A Study of Autonomous Vehicles: Background, Current Issues, & Outlook of Self-Driving Cars

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Abstract

This paper will discuss the background, industry overview, and considerations surrounding autonomous vehicles and self-driving technology. To better understand why there is such momentum in markets for this technology, this study examines its underlying components—the technologies' intended goals, progress, and current issues. Furthermore, this study explores the economic considerations and state of regulations for self-driving cars by comparing discussions between Germany and the U.S. This study will conclude with a summary on my own experience working in the autonomous driving division at BMW of North America, and forecast how self-driving technology may be moving forward in the future.

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1 Introduction

This paper will discuss the emerging technology of autonomous systems, mainly autonomous vehicles (AVs), and their ongoing transformation of the world's technological landscape. As a data professional and data scientist student, I am enthused to explore how autonomous systems are poised to change our technological landscapes. While there is a lot of discussion about artificial intelligence systems and machine learning when it comes to autonomous systems, AVs are a technology that will more directly impact our everyday lives as more companies adopt their solutions and as more mainstream consumers obtain AVs of their own. This paper will explore the background, current issues, and the future outlook of AVs. The terms "autonomous vehicles (AVs)" and "self-driving cars" will be used interchangeably, with specific context added as necessary.

The motivation for this paper is my own work within the automotive industry as a data science specialist supporting the autonomous driving division at BMW Group. While the broadening field of autonomous systems includes many fascinating emerging technologies that surround artificial intelligence systems, I became most interested in autonomous vehicles as it became clear that these systems were set to be first-in-line for adoption from mainstream consumers. Indeed, auto conglomerates such as BMW have made huge investments in testing and manufacturing AVs, alongside even bigger AV heavyweights like Waymo and Tesla. In my work with AVs, I perform exploratory data analysis on anonymized customer data pulled directly from the vehicle signals. Using data science methodologies such as time series analysis and unsupervised machine learning, I’ve learned how to extract insights from autonomous vehicles that product development engineers utilize to improve the performance of autonomous driving features. Performance metrics will often surround matters of safety, reliability, and predictability of the autonomous driving behaviors. These metrics are used to fulfill regulatory requirements surrounding the use of AVs, which is centered mainly around safety and practicality of the features for commercial and consumer use.

The race for self-driving technology is fueled by science concluding that they will facilitate better transportation services and logistics, improve safety and gridlock conditions on the road, and also support goals for lower carbon emissions. As an emerging data scientist, I wanted to explore this emerging industry in more thorough study to better forecast how AVs will affect the mainstream consumer and our rapidly changing technological landscape. Indeed, while AVs are expected to greatly improve transportation logistics and conditions on the road, the technology is still in development stages and trust from the public may take time to build. There are key aspects within the context of AVs that should be examined more closely to better understand where AVs are now in our world and where they may be going.

2 Background & Industry Overview

The first idea of an autonomous or “self-driving” vehicle was said to be first brought to life around early 1930’s Japan, using novel on-board camera technology. Today, AVs use advanced camera and light detection/ranging technology to provision advanced driver assistance systems and self-driving features. The main purpose of these technologies is in the context of AVs is to detect objects in a scene and their movement, which allow the vehicle to make automated maneuvers based on what it detects, effectively mitigating the human error factors that go into standard driving such as lane keeping, lane changes, and adaptive speed controls. In the automotive and logistics industries, AVs are showing the highest promise in transforming how services such as food delivery, taxi service, and transportation will function in the future. In the consumer markets, self-driving cars are a unique selling point for vehicle manufacturers as autonomous driving features are added as safety and advanced technology packages at time of purchase. While the usage and attitude towards self-driving cars has changed considerably in the past few years, that change in paradigm is still slow. As can be seen in Figure 1, the average consumer is warming to the idea of using self-driving cars for everyday use, with consumers in China being the least concerned about AV safety consistently since 2018 into 2020. Other markets are also showing signs of declining concerns, with the exception of India.

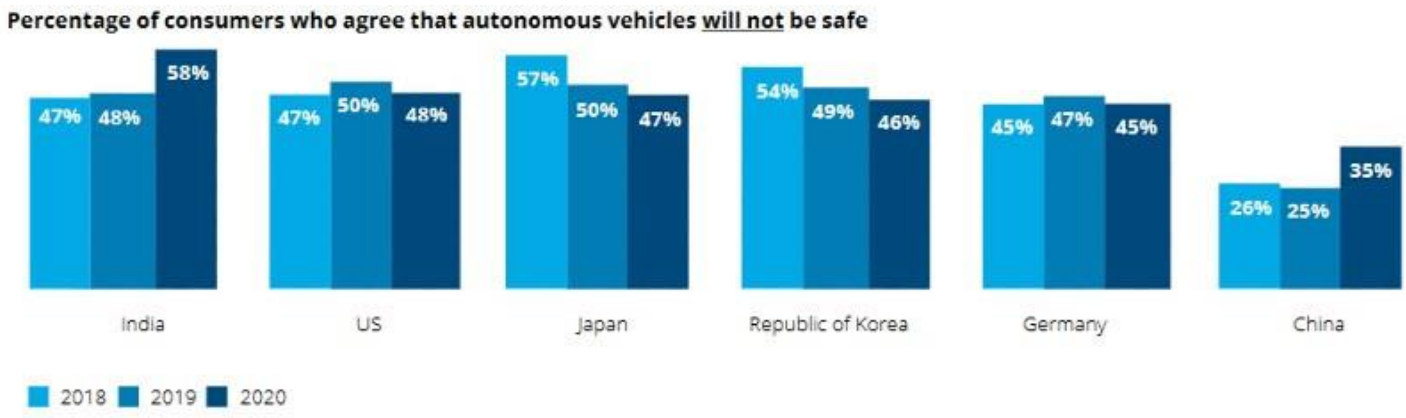

Figure 1: Consumers in most markets are warming up to AVs, lessening safety concerns. [1]

The mobility of everyday people, goods, and services is the lifeblood of an integrated global market, and in the age of COVID-19 the efforts to drive this integration has become even more urgent as the way people travel, work, and shop has changed immensely in such a short amount of time. Self-driving vehicles are set to be the premiere novel mobility concept for people and goods, as overcrowded cities and limited road space demand sustainable and efficient mobility solutions [2].

Furthermore, the explosion of interest for autonomous system use-cases is made possible by the huge amounts of data being generated every day since mainstream adaptations of Internet of Things (IoT) devices for commercial and consumer markets started about a decade ago. In the automotive industry, consumers demanded IoT in their cars that gained them access to their favorite music and navigation apps through integrations such as Apple CarPlay, SiriusXM, etc. The modern car was becoming more interconnected, with more data moving through on-board computers than ever before. It is unsurprising that engineers found huge potential for innovation as more on-board computers and extraction of real-time information from vehicle trajectories became possible. “Big data” is as big as it gets with autonomous driving, as the amount of data necessary to facilitate accurate machine learning and computer vision models is massive.

AV features are based on building accurate predictive systems, so the veracity, volume, and velocity (the “three V’s” of big data) are of utmost importance for autonomous driving. As with any new technology, autonomous driving has come with its own set of challenges and considerations as the world is increasingly exposed to it, which this paper will further explore in detail by outlining the different vantage points that are often at play when it comes to the benefits and pitfalls of widespread adoption of autonomous driving technology.

3 Economic & Ethical Considerations

A major part of the conversation surrounding autonomous and artificial intelligence systems has been its anticipated impact on economic markets and defining standards in which technologies can adhere to. When it comes to autonomous driving specifically, the economic shifts are expected to be most significant in the transit and transportation industries. Self-driving automobiles have the potential for displacing human drivers if used for commercial trucking and taxi service fleets, as well as for school and transit bus services. This impact cannot be understated, as transportation workers account for roughly 9.1% of all workers in the United States. [3] However, not all arguments regarding displacement are the same; for those who work in farming, manufacturing and construction industries can feasibly be replaced by self-driving vehicles that accomplish specific, repetitive, and often unsafe tasks that are performed in those fields. As AVs become more mainstream and affordable, the mining and farming industries have adopted these technologies to increase worker safety in high-risk operations, such as jobs where one can become submerged or trapped in collapsing tunnels.

The insurance industry will also be significantly affected by autonomous driving technology. As research has shown that human-caused accidents will decrease with increased adoption of AVs among the everyday consumer, insurance companies can rethink their traditional business models. For example, experts have considered shifts toward ensuring car manufacturers against liability resulting from technical failures associated with AVs. As of 2019, AV manufacturers such as Google (Waymo) and Mercedes have already begun self-insuring their products. [4] Another feasible way in which the insurance industry may change is through increased consumer use of AVs. Similar to how many insurance carriers provide benefits to those who have certain safety features in their cars, AVs regulatory compliance will be centered around safety and the insurance industry will be involved in validating those standards. Continued adoption of AVs is expected to reduce traffic incidents, as major catalysts for accidents such as improper lane changes and merging are the focus of autonomous driving technology. One study from McKinsey & Company found that AVs could reduce accidents by up to 90 percent in widespread adoption, potentially remedying the enormous impact car crashes have on the US economy and thousands of lives lost each year. While AVs are expected to greatly improve safety conditions on the road, the technology is still it's development stages and consumers are aware of this—as such, trust from the public may take time to build. This point raises the question of what ethical considerations must be made for AVs and how our lives may be affected by it.

While there are considerable investments being made into AVs in 2021 and the industry has seen some growth in consumer markets, there are still several barriers to widespread adoption. Tragically, self-driving vehicles have incurred fatalities during testing phases which has naturally lowered public trust in its development. As of 2021, six fatalities have been reported involving AV's manufactured by Waymo and Tesla Motors; the vehicles were specifically noted to be in "autopilot" or self-driving modes [5]. In response to these incidents, more focus has been put on the testing efforts of the distinct autonomous driving levels that AVs reach today. Accidents that occur due to human error are different from those that may happen with AVs. While a variety of factors may lead to an accident when there's a human operator, AVs can experience failure of technologies; of particular concern is failures in the on-board cameras or radar-like systems that are fundamental to autonomous driving functions. More specifically, the errors AVs may experience have the potential to result in sensing and decision-making errors in a mixed traffic environment [6]. As can be expected, manufacturers will defend their technologies, and technologies dealing with applied data science or artificial intelligence systems will naturally be a sort of black-box operation to not only the typical consumer but also to policymakers. In the case of a 57-year-old pedestrian who was struck and killed by a Waymo AV being operated by a ride-share service driver, the manufacturer says the tragedy occurred because the driver ignored takeover requests sent by the vehicle. This conclusion was disputed by the driver. A similar situation occurred when a Tesla AV was said to be stuck in "autopilot" mode for dangerously too long when it sent the vehicle crashing into a truck, killing the driver who was suspected of having fallen asleep. Both cases highlight the complexity of how such tragedies can occur and the challenges being faced when the root cause of an AV accident is being investigated. This complexity creates a fog when you combine the logistics of accident investigation with the literal webs that machine learning and artificial intelligence technologies are made of. In an effort to explore this technology more in-depth and in result understand significant issues, the next section will explore the main tech behind self-driving cars and their features.

4 Technology Behind AVs & Their Goals

To understand how driving automation systems are defined, it is helpful to know the six levels of driving automation as defined by the Society of Automotive Engineers [7]. At Level 0, a vehicle is considered manually controlled; the human is providing the dynamic driving task, although assistance feature such as emergency braking may be possible. Level 1 is the first and lowest automation level, where vehicles in this category feature a single system for driver assistance for steering and accelerating—this is the cruise control feature most people are familiar with. With adaptive cruise control, the vehicle is capable of controlling distances from a car ahead, but the human driver continues to be responsible for monitoring steering and braking. At level 2, there is an advanced driver assistance system: this means the vehicle controls steering, acceleration, and deceleration. The human is still in the driver's seat and can take control at any time; Tesla's Autopilot, GM's Super Cruise, and BMW's iX model qualify under Level 2.

At Level 3, there is a substantial difference from a technical standpoint: these vehicles can detect their environments, and work to make decisions for themselves. However, a human driver is still required to be alert in the event of a failure. At Level 4, the automation enables the vehicle to intervene in the case of system failures, hence a driver is not required in most scenarios; however, a human can still make manual overrides if necessary. This is considered full self-driving mode, but legislation and infrastructure limit where implementation and testing is possible. Thus far, Level 4 AVs in use today are implemented for ridesharing services such as Waymo in Arizona, and Baidu in China.

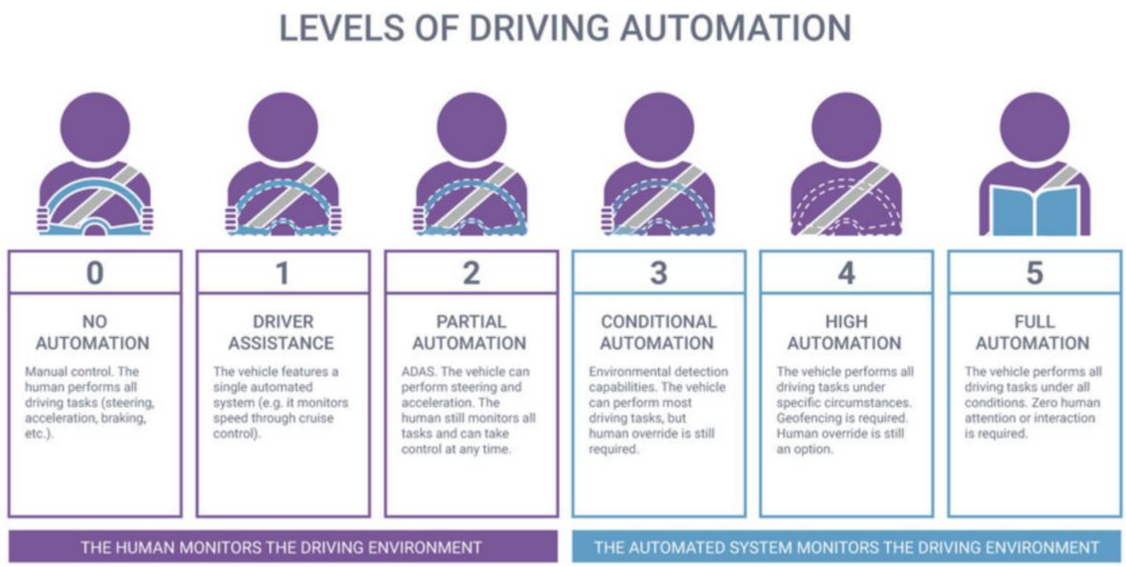

Figure 2: Automation levels in autonomous vehicles. [12]

Self-driving technology can be broken down into four major steps that make autonomous driving possible: The first step will be a combined use of a software system over a sensor array that includes cameras, and specialized radar sensing known as LiDAR; the acronym is seen often when AV technology is being explained. It stands for light detection and ranging and is a remote sensing method that uses light in the form of a pulsed laser to measure the time for a reflected light to return to the sensing device. This can be compared to the way a human uses their senses of sight, scent, etc. to understand objects in their environment and make distinctions between them. Next, an AV system must make sense of what the different objects around the vehicle are, which is usually powered by classification algorithms. A prediction system is then used to determine what these objects may do; examples include the movement of bicycles, other vehicles, and what a pedestrian might do within the next few seconds. Once that prediction is outputted, the system must plan a trajectory for the vehicle to drive within that environment. Finally, the system must control steering, braking, and acceleration by sending signals so the vehicle can go where it needs to. Trying to predict the behavior of human pedestrians can be tricky, as humans are unpredictable especially when moving in an environment such as an intersection in a densely populated city. The wrong configurations in the object detection algorithm in one of these systems could spell trouble in a testing or real-world scenario and could make all the difference in systems that can detect the sudden movements of a pedestrian and ones that can't. As such, it is of paramount importance in autonomous driving that the underlying computer vision technology is as developed as possible.

Computer vision and object detection are the mainstays behind many innovations in the past decade, with AVs being among the most important. Computer vision is defined as extracting high-level information from images and video, which is then used to inform many technologies used in industry. Besides advanced driver assistance systems and self-driving tech, computer vision has transformed agriculture, logistics, banking, and surveillance. Computer vision is behind the advancement of robotics in manufacturing and logistics, as well as in the form of face recognition for banking and surveillance applications. Computer vision has seen major innovations through the advancements of camera technology, using “frames” in a way a camera does but with high-performance computing and data science to fully realize its power. Many of the use-cases for which computer vision is used require that the algorithms be run in real-time on embedded systems, which may need to run on low-power depending on the condition. As such, delays are a major concern in computer vision algorithms when it comes to accuracy. In the context of autonomous driving, a car moving at 55 miles per hour could suffer a delay of up to 3 feet of braking distance if the computer vision algorithm missed a frame in processing. In the example of pedestrian detection, the algorithm running in the vehicle must process each input frame without delay for the sake of safety. [8] The next section will briefly explore how object detection in computer vision tech is crucial to building self-driving tech that is reliable, with focus on the particularly difficult task of pedestrian detection; this has been of the main concern surrounding the technologies’ reliability in recent times, as previously mentioned.

The illustration in Figure 3 shows how computer vision algorithms, backed by machine learning methods based on artificial neural networks, are the main technology powering self-driving cars.

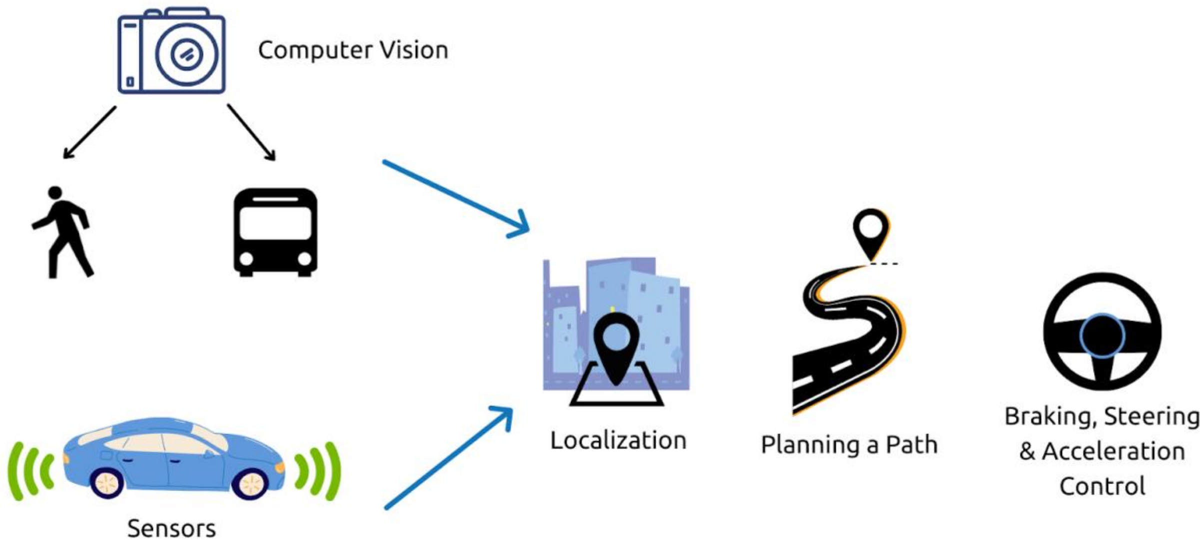

Figure 3: A flowchart of how self-driving cars work with computer vision technology.

The accurate and reliable detection of objects is a critical requirement to realize autonomous driving. As urban areas become denser, the ability for AVs to gain awareness of other traffic participants and potential obstacles are crucial to avoiding accidents that can be fatal. What makes pedestrian detection in particular a challenge is the complexity within the frames. Pedestrians have highly varying motions when moving in urban environments, and a large variety of appearances in clothing and poses. [9]

The various interactions between pedestrians and other pedestrians, and other factors in the environment will often cause an occlusion–blocking of crucial frames for the objection detection algorithm to work accurately. Today, pedestrian detection problems are being deeply investigated in the AV industry;

manufacturers put a high priority on acquiring a lot of testing hours towards improving their detection systems.

Figure 4: Through 2019, companies spent over $20 billion in developing self-driving cars. [10]

AV manufacturers have made huge investments into their R&D so they can accumulate more testing hours. AV companies know that the more testing hours are reported, the better chance that the public and any regulating bodies can build confidence in AV reliability. Of course, the opposite will be true if these detection systems are failing during testing, hence why manufacturers are piling their resources into these technologies at a record rate. It should be noted that although investments into AVs have been high, they have yet to bring any significant revenue to any manufacturer. This is no surprise as this is historically the case with many new technologies. The adaptation is expected to be slow but steady, with one barrier being the slow and inconsistent work being done in towards establishing regulatory guidelines for self-driving tech. The next section will explore the current AV markets in the United States and Germany in this context.

5 The State of Regulations for Self-Driving Cars: U.S. vs Germany

The market for self-driving cars has seen considerable interest on all sides of the world in the last few years, with automakers within their respective countries moving towards a sort of "arms race" comparable to when the U.S. and Russia wanted to land on the moon. In this race, the U.S. has lost some momentum due to developers and automaker disagreements over which guidelines should be implemented. The lack of agreement has led to stifles in Congress, where lawmakers have yet to pass regulations on a country-wide level. Thus far only a handful of states have passed meaningful regulations regarding self-driving cars and the places they can be driven; this is a problem precisely because they are state-level regulations, and driving is inherently an interstate matter. [11]

In contrast, Germany passed a law in May 2020 that allows automakers to implement self-driving car services country-wide. The major distinction from U.S. law is that driverless cars can now be operated anywhere in the country, with a requirement that a technician supervise the vehicle nearby and take over as needed. This stipulation in the law is a reminder that the technology is not yet fully trusted to operate entirely on its own in unpredictable traffic environments.

Regardless, the law opens the door for German automakers to not only monetize their AVs, but also to collect huge amounts of data that can lead to further development (with the help of some of that driverless car service cash).

The patchwork being done on regulations in the U.S. thus far could mean that automakers in Germany have an edge in their investments toward AVs; the lack of guidelines could deter the technology from reaching higher scales in the U.S. to a point where the technology can be profitable and make returns on the huge investment of efforts going into AVs.

6 Summary of Internship: BMW Autonomous Driving Team

This section will summarize my experience in the autonomous driving division at BMW of North America. The autonomous driving sub-division exists within BMW's engineering department, and spreads across different teams spread throughout North America, Europe, and China under BMW Group. This team is known officially as the ADAS team, which stands for "Advanced Driving and Autonomous Systems". While BMW is well-reputed as an iconic German luxury brand, the company's autonomous driving subdivision has made significant progress in developing self-driving tech. As the third largest European automotive manufacturer, BMW joined the race of self-driving cars alongside Mercedes-Benz and Audi and competes directly with AV giant Tesla Motors. Like Tesla, BMW offers autonomous driving packages to customers as an extension that can be added to their vehicle purchase. BMW’s latest development in AVs is the iX, which launched in North America in November 2021; the all-new model is an electric crossover that runs on a Level 2+ autonomous driving system, with an impressive technology stack consisting of 12 ultrasonic sensors, 5 cameras, and 5 radar sensors on-board. With specified consent from customers, BMW sends sensor data from critical driving scenarios through the cloud to their backend systems, where the ADAS teams analyze the data for feature optimization. The teams are made up of engineers of diverse backgrounds in computer engineering and automotive product developers.

7 Conclusion

The race for self-driving cars is yet another example of history repeating itself with what we saw in the “race to space” several decades ago: the key difference is that we live in a vastly different world in 2021 than we did in the 1980’s, and the race is mainly fuelled by the strong potential for profits. It may in turn be mutually beneficial for both the consumer and the automakers, as there are signs that the average driver has progressively warmed up to self-driving cars—particularly in the ride service industry in Europe & China. There is less momentum in the U.S. due to a lack of agreement among stakeholders on how to pass regulatory guidelines, and possibly due to incidents which lead to fears of continued failures in AV technology. These incidents have caused several automakers to make large investments into developing the technology, which are expected to bring significant innovation in the next decade, especially with the development of advanced computer vision algorithms. Indeed, AVs will affect the mainstream consumer’s everyday life and rapidly change the technological landscape.

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