HUMAN-MACHINE INTERFACE IN AUTONOMOUS VEHICLES

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By

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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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According to Mitchell Waldrop (2015), just about every automobile manufacturing company is working to develop some form of autonomy (p. 20). As autonomous vehicles (AVs) are becoming more popular, the question of safety becomes dominant in everybody's mind. Autonomous vehicles will decrease some danger caused by human error on the road, but there are still gaps in safety that need to be filled in order to create the safest autonomous vehicle possible. This analytical paper will answer the question: how can Human-Machine Interface (HMI) be implemented in the design of autonomous vehicles in order to increase the safety of the vehicle? For the STS project, Pinch and Bijker's Social Construction of Technology (SCOT) framework will be used to determine the influence of different social groups on the development of Human-Machine Interface (HMI) in autonomous vehicles. With this, the influence of each of these social groups on autonomous vehicles will be assessed in order to determine each of their respective rolls in the influence of HMI technology in order to create safe AVs on the road. The tightly coupled technical project is centered on the creation of an autonomous platooning vehicle using golf carts. For this project, Mechanical Engineering undergraduate students Janani Chander, Gregory Breza, Sara Khatouri, Zackary Kim, Charles Rushton, and Harjot Singh, advised by MAE Professor Tomonari Furukawa and with the assistance of MAE graduate student William Smith, will design and implement autonomous features in one golf cart and program that cart to autonomously follow another golf cart. While creating an autonomous vehicle, students must be mindful of the societal factors at play with this technology, namely the users that will be riding in it. Safety of users during operation is the top priority. In order to increase both the comfort and safety of the users, this technical project will implement some of the HMI techniques assessed in the STS project.

Autonomous vehicles seem like a giant leap in transportation technology, but we have been riding in cars that have autonomous capabilities for several years now. Almost all new cars today include features such as adaptive cruise control (ACC) and lane assistance that classify as autonomous, even though they do not create a fully autonomous vehicle (Fisher et al, 2020). According to Choksey and Wardlaw, there are six levels of autonomy (levels 0-5) defined by the Society of Automotive Engineers (SAE), as shown in Figure 1 below (2021).

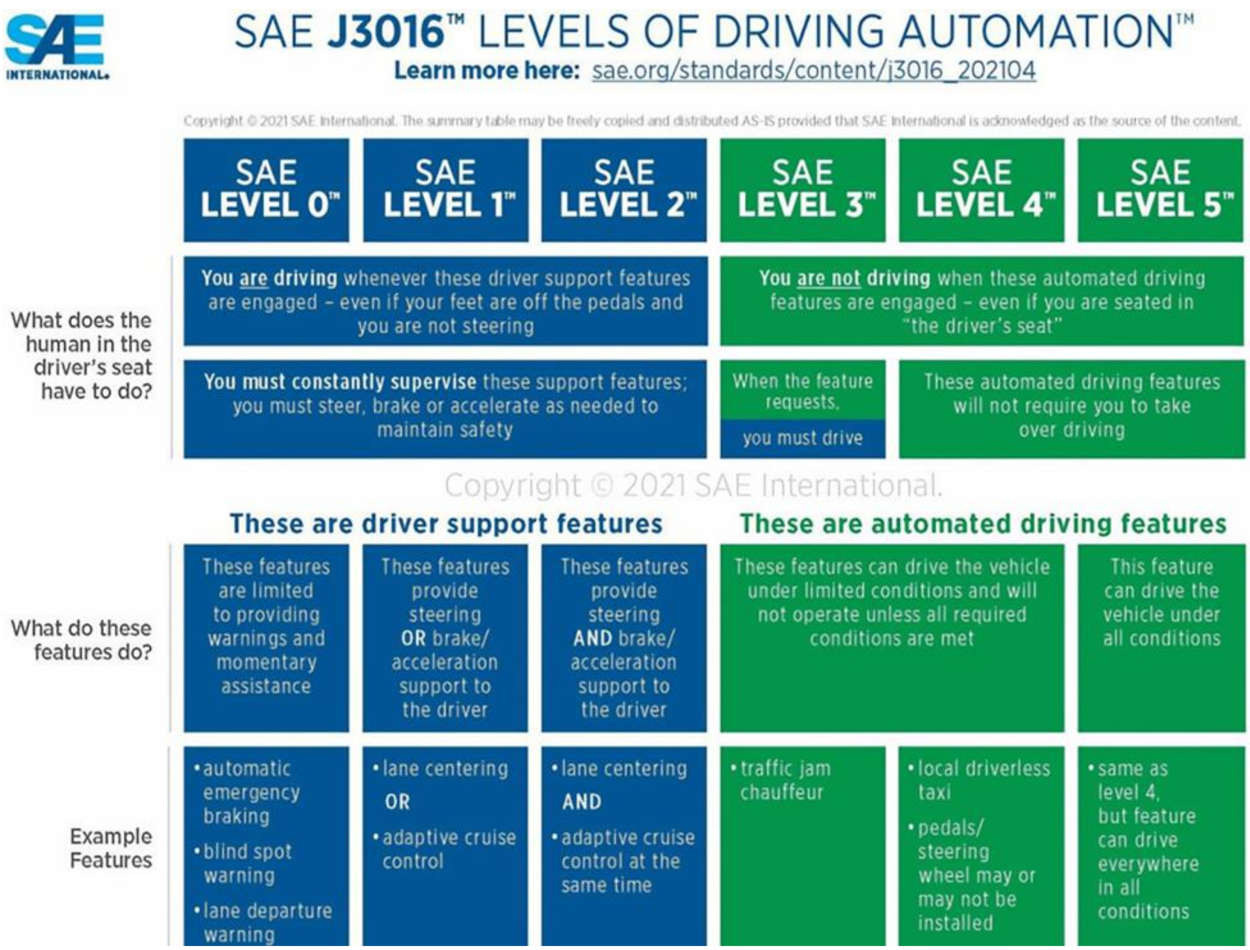

Figure 1: SAE levels of driving automation. This figure depicts the requirements of the driver and the features of the car for each of the six levels of autonomy (Choksey & Wardlaw, 2021).

As depicted in Figure 1, each of these levels of autonomy require a different amount of user input, with level 5 autonomy requiring no user input (Choksey & Wardlaw, 2021). The passenger can simply sit back and take a nap if they are riding in a car that has level 5 autonomous capabilities. As of May 2021, no cars have been able to achieve levels 4 or 5 autonomy (Choksey & Wardlaw, 2021). Until automobiles are able to achieve full autonomy (level 5) in all situations imaginable, the driver will be responsible for at least some of the driving tasks. Because both the driver and the automobile will both be in charge of certain driving tasks, the interaction between the vehicle and the driver is going to be a key factor to consider during the development of these semi-autonomous vehicles. Fisher et al (2020) suggest that elements such as the transfer of controls from car to driver or driver to car, the situational awareness of the driver of what decisions the car is making, and alerts of things that go wrong are all situations that need communication between the vehicle and the driver in order to be executed safely. Without a tool for communication between the vehicle and the user, AVs would have a major gap in safety that could result in a danger to the driver and others. This indicates the necessity for a sophisticated HMI to be implemented in the AV in order to communicate with the driver.

DRIVER TRUST WITH HUMAN-MACHINE INTERFACE

According to Harrington & Schenck (2017), autonomous vehicles will drastically reduce the number of accidents on the road when implemented at a wide scale, but the public has to adopt the technology in order to reap the benefits of it. The level of a consumer's trust with the technology will largely determine how, or even if, they use that technology. There are many different factors that influence a user's trust in a technology, such as their prior experience with similar technology, the perceived capabilities of the technology, which may differ from the actual capabilities, and the reputation of the company (Fisher et al, 2020, p. 72). Too much trust in a technology can result in over-reliance on that technology past its capabilities (Fisher et al, 2020, p. 78). Too little trust can result in people not using the technology, which results in a loss of the potential benefits that may be achieved with the technology. Trust can vary widely from person to person and may depend on the situation. With the potential of AVs to drastically increase the safety of roads, increasing an individual's trust in the technology is an important step toward getting them to adopt the technology and thereby reap the safety benefits that AVs present.

Before discussing methods for increasing the user's trust in AVs, it is important to note that too much trust in the technology could potentially be harmful. Lack of honest, transparent communication from car companies could cause a consumer to overestimate an AV's capabilities and place too much trust in that vehicle. If consumers are not fully informed about the limitations of the cars that they ride in, they could assume that their car is able to handle situations that a human may actually need to step in for. Every car that has some autonomous capabilities goes through Function Allocation, which is the delineation of tasks that either the human or machine would be responsible for (Fisher et al, 2020, p. 154). For example, if a driver has adaptive cruise control enabled, the driver is responsible for monitoring the road, steering the car, and braking in an emergency while the vehicle is responsible for controlling acceleration and deceleration. The over-trusting of the car may cause the passenger to not be prepared to take action fast enough or not be capable of taking action at all. For example, if a driver believes that the engagement of the "autonomous" mode in a car allows the car to be fully autonomous, then that person might take their attention away from the road because they believe the car would be able to handle all driving functions, including accident avoidance. Then, in the occurrence of an accident that the autonomous features of the car are unable to handle, the driver would not be able to take control of the car in order to prevent the crash. This highlights the dangers of misplaced trust in the vehicle in an extreme case.

While being overly trusting in AV technology has clear dangers, complete distrust of AVs could cause more indirect harm. Autonomous vehicles have the potential to decrease accidents caused by human error and increase the efficiency of cities if they are implemented safely (Arem et al., 2006, p. 429). However, if the public does not trust the technology, then it will not be adopted and these benefits will not be realized. 94% of accidents are caused by human error, and AVs have the potential of reducing human error (Harrington & Schenck, 2017, p. 3). Even though AVs still fail on occasion, they fail less often than manually driven cars, thus allowing for an overall decrease in accidents when they are adopted. It is natural for people to point at Tesla's autopilot feature's high rate of failure as evidence for the high risks involved with AVs, but in reality, this autopilot feature increases the safety of the car. Tesla's accident data for every quarter since Q3 2018 demonstrates that the engagement of the autopilot feature decreases the frequency of accidents (Tesla, 2022). The most recent data shows that in Q4 2021, an accident occurred once every 4.31 million miles when Autopilot was engaged, while there was an accident every 1.59 million miles when drivers did not use Autopilot technology (Tesla, 2022). The novelty of AV technology naturally attracts a spotlight and scrutiny from the public, so crashes that involve this technology tend to attract national attention. This technology has the potential to decrease the loss of human life, but due to several high-profile examples of autonomous vehicles failing, many people are very hesitant to adopt AV technology in their own lives. Increasing the public's trust in the technology will allow the technology to become adopted and accepted, therefore allowing society to reap its benefits.

Increased HMI has the ability to enhance the user’s comfortability and trust in the AV. Stanton, N., Revell, K. M. A., & Langdon discuss the results of their research on user experience with increased HMI in their book *Designing Interaction and Interfaces for Automated Vehicles* (2021). In their research, Stanton, N., Revell, K. M. A., & Langdon analyze the situation involving the takeover of control of the vehicle by the driver both with and without HMI assistance. They found that providing the driver with situational feedback during the takeover of control resulted in a better overall user experience (Stanton et al., 2021, p. 110). The results of this study indicate that increasing HMI in AVs would contribute to more satisfaction by the user and therefore increase the user’s trust in the technology. If more AVs implemented HMI in their vehicles, then perhaps this increased comfort would decrease some hesitancy toward the technology and allow for its adoption by society.

SAFETY REQUIREMENTS FOR AUTONOMOUS VEHICLES

Safety standards are important in ensuring that automobile companies create technology that is safe for the consumer and others on the road, but the recent advancement in AV technology has managed to evade scrutiny from regulatory agencies. The National Highway Traffic Safety Administration (NHTSA) is the government agency that is in charge of setting safety standards for automobiles (Skwarczek, 2022). In 2018, the NHTSA began allowing “steering wheels, pedals, mirrors, and other required equipment” to be “either loosely defined or entirely optional” in order to allow for prototype testing (Atiyeh, 2021, para. 1). The NHTSA has taken other steps toward decreasing the roadblocks that autonomous vehicles face in development, but has taken a "hands off" approach to increasing the regulations in this sector in order to allow for continual innovation (Atiyeh, 2021). While increased regulations do create roadblocks for innovation, the lack of any regulations at all is alarming and indicates that there likely are gaps in safety within this sector.

The Insurance Institute for Highway Safety (IIHS) is a private organization that uses research to determine the safety of automobiles (Skwarczek, 2022). Although they are not affiliated with the government, they are arguably a better indicator of safety than the NHTSA (Skwarczek, 2022). However, the IIHS is unable to actively enact legislation requiring cars to have certain safety measures in place - they can only provide a rating according to the safety features of cars currently on the market (Skwarczek, 2022). The safety rating does not indicate any legislative repercussions for not abiding by the recommendation, however, it does incentivize automobile companies by influencing market demand. Consumers are more likely to buy cars that are an "IIHS top safety pick", therefore companies will be incentivized to appeal to their customers and implement the recommended safety features.

Starting in 2022, the IIHS will include partially-autonomous cars in its rating system, giving cars a rating of Good, Acceptable, Marginal, and Poor (Insurance Institute for Highway Safety, 2022). According to the Insurance Institute for Highway Safety (2022), in order to receive a rating of Good, a semi-autonomous vehicle must ensure that the driver's eyes are on the road and hands are able to grab the wheel, and alerts and emergency procedures must be performed if those criteria are not met (para. 2). These regulations, if implemented, would assure that the driver does not rely too heavily on the autonomous features of the vehicle. However, as of January 25, 2022, not a single semi-autonomous car on the market would receive an IIHS rating of Good for their partial-autonomy technology (Skwarczek, 2022). The fact that no semi-autonomous car has all of these features is alarming and indicates that harsher enforcement needs to be imposed in order for vehicles to cooperate with the safety standards.

Because the IIHS has less influence on the development of AV technology, the NHTSA must be responsible for creating legislation to keep AVs safe for the consumer. Currently, the NHTSA is focused on allowing for continual innovation in this sector, but there should still be legislation in place that ensures a safe vehicle while also allowing for continual advancements in the technology. One thing that would allow for the NHTSA to impose HMI legislation would be concrete evidence that HMI substantially increases safety without hindering future innovation of AVs. This emphasizes the importance of continued research on the effect of HMI on safety in order to determine the legislation necessary to achieve this balance.

CURRENT HMI OPTIONS IN AUTOMOBILES

HMI "refers to displays that present information to the driver and controls that facilitate the driver's interactions with the vehicle as a whole and indicate the status of various vehicle components and subsystems" (Fisher et al., 2020, p. 338). For lower SAE levels, HMI often involves simple hazard warnings, but higher-level autonomous vehicles would require more sophisticated HMI in order to provide situational awareness information and facilitate the transfer of control to the driver (Fisher et al., 2020, p. 338). Fisher et al.'s *Handbook of Human Factors for Automated, Connected, and Intelligent Vehicles* suggests several examples for HMI that should be implemented in certain situations such as displaying warnings when systems fail, facilitating the transfer of control from the vehicle to the driver, facilitating the transfer of control from the driver to the vehicle, and increasing situational awareness in the driver during automation. However, even with these recommendations, the authors conclude that there is still much to research in order to develop the best HMI designs (Fisher et al., 2020, p. 338). Much of the research that currently exists is dated before AVs advanced to the level they are now, and AV technology continues to advance at a much faster rate than HMI research can keep up with (Fisher et al., 2020, p. 338). Increased research would not only indicate the ability of current HMI technology to increase the safety of a vehicle, it also will allow newer, more sophisticated HMI techniques to be developed, allowing for an optimal driving experience.

SOCIAL CONSTRUCTION OF TECHNOLOGY ANALYSIS

The ideas discussed in this paper lead to the use of the Social Construction of Technology (SCOT) framework in order to analyze the development of HMI technology. The SCOT framework is a tool that portrays the influence of a technology on society and also the influence of different social groups on the development of the technology (Pinch & Bijker, 1984). Applying this framework to the analysis of the development of HMI technology allows for the determination of the most influential groups at play in the development of HMI technology. Figure 2 below illustrates the multiple social groups that influence HMI technology.

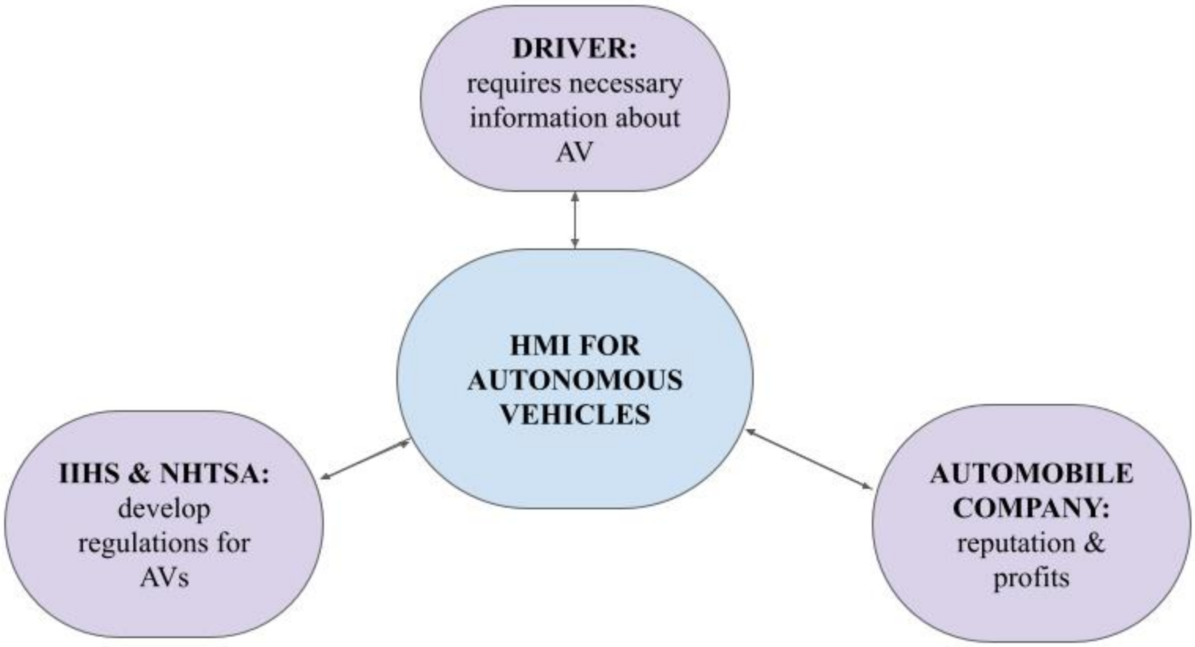

Figure 2: SCOT Framework. This figure depicts the relationship between the HMI technology and the different groups that affect and are affected by the technology (Khatouri, 2022).

As shown in Figure 2, there are three main groups that affect the development of HMI. The first, arguably most important, group is the driver. HMI should be heavily designed with the driver in mind because that is the person that will be most affected by the technology. HMI should be designed in order to increase driver trust in the vehicle by indicating the autonomous decisions that are being made real-time. In addition to this, it is also vital that HMI provides necessary information that the driver needs in order to safely operate the vehicle. This includes warnings and alerts when something goes wrong. The next social group that has an influence in the development in HMI technology is the car company that develops AVs. The company knows the exact restraints of the AV, so they have a responsibility to design HMI that communicates those restraints to the driver through tools such as warning signals. However, car companies also have the goal of maintaining their reputation and increasing profits. These secondary goals have the potential to influence the inclusion of HMI in automobiles if the company determines the

HMI to be too costly. The potential for hesitancy among car companies to include HMI requires the third social group, regulatory agencies, to be included in the SCOT framework. The two main regulatory agencies in this social group are the NHTSA and the IIHS. The regulatory groups are able to incentivize the car companies to include sophisticated HMI in their vehicles because a failure to follow their requirements will either tarnish the company's reputation or even put them in legal trouble. These regulatory groups are responsible for determining the criteria necessary for an automobile to be safe. With respect to AVs, these criteria could involve the inclusion of HMI. While both regulatory agencies have influence on technological development, the NHTSA is the only agency that is able to enact legislation according to their recommendations, giving them more direct influence on the technology. While the main priority for the NHTSA is to the safety of the consumer, they also have to be mindful of the impact of their legislation on the advancement of technology. While balancing harsh regulations to keep the driver safe with relaxed regulations to allow for technological advancement, the NHTSA has a large influence on the development of HMI technology.

THE IMPORTANCE OF HMI RESEARCH

Through the SCOT analysis, it is clear that both the automobile companies and regulatory agencies have the responsibility to ensure the implementation of sufficient HMI in order for the driver to be in the safest conditions possible. While the consumer may not have as much influence on the inclusion of HMI specifically, the adoption of AV technology at all is almost entirely based on the consumer. Trust is determined to be an important factor in the adoption of the technology, which allows society to benefit from the increased safety that AVs create. This trust, however, can still be influenced by the automobile companies, and the automobile companies are heavily influenced by the regulatory agencies. It is apparent that these regulatory agencies have the largest influence on the safety of highways. It is indicated that there is not sufficient research into the increase in safety resulting from HMI technology. This lack of research could be contributing to the slow progression of HMI regulations in AVs, so more research in this area is necessary to allow for more laws to be created to require HMI on AVs, which would create a safer road for everyone.

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