DIFFUSION OF AUTONOMOUS VEHICLES AND ISSUES THAT COME WITH ADOPTION

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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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AUTONOMOUS VEHICLE BENEFITS

As artificial intelligence continues to develop and autonomous vehicles become more advanced, there will be many benefits to society including safety, efficiency, and accessibility (Hoybjerg & Buck, 2018, p. 34). There will also be societal changes because of the transportation industry being transformed. This includes loss of jobs due to AV replacements and the introduction of legislation regulating this new technology. The capabilities of autonomous vehicles are measured by the five levels of automation. The benefits will be further heightened if the technology is completely adopted by everyone in a community. There are obstacles standing in the way of diffusion of AV in society. Any new technology relies on communication of benefits to make the technology successful. In order for the technical portion of this project to be successful, communication of the benefits must be made apparent. The technical portion is the creation of an in-home nursing application called NurseLink which matches nurses with patients.

There are a number of benefits that the innovation of AVs will bring. Driving will become safer and it is estimated that 94% of motor vehicle accidents can be avoided with the use of AV technology by eliminating human error (Matthews, 2020, p. 295). The reaction times of humans as compared to computers/automated vehicles is much slower. Drunk, tired, and distracted drivers are a major cause of motor vehicle accidents in the United States and abroad. AVs will also be able to communicate in a network and learn each other's positions, which should increase their safety further (Nanda et al., 2019, para. 8). This feature will also boost efficiency, because the car will know where slow downs and traffic jams will occur, which may cause a decrease in traffic and congestion (Liu & Song, 2019, para. 2). Computers process information quickly which should boost efficiency at driving and navigating. This would lead to a decrease in fuel consumption in the range of 4% to 25% (Wadud, 2016, paras. 3-5).

Autonomous vehicles will likely improve transportation access and convenience for lots of people. Autonomous vehicles may give people who are not able to drive access to transportation, for example: the elderly, blind, disabled, and those too young to drive, because they will not have control of the vehicle. An AV could function as a designated driver for those attending parties. This will both reduce dangers on the road and improve access to transportation to this significant segment of the population. People spend an average of 50.6 minutes per day driving (Tefft, 2018, para. 8). Autonomous vehicles will allow more time for sleep or other activities for the user while the car is driving itself that will increase productivity by freeing up the time spent driving to and from work.

It may be difficult for this technology to reach all members of society. This inability to spread can be explained by the Theory of Diffusion of Innovation which “is the process by which an innovation is communicated through certain channels over time among the members of a social system” (Rogers et al., 2003, p. 3). Technology is diffused by communication to members of society and the degree to which technology is diffused depends on the effectiveness of communication. Many obstacles that will challenge the spread of this technology. One major difficulty is the reliance of AVs on the infrastructure in a specific area. In order for an AV to operate effectively on the road, the lines on the road must be clear and well painted, which may be difficult in rural areas. Data collection is also important for the operation of AVs and this may be difficult in rural areas. The cost-benefit tradeoff will be a determining factor in the rate of diffusion. Benefits, like safety and efficiency, will need to be communicated effectively in order for this technology to spread more rapidly. Many technologies can be modeled by Diffusion of

Innovation and there are similarities between the diffusion of AV technology and small applications that are being developed.

IN HOME ASSISTANCE

The idea of Diffusion of Innovation is especially important for small and unknown applications that have trouble reaching the demographics they want. Building a small application like this was the technical part of this thesis. This project includes the design and implementation of an independent nursing website for in-home care, called NurseLink. Today, over 65% of Americans who need long term care choose to hire in-home assistance instead of other care alternatives ("How Much Care Will You Need?", 2019, para. 1). However, even with this large demand, there is unfortunately no existing system that makes hiring these nurses affordable and efficient. While word of mouth is unreliable and limited, the agencies charge an additional fee of 15%-30% on top of the nurse's rate (NNBA, 2019, para. 8). This project aims to remove the middleman and allow patients to communicate directly with nurses that fit their needs.

This has the potential to be a very useful technology that can help people save money and make finding in home nursing assistance more efficient. Like many technologies, communicating the benefits of the technology so that people will use it is a challenge. Diffusion of Innovation is a way to model how quickly technology will be adopted and accepted by society. Communication of the technology speeds up this process of widespread implementation in society. Small applications like this nursing one and AVs are similar in that communication of benefits and convenience are key to increasing widespread adoption.

RESEARCH GOALS

What will the challenges of adoption of this technology be, and what problems will arise from this? This research aims to understand the difficulty that AV technology will encounter when diffusing into various demographics in society. This is due factors like the cost of the vehicle, cost of infrastructure maintenance, and lack of appeal from many potential users. The consequences and ethical challenges of this technology in society will also be discussed.

DIFFUSION OF INNOVATION

Autonomous vehicles are likely to encounter a lot of difficulty being widely adopted in society due to economic and social reasons. This technology will have a hard time diffusing to all corners of society, and it may be impossible for it to diffuse to everyone. There are problems that will arise if disparity exists with certain segments of society being unable to use this technology, while other portions have access.

The Diffusion of Innovation is a way to model how quickly technology will be adopted by society (Rogers et al., 2003, p. 3). Many factors can affect the speed at which an innovation will reach all members of society, which may include age, economic status, or geographic location (McGinnis, 2019, p. 30). Figure 1, as seen below, where? shows the breakdown of groups of people adopting a technology. AVs will encounter a lot of resistance diffusing to the group labelled as laggards. The S-curve of diffusion

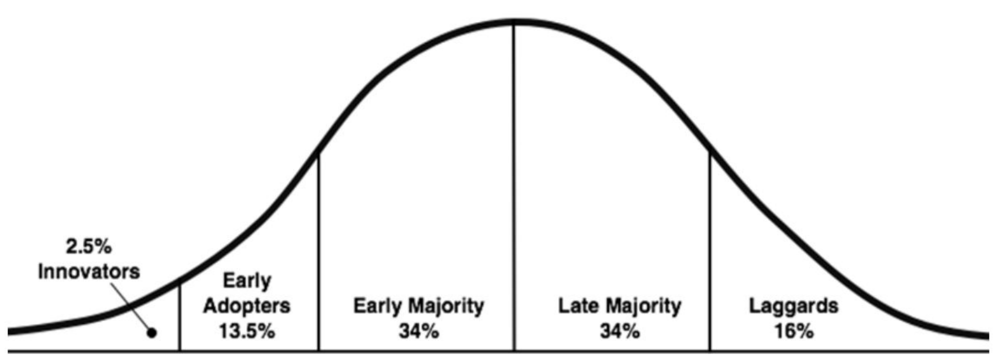

Figure 1: Diffusion of innovation S-curve displays the stages of diffusion and the percent breakdown of each stage (Rogers, 2003, p. 247).

can be used to show how quickly a technology will be adopted. Factors that could impact this include communication of ideas and socioeconomic status (Rogers et al., 2003, p. 5).

INFRASTRUCTURE

Road infrastructure is an area that suffers from neglect especially in rural and low income areas. This type of infrastructure is expensive because of the scale at which it needs to be improved. In 2014, the United States spent $165 billion to build, operate, and maintain highways (Geddes & Madison, 2017, para. 6). Autonomous Vehicle (AV) navigation relies on lane control and on the road lines being clear and consistent, which is an expensive task. Maintenance of roads is a large cause of the cost of infrastructure and increasing funding for this maintenance will require substantial tax revenue (Geddes & Madison, 2017, paras. 24-26). Low income areas will not receive the necessary infrastructure because of lack of funding. In rural areas or areas that are not densely populated, many roads do not have lines. Additionally, unpaved roads will be nearly impossible for AVs to navigate. This means that AVs will have a difficult time navigating rural and poor areas. This will be a further impediment to individuals living in those areas to buying cars with self driving capabilities.

Personal electric vehicles (PEV) and autonomous vehicles (AV) have a similar reliance on infrastructure in order for them to be effective. "The positive correlation between charging infrastructure availability and PEV diffusion is broadly documented in the literature and PEV sales increase with public charging infrastructure" (Funke et al., 2019, para. 31). Places with inadequate infrastructure will slow the diffusion of the technology. Places that are not densely populated will have more trouble improving their infrastructure, because not as many people use roads in these areas (Funke et al., 2019, para. 57). Places with low population densities will have trouble with necessary infrastructure, but will also have problems with lack of data collection due to the large amount of roads that must be mapped.

DATA COLLECTION

The lack of data collection in rural areas will negatively impact the performance of AV technology. Self driving technology uses data collected from previous experiences by cars reacting and making decisions in a given situation or area. AV companies have been collecting massive amounts of data in recent years, which will facilitate navigation in a given area. This includes monitoring how humans react in situations and gaining insight on the most effective way to navigate the road (Kehtarnavaz et al., 1998, p. 694-695). Areas that have more data collected on them for a longer period of time will be more easily operable by AVs before areas that have less or no data collected on them.

According to the American Road and Transportation Builders Association, there were 4.18 million miles of road in the United States in 2017 ("ARTBA FAQ", 2017, para. 1). Data collection on every mile of these roads would be a difficult task, especially on rural and low traffic roads. This is another impediment to diffusion of this technology. The additional challenges to data collection in rural areas is likely to extend the time needed to achieve a critical set of data that allows for truly autonomous vehicles to be effective.

COST VERSUS BENEFIT

A major obstacle that AVs face in total diffusion is cost. Currently cars with low levels of autonomous navigation, such as lane assist, blind spot sensors, and backup sensors, are more expensive than cars without these features. This cost increase can be seen in the base price of the car, but also in repair costs and insurance prices (Preston, 2020, paras. 10-13). These features are much less expensive than the technology required for fully autonomous vehicles. A fully autonomous vehicle requires a fast computer for processing large amounts of data and various sensors and cameras to take in the car's surroundings. Autonomous vehicles require a huge amount of computing power (Shankland, 2019, para. 4) and the Nvidia chips that were used in Tesla vehicles cost thousands of dollars. This cost was a major reason why Tesla brought their hardware technology in-house and are now making faster chips for self driving at a better price point (Hollister, 2019, paras. 3-4). Additionally, the software necessary to control this will be expensive to develop and maintain (Banker et al., 1993, p. 81). These factors combined will result in AVs being significantly more expensive than a vehicle without this technology. This will increase the disparity in the diffusion of this technology along economic lines.

Personal electric vehicles (PEV) are most widespread in countries with higher GDPs and low income inequality (Funke et al., 2019, paras. 27-28). Electric vehicles and autonomous vehicles are similar in their rate of diffusion and adoption. They are similar, because they are not mandatory improvements to automobile transportation, but provide benefits to both individuals and society in general. Choosing to drive the same car or buying a used car is a cheaper alternative to buying PEV or AV. We can compare AV usage to PEV usage and conclude that economically disadvantaged countries and individuals will be less likely to use AVs. The benefits that come with AV and PEV may not be more important to people than the extra cost of the technology, which is discussed below.

This technology may not appeal to people, because they may not see the benefits that come with this technology. “Clearly, safety will be an important factor that will affect acceptance of self-driving cars, but the criterion for acceptable safety in vehicle automation for the general public is currently unknown” (Nees, 2019, para. 1). In a poll conducted by Deloitte from January 2019, 42% of Americans believe self driving cars will not be safe. Other developed countries were within 10% of the United States percentage (McGinnis, 2019, p. 30). Another poll conducted by ANSYS found that 22% of drivers believe humans are better drivers than autonomous cars. However, 34% of drivers believe humans are better drivers currently, but believe this may change as AVs improve (Mircică, 2019, p. 45). Just because a technology is available that will make people’s lives more convenient and more safe does not mean it will be readily accepted as a viable replacement. Even if there is a belief that AV technology is safer, a significant number of people would not spend extra money to receive this safety benefit. This is particularly true for less economically advantaged people. A McKinsey & Co poll from December of 2018 showed that even with no additional cost, there are still many people that would not use AV technology, and Figure 2 shows the age breakdown of interest in AV technology (McGinnis, 2019, p. 31).

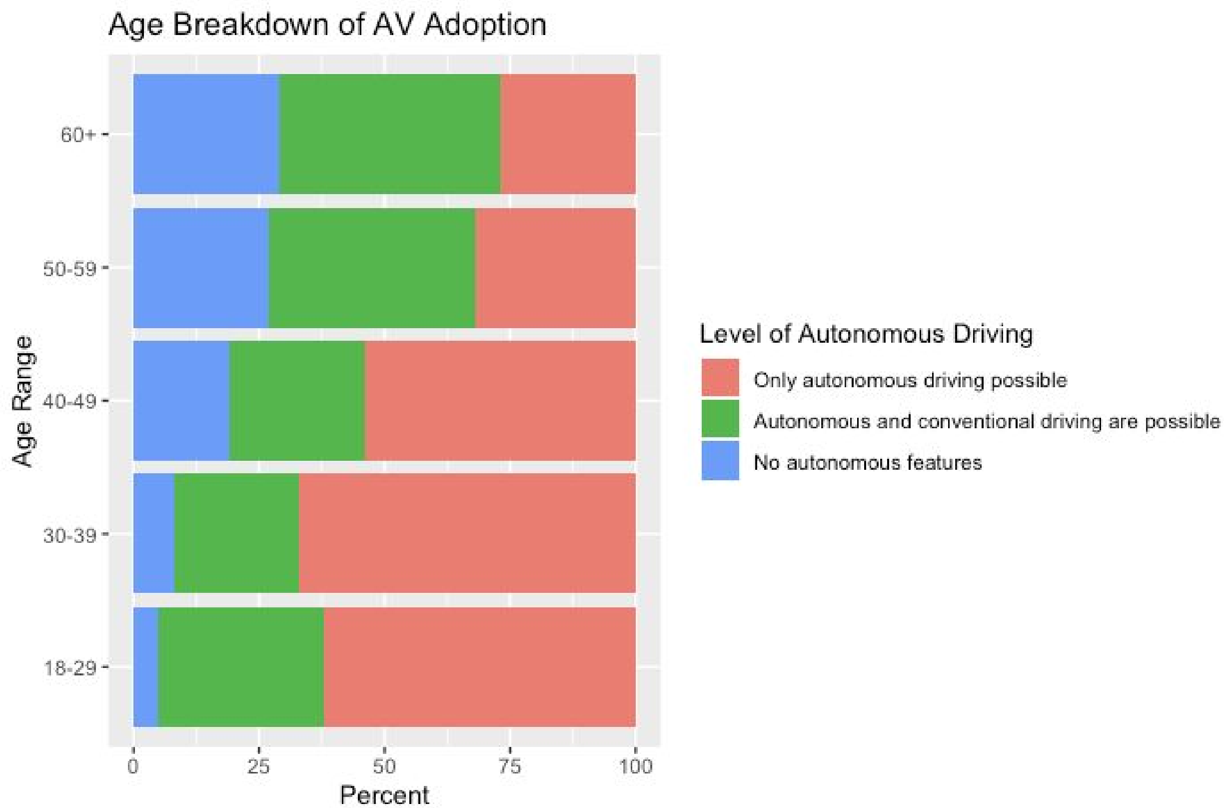

Figure 2: Would you choose an autonomous car at no additional cost over a conventional car with no option to drive yourself? Would you drive an autonomous car that has the option to drive conventionally? (Girerd, 2020)

Figure 2 makes it apparent that large portions of society are still hesitant to use this technology. Even with no additional cost, there is still reluctance to adopt this technology, which comes down to a distrust of artificial intelligence and its ability to perform safely. Rogers discusses the importance of communication and how the rate of diffusion depends on the effectiveness of communication (Rogers et al., 2003, p. 3). AV companies will need to increase communication of the benefits in order for more people to want to use the technology. As shown in Figure 2, older demographics are less willing to embrace this technology and will need reassurance that the technology is safe. The more effectively companies communicate the benefits of AVs, the faster the "laggards" will adopt the technology.

INCREASING RATES OF DIFFUSION

The key to increasing the rate of diffusion for those who are hesitant to use the technology is to effectively communicate the benefits of the technology. Rogers argues that communication is the driving force in diffusion of innovation (Rogers et al., 2003, p. 3). Communicating the benefits of a technology, mainly safety, must involve a third party or an external entity. Using the hand-off model as shown in Figure 3, there must be external safety evaluators before the consumer gets access to the vehicle.

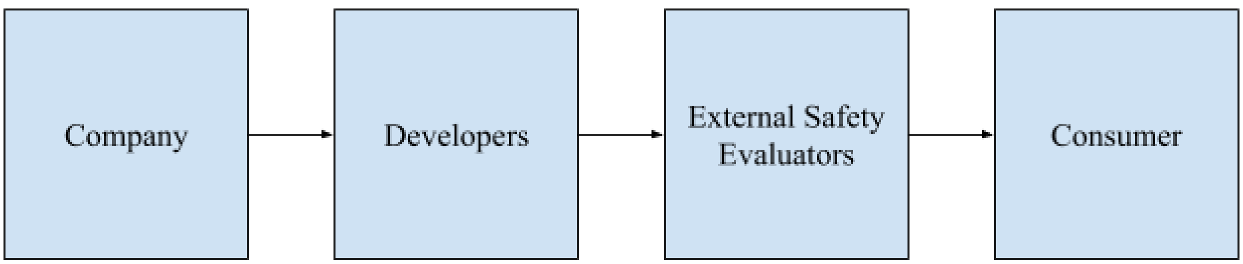

Figure 3: Hand-off model depicting how companies will need to go through third-party evaluation before reaching production (Girerd, 2020).

Companies can claim safety benefits with their product, but consumers typically need a third-party evaluation of the safety of the car in order to believe that the technology is safe. The National Highway Traffic Safety Administration (NHTSA) currently evaluates the safety in a number of categories for all year, make, and model of cars ("Strategic Planning and Performance Measurement", 1996, p. 6-7). Consumers look to third party entities like this for impartial evaluations. Self driving car companies will need to seek the endorsement of organizations like the NHTSA to evaluate the safety of their products. If these evaluations prove the technology to be safe, specifically safer than human drivers, then this safety evaluation will be communicated to the public and speed up the rate of diffusion. In the result that these evaluations do not prove the technology to be as safe as the company claims, then the company is incentivized to further improve their product.

Incentives may spur the adoption of AV technology for people that would not adopt on their own. A comparison can be made to the push for electric vehicles and the incentives created to do so. Due to the present high baseline cost of PEVs, Electric vehicle incentives are mostly reaped by wealthy people, so this strategy will likely only increase diffusion rates for wealthier people (Canepa et al., 2019, para. 9). It is likely that incentives to adopt AVs will not be used by the slowest adopters. The best way to incentivize more AVs may be to boost the infrastructure surrounding AVs, so people can use them in their communities. This can be compared to Personal Electric Vehicles (PEV) and their adoption: "Accordingly, public charging infrastructure is not built due to more PEV, but PEV sales increase due to more public charging infrastructure" (Funke et al., 2019, para. 11). Additionally, decreasing the price of the vehicles is an alternative way to make the technology more accessible.

The theory of Social Construction of Technology (SCOT) gives insight into why a third party entity would make such a difference. SCOT states that society drives innovation and development of technology in response to specific problems (Bijker et al., 2012, p. 45). In a basic sense, AVs were developed because of society's desire to make automobiles safer and more efficient. An average of 102 people throughout the United States are killed per day due to motor vehicle accidents ("NHTSA Quick Facts," 2018, p. 1), and this was a major incentive in the creation of AVs. This is a societal problem that encouraged the development of a new technology that could solve the problem of motor vehicle deaths.

If parts of society are unwilling to trust AVs, then companies have to prove their products are safe. The introduction of third-party evaluations will spur these companies to make their technology as safe as possible. The main concept of the SCOT model argues that technology is determined and molded by human actions (Cozzens, 1989, p. 706). The public image of their product's safety is what will drive companies to continue to improve and refine their product. They need to gain the trust of skeptics in society and an external force may be the way their trust is built.

ISSUES DUE TO INCOMPLETE DIFFUSION

There are disadvantages that come with incomplete diffusion of AVs, including the AV technology not functioning to its maximum potential. Autonomous vehicles work most effectively when all cars on the road are AVs. This network of AVs is called the Internet of Autonomous Vehicles (Nanda et al., 2019, para. 8). If all cars are being monitored in a large network then it will be easier for the vehicles to know what is occurring around them. The Internet of Autonomous Vehicles can be beneficial on a small scale, cars within a certain radius of the vehicle, or on a large scale, traffic patterns miles away. If there are significant numbers of non-AVs on the road, the network will not operate at full capacity. The effectiveness of the Internet of Autonomous Vehicles (IoAV) may depend on "the user behaviors of legacy vehicle drivers in the presence of autonomous vehicles" (Jameel et al., 2019, para. 38).

ETHICAL CHALLENGES

Another issue resulting from the difficulty of diffusion of this technology is how the software will result in the event of a crash. A good example that illustrates possible ethical problems of AV technology is the "trolley problem". It is a dilemma based on the question of:

“Is it ethical to kill one person to save the lives of five people” (Graham, 2017, p. 168)? This brings up ethical questions about what decisions should be made when dealing with human life. Should a car prioritize the life of the driver, the life of a pedestrian, or the life of other drivers? There will need to be standards on how Autonomous Vehicles (AVs) make moral decisions in the future.

Utilitarianism is a moral framework arguing for a decision that provides the most cumulative good for people and gives equal consideration to everyone (Martin & Schinzinger, 2000, p. 55). The Utilitarian standpoint on this issue is to minimize the amount of harm done in general and would argue that the driver’s life is less important than the hypothetical five people around the driver (Wolkenstein, 2018, para. 6). Under Utilitarianism, a crash algorithm would try to maximize the amount of lives saved, rather than prioritizing the driver. Another moral framework that can be used in this situation is Duty ethics, which focus on respecting the duty of the individual and their rights (Martin & Schinzinger, 2000, p. 52). A Deontological perspective would argue that it is the duty of the company to protect the driver regardless of the consequences (Wolkenstein, 2018, para. 6). The car was purchased with the assumption that it would keep the driver safe, and it is the duty of the company to protect the driver to the best of its ability. Automotive makers will be encouraged to create Duty ethics based crash algorithms that prioritize the driver’s life over everything else, because “Who would be willing to pay for a car that would sacrifice his life to save three children” (Coca-Vila, 2018, p. 63)? Although, they may not be creating the algorithm in this way to adhere to an ethical code, but to appeal to their consumers.

As discussed previously, the public image of the safety of a technology is important for how quickly it will be accepted. A technology viewed to be unsafe for the user or puts the user at risk, will take longer to diffuse to all members of society. The different decisions that utilitarian and deontological crash algorithms make, may have an impact on how quickly people adopt the technology.

Autonomous vehicles prioritization of life could result in problems for those who have not yet adopted the technology. Under a deontological ethics code, companies will prioritize the needs of their customers over the needs of others (Coca-Vila, 2018, p. 74). This means that an AV on the road will prioritize the driver over the lives of other drivers/pedestrians. An AV will also prioritize another AV owned by the same company over a non-AV. If this is the case, then low-income people, who cannot afford AVs, will have fewer rights on the road than people who can afford to drive AVs. This is a major flaw when considering a duty based crash algorithm.

Systems based on artificial intelligence, like autonomous vehicles (AVs), make decisions based on previous trials and the outcomes of these trials (McLellan, 2016, p. 8-9). In a basic sense, decisions are made based on probabilities, and the decision with the highest probability of success will be selected (Hume, 2018, para. 42-43). If there is a 99% chance of success for a certain action, the system will choose that decision. A scenario depicted by Figure 4 below shows a flaw in the duty based crash algorithm described above, which would select Option 2. Option 2 ensures that the user will be protected, while the bystander has a relatively low chance of survival. Option 1, ensures that the bystander will be protected, while the user has a good chance of survival (three times the survival percentage of the bystander in Option 2).

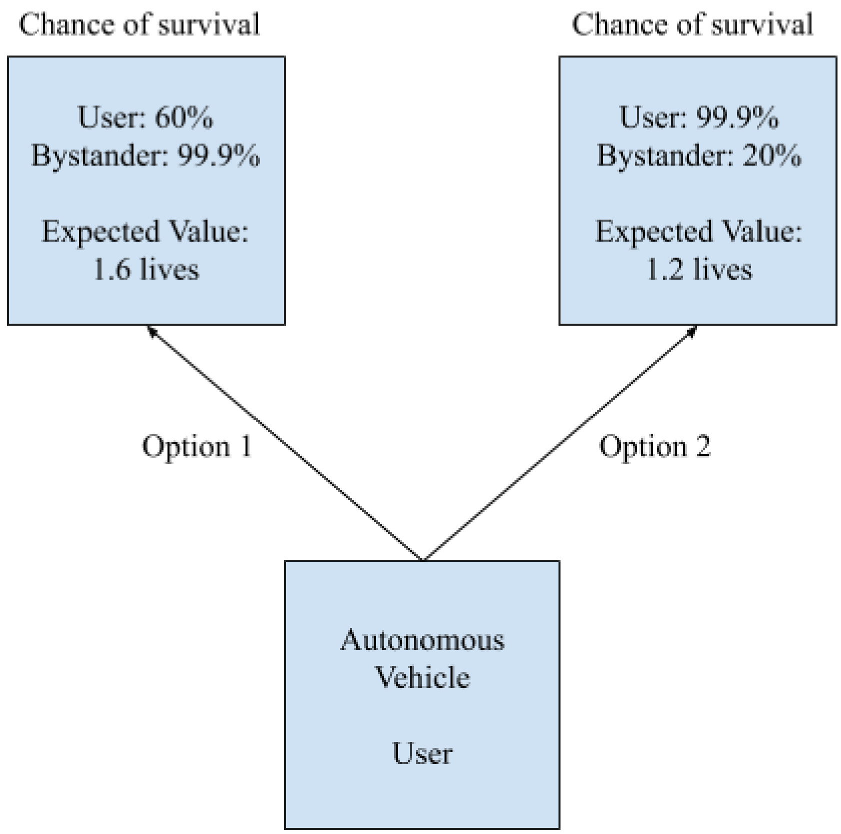

Figure 4: Scenario where an AV has two options both with estimated chance of survival/success for both the user and a bystander (Girerd, 2020).

This is a simplified example of the decision making process and is abstracted to be more clear and understandable. This is an extreme example that displays a scenario where the duty based crash algorithm is flawed. Less extreme examples of this logic will occur frequently when an AV is in use. Where will the algorithm draw the line for how much risk it is willing to accept on behalf of others? For example, how high would the user's chance of survival in Option 1 have to be for the algorithm to choose Option 1? If all cars on the road are operating in such a self centered manor (valuing the life of the driver over any other parameter), then chaos will ensue because of the lack of safety for others. This lack of safety is especially meaningful for those unable to afford AVs because they will be valued less than AVs these scenarios.

If companies are left to make decisions on how to value human life, then they might choose something harmful for those around them. It is up to governments to regulate how crash algorithms will behave. The government protects the good of the public and will hopefully create regulations that keep people safe. Regardless of their decision, certain groups in society will be unhappy and feel that this is unethical and may sway how governments make their decision. These different opinions will create, "various groups [who] will decide differently not only about the definition of the problem but also about the achievement of closure and stabilization"(Bijker et al., 2012, p. 7). These different groups will have a direct impact on the development of technology. Social factors like this are a driving factor in technological development.

LAWS AND REGULATIONS

In addition to regulations on crash algorithms, there will be a need for laws governing who is responsible in the event of a crash. If there are errors in the software that cause injury or death, many people will blame the creators of the software. The judicial system will have to make difficult decisions about who will be held accountable (Coca-Vila, 2018, 67). In the current legal system, a driver that is at fault has to compensate the other driver for any damages that have occurred. In the case of an AV, there is no driver to place blame on, so the blame will fall onto the car's company, which will cause liability for these companies (Koopman & Wagner, 2017). This is because "it is difficult to argue that any persons being carried in the vehicle could be described as driving" (Collingwood, 2017, para. 13), and if there is no human driver, then the liability is placed on the creator of the software.

The regulations on who is to blame in the event of a crash can also cause ethical problems. Currently, if someone gets in a car accident or a work related accident, and they aren't using the correct safety measures, such as headlights, turn signals, and their car being serviced, then they may be at fault. This is called comparative negligence and is covered under tort law (Larson, 2018, paras. 3-5). Since AVs enhance the safety of others around the user, this could be seen as an essential safety feature. This could make it easy to shift liability onto a non-AV driver, which would not be fair to people who do not have this technology.

As artificial intelligence improves and gains more applications, people may lose their jobs to a computer that can do it faster and more economically (Aghion et al., 2019, p. 153). Various jobs that humans currently have involving cars will compete with self driving technology. People whose jobs rely on using vehicles, such as truck drivers, taxis, and delivery drivers, may become obsolete, because AV technology, although initially more expensive, is less expensive in the long run due to not having to pay drivers for their time (Anderson et al., 2018, p.53). This could put many people out of work in transportation related industries. This is an unintended consequence of widespread AV use that has a chance of causing unemployment for large groups of people.

AUTONOMOUS VEHICLE AND SOCIETY

The rate of diffusion for AVs will be slow for many demographics as discussed previously. This has to do with the cost of the car itself and many people's unwillingness to accept the technology because of its perceived lack of benefit. The safety and cost tradeoff will be a major factor on the rate at which people will buy AVs. The more companies can lower the cost of the technology enough and communicate the benefits of the technology, the faster the technology will diffuse. The government also has a role to play in speeding up the rate of diffusion by increasing the funding of AV related infrastructure. Some areas will not have support for the use of AVs because the infrastructure is not good enough for them to operate effectively.

Among the problems arising with AV technology is the fact that the rewards of the technology are overly distributed to the wealthier segments of the population. These rewards can be something as small as saving time commuting to and from work or spending less on gas. It can be something as important as a person's life being valued differently based on whether or not they drive an AV or don't drive an AV. Companies prioritize their customers, so they will value the life of someone using their product over someone not using their product in the event of a crash. AVs are more efficient and less expensive than human drivers, so jobs that require humans to operate cars, will become obsolete. The increased efficiency will put many people out of work because the transportation industry will be disrupted and taken over by AVs.

The introduction of AVs into society will come with many benefits in areas like safety and efficiency. These benefits will increase as more people adopt the technology, which may prove to be difficult, due to factors like cost and infrastructure. Complete diffusion is important for this technology because the more AVs present on the road, the more effective they are (Nanda et al., 2019, para. 8). The introduction of AVs will cause a variety of problems including loss of jobs and ethical problems relating to crash algorithms.

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