I-Pace is expected between 2020 and 2022.

Voyage

Voyage is a self-driving taxi company deploying their fleet into geo-fenced communities. Residents use an app to summon the vehicle and it takes them to their destination. Voyage has deployed their service to the Villages in California, and the Villages in Florida. These communities are both self-contained retirement communities with downtowns and shopping stores, and represent ideal testing laboratories for the technology. Voyage is not charging customers for this service as of late.

Voyage's first autonomous vehicle, affectionately referred to as "Homer" contained Velodyne's HDL-64E LIDAR. Its first deployed taxi, the G1, was a Ford Focus costing approximately $250,000 in all. The G2, which is their second generation vehicle is based upon the Chrysler Pacifica hybrid, cost approximately $200,000. It utilizes Voyage's own autonomous vehicle technology as well as Velodyne's VLS-128 LIDAR, a significant improvement over the LIDAR in Homer. The new vehicle employs improved sensors and best in class safety systems. Teaming up with Enterprise, Voyage will not own their vehicles, but will instead leverage the strength of Enterprise's fleet management and maintenance program, and lease the vehicles from Enterprise.

GM

GM's approach to Autonomous Vehicle Technology is multi-faceted. Level 2 technology is available on their Cadillac line, and they are working diligently on fully autonomous or L5 technology for vehicles through the Cruise Holdings division. GM's Cadillac CTS 2018 model has some of the most advanced autonomous vehicle technology available to consumers today. The Level 2 "Super Cruise (Also has some Level 3 functionality) is available on their 2018 Cadillac CT6 that allows hands-free driving on highways. Super cruise is limited to divided highways and is designed for individuals who drive long distance commutes. The system will automatically prompt the driver to return to control during periods of congestion or when conditions warrant and will alert the driver to resume control.

According to GM CEO and Chairman Mary T. Barra, GM has the ambition, the talent and the technology to create a world with zero crashes, zero emissions and zero congestion. It's not only their slogan, it's their mission. With bold statements such as that GM is putting its money where its mouth is. In 2016 they purchased Cruise Automation for upwards of $1 billion, creating a new division, GM Cruise Holdings. Cruise Automation was known for creating an after-market kit for consumers to convert certain cars (Audi A4 and S4 models) into autonomous vehicles. This technology has now been integrated into the new divisions vehicles. GM invested another $1.1 billion into the company along with Softbank which invested$ 2.25 billion. Both Softbank and GM have stakes in Lyft as well. GM invested $550 million in Lyft in 2016. GM's deal with Lyft is not exclusive, however. Lyft also recently inked a deal with Waymo.

> **With a recent massive cash infusion, GM now has the resources to continue testing A/V technology... Ford has committed to bringing a fully Autonomous Vehicle to market by 2021.**

Chevrolet Bolts were the first Cruise AV's and use two Lidar sensors mounted on the roof. Thus far GM has built 180 Cruise AV's which are second generation and include a bigger suite of sensors. These vehicles are being tested by employees in the San Francisco area. GM already owns a ride-sharing company, Maven, and is utilizing its own app, Cruise Anywhere, with its San Francisco employees and the Cruise A/V's.

With a recent massive cash infusion, GM now has the resources to continue testing A/V technology and has the partnerships to monetize their technology in ride sharing services. They are also expert in the mass production of vehicles, something that Tesla has still not completely mastered. In March of 2018, GM announced they would begin mass production of the Cruise A/V in 2019, describing it as "the first production ready vehicle built from the start to operate safely on its own, with no driver, steering wheel, pedals, or manual controls." The vehicle will contain 5 LIDAR units, 21 sensors, 16 video cameras, three interior touch-screens and will interact with passengers via a phone app. GM will require an exemption from existing Federal law in order to field it's A/V fleet.

Ford

In 2017, Ford purchased Argo AI for $1 billion in order to jump start its autonomous vehicle technology portfolio. While not the most advanced in current A/V technology, Ford is playing the long game when it comes to the deployment of these vehicles. Ford's safe bet approach is exemplified by the following quote from Argo AI CEO Bryan Salesky: "Those who think fully self-driving vehicles will be ubiquitous on city street month from now or even in a few years are not well connected to the state of the art or committed to the safe deployment of the technology." Ford's commitment is real, having pledged another $3 billion investment (through 2023) to its newly formed A/V subsidiary, Ford Autonomous Vehicles LLC. This new division will include self-driving systems integration, A/V research, and advanced engineering/A/V transportation as a service network development. These operations are moving away from the headquarters and are open to accepting outside investments. Given the state of the industry, it would not be surprising for Ford to announce new partnerships with the new division in the future.

Ford has committed to bringing a fully Autonomous Vehicle to market by 2021. In addition to the Argo AI purchase, Ford has also invested in Velodyne, due to Velodyne's track record in the development of their LIDAR technology. Ford also purchased an Israeli company, SAIPS, an AI company focused on Deep Learning, and has licensed Nirenberg Neuroscience LLC technology, which provisions system vision tasks like navigation, collision avoidance, and object and facial recognition. Lastly, Ford has invested in a Berkeley California company that produces 3D mapping abilities.

Ford is dispatching a fleet of A/V test vehicles to Miami, Pittsburgh, Dearborn and Washington DC beginning in 2019 in order to collect data and map the areas.

Uber & Lyft

Uber and Lyft are both ride-sharing transportation companies providing mobility via the utilization of a phone app. Uber suffered a number of devastating setbacks earlier this year. One of its autonomous vehicles (Volvo XC90) was involved in a deadly pedestrian fatality when it failed to stop. It was the first known pedestrian fatality involving an Autonomous Vehicle and after the accident, Uber halted the testing of its vehicles on public roads in Phoenix, San Francisco, Pittsburgh, and Toronto. The National Highway Traffic Safety Administration opened up an investigation into the crash, and preliminary results from the investigation indicated that the emergency breaking feature on the vehicle was disabled. Uber also settled a lawsuit with Waymo earlier this year that cost them $242 million in equity.

Uber created its own separate Autonomous Vehicle subsidiary, the Uber Advanced Technologies Group, based in Pittsburgh, Pa. The division is responsible for the research and testing of its Autonomous Vehicles. Despite aforementioned setbacks, they continue to move forward and have announced that Autonomous Vehicle technology is in their future. They are in talks with Toyota to possibly partner up or license their technology. Uber was scheduled to launch their IPO in 2019, so these setbacks do not bode well.

Lyft is also scheduled for an IPO in 2019 and has had more success than Uber this year. They purchased Blue Vision Labs, a London based start-up that uses smartphone cameras to develop imagery in augmented reality layers. Lyft, which received a major cash investment from General Motors, is collaborating and partnering with Waymo, as well as Magma, a Canadian Auto parts manufacturer. The first cars from Lyft's Level 5 Autonomous Vehicles will be Ford Fusions equipped with Lyft's own technology. In May, Lyft announced they were partnering with Aptiv and would launch 30 ride-hailing autonomous vehicles in Las Vegas. The vehicles will use the Aptiv technology platform on the Lyft network. Lyft's corporate strategy appears to be fostering forward motion as the collection of its partners and collaborators continues to expand.

Laws & Liability

Currently, individual states establish their own rules regarding the operation of autonomous vehicles. The federal government has taken a relatively agnostic view of legal and regulatory involvement when it comes to autonomous vehicles regulations and instead has been encouraging these companies to develop the technology and providing guidance through the Department of Transportation. Since 2012 each year more and more states have considered enacting Autonomous Vehicle legislation. Thus far twenty-nine states (National Conference of State Legislatures 2018) have passed laws related to Autonomous Vehicles. Governors in another 10 states have issued executive orders enacting regulations referencing Autonomous Vehicles.

There are liability laws which already exist, and have been tried and tested for decades in the courts. Product liability precedence has been established and product liability laws are already in place and should be sufficient to handle the modification and changes coming to the automotive industry. Until full automation, the question will be how to determine proportional responsibility in autonomous vehicle accidents, involving one or more partially autonomous vehicles where the driver and the technology could both be at fault.

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The on-demand mobility business model planned by many of the industry stakeholders for full L5 automation may very well reduce individual ownership of vehicles as customers will be able to summon transportation on their phone apps. The courts have thus far been successful in handling technical issues brought before them, and the expectation is they are well positioned to handle them in the future. That doesn't mean that there will not be challenges ahead, or that specific fact patterns will be the same. But history shows that the courts have evolved, and have been able to handle extremely technical issues brought before them.

Safety

Automobile safety technology has advanced greatly since the first vehicles were introduced. According to the National Highway Safety Administration, there are five Eras of safety (see Table 3):

An NHTSA study indicated that in 2010 vehicle crashes costed $242 billion in economic activity, $57.6 billion in lost worker productivity, and $594 billion in loss of life and reduction in quality of life due to injuries sustained in traffic accidents. These

Table 3: Five Eras of Safety

Era of Safety	Technology
First	**1950-2000 Safety/ Convenience Features-Cruise Control, Seat belts, Anti-lock brakes**
Second	**2000-2010 Advanced Safety Features- Electronic Stability Control, Blind spot Detection, Forward Collision Warning, Lane Departure Warning**
Third	**2010-2016 Advanced Driver Assistance Features- Rearview Video Systems, Automatic Emergency Braking, Pedestrian Automatic Emergency Braking, Rear Automatic Emergency Breaking, Rear Cross Traffic Alert, Lane Centering Assist**
Fourth	**2016-2025 Partially Automated Safety Features- Lane Keeping Assist, Adaptive Cruise Control, Traffic Jam Assist, Self-park**
Fifth	**2025- Fully Automated Safety Features- Highway Autopilot**

costs have gone up every year as the number of accidents and traffic fatalities has been increasing. Last year there were 1.4 million traffic fatalities worldwide and US fatalities increased 14% from 2014 to 2016 (Naughton, 2018). US traffic fatalities for 2017 were 40,100. The earlier Autonomous Vehicle and Connected Vehicle technology can be delivered to the market on a mass adoption basis, the sooner we can begin to see a decline in these rates.

Currently there are 55 companies permitted in California to test A/V. California state government requires each of these companies to file safety and accident reports. From 2014 through August 2018 there have been 54 accidents reported on California roads (Kokalitcheva, 2018) involving self-driving cars. The interesting statistic here is most of these incidents occurred when a human driver bumped into or rear-ended the A/V. A/V technology was blamed in four of the incidents, and only one incident involved a vehicle in full autonomous mode. Safety is the primary concern for passengers in A/V and the industry has not done a good job allaying the fear of the general public. Statistics point out the opposite as they are much safer that human drivers, but perception is driving these fears not fact. The two fatal accidents involving partially autonomous vehicles in March have stoked the fears of the technology and have overshadowed the technological advancements registered with the companies testing the technology. Waymo recently recorded its 10 millionth mile self-driven milestone and every foot of their experience is recorded and analyzed by AI and machine learning so any incidents and all experiences can be analyzed. Reaction and responses can be catalogued and shared with all their other vehicles enhancing road safety. They self-report that an incident occurs only once every 50,000 miles which is an enviable statistic that human drivers can only dream of matching.

Morning Consult released a study in January of 2018 surveying over 2,000 adults on their thoughts and perceptions of Autonomous Vehicles. Fifty-eight (58%) of respondents don't trust A/V's right now, but say that as technology evolves they could learn to trust them (Ramlet, 2018). This statistic was reported prior to the widely publicized Autonomous Vehicle accidents resulting in death. An information gap about Autonomous Vehicle technology also exists as "60% of Americans know little to nothing about autonomous vehicles". (Ramlet, 2018)

Cybersecurity

Blockchain technology may be coming to autonomous vehicles in the near future. According to Frost & Sullivan, a market research firm, "By 2025, 10–15% of the entire CV industry transactions are expected to be on Blockchain; which will push OEMs and suppliers to invest actively in the Blockchain infrastructure in partnership with tech consortiums, financial institutions, and regulatory establishments" (Gadam, 2018). That certainly can address concerns for the safety of transactions, but what about the actual Autonomous Vehicle technology and its susceptibility to hackers and bad actors?

With advanced technology containing millions of lines of code, in conjunction with vehicle to everything communication the vulnerability of these systems to hacking increases exponentially. Safety concerns are already of paramount importance and technology safety is even more imperative. Cyber security, just like safety, impacts the public's trust and acceptance of Autonomous Vehicles. Recently a Tesla Model X and a Jeep Cherokee were hacked with the result of vital vehicle functions being controlled outside of the vehicle (Jaisinghani, 2015). Chrysler-Fiat recalled over 1.4 million cars as a result of the hack, and Tesla repaired the breach within two weeks of being alerted.

While these incidents are isolated they still highlight the vulnerabilities of the vehicles. More must be done to strengthen the vehicles from potential hackers. Blockchain utilizes cryptography and advanced algorithms so that all data can be verified and checked in real time. Blockchain, which is usually discussed when the subject of cryptocurrencies is broached may provide the technological answer to the cyber security question.

Table 4: Critical Autonomous Vehicle Technology terms & definitions

Technology	Definition
Lidar	Surveying method that measures distance utilizing pulses of laser light and quantifying the reflected pulses with a sensor.
Radar	Surveillance utilized for detecting objects and their distance by projecting high frequency electromagnetic waves to the object which bounce off back to the source.
Odometry	Motion sensors generate data to determine a vehicle's current position relative to its a starting point.
GPS	Global Positioning System owned by U.S. government is a satellite navigation system constantly sending out radio wave signals to Earth received by users and given precise location coordinates.
Smart Cities	An urban area that utilizes sensors to receive and transmit data in order to more effectively utilize assets and resources, thereby optimizing traffic and safety.
Sensors	Devices which are designed to collect data from its environment and transmit that data.
DSRC	Acronym for dedicated short-range communications. Utilizes the IEEE's 802.11p standard. Auto communication standard.
C-V2X	Acronym for cellular vehicle-to-everything. Next generation technology utilized by mobile phones and devices utilizing 5.9 GHz ITS spectrum. Builds upon DSRC.
Geo-fence	Virtual boundary around an actual physical area.

Terminology

Table 4 summarizes some of the most critical definitions for key terms in Autonomous Vehicle technology.

Discussion

Reviewing the information gathered from the industry analysis we can see two areas of technology focus. The first area is on the autonomous vehicle technology. The second area is on the connected vehicle. These are two separate and distinct technology platforms. No convergence exists with these two technologies as of late as each side is continuing to develop, test, and perfect. This bifurcation of two different technologies and lack of convergence prevents the autonomous vehicle from containing the best of both worlds in combining the technologies available and providing the public with the safest possible product. It may be detrimental to the overall safety of the Autonomous Vehicle technology industry and we have seen a reduction in the polling numbers of the American people in the acceptance of Level 5 automation to reflect that. The Morning Consult conducted two polls earlier this year (Ramlet, 2018), one before the two fatal autonomous vehicle accidents and one just after. The proportion of respondents who perceived Autonomous Vehicles to be less safe than human drivers rose from 36% in the January survey to 50% in the April survey.

In order to overcome these objects, safety is of paramount importance. Although the statistics of safety and driving show Autonomous Vehicle technology to be safer than human driving, in order to develop a more accepting environment, this technology must be experienced and shared with the general public. Statistics are one thing, but when passengers ride in these vehicles, experiencing them first hand, it changes their perceptions in a way that no statistic could. If the industry wants to realize the enormous economic potential of this technology, it must not only be safe, but be perceived as safe as well.

Conclusions

We are at a tipping point with autonomous vehicle technology as the players are beginning to hunker down with their differing technology platforms and have begun to identify, pursue, and conclude deals with manufacturers, software and hardware providers, ride sharing companies, data and bandwidth companies, and car rental companies so that they may position themselves within the industry to sweep up the market share once the technology has developed to the point of coalescing around a business model that is practical, safe, and makes economic sense.

These companies recognize the enormous revenue potential as well as expense in technology testing. Many companies have no desire to be "blockbustered", which entails ignoring the competition to the detriment of their own business. This verb was created by the author to describe the process of an existing business too arrogant and stale in its management to recognize an upstart disruptor that will eventually destroy the business.

Level 5 Autonomous Vehicles still require advancements in technology that will take additional time. Connected vehicle technology must be combined with Level 2 and Level 3 Autonomous Vehicles now so that we can take advantage of the inherent safety benefits to prevent traffic fatalities from both technology platforms. Embracing and rolling out this technology will highlight improvements in safety that would be embraced by the general public. We must walk first with the lower levels of A/V technology and later combine them with connected vehicle technology which includes V2V, V2P and V2X.

Fatal accidents compromises the general public's trust in this new technology despite the facts from the actual safety records. How does the industry overcome the effects of these false perceptions? These perceptions while valid in the reflection of the opinion of the survey respondents, they represent fake news as it relates to the actual facts. Unfortunately, perception trumps facts in this instance. If the Autonomous Vehicle Industry wants mass adoption they are going to have to do a better job of convincing Americans of the efficacy of this technology. Road shows and demonstrations, continued testing and a cessation of fatal accidents would go a long way in reversing these perceptions. Autonomous Vehicle technology may need to perform virtually flawlessly in order to gain widespread acceptance.

Empirical analysis of crash data showed that connected vehicle technology may assist in reducing traffic accidents (Yue & Abdul-Aty, 2018). Combining this technology with autonomous vehicle technology in the Level 2 & 3 area may further aid in the reduction of accidents by removing the human element. If pedestrians have this connected vehicle technology as well, they can receive alerts to better assist in their navigation of our roadways as well. Further study is needed to ascertain the full benefits of combining these technology platforms.

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Review

This article was accepted under the ***constructive peer review*** option. For futher details, see the descriptions at:

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