Considerations for Implementing Autonomous Vehicles' Behaviors

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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

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Introduction

"[Autonomous vehicles (AV)] have the potential to fundamentally alter transportation systems by averting deadly crashes, providing critical mobility to the elderly and disabled, increasing road capacity, saving fuel, and lowering emissions" (Fagnant & Kockelman, 2015, p. 167). Many different manufacturers are working toward developing AVs, each with their own philosophies on how to design their behavior. While a study by Haboucha et al. (2017, p. 41) found that 56% of a surveyed group preferred autonomous vehicles to regular cars, people are still unsure how the assimilation of AVs onto roads will work. The primary question is where, on the scale of conservative to aggressive, the behavior of AVs should fall. Should AVs lean toward overly polite and cautious or more aggressive and assertive? An additional question is upon whom the liability for accidents involving AVs falls. Should the "driver" be responsible, or the manufacturer?

The consequences of assimilating AVs onto roads are varied. More conservative driving on the part of AVs creates bottlenecks in traffic flow (Schwarting et al., 2019, p. 24972), and this, in turn, may increase the aggression of nearby human drivers. Schwarting et al. (2019, p. 24972) also note that this conservative behavior may inhibit the understanding of surrounding drivers, which may alter their expected reactions and endanger others. Stewart (2018) found that AVs have a comparatively high proportion of accidents in which the AV is rear-ended, which is likely a symptom of overly courteous driving. How AVs assimilate into driving culture has the potential to drastically change the nature of driving in society, as well as the driving behavior of humans.

In this paper, pulling research on attitudes of people toward AVs, as well as the issues associated with their assimilation, I synthesize the research to determine the likely balance between law-abiding and overly courteous AV behaviors and assertive and rule-bending AV behaviors, and I analyze the resulting effect on our road systems.

This paper begins by considering the pros and cons of AVs, as well as the mutual effect of AV driving behavior on human driving behavior and vice versa. It then moves on to discuss the steps for applying the framework known as social construction of technology (SCOT) to a technology, as laid out by Bijker. This paper concludes by enumerating the insights gained by using SCOT to emphasize the importance of considering how we implement AV driving behavior.

Part 1: Autonomous Vehicles: Pros and Cons

Bagloee et al. (2016, p. 285) describes the potential positive social impacts of AVs on our transportation system as increased safety, decreased expense, and more accessibility for the non-ambulatory and disabled. This decrease in expense would make transportation more accessible for those in lower-income households. A study by Manyika et al. (2013) estimated that the societal value from AVs will be between 0.2 and 1.9 trillion dollars by 2025. On the flip side, autonomous vehicles come with negative impacts including pollution, accidents, and human casualties (Bagloee et al., 2016, p. 287). Additionally, hidden costs include traffic congestion, liability, accidents and environmental degradation, and security (Bagloee et al., 2016, p. 287). "Although there could be significant disadvantages associated with AVs, it is widely believed that these disadvantages are largely outweighed by the advantages," (Bagloee et al., 2016, p. 288).

Concerns with Assimilation

While AVs come with many upsides, including improved traffic and reduced car-crash rates, many have cited concerns with negative impacts, such as security. A lot of evidence surrounding the potential positive and negative effects of AVs is speculation, as few have been released into society. Fagnant and Kockelman (2015, p. 172) note that it is difficult to precisely anticipate actual outcomes since AVs are largely in their testing phase.

However, in the vein of security, we can look to cars that currently have software included in their driving behavior, such as many of Tesla's cars. Tesla's cars receive over-the-air software updates that add and modify existing features. Because no technology is without security risks, this leaves the code vulnerable to attackers. One group of researchers hacked a Tesla car using an exploit delivered by drone (Lambert, 2021). Although Tesla has since patched the vulnerability, this incident shows that it is possible for them to be hacked.

Upload, a TV show released in 2020, opens with a scene involving a man, Nathan, in a self-driving car. The self-driving car crashes despite Nathan's attempts to manually override it, and the audience later learns the car was hacked. Although the show is centered around a made-up futuristic society, it includes a lot of feasible elements, such as self-driving cars. Both the example of Tesla being hacked and Nathan's crash show the serious risks associated with self-driving cars. Software could be modified to angle towards roadblocks and put drivers at risk of extreme injury and death. This could also create an easier avenue for malicious attacks on prominent people, such as world leaders.

Another potential negative impact of assimilating AVs is liability. Marchant and Lindor (2012, p. 1335) note that the assigning of liability has the potential to deter the development of AVs, even though there could be an overall safety benefit. As pointed out by Duarte and Ratti (2018, p. 4), there is an incentive on the part of the manufacturer to incorporate their risk of

liability into the price of AVs, especially if accidents virtually disappear. This could negate the decrease in insurance costs, and impact the affordability of AVs. Hancock et al. (2019, p. 7688) discuss how the issue of liability is further complicated by our legal system's innate emphasis on correcting human action and human consequence. AVs, to some degree, remove the role of the human in driving, and therefore punishing the human raises questions about the purpose of our legal system. These ambiguities make assigning liability a more nuanced question, with no straightforward answer.

Effects on Road Capacity

Friedrich (2016, p. 317) claims that AVs improve the safety and efficiency of road transport and investigates how specifically the efficiency of our transportation infrastructure is affected by AVs. To begin, one must understand how capacity is determined. Capacity is highly dependent on the maximum flow of traffic possible on road sections as well as entry, merging, and exit lanes. Friedrich (2016, p. 329) examines the factors that cause "capacity drops" in traffic. He points to the ability of AVs to anticipate the actions of preceding vehicles through communication, which contributes to a stabilization of traffic flow. Moreover, he notes that in purely autonomous traffic, full stability leads to an avoidance of capacity drops, as speed and gaps between vehicles are more homogeneous. Friedrich (2016, p. 330) continues to discuss city traffic specifically, citing a potential 40% increase in capacity with purely autonomous traffic, and an 80% increase for highway sections. This is largely because AVs, while able to drive more efficiently, are still constrained by traffic signals, whereas highways lack this constraint. Figure 1, shown below, shows the potential capacity increase from human-drivers to a purely autonomous road system. From the diagram, it is evident that the capacity increase for AVs is greater at greater speeds.

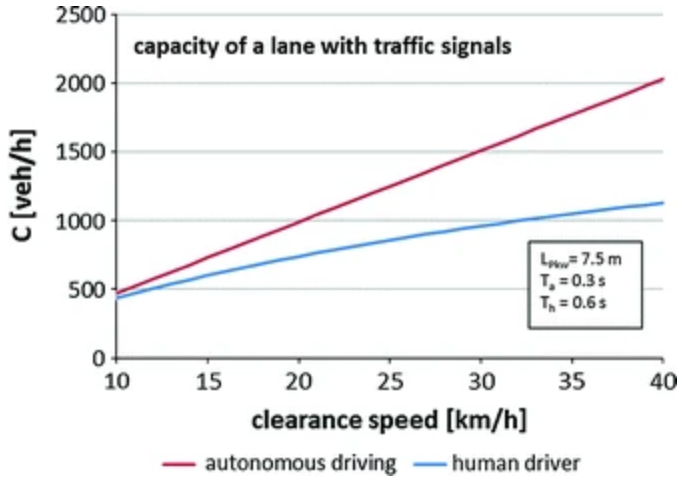

Figure 1. Traffic Capacity for Autonomous Road Systems versus Human Road Systems. The increase in road capacity for AVs is greater at higher speeds, as the gap between capacity increases as speeds increase (Friedrich, 2016, p. 331).

The findings of Friedrich (2016) show that AVs are likely to significantly increase road capacity and could take better advantage of our existing transport infrastructure. Because traffic intersections are self-organizing, Friedrich (2016, p. 333) emphasizes that communication and cooperation between AVs will play an important role in developing algorithms for autonomous driving. Friedrich's (2016, p. 331) research also suggests that because traffic jams and lost time would be reduced, we could expect lower emissions from both AVs and human-driven vehicles.

In addition to improving traffic flow and increasing capacity, Fagnant and Kockelman (2015, p. 169) cite a potential 40% decrease in fatal crash-rates for AVs, assuming automated malfunctions are minimal. They point to speeding, aggressive driving, overcompensation, inexperience, slow reaction times, and inattention as primary reasons for fatal crashes. These are all mitigated with quality software driving the behavior of AVs. Additionally, driver error is thought to be the primary reason behind upwards of 90% of all crashes (Fagnant & Kockelman, 2015, p. 169). Even in cases where the environment or other abnormal conditions are the main culprit behind crashes, human factors often increase the severity and crash occurrence (Fagnant

& Kockelman, 2015, p. 169). Fagnant and Kockleman (2015, p. 169) acknowledge that fog, snow, and partially obscured impediments complicate AV sensor recognition, but counter that humans still often have a harder time recognizing these same obstacles.

AVs and Driving Behavior

While we are able to pull evidence from existing sources to speculate on the discussed pros and cons of AVs, there are some questions surrounding the assimilation of AVs that are more speculation than fact. These include how humans will respond to AVs, how AVs will shape human driving behavior and vice versa, and which decisions AVs should make in certain ethically ambiguous dilemmas.

Schwarting et al. (2019, p. 24972) cite interacting with human drivers as one of the greatest challenges of AVs. They also note that AVs current lack of understanding of human behavior is forcing them to take a more conservative driving style. In contrast to Freidrich's (2016) discussion of AVs reducing bottlenecks, Schwarting et al. (2019, p. 24972) claim this conservative behavior leads to more bottlenecks and leaves AVs vulnerable to aggressive driving of nearby human drivers. They argue that to achieve socially compliant driving, AVs must act as human-like as possible, which can be achieved through imitation learning. However, this calls into question the suspected increase in safety. If machines are learning from humans, and humans are prone to error, we must find a way to select only the positive characteristics of human driving behavior to map onto AVs.

There are also ethical dilemmas that AVs could face. For example, say an AV is driving down a street, and there are three pedestrians crossing the street. It does not have the ability to brake in time. How does the AV decide who it should hit?

From this discussion, the importance of how we implement AV driving behavior is evident, as it will affect our driving community in so many ways. Thus, we must consider how to balance mimicking human driving behaviors while excluding law-breaking ones, without significantly increasing the risk of accidents or injury. Additionally, we must determine how liability should shift depending on the level of autonomy of an AV. Lastly, companies manufacturing AVs should invest significant resources in protecting their software and preventing attackers from harming consumers.

Part 2: How Human Drivers and Autonomous Vehicles Shape Each Other

To analyze the integration of AVs onto road systems, I use SCOT. As discussed by Bijker (2015, p. 135), SCOT suggests that humans shape technology. This is in contrast to technological determinism, the thought that technology is the main influencer for transformation in society (Hauer, 2017, p. 1). While earlier definitions of SCOT reject technological determinism entirely, Bijker (2015, p. 136) concedes that it is a two-way street; human behavior is shaping technology as technology is shaping human behavior.

This is a useful lens for understanding the assimilation of AVs, as AVs are likely to shift human driving behavior, just as human driving behavior is shaping that of AVs. What is more, some manufacturers are attempting to use neural networks, which learn and shape algorithms based on input, in this case, human driving, to implement AV algorithms. Thus, by definition, AVs would be changing based on human driving behavior. Many other factors, such as ambiguous liability, will alter the driving behavior of both AVs and humans, and they will, in turn, shape each other. Figure 2 breaks down the 3 steps proposed by Bijker for using SCOT to analyze the integration of a technology into society (Bijker, 2015).

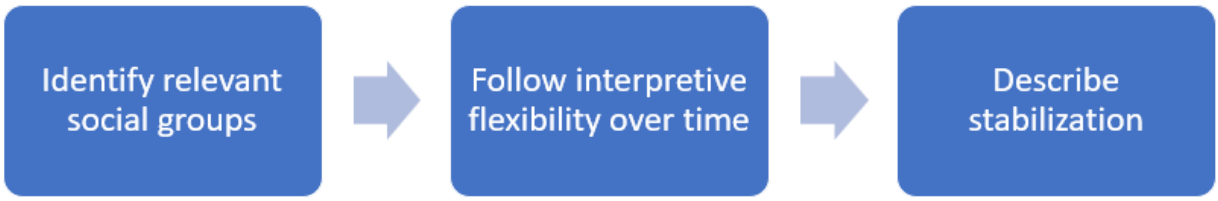

Figure 2. Steps for Using SCOT to Analyze Technology. Bijker (2015) discusses the steps taken to analyze the integration of a technology into society, which are broken down in the figure above. (Created by author).

Bijker (2015, p. 136) argues that the first step in using SCOT as a heuristic for studying technology in society is to identify the relevant social groups, as they give meaning to the artifact under study. For AVs, the relevant social groups are, in a broad sense, users, manufacturers, and legislators. However, for purposes of analyzing how AVs will assimilate, it is helpful to break down broad groups.

Some user groups are daily commuters, the disabled, those without a driver's license/a suspended one, and truck drivers. AVs are a promising technology for daily commuters, as many people spend upwards of an hour in the car each day. Not only is driving tiring, but this is a lot of lost time for productivity. AVs, especially for highway driving, could allow people to sleep, relax, or work. Many disabled people rely on external services or friends for every-day tasks, such as traveling, grocery shopping, and even just engaging in social activities. AVs would grant a new level of independence to the disabled, as they would be able to more easily locomote and not have to work around the people helping them. People without a driver's license, in a similar vein, would be able to rely less on public transportation or peers to help them travel. Lastly, many large companies rely heavily on truck drivers to transport products. AVs, unlike human-driven trucks, would not require companies to pay drivers, and would lead to faster delivery times, as they could drive through the night and take fewer breaks than human-driven

trucks. Although, it is important to note that this could lead to a loss of truck-driving jobs, and companies would still have to pay other expenses for the upkeep of AVs.

The second step, according to Bijker (2015, p. 137), is to follow how interpretive flexibility diminishes over time. The relevant artifacts in the case of AVs are autonomous vehicles and human-driven vehicles. To understand how AVs will reach stabilization, we must analyze the obstacles to assimilation of AVs and predict the intertwined responses of AVs and human drivers. Using research on concerns surrounding traffic flow, security, liability, as well as the reactions of human drivers to different AV driving behaviors, we can predict how AVs will veer toward one style as opposed to others. The end goal and likely future is a traffic system comprised purely of AVs. To reach this state, however, we must carefully consider the initial implementation of AVs and how it will affect our driving society, which is discussed in more detail in the next part.

The third step Bijker (2015, p. 137) lists is closely tied to this end goal, where one explains why the social construction process follows one course as opposed to others, and describes stabilization. One of the biggest constraints on the social construction process for AVs is the law, as it limits the freedom manufacturers have to design behavior and forces AVs to take a tamer path to assimilation.

Part 3: Shaping the Behavior of Autonomous Vehicles

SCOT: Learning from Relevant Social Groups

Using the steps for SCOT laid out by Bijker, we can speculate on the trajectory of AVs and their later stages in society before the technology mostly stabilizes. As discussed as part of step one, relevant social groups include daily commuters, the disabled, those without a driver's

license, and truck drivers. To understand the interpretive flexibility of AVs, we must consider how these groups would conceptualize AVs.

Bijker (2015, p. 137) argues that relevant social groups are likely to describe the artifact differently. For example, truck drivers may describe AVs as being longer vehicles, and mainly confined to highways, whereas commuters may view AVs as being shorter, thinner vehicles, and more able to zip through traffic. People with disabilities, specifically those in wheelchairs, may envision a ramp that can fold out from the door of an AV, to allow easier access. Enlisting the views from a variety of social groups is likely to shape the way in which we construct AVs. Two of the core concerns that each user group likely shares are safety and efficiency. Beyond these concerns are factors such as comfort and accessibility. Then, more niche desires include accommodations such as bunking areas for truck drivers. These emphases on different components from separate user groups is interpretive flexibility, but we can see that safety and efficiency are constants, which points to our need to consider them in how we implement driving behavior.

SCOT: Following Interpretive Flexibility and Stabilization

It is likely that AVs will become the primary form of transportation, perhaps even the sole type of car on our roads. Because daily commuters comprise a sizable portion of drivers, it is likely that most AVs will be designed to fit the needs of this user group, which could lead to smaller cars focused on comfort and efficiency. However, smaller AV markets for groups such as the disabled and truck drivers are likely to remain and become accommodating to the more niche concerns of these groups, including wheelchair access into cars and bunking areas for truckers. Because humans will rapidly become less involved in the functioning of AVs, it is important to

design them such that they function independently and safely, which we have established as an important concern from user groups.

Result: Spectrum of Autonomous Vehicle Driving Behavior

The first iteration of implementation for AVs will carry consequences into our road systems for a long time to come, so we need to carefully consider the effects of the choices made. To begin with, AVs should abide by all laws, even ones commonly broken. This includes obeying speed limits, stopping fully at stop signs, and never running red lights - even when it is close or seemingly safe to do so. The primary reason for this behavior is liability. If manufacturers included code that would cause AVs to drive five miles per hour over the speed limit, or only slow down to three miles per hour before continuing through a stop sign, they would likely face legal consequences, and AVs would have a far more arduous time breaching the market. However, other effects include altering the behavior of nearby human drivers. A large part of learning to drive is observation, as much of human learning is through imitation. Other drivers, especially new ones without established habits, are likely to see and imitate the law-abiding behaviors of AVs. Blatant disregard for the law sends a message to other drivers that this behavior is okay, and could lead to more speeders and dangerous incidents. This has huge implications for the safety of our road systems, as many accidents are the result of law-breaking.

In addition to following listed laws, we must consider which types of behavior will maximize the safety and efficiency of our road systems, as these are primary concerns of the user groups. I believe a middle ground between timid and aggressive would be the optimal place on the spectrum for AVs to fall. Figure 3 shows a summary of AV driving behaviors as compared to timid responses and aggressive responses, with the central column being where I believe their behavior should fall.

Behavior	Timid	AV Behavior	Aggressive
Speeding	Driving well below the speed limit	Driving the speed limit	Driving well above the speed limit
Passing lane	Always remaining in the right lane	Staying in the right lanes except to pass	Always remaining in the left lane
Zippering	Letting multiple drivers in between you and the car in front	Letting one driver in between you and the car in front	Letting no drivers in between you and the car in front
Letting motorcyclists pass	Getting over when a motorcyclist passes between lanes	Maintaining speed and veering slightly to the other side of the lane to allow motorcyclists to pass between lanes	Cutting off motorcyclists to prevent them from passing between lanes
Brake checking	N/A	Refraining from brake checking other drivers	Brake checking other drivers
Parking	Parking very far over and continuing the chain of cars parked over the line	Parking as centered as possible while leaving room for passengers to enter and exit the neighboring car	Parking in the center and preventing neighboring cars from entering and exiting their vehicle

Figure 3. Summary of AV Driving Behavior as Compared to Aggressive and Timid Behaviors. AVs should lean toward behaviors in between timidness and aggression, following the examples listed in the chart. (Created by author).

These courteous behaviors on the part of AVs are likely to slowly mold human driving behavior. For example, humans may learn to maintain a constant speed, zipper one at a time, and be more forgiving to motorcycles. Additionally, humans may learn to let AVs over into lanes farther to the left, as they become aware that it is only to pass slower traffic. If AVs stick to lanes farther to the right, they are also less likely to experience brake checking, as faster and more aggressive drivers tend to be in the left-most lanes.

Another modification we could make to AVs is a screen on the back and sides of the vehicle. Part of our driving system is human communication, which AVs lack, as there is no driver. AVs could display messages of gratitude to nearby drivers using these screens. For example, if one car lets an AV merge into their lane, the screen could display a “thank you” message. Not only would this improve the attitude of nearby drivers, but humans may learn that they do this, and consciously or subconsciously be kind to AVs to receive these visible expressions of gratitude. This could in turn reduce general hostility, improve traffic flow, and increase feelings of community on the road.

Over time, the proportion of AVs to human drivers on the road will increase, and fewer and fewer human drivers will be driving on the road, which is the stabilization predicted using SCOT. One effect of this is a perceived increase in the number of tickets given to humans who drive. This is because AVs will be generally law-abiding, and this reduces the number of cars eligible to be pulled over. In addition to the behavior of AVs increasing road safety, this perceived increase in tickets may also motivate drivers to follow laws, such as not speeding or running stop signs.

What is more, part of the reason for speed limits is to reduce disparities in driving speeds of drivers on the roads. As more and more vehicles on the road become autonomous, their driving speeds are likely to deviate by less as well. This may lead to increased speed limits, which would reduce time spent in the car, and consequently an improvement in efficiency, another common goal of user groups.

In addition to smoother traffic flow, the liability for AV accidents is likely to simplify significantly as time goes on. This is because vehicles will become more and more autonomous as AVs dominate roads. Thus, liability will fall on manufacturers. However, liability for

corporations means in most cases shareholders are not personally responsible. What is more, the manufacturers that succeed will have entered a new market that is estimated to be worth enough money to offset the cost of lawsuits. Additionally, a purely autonomous driving system, which seems the most likely future, will probably result in far fewer accidents, as human error, the culprit behind the vast majority of accidents, is eliminated.

AVs and human drivers will grow and shape one another as AVs slowly begin to dominate road systems. The first stage will be humans implementing AVs, as we shape them based on our complex road rules and behaviors. Then, AVs will begin to shape human behavior, and we will reshape AVs. The cycle will continue rapidly until AVs likely become the sole vehicles on the roads.

Conclusion

In order to encourage safer driving behavior and mitigate the risks associated with the assimilation of AVs, we should design AVs to abide by all laws and to follow the unspoken rules of the road. Additionally, they should be neither overly aggressive nor timid. While some may argue that AVs abiding by all laws, such as the speed limits, will ultimately slow traffic, manufacturers would almost certainly face lawsuits if they released vehicles that did not. Additionally, as AVs become a larger and larger proportion of vehicles on the road, speed limits could eventually increase and traffic patterns could shift to improve traffic flow even more. The importance of the safety and efficiency of AVs we could achieve through these behaviors is derived from the values of the relevant social groups identified through SCOT.

The findings of this paper could be used by manufacturers such as Tesla, which is currently developing AVs. Some manufacturers are wary because law-abiding vehicles often come with longer transit times; thus, they are concerned consumers will be more hesitant to

invest in their products. However, as discussed in this paper, there is still a large target audience to whom AVs, even if initially slower, would be life-changing. Manufacturers such as Tesla could use this advice surrounding AV behavior when implementing the code to drive AVs.

While law-abiding vehicles will likely experience lower accident rates, some will still occur. The problem of liability remains, even with an implementation of AVs that follows the guidelines listed above. This limitation still needs to be addressed, and states with little legislation regarding AVs will need to step in and create fair rules that protect manufacturers.

The initial behavior of AVs will dictate the relationship between AVs and human drivers for a while to come, which is why it is so crucial that we get it right.

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