Obstacles and Setbacks in the Development and Adoption of Autonomous Vehicles

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Dennis Tian

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Advisor

Joshua Earle, Department of Engineering and Society

Introduction

On October 2, 2023, an autonomous Cruise robotaxi struck and dragged a woman 20 feet across a busy street in San Francisco (Marshall, 2023). This caused widespread shock and outrage, and most wondered: how and why did this happen? This is just one of many setbacks in the automotive industry's push toward integrating autonomous vehicles into general society. Not only do manufacturers have to deal with safety concerns and testing regulations, they also have to consider the public's opinion and trust regarding this new technology.

Manufacturers' persistent drive toward advancing this budding technology is completely understandable, though – besides the obvious motivation to be the first to achieve full automation, the technology itself has great potential due to how ubiquitous vehicles are nowadays. Every day, countless people drive and ride in vehicles without a second thought for their safety. Unfortunately, the transportation system that provides so much convenience and flexibility is also one of the leading causes of death around the world (CDC, 2023). Vehicular autonomy has not only technological and scientific implications but also ethical and social ones, so it is crucial to facilitate progress as much as possible.

There have been countless bold statements that full autonomy is just around the corner, yet it is apparent that we are still a long way from achieving that lofty ideal. What is causing the wide discrepancy between these optimistic claims and reality? It is important to try to analyze why the development of autonomous vehicles has hit so many snags in order to determine if a different approach is needed for testing, implementation, and integration, and if so, what strategies should be involved. In this paper, I explore the possibility of these efforts being redirected toward public transportation with a focus on infrastructure. I first provide some background on the different classifications of autonomy, then detail the research methods and

STS framework I employed. After that, I present several case studies and literature review and analyze the implications in the context of my STS framework. Finally, I discuss the broader context around the analysis and explain why I believe the direction I suggest is beneficial.

Case Context: *How are autonomous vehicles classified?*

Vehicular autonomy is typically categorized into six distinct levels (Herrmann et al., 2018). Level 0 is ordinary, non-assisted driving: the driver must be the one performing all aspects of the driving at all times; there are no other systems that provide aid. At level 1, some system in the vehicle can either control the steering or the acceleration/braking, and the driver must control the other function at all times. A common, present-day example of this is cruise control, where the acceleration and braking are automated to maintain a constant speed. Level 2 describes when both steering and brake/acceleration are automated, though the driver must be constantly be monitoring the situation. This level is where the current state of autonomy stands. Levels 0 through 2 are defined such that the driver is still considered the one operating the vehicle and is liable for any accidents. Level 3 is similar to level 2, but the driver is no longer considered the one driving when the self-driving feature is turned on. However, the driver must be prepared to take over all driving functions whenever the system requests. Levels 4 and 5 are much more technologically advanced, being able to be the sole operator of the vehicle and not require driver supervision or takeover. The only difference between levels 4 and 5 is that level 5 vehicles can operate in autonomy everywhere, in all conditions. Figure 1 below shows a chart summarizing the definitions, expectations, and examples of the different autonomy levels.

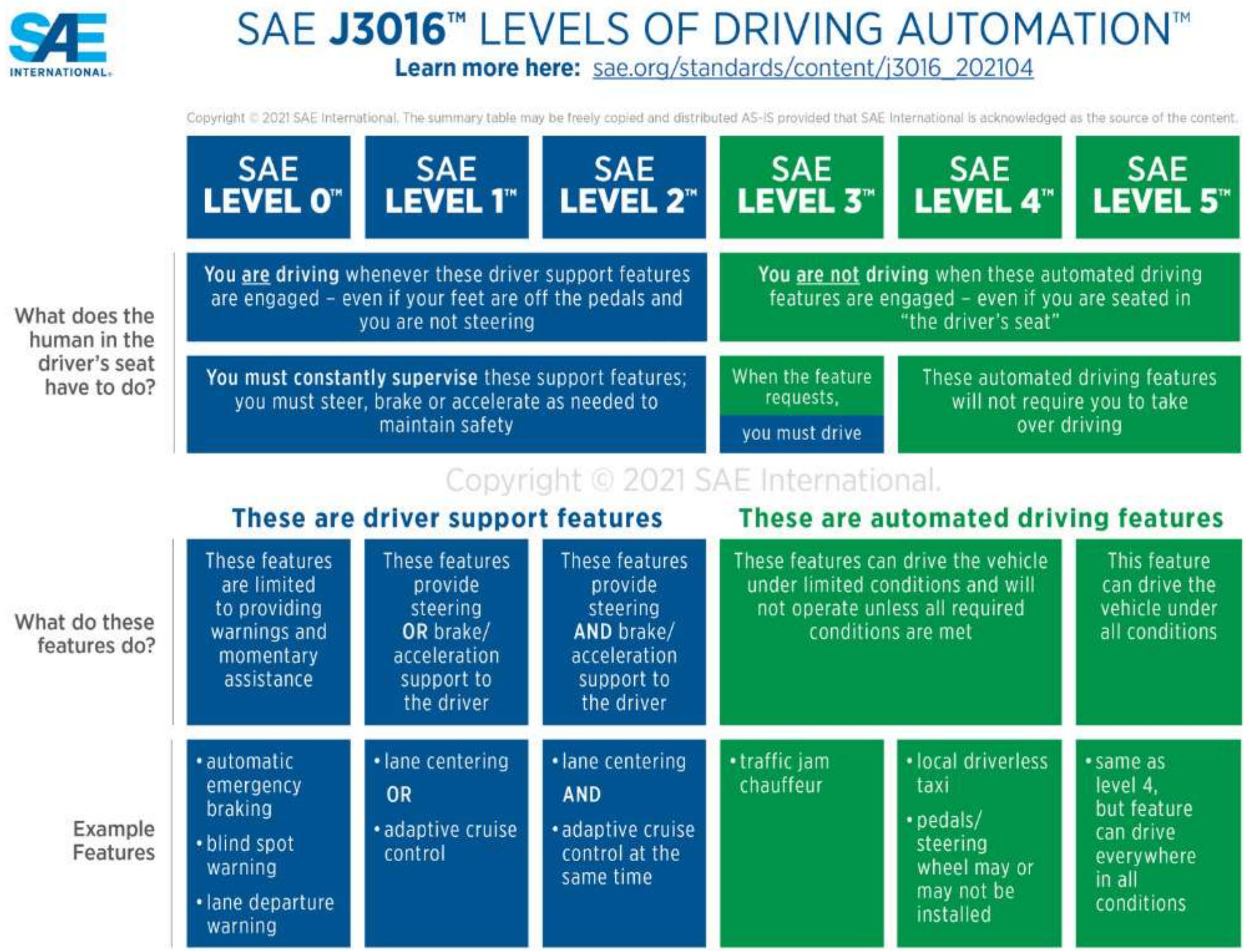

Figure 1. SAE Levels of Driving Automation Chart

Autonomous vehicles offer more benefits than just eliminating human drivers, though. A large-scale system of fully autonomous vehicles can, at least in principle, greatly reduce traffic congestion, fuel consumption, and accidents (Fleetwood, 2017). This will make a significant impact on general public safety, as driving-related accidents are a critical problem worldwide – they are the leading cause of death for people between the ages of 5 and 29, with nearly 3,700 people killed daily and 1.35 million fatalities annually. Furthermore, traffic accidents impose a huge burden on the economy, estimated to "cost the world economy approximately $1.8 trillion dollars from 2015-2030. That's equivalent to a yearly tax of 0.18% on global GDP" (CDC, 2023). The dream of widespread vehicular autonomy has been promised time and time again, but it is still nothing but that – a dream – in the current day.

Methods

Autonomous vehicles on the road have the ability to affect virtually anyone, and understandably, their development, regulation, implementation, and utilization span a multitude of scopes and social networks. It can be difficult to pinpoint sources of causation in an environment that has so many moving parts, both technologically and socially.

As such, the STS framework I use for this paper is actor-network theory, or ANT. This framework asserts that a technology and its interactions in the social landscape can be represented as a network composed of both human and non-human actors. Non-human actors are a unique feature of this framework; the framework employs general symmetry, which stipulates that both human and non-human actors should be integrated into one network, and that all actors should be assigned equal agency (Latour, 1992). These actors all have individual interests, and they may work with or against each other to shape the network (Sismondo, 2010). The framework emphasizes the interconnectedness of the actors and the networks of relationships that shape technological development. ANT was a suitable framework for analyzing my research question because it helped uncover the diverse range of actors involved, including car manufacturers, software companies, drivers and pedestrians, traffic infrastructure, etc. It aided in the process of untangling the complex web of relationships surrounding the technology and helped me pinpoint the relevant ones. One key aspect of the framework is identifying obligatory passage points, or OPPs, in the network, which are elements that are fundamental to the network itself; they are critical points in the network that must exist in order for all of the actors to achieve their interests (Callon, 1984). This was especially relevant to the discussion of autonomous vehicles because it helped shed light on the key parts of the relationships within the network to identify the root causes of the problems. By tracing the relationships and interactions between the aforementioned actors as well as comparing their individual interests, ANT provided a comprehensive understanding of the complex sociotechnical dynamics influencing the autonomous vehicle ecosystem.

Furthermore, I combined the framework analysis with two primary research methods: finding, reading, and synthesizing previous literature and case studies. The first step in my research was to analyze literature regarding the history of autonomous vehicles to gain a more comprehensive understanding of its evolution, both as a technology and a societal influence, as well as the different levels of autonomy. I then investigated the current progress of autonomy, including aspects that were still in development; this encompassed the technologies themselves, the benefits they have been able to provide, and the difficulties that accompanied them. After that, I reviewed case studies centering on several industry-leading companies, such as Cruise and Tesla, and incidents that impacted their progression. These case studies demonstrated the impact autonomous vehicles had and continue to have on society and the public perception of them, and they also highlighted recurring and common hurdles that have been encountered. To understand the underlying problems in current approaches, I consulted other literary sources discussing the pitfalls in the progression of the industry and how they were overcome (or why they have yet to be overcome). By combining these sources with the analysis of the ANT framework, I successfully identified actors and relationships that support the technology's development and ones that should be addressed to avoid setbacks.

Results

In this section, I examine the missteps of two prominent companies in the sphere of autonomous vehicles, Cruise and Tesla, as well as two of the main pieces of literature used to formulate my argument.

Case study: Cruise robotaxi incident

As mentioned previously, a gruesome incident involving a Cruise robotaxi made headlines only a few months earlier. In August 2023, the state of California cleared Cruise and Waymo to launch their robotaxi services in San Francisco. People could hail a robotaxi for a ride in just a few taps of a phone. Despite having claimed to have performed extensive and rigorous testing, the performance of these autonomous vehicles was questionable. There were numerous cases where a fleet of robotaxis would simply freeze and refuse to move for extended periods of time due to communications errors, resulting in chaos on the road and human drivers being trapped. Later on in the year, one vehicle collided with a fire truck that ran a red light on the way to an emergency, which understandably raised some eyebrows regarding the thoroughness of Cruise's testing. The misfortunes of Cruise's robotaxi service finally culminated on October 2, 2023, where a woman crossing the road against a red light was struck by a car in the adjacent lane to a robotaxi. The car pushed the woman into the robotaxi's lane, and despite the robotaxi braking to try to avoid her, it still made impact. However, it did not stop; instead, it continued forward for a short period of time, dragging the woman underneath it and 20 feet across the road. This immediately sparked an in-depth internal investigation and the suspension of all Cruise vehicle operations in San Francisco (Marshall, 2023). Despite the recalls and removal of all of its vehicles from the roads of the United States, Cruise made the controversial decision to continue with their overseas testing, primarily in Japan and Dubai (Bensinger, 2023). People have argued that it is unethical to keep testing in other areas when they themselves have deemed their vehicles unfit for operation in the United States.

Case study: Tesla's timelines & claims

Tesla is one of the biggest names in the automotive industry, especially known for its CEO, Elon Musk, and his persistent drive toward the ultimate goal of full, level 5 autonomy. As early as 2016, Musk and company announced: "all Tesla vehicles produced in our factory – including Model 3 – will have the hardware needed for full self-driving capability at a safety level substantially greater than that of a human driver" (The Tesla Team, 2016). This was a very bold and aggressive claim, and many criticized them for being too hasty in rolling out technology that was not mature enough. Tesla's plan was to employ a technique they called Shadow Mode – for the first few months, the autopilot system would run in the background as humans drove the cars normally; it would then compare the actions of the human to what it would have chosen to do and send the data back to Tesla for engineers to investigate. After this collective data gathering took place, Musk made yet another bold promise: to have a vehicle drive from Los Angeles to New York with zero human intervention. None of this ended up happening (Marshall, 2019). In 2019, Musk made another assertion that by the end of 2020, Tesla would have produced a vehicle capable of taking people to their destinations while they slept in the driver's seat. Again: another promise, another letdown. Recently, in December 2023, Tesla faced a mass recall of over 2 million vehicles after people found that the Autosteer mechanism of their autopilot system was prone to being misused (TechHQ, 2023). Drivers were relying too heavily on the self-steering technology and failed to take control of the vehicle when necessary. This is one of the major downsides of Tesla marketing their products as "autopilot": the name may easily lead people into thinking that it is acceptable to completely disengage from the driving task when autopilot is on, even though the technology is nowhere near that level of sophistication. In fact, the German government even requested Tesla to stop using the term for these exact concerns (Page, 2020).

Literature review

Venkata Kosuru & Ashwin Venkitaraman (2023) explored the recent developments and setbacks in the field of autonomous vehicles in their paper *Advancements and challenges in achieving fully autonomous self-driving vehicles*. They argued that one of the major roadblocks to the integration of fully-autonomous vehicles in society is the lack of infrastructure. Currently, there are no countries with any sort of autonomous vehicle infrastructure at a larger scale, so naturally the technology's progress is inhibited: "While some optimists believe that level 5 vehicles will be commercially available in the next five years, most agree that it could only hit the roads at least a decade from now. This limitation is because it requires a not yet invented disruptive technology, and there will be a need for many infrastructure developments before they can be used commercially" (Kosuru & Venkitaraman, 2023, p. 162). These developments include, but are not limited to, high-speed and extremely reliable connectivity systems to communicate with and regulate autonomous vehicle traffic and similarly robust vehicle-to-vehicle communications protocols. The key point here is that even though they may function relatively well on their own, because autonomous vehicles are such a fundamental disruption to the way traffic operates with human-driven vehicles, they cannot succeed on a larger scale without infrastructure adjustments. Kosuru & Venkitaraman surmised that it will take at least ten years to upgrade infrastructure to an adequate degree, which makes Elon Musk's timelines look absolutely absurd. Furthermore, they found that although the technology for level 3 and level 4 autonomy has been more or less achieved, the United States has refused to approve them for mainstream use due to security, safety, and legal concerns.

Analysis

The first step in the Actor-Network Theory analysis process is to define the actors. I used several broad categories of actors: car manufacturers, system developers, commuters (people who use the roads, such as drivers, bikers, and pedestrians), traffic infrastructure, and the vehicles themselves. It is worth noting that I deliberately left out some important actors, such as regulatory agencies and government organizations, because I did not focus on regulations or legal considerations in the analysis. Each of these actors have their own interests and relationships with other actors: car manufacturers want to maximize efficiency and profit while minimizing accidents, and they direct and employ the systems developers; developers want to create reliable systems while earning a high salary, and they produce and test those systems that control autonomous vehicles; commuters want to be able to use the roads efficiently and safely; traffic infrastructure enables the transportation system to function; and the vehicles are used by drivers and affect nearby commuters.

I was able to identify two obligatory passage points; one of these was traffic infrastructure, a key actor in the network. Without the necessary infrastructure, vehicles would not be able to logistically or legally navigate public spaces. If the vehicles themselves were then unable to function, the rest of the actors would not be able to achieve their interests.

Currently, the traffic infrastructure is simply not designed for autonomous vehicles, as Kosuru and Venkitaraman mentioned in their paper. Ongoing efforts for many manufacturers are solely trying to integrate this new technology into a system that is highly incompatible with it. The unpredictability of human actions as well as the large number of edge case situations results in autonomous vehicles having a much poorer performance than theoretically possible. So, it would seem that developing compatible infrastructure together with the vehicles is the more logical course of action. One of the most difficult parts of developing infrastructure is deciding how tightly integrated it should be with the vehicles themselves. Direct communication and dependence between infrastructure, a vehicle, and the surrounding vehicles allows for a very efficient, safe environment for everyone. However, this dependence is also what makes it so problematic – this huge efficiency boost is only applicable when things are going as expected.

Traffic infrastructure is something that is so ubiquitous that most people take it for granted: when you are at a red light, you assume that it will turn green after a reasonable amount time. What if all the lights just stayed red? When elements such as traffic lights fail, humans must be called upon to direct vehicles, which significantly slows down the overall flow but is still effective. In a tightly-integrated autonomous vehicle system, though, it would likely be much more difficult to realize a temporary solution like this – fully-autonomous vehicles are designed to eliminate the need of any human intervention, but this is mostly focused on the driving itself. When (not if) the infrastructure they operate within malfunction, too much interdependence would result in entire swaths of traffic being rendered immobile. Considering this, I believe that although infrastructure should be improved to communicate more effectively with vehicles, dependence should be avoided, no matter how much potential efficiency is being sacrificed. These gains are all lost in the event that something goes wrong.

The other obligatory passage point that I uncovered was the developers of the autonomous systems, the creators of the vehicles' "brains." These actors are the experts on the technology itself, upon which the autonomous vehicle network is clearly dependent. Unfortunately, they sometimes have to juggle conflicting interests between themselves as developers and the car manufacturers that employ them. As a software engineer myself, I can say that most of us strive to write code that is as reliable and efficient as possible. However, this is often not possible, at least to the extent that we would have liked, due to external constraints imposed by the project or team. One can only wonder about the quality of the autonomous systems produced by a company like Tesla that pushes to get a technology out to the public almost a decade before many predicted. It is not unreasonable to assume that speed is one of their highest priorities, and speed being a top priority directly conflicts with quality development and testing. Waymo, owned by Alphabet, one of Cruise's main competitors, has grappled with the task of full autonomy for over fifteen years, and they still have not made significant breakthroughs. This starkly contrasts with Cruise, for example, which attempted to deploy full fleets of autonomous robotaxis in a matter of years. Additionally, if companies actually put as much importance into the lifesaving potential of the technology as they said, there would be much more collaboration going on, like previous major developments, instead of the corporate, profit-driven agendas seen presently.

Unfortunately, the reality is that conflicts of interest go beyond those between developers and business leaders. Almost all of the actors I focus on have different priorities, some of which are difficult to coexist with autonomous vehicles. One would think that commuters in general have similar interests, but the three main ones – drivers, bikers, and pedestrians – each have their own needs. Drivers, of course, require well-maintained roads with infrastructure that balances order and flexibility. Typically, there are clearly-marked bike lanes so bikers do not impede cars. For commute to be safe for pedestrians, there must be sidewalks and crosswalks that other commuters yield to. This is alone a tall task for autonomous vehicles to master, especially since different regions may have vastly different traffic patterns, regulations, and infrastructure appearances. Autonomous vehicles operate most effectively with a rigid infrastructure tailored to them, minimizing unpredictability and emphasizing order. This is directly at odds with human commuters, since bikers, pedestrians, etc. have inherently unpredictable behavior.

Furthermore, all of the above is under the assumption that autonomous vehicles are perceived as a worthwhile and positive investment, both to businesses and to society. Considering the amount of time and effort that has been spent and the myriad of problems yet to be tackled, such as job displacement, ethical dilemmas (like the trolley problem), and cybersecurity risks, it would not be too surprising if companies started to move away from developing privately-owned autonomous vehicles and direct their focus elsewhere, since their main goal is profit—all of the research and development is wasted if it is directed toward an ultimately infeasible goal. Additionally, if urban areas decided to move infrastructure in the direction of public transportation and ease of access, current efforts would also be fruitless.

The pursuit of vehicular autonomy is not incompatible with this ideal, though; in fact, public transportation in cities might be the most logical first step in investigating the feasibility of integrating it into society while reconciling the interests of all of the various actors as much as possible. First, public transportation operates on much more predictable schedules and is typically confined to one specific locale, so two major variables are made much more manageable: time and location. Autonomous vehicle systems struggle greatly on operating in all environments in any condition, but public transportation systems could tailor their systems to be much more accurate in the specific times and locations that they operate in. Furthermore, public transportation emphasizes the development of quality infrastructure, which aligns perfectly with the current needs of autonomous vehicle technology. Additionally, although manufacturers would no longer be producing vehicles for private use, they could still partner with different cities to develop the most effective public transportation solution, which then fuels competition.

However, the implementation of the system would have to be compatible with other means of transportation, so a separate bus lane would make the most sense; it would introduce the least interference to the surroundings, especially if the autonomous vehicle breaks down. Efforts in autonomous public transportation have already begun, with promising results manifesting all over the world (Robare, 2023). Finally, this particular application for vehicular autonomy serves as a good testing ground to gauge whether or not and when the technology is mature enough to move into wider scopes.

Discussion

Autonomous vehicle technology has come a long way since the concept was first introduced decades ago, but it has been anything but a smooth ride. Recently, every new development has seemingly been accompanied with one or even multiple subsequent incidents, negating the effect on public perception. Although the root causes of these recurrences are hard to pinpoint, my analysis revealed two possible and significant factors.

The first of these is the overzealousness of businesses trying to become the industry-leading pioneer in this budding field. The result is that the research, development, and testing processes are primarily driven not by the desire to perfect safety, reliability, and performance but by the aspiration for profit and haste. After all, the company that creates the first approved, fully-autonomous vehicle will likely be hailed as the most influential group in the industry since the likes of Henry Ford. Manufacturers should treat autonomous vehicles as a completely new concept instead of simply software and hardware add-ons to the existing ideals; their testing and quality control should be held to the same critical standards as a technology still in relative infancy, which it ultimately is. It is quite apparent that many frontrunners in the field, like the aforementioned Cruise and Tesla, fit into this "speed first, quality second" category. I believe that there should be increased and stricter requirements and regulations on quality of both the computer system and the vehicle testing. This would benefit the manufacturers as well, as companies like Tesla have been repeatedly bogged down by lawsuit after lawsuit upon mishaps. Avoiding these time-consuming annoyances, even if it takes longer to release, will save time and money in the long run.

The second of my findings revolves around the nature of testing and implementation. The current traffic system is quite disorganized, and any unexpected occurrence has the potential to delay hundreds, if not thousands, of commuters. Unpredictability is the worst enemy of autonomous vehicle systems, and it is evident that they achieve the highest performance in rigid, regulated settings; that is, they have the highest success when operating around other autonomous vehicles and a traffic infrastructure that is tailored to them. Trying to fit localized instances into a larger system that is unfavorable to them, especially at this stage of maturity, is akin to asking for accidents to happen and people to object. I believe that it would be much more appropriate to develop the infrastructure, as well as the communications between autonomous vehicles and with the infrastructure, alongside the actual algorithms themselves. Although one downside of this approach is that it requires significantly more time and funding to realize these systems, even at a small scale, I still think that this is the best course of action. It is difficult to foresee all of the possible roadblocks to this newly-emerging technology, but one strong candidate for vehicular autonomy is public transportation, with its rigid schedules and localized use. Only after being able to successfully implement autonomous public transportation would we be technologically and societally ready for a wider adoption of autonomous vehicles extending to private use.

With so many well-funded organizations striving for the common goal of full autonomy and lives on the line every day, we should aim to look ahead and take a more holistic approach on the development of vehicular autonomy, as rushing to meet short-term goals will only end in more and more mishaps. Everyone will be affected by this revolutionary and inevitable change, and we have the power to pave the way for the future.

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