Autonomous Vehicles: An STS Perspective into the Development, Production, and Deployment of Autonomous Vehicles in the United States

An **STS Research Paper submitted to the**

Faculty of the School of Engineering and Applied Science
University of Virginia • Charlotteville, Virginia

In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science, School of Engineering

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Fall, 2020

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

For more than 100 years, technological revolutions have upended and reshaped the automotive industry- the Ford assembly line, the gasoline engine, and electrification. The next revolution is autonomy. First researched in the early 1900s, autonomous vehicles are vehicles equipped with technology to enable self-driving, that is, the ability to function without a person driving the vehicle. The development of autonomous vehicles (AVs) has accelerated within the past 10 years, and the technology has recently begun the transition from explorative research projects to the introduction of products available to the public (Bimbraw, 2015). Proponents of autonomous vehicles promise that the technology will revolutionize society—from providing mobility to populations such as the elderly and making everyday transportation safer.

Autonomous vehicles rely on a vast array of technologies to enable their functionality, using advanced sensors such as radar, lidar, and cameras. Paired with powerful computing resources and deep learning algorithms, autonomous vehicles attempt to understand and navigate the complex world around them. According to the Society of Automotive Engineers (SAE), there are five levels of autonomy. At Level 0, the driver performs all of the tasks regarding driving. By Level 5, the vehicle requires no input or action from passengers in order to operate in any driving situation (Lynberg, 2020). As the levels rise, the difficulty to advance increases exponentially. This is due to the complexity of the real world—when driving without intervention, edge cases and scenarios arise that are extremely difficult for algorithms to account for. However, once Level 5 autonomy has been reached and is commercially viable, autonomous vehicles are predicted to have wide-ranging impacts on society. Each year, on average 1.35 million people lose their lives in car accidents, with millions more injured (CDC, 2020). As self-driving cars become more prevalent, they are predicted to vastly reduce the number of accidents, as autonomous vehicles drive much more carefully and less aggressively than human drivers. In addition, those in society with limited mobility, such as the elderly or people with disabilities, will have a greater ability to travel without assistance. On a macroeconomic scale, without the need to drive, productivity will rise as passengers can perform other tasks such as working or consuming entertainment during the times they would have previously driven. In theory, the increased productivity will boost economic growth or increase leisure time, resulting in improved quality-of-life.

While research in autonomous vehicles first began during the late 1900s, research and development has accelerated in recent years. Companies such as Waymo (owned by Google) and Cruise (owned by GM) have launched pilot programs this year in Phoenix and San Francisco, respectively, operating driverless cars in both cities (Hawkins, 2020). However, commercialization has been slower than initially expected by the industry. Costs have remained high, with essential sensors such as lidar, a laser sensor used to measure distance, costing upwards of 70 thousand dollars. Meanwhile, despite progress, deep learning algorithms and neural nets have not yet improved enough to offer 100% reliable self-driving vehicles. Most importantly, consumers simply don’t trust computers with their lives yet—90% of Americans would not currently trust a self-driving vehicle to keep them safe (Wagner, 2015).

A Sociotechnical Perspective

While it remains an emerging technology in the computer science and engineering fields, autonomous vehicles also present many interesting social and political debates. From the beginning of their development to their eventual introduction into society, debates regarding their usefulness, effectiveness, and ability to transform society have continued. Furthermore, the development of this specific technology serves as an insight into the difference between how engineers and general members of society rationalize. In other words, autonomous vehicles serve as a vignette for positivist and constructivist models of thinking. Positivism is how many engineers think—knowledge and facts are generated in a scientific method. On the other hand, constructivism is a philosophy that knowledge and facts are also socially constructed—society determines the truths and knowledge it accepts. A sociotechnical analysis of autonomous vehicles leads to several questions: As autonomous vehicles were developed as a technology, how did the public initially react to their introduction? Why do users distrust the technology and what factors affect the level of trust, and finally, what will the future of autonomous vehicles be in our society?

In particular, in American society cars are viewed much differently than other modes of transportation. American car culture is well documented, with an emphasis on individuality, adventure, and freedom (Humes, 2016). Compared to other forms of transit, cars are much more personal. When you ride a bus or subway, the color, speed, or reliability aren't considered to the same extent as a car. In addition, regarding automation and technology, the public treats cars differently from other methods of transportation such as trains and airplanes, which have had automated elements for decades. Due to the pervasive nature of cars—present in our neighborhoods, on highways, and urban centers, people who don't drive cars are still affected by any changes in how they function. Thus, non-users, such as pedestrians and bicyclists, who will need to interact with autonomous vehicles on a daily basis, have held a significant impact on the development of the technology. As some consumers begin to utilize autonomous vehicles and travel on public roads and integrate within society, the non-users of the technology will be impacted as well, given that public roads are shared between all vehicles.

As such, when approaching autonomous vehicle technology from a sociotechnical perspective, the impact of both users and non-users of the technology must be examined. As autonomous vehicles are developed, the key to the success of the technology is trust. The development of autonomous vehicles is dictated by several parties. There are numerous companies, ranging from startups to established corporations that have invested billions of dollars into the technology. In addition, the integration of such technology into society is regulated by various governmental entities, tasked with ensuring safety and security before autonomous vehicles are approved for public use (Bimbraw, 2015). Finally, the eventual success of the technology will be dictated by consumers. Autonomous vehicles are primarily marketed as a consumer product, packaged with cars and trucks. Comprising a portion of the transportation system, autonomous vehicles share the roadways with standard cars, bicyclists, and pedestrians. Due to their wide-ranging sociotechnical network and impacts of the technology, autonomous vehicles must be studied.

STS Frameworks

To better understand the key questions regarding autonomous vehicles, several different STS frameworks can be used as a lens to analyze emerging technology. Through STS frameworks, complex technological and sociological developments can be analyzed using a variety of established principles regarding the nature of technological developments within society. Most importantly, these frameworks enable technical topics and problems to be viewed as an element of society, rather than within a vacuum of pure science and engineering. This methodology applies to the development of autonomous vehicles, as a pure engineering analysis misses many of the important complexities and nuances of the technology due to the intertwining of the technology with society. All technology is woven in the fabric of society, thus, sociotechnical frameworks must be used to more deeply understand the issues.

Large Technological Systems

The first framework applied to autonomous vehicles is the Evolution of Large Technological Systems, a theory articulated by Thomas Hughes. Technological systems are complex networks composed of both physical and nonphysical components. For autonomous vehicle research, components of the technological system can include weather/road conditions (physical) and the regulatory environment (nonphysical). These systems also evolve over time, changing in structure and composition. Instead of a linear development path from research to integration within society, autonomous vehicles comprise a vast network with many components affecting the eventual outcome. Viewing the technology through this framework allows for individual components and pieces within the network to be analyzed, enabling a more detailed and specific analysis.

Within the sociotechnical system of autonomous vehicle research, the most visible subsystem is the engineering research and development of the technology. Contributing to the evolution of the technology is a wide array of automotive companies, component suppliers, and research-focused firms. Early entrants into the field were traditional automotive companies such as General Motors (GM), which as early as 1939 introduced a ‘self-driving’ vehicle controlled by electromagnetic waves from signals embedded into the roadway (Lienert, 2019). Later, in 1977, the University of Tsukuba’s Mechanical Engineering Lab in Japan developed the first self-driving vehicle using cameras (Lienert, 2019). While both prototypes were functional in controlled environments at limited speed, between the limitations and cost of production the technology faltered. In the late 20th century, a parallel development occurred within the network—the rise of personal computers. Following Moore's Law, a famous principle by the co-founder of Intel, the number of transistors doubled roughly every two years, exponentially increasing computing power (Waldrop, 2016). The rapid development and improvements in computers laid the foundation for future iterations of autonomous vehicles. The semiconductor and personal computing fueled the development of Silicon Valley and the new age of high-technology companies.

During this time, as commercial ventures of autonomous vehicles faltered, research institutions led the forward progress within the field. In the late 1990's Carnegie Mellon University produced a self-driving car prototype powered by a novel new development within the Computer Science field, an artificial neural network (Lienert, 2019). In the early 2000s, the United States government encouraged further research through the Defense Advanced Research Project Agency (DARPA). Through the government program, an American university—Stanford, won accolades with its implementation of artificial intelligence to power autonomous vehicle technology (Lienert, 2019). Fast forward to present times, autonomous vehicle research returned to the private sector, with leaders in the field owned by companies such as Google, General Motors, and private venture firms. Connected to each firm is a vast network of suppliers, such as Velodyne, a component manufacturer of Lidar sensors. Lidar uses lasers to measure the distance of objects in real-time, as far as 200 meters. Roughly 10 years ago, these sensors cost upwards of $100 thousand—today they cost between $500 to $1500 (Halterman & Bruch, 2010). Processing the information output by the sensors are supercomputers, manufactured by companies such as Nvidia and Tesla, producing chips capable of up to 144 trillion operations per second.

Outside of the engineering research and development subsystem, a network of government institutions and social constructs have also influenced the development of autonomous vehicle technology. Through funding and regulation, governments and regulators influence the ability of autonomous vehicles to integrate within society. For any autonomous vehicle technology to become widely adopted, government approval must be earned. Rules and regulations regarding transportation can help promote the development of autonomous vehicles, or outright prohibit their use. In the past, private firms and public institutions have collaborated with the government, such as joint ventures with DARPA or the creation of self-driving corridors, portions of public roads where driverless cars are legally able to be driven. Over the past 100 years, each element of the sociotechnical network has influenced the direction of the technology. Without government research funding, the rapid improvements in semiconductors, or even the rise of Silicon Valley and high-tech firms, autonomous vehicle technology would not exist as it is today.

Users as Agents of Technological Change

An additional relevant framework for autonomous vehicle technology is the Social Construction of Technology (SCOT), in which users are the agents of technological change. In other words, the interpretation and reaction social groups have toward a technology shape how it develops (Kline et al., 1996). When introducing a novel technology into society, the way in which prospective or current users react influences the development and eventually the success or failure. This is useful when analyzing the development of autonomous vehicles, as the social acceptance of such technology—both believing the technology is an improvement over current standards and trusting in the technology—determines whether it is adopted or disregarded.

Since automobiles were first introduced, they have grown to become symbolic of personal freedom (D’Costa, 2016). From traversing sandy dunes to traveling between cities, driving a car is not seen as a passive activity, instead, individuals view driving as enabling individualistic freedoms, the pursuit of happiness, and simply fun. Whether it’s luxury, adventure, or performance, driving is currently accepted to be an active activity. Thus, a challenge posed to autonomous vehicles is the need to change the notion and gain acceptance for driving to become a passive activity. Furthermore, transferring control from users to autonomous vehicles has created challenges, particularly in trust. As users have reacted to autonomous vehicles technology development, their reactions to the technology have worked as an agent of change.

Because cars and driving represent freedom to many people, the introduction of autonomous vehicles threatens that ideology. This fundamental change in how cars are viewed is a challenge for autonomous vehicles to overcome. Thus, because users have traditionally viewed driving as an active activity, this has changed the way in which the technology has been introduced into consumer markets. While the computers and algorithms powering the vehicle are wholly contained within the car, the current information and future decisions are displayed on screens for the occupants. This feature was not necessary for the product to function. However, through consumer demand, users showed a preference for systems that display additional information to build trust. In addition, the SCOT framework emphasizes the “interpretive flexibility” of social artifacts. In other words, this means that different users can view technology differently. For a busy middle-aged worker, an autonomous vehicle may mean additional productivity during their daily commute. For a transportation-limited elderly citizen, autonomous vehicles may mean gaining independence back. As such, each social group of users exerts influence over a technology and shapes the development.

Over time, autonomous vehicles have adapted to respond to the various needs and views of different sociotechnical interpretations of the technology. The introduction of limited autonomous driving in luxury cars has responded to the demand for additional comfort and convenience of wealthy suburbanites who own cars, which autonomous taxi services have launched to democratize independence to mobility challenged populations such as the elderly. As the technology has become more prevalent within society, it has continually morphed into the specific needs demanded by users. Automatic emergency braking and adaptive cruise control were early applications of such technology. Once technology has responded to the users is it viewed as progress. In other words, autonomous vehicle technology in a vacuum as a feat of science and engineering is not true progress for society. Instead, only once the technology filled the needs of users such as comfort and safety were autonomous or semi-autonomous vehicles viewed as progress. Instead of an immediate introduction as a replacement for current cars and driving, autonomous technology has been slowly introduced as an aid or improvement to current solutions.

The Sociology of Science

The Sociology of Science is the idea that scientific facts and information are socially constructed. That is, a scientific fact is accepted as truth due to the agreement between many different sociological components, from scientists to television networks (Jasanoff, 1992). The way scientific facts are interpreted and accepted by society is important and relevant to the study of autonomous vehicles. This is because while statistics show that self-driving vehicles are safer on average than regular vehicles, getting into fewer accidents per mile of driving than human-driven cars, society as a whole doesn't trust the technology (Stewart, 2019). In fact, data released by Tesla regarding their 'Autopilot' feature showed that vehicles with no active autonomous technology got into accidents ~2.56 times as often. Tesla vehicles were involved in one accident for every 4.59 million miles driven on autopilot, while on manual driving an accident occured every 1.79 million miles (Tesla, 2020). In contrast to this data, surveys show that 90% of Americans distrust fully-autonomous driving technology's safety, despite the statistical evidence pointing to otherwise (Wagner, 2015). This comes down to the fact that safety is a socially constructed principle. Nothing is ever perfectly safe, but instead, society agrees on an acceptable level of risk.

For autonomous vehicles, it has become apparent that the acceptable level of risk is not the same as for human driving. 1.5 deaths per 100 million miles driven are accepted as safe enough for users, as this is the average rate of passenger deaths in motor vehicles, but for autonomous vehicles, that number is much lower (CDC, 2020). The reasoning for why society has reacted in this way to the technology can be found using the sociology of science (Lienert & Caspani, 2019). The interpretive flexibility of accepted facts is influenced by political, cultural, and historical factors. What this means is mathematical statistics are not enough to convince society about the safety or efficacy of a technology. Instead, social institutions such as regulatory bodies, the media, and individuals collectively interpret the facts and make a decision regarding safety. Because the idea of control being taken away from drivers and placed in the hands of a computer goes directly against the longstanding cultural emphasis on the ability of individuals to make decisions, the threshold for which autonomous vehicles are deemed 'safe' is higher. Even though a 10% improvement in safety for autonomous vehicles over human drivers would result in millions of lives saved from accidents over the long-term, the lack of trust prevents the technology from being introduced immediately.

Taking the ability of humans to make their own decisions away leads to skepticism—if an autonomous vehicle finds itself in a crucial decision, perhaps in the event of a crash, would it make the same decision as if the occupants had been driving? Despite causing fewer accidents on average than human-driven vehicles, are the situations in which a self-driving vehicle would fail be the same as if a human had been driving? This uncertainty is the root of why society views autonomous vehicle technology as less safe. Edge cases, such as driving in the snow with low visibility or unpaved roads, which autonomous vehicles struggle with, have proved an impediment in building trust. Unless autonomous technology is on par or better than humans in every possible scenario, society will not trust the society. Thus, the question remains: how can trust be built?

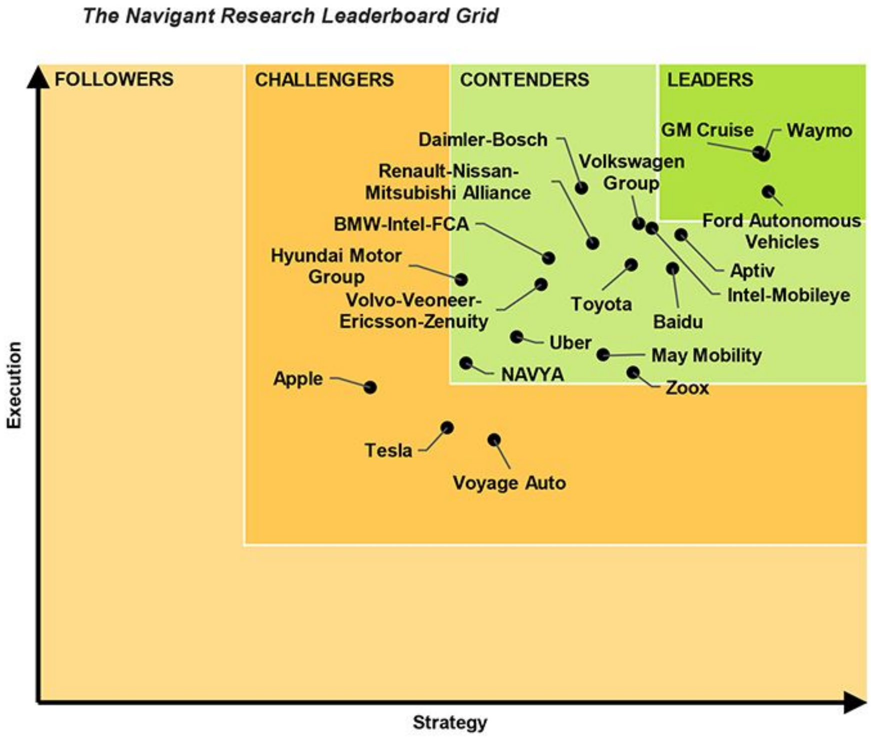

Figure 1. Autonomous Vehicles Leaderboard. Retrieved from Navigant Research, 2019.

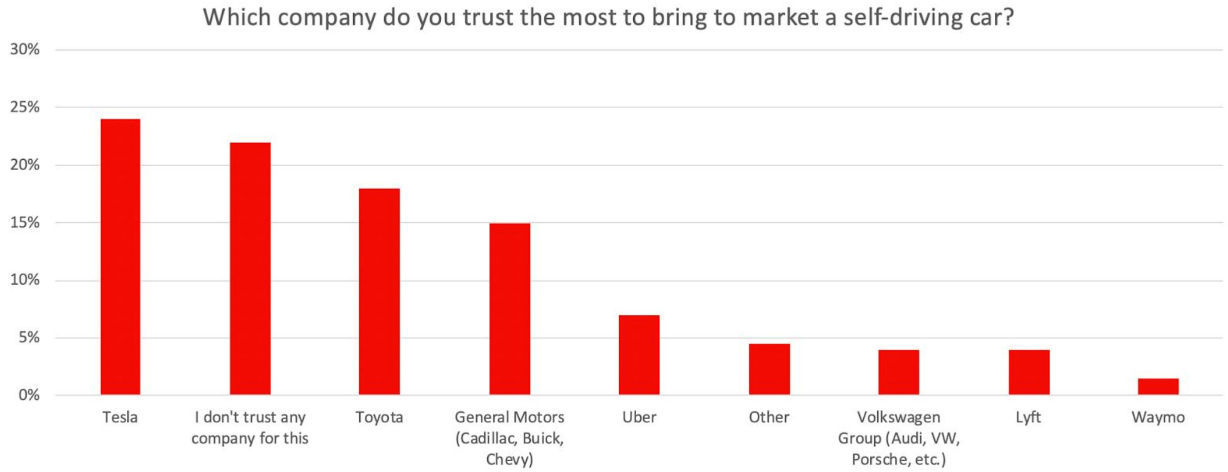

Figure 2. Self-driving Competitors Trust Survey. Retrieved from Autolist.com, 2019.

In order to build trust and become socially accepted as safe, autonomous vehicles must demonstrate themselves to be safer in dangerous situations. As automation has been slowly integrated into vehicles, through features such as automatic emergency braking and lane-keeping cruise control, trust is built by demonstrating the efficacy of the technology. When a vehicle applies the brakes without user control, it alerts the occupants, who internally compare the actions of the vehicle to the actions they would have personally taken. If the system acts in a similar or better way than the occupant would have reacted, trust is earned. The best example of building user trust in autonomous technology is the Autopilot product by Tesla. When autonomous features are activated, the vehicle displays exactly what it sees—the surrounding cars, the lane marking, and the path the vehicle will take. Employing audible and visual cues, Tesla's Autopilot is the most trusted autonomous vehicle technology on the market (Taub, 2016). This validates the strategy of Tesla and the slow introduction of autonomous features to consumers. In an analysis of autonomous driving companies, Tesla ranked near the bottom for execution and strategy, as shown in Figure 1. However, this analysis primarily focused on the technical proficiency and engineering behind each system, without taking into account the strategy for introducing the technology to consumers. Thus, despite being identified as falling behind its competitors, Tesla earned the highest level of trust among its competitors regarding the use of its self-driving technology in an Autolist 2019 survey, shown in Figure 2. Meanwhile, Waymo, the most technically proficient autonomous vehicle system, is the least trusted by consumers. This is due to their strategy of withholding the introduction of their product until the system is able to attain Level 5, or fully self-driving, ability. Thus, to build trust, autonomous vehicles must provide points of comparison and reference for occupants—trust and acceptance of safety isn't given, but earned over time through a careful introduction of features.

Users and Non-Users

Users and Non-Users is the principle of how people influence socio-technological change. Users and non-users of a technology exert influence over its development, including design, implementation, and widespread use (Oudshoorn et al., 2003). For autonomous vehicles, it is particularly important to study the non-users—the skeptics, disinterested, and indirect users of the technology. Non-users exert tremendous influence, as autonomous vehicles are dictated by regulation, legislation, and the acceptance of the technology into the public. Vehicles share roads with pedestrians, bicyclists, and construction workers, all of whom are non-users. As any new technology not yet widely introduced to the market has few users, the non-users of technology create the largest impact early in a technology's development.

For autonomous vehicles, a particularly influential group of non-users are regulatory boards and oversight committees. In order for any vehicle to operate on public roads and be sole to consumers, regulators must approve the vehicle. For autonomous vehicles, regulatory bodies must be convinced of the safety and efficacy of such technology in order to gain access to the market. When making regulatory decisions, non-users of any technology must also be considered. In addition to user safety of autonomous vehicles, externalities need to be considered, such as the impact on other drivers and pedestrians. Autonomous vehicles do not operate in a sanitized environment—they must be developed to account for irrational human drivers, pedestrians running into the road, or extreme weather conditions. As such, because non-users comprise the majority of the interactions autonomous vehicles will encounter, they must be considered in the development of the technology. This can be seen in how cautious autonomous technology behaves. For example, autonomous vehicles strictly follow speed limits, road signs, and yield to pedestrians in all situations. This differs from the way most human drivers behave, where they tend to speed and drive more aggressively. So instead of imitating the behavior of real human drivers, the technology has been influenced by non-users to become more cautious and less aggressive.

For the future, autonomous vehicles must account for non-users as the technology is introduced into society. In addition to occupants trusting the safety and efficacy of autonomous vehicles, non-users must share the trust in order for the technology to succeed. While current partial implementations of the technology have found success, for fully autonomous vehicles to be successful, they must be able to handle every function a human operator is capable of without limitations. For this reason, many optimistic projections regarding the timeline of autonomous vehicles have fallen through—instead, a measured, careful approach towards development and integration will generate the best result.

Conclusion

With approximately 270 million vehicles on the road in the United States alone and 6 million crashes within the past year, vehicles represent an integral component of American society. From drive-throughs to highways, American culture and society view driving and automobiles as a staple (Humes, 2016). As new technologies emerge such as autonomous vehicles that are set to change this aspect of society, a sociotechnical analysis approach offers the most compelling insights into the history and future development of the technology. As a large technological system, autonomous vehicles are influenced by a vast network of actors besides the direct manufacturers of the technology. From public research institutions, government agencies, component manufacturers, to Silicon Valley, the interconnected sociotechnical network contributes to the development and future path of autonomy. As autonomous vehicles attempt to commercialize and integrate within society, in order to be successful society must view the technology as a positive improvement and trust in the technology. To earn approval and acceptance in society, both the users and non-users of the technology must be considered—without successfully integrating into the lives of both, widespread adoption will never be reached. Furthermore, trust in the technology must be earned through the sociology of science, as engineers must account for the sociological constructs and interpretations of autonomous vehicles. As the development and technology move ahead into the future, the key to success will be integrating this sociotechnical network of autonomous vehicles with the outstanding social constructs of society.

References

2019 Navigant Autonomous Leaderboard. Society of Automotive Engineers. (2019, March 13). https://www.sae.org/news/2019/03/2019-navigant-autonomous-leaderboard.

D'Costa, K. (2013, April 22). Choice, Control, Freedom and Car Ownership. Retrieved from https://blogs.scientificamerican.com/anthropology-in-practice/choice-control-freedom-and-car-ownership/

Halterman, R., & Bruch, M. (2010). Velodyne HDL-64E lidar for unmanned surface vehicle obstacle detection. *Unmanned Systems Technology XII*. doi:10.1117/12.850611

Hawkins, Andrew J. (2020, Oct 5). “Waymo and Cruise Safety Drivers Face a Bleak Choice: Pandemic or Pollution?” *The Verge*, The Verge, from www.theverge.com/2020/10/5/21473719/waymo-cruise-self-driving-car-backup-safety-driver-pandemic-wildfires-california.

Hughes, Thomas. (1987). “The evolution of large technological systems.” The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology. 51-82.

Humes, E. (2016, April 12). The Absurd Primacy of the Automobile in American Life. Retrieved April 17, 2020, from https://www.theatlantic.com/business/archive/2016/04/absurd-primacy-of-the-car-in-american-life/476346/

Jasanoff, S. (1992). What Judges Should Know About the Sociology of Science. *Jurimetrics, 32*(3), 345-359.

Kline, Ronald, and Trevor Pinch. (1996). “Users as Agents of Technological Change: The Social Construction of the Automobile in the Rural United States.” Technology and Culture, vol. 37, no. 4.

Lienert, P., & Caspani, M. (2019, April 01). Americans still don't trust self-driving cars, Reuters/Ipsos poll finds. Retrieved April 17, 2020, from https://www.reuters.com/article/us-autos-selfdriving-poll/americans-still-dont-trust-self-driving-cars-reuters-ipsos-poll-finds-idUSKCN1RD2QS

Lynberg, Matthew (2020, June 15). “Automated Vehicles for Safety.” *NHTSA*, www.nhtsa.gov/technology-innovation/automated-vehicles-safety.

Oudshoorn, N. E. J., & Pinch, T. (2003). Introduction: How users and non-users matter. In N. E. J. Oudshoorn, & T. Pinch (Eds.), *How users matter. The co-construction of users and technology* (pp. 1-25). Cambridge, Massachusetts: MIT Press.

“Road Traffic Injuries & Deaths: A Global Problem.” (2019, Dec 18). *Centers for Disease Control and Prevention*, Centers for Disease Control and Prevention, www.cdc.gov/injury/features/global-road-safety/index.html.

Stewart, E. (2019, May 17). *Self-driving cars have to be safer than regular cars. The question is how much.* Recode. https://www.vox.com/recode/2019/5/17/18564501/self-driving-car-morals-safety-tesla-waymo.

Taub, E. A. (2016, September 23). Can Tesla's Autopilot Be Trusted? Not Always. Retrieved from https://www.nytimes.com/2016/09/24/automobiles/autoreviews/can-teslas-autopilot-be-trusted-not-always.html

Tesla Vehicle Safety Report. Tesla, Inc. (2020, October 23). https://www.tesla.com/VehicleSafetyReport.

Undercoffler, D. (2019, April 18). *Survey: Tesla repeats as most-trusted brand for self-driving car*. Autolist. https://www.autolist.com/news-and-analysis/survey-tesla-repeats-self-driving-autonomous-leader.

Wagner M., Koopman P. (2015) A Philosophy for Developing Trust in Self-driving Cars. In: Meyer G., Beiker S. (eds) Road Vehicle Automation 2. Lecture Notes in Mobility. Springer, Cham. https://doi.org/10.1007/978-3-319-19078-5_14

Waldrop, M. (2016, February 09). The chips are down for Moore's law. Retrieved October 19, 2020, from https://www.nature.com/news/the-chips-are-down-for-moore-s-law-1.19338