Zoox: A Moral Analysis of Autonomous Vehicles

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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

Imagine driving on a dangerous road in bumper-to-bumper traffic along the coast in Big Sur, California. While approaching a sharp curve, a car in front slams on its brakes to avoid a bear. The average human reaction time is not quick enough to stop and avoid a fender-bender. There are two options for the driver: crash into the car or swerve off the road. Unfortunately, both options will lead to potential casualties, and neither one is better than the other. Because there are no other viable options, which option is best?

No one hopes to face such a dilemma, yet this and many other challenges highlight critical decisions that must be made while driving. This hypothetical example resembles the ethical issue known as the trolley problem. The trolley problem example is with runaway trains, but both scenarios involve deciding between two possibilities that will lead to death or despair. Such instances emphasize the complex challenges associated with decision-making under uncertainty and with limited choices. This scenario is one of the main sources of discussion about the use of autonomous vehicles (AVs), representing a significant ethical and technological barrier. How would an AV car respond, and would it be the same response as the average human driver? Naturally, this question and many others form the foundations for an ongoing public debate about the ethics of deploying AVs.

This project will discuss the arguments of AVs under the framework of many societal implications via case studies on a specific start-up company in the industry. Zoox, Inc. is a current subsidiary of Amazon's Devices and Services Organization that has influenced the design of AVs and has contributed to many technologies over the years, especially its navigational and collision avoidance strategies. This research project will focus on Zoox's

development, its involvement with policy and regulation, and its associated ethical debates. The goals for this project are to help shape the public perception of AVs and to demonstrate Zoox's role in the future of transportation.

Zoox: A Company

"The future is for riders." "Built for riders, not drivers." "We are building a new kind of transportation." These slogans are the first things seen when visiting the website of the Silicon Valley-based AV start-up, denoting an Apple-like essence with simplicity and affluent appeals. Zoox's mission is to introduce a new kind of transportation for cities and high-density urban areas that relieves some of the adverse effects of the climate crisis and provides people with more safety and conveniences than traditional standard cars. Zoox's main product is "mobility-as-a-service," which is a taxi-like service of a fleet of self-driven vehicles that allows passengers to request pick-ups from one location and drop-offs at another. In addition to this innovative concept, all the vehicles in the fleet have no steering wheels. (We Are Building a New Kind of Transportation, n.d.).

In 2014, Zoox was founded by Jesse Levinson and Tim Kentley-Klay. They first connected while working with AVs on a research project while they were students at Stanford University, and from there they decided to create a company to design a new type of vehicle based on their work. Over time, they made multiple prototypes from their concepts. One allows the vehicle to have bidirectionality enabling it to freely move without going forward or reverse. The company has been in the news for many years and has hosted Bloomberg News which advertised it as the best competitor to Google's Waymo. In 2019, Aicha Evans, the Chief Strategy Officer from Intel, became the Chief Executive Officer of Zoox, and in 2020, Zoox was

acquired by Amazon. That same year, they officially announced their product after testing the prototypes in San Francisco and Las Vegas. Zoox has since expanded to Seattle, Austin, and Miami. Additionally in 2022, Zoox was the first AV company to certify an electric vehicle under the Federal Motor Vehicle Safety Standards (FMVSS). As of 2023, Zoox's vehicles have been in use on roads in many U.S. cities (We Are Building a New Kind of Transportation, n.d.).

Zoox convinces the public to use its vehicles by emphasizing its innovative technology while also demonstrating its safety and comfort to consumers. For example, Zoox wants consumers to know that riding in their vehicles will be a better experience than using any other form of transportation. The cars are comfortable and spacious and allow for the ease and convenience to stay productive or relaxed. The vehicles keep track of the journeys for customers including time, distance, and routes. The vehicles are compact, allowing for easy maneuverability on busy streets. Zoox has been working hard with marketing and increasing its consumer base, but how has Zoox been able to be unique in the industry?

Zoox: The Technology

Zoox's design has incorporated many pieces of hardware technology. For example, Zoox uses sound and light for communication with its passengers, other vehicles, and pedestrians in the area. The cars have a 133-kWh battery allowing the cars to drive passengers all day without stopping. Dual motors and four-wheel steering allow for efficient travel and for easy transition from moving in both directions. These and many other features will be discussed in this section.

Zoox calls their autonomous driving software "groundbreaking technology," and how they created it is fascinating. Firstly, Zoox integrates into their cars cameras, lidars, and radars. These features interpret the vehicles' environment using a "unique sensor architecture." Cameras

are used to perceive color, radars are used to perceive moving objects and determine speed and direction, and lidars are used to create a 3D environment of the surroundings. The sensors' device specifications and position on the vehicles create a "360-degree field of view," in which the vehicles "can see over 150 meters away in all directions." The cars have a built-in computer system that stores Zoox's trademarked software, allowing for communication between the sensors and the actuators. The actuators of the cars consist of the wheels, the brakes, lights, sound, and other devices that allocate an output. The computers also must make decisions with low latency and high performance for the vehicles to drive efficiently, safely, and effectively (The 'Full-Stack,' n.d.).

One of the most important features of the software is its geographic information system. The vehicles store a predefined map of the area that it drives in in which geometric details are given as well as traffic details of the roads, such as the locations of stop signs. Another important feature of the software is its classification model where the car identifies objects that it perceives in its environment. The system is capable of classifying pedestrians and all kinds of vehicles including bicycles and trucks. Based on its perception and geographic data, the main computers of the cars create a prediction model using artificial intelligence in which machine learning algorithms foresee what these objects may do next. What is fascinating about this algorithm is that it can coordinate multiple events simultaneously from multiple objects and plan accordingly. Using techniques for planning and control, the perception and prediction models create an output that controls the actuators of the cars including actions such as increasing velocity and changing turning radius (Zoox, 2020).

Zoox: Current Progress

Multiple YouTube videos talk about the software and hardware that goes into designing, manufacturing, and testing their cars. One video presented by Taylor Arnicar, a Staff Technical Program Manager, discusses the calibration, localization, and mapping of the Zoox. He described Zoox vehicles as needing three main things: “knowing the exact positioning of their sensors,” “a map of the world,” and “understanding their location on the map.” Calibration is the same way as in other devices: the vehicle determines where the sensors are relative to each other, creating perception that the engineers deem acceptable and appropriate for data collection. Zoox, interestingly, uses the natural environment to calibrate the sensors instead of using predetermined calibration techniques that other sensor-driven programs use. The mapping strategy that Zoox uses is not as interesting as its calibration process. A car drives around the city collecting data on object positioning creating a three-dimensional map of the area signifying the area that Zoox vehicles are allowed to drive on. Zoox, however, does not use traditional strategies for data collecting such as satellite data via Google Earth, which could be a cost-effective approach for the company. Collecting data using a car looks at stationary objects such as vegetation and infrastructure seen from the road as well as concrete indications of the road conditions such as bike lanes, sidewalks, and crosswalks. Localization involves matching the map that is stored in the hardware and software of the car and the current map stored in their databases. For example, if there is current road construction, then the car can adapt to its environment using its models and make adequate decisions when necessary (Zoox, 2022).

There are other technical projects that Zoox is working on that are mentioned on the YouTube channel. The first is TeleGuidance, introduced by Ravi Gogna. It is a source of assistance in case the vehicle is in a situation where it is unable to navigate or plan accordingly based on its algorithm. About one percent of their cars need guidance from humans, and Zoox is

confident that this needed guidance will continue to decrease as the artificial intelligence model learns more about these complicated scenarios. The Zoox team uses a graphic user interface (GUI) that sends waypoints to the car for it to follow or to help solve ambiguity (Zoox, 2020).

The simulation division, told by Yongjoon Lee, a senior manager, describes how new software needs to be applied to the cars. It is first tested using simulations that create realistic and detailed environments of the real world. It is used to "test challenging situations with no physical risks," and each simulation replicates the "geographies, topographies, and traffic situations" for these designated areas. It also adds fake vehicles and pedestrians to create accurate scenarios of situations that are common experiences.

Lastly, Sarah Tariq, the senior director of the perception division, described the current computer vision technology. The data collected from the sensors goes through a neural network to calculate specific outcomes that are necessary for autonomy. This is done by creating a two-dimensional box and mask that classifies pedestrians, vehicles, and other objects. Every object has attributes and gestures that inform the car about what they are doing as well as predict what it will do next. For example, the car can tell the difference between a standing and a walking pedestrian. It can identify specific roles that pedestrians might be doing, such as construction workers, and the technology can detect signals and sirens (Zoox, 2020). After reviewing many of Zoox's technological innovations, the company has taken its expertise seriously, and many of its designs have influenced the development of AVs.

Zoox: Discussion of Safety

One of the major aspects of the company that is emphasized is redundancy. Wouldn't redundancy be a bad thing? Isn't one of the goals for any company to balance budgets to spend

as little time and money? Fortunately, though, redundancy is a good thing for Zoox's development. There are, for example, multiple sensors on the car that might look at specific angles. There are also two engines in the car. This redundancy is a safety constraint for if something fails, then the whole car does not fail. This practice is one of the many aspects of the company that makes other AVs unique.

Safety is Zoox's number one priority. Other than redundancy, there are many safety protocols that are important to Zoox. Zoox advertises that there are “more than 100 safety innovations that don’t exist in conventional cars.” The airbag system in the cars is deployed in many places such that all riders are protected at every angle. The seat belts are uniquely designed for Zoox, and the cars can detect if a passenger is not wearing a seatbelt and will halt if a seatbelt is detached. Zoox also conducts crash tests so that each aspect and configuration of the car’s structural integrity and electrical system allows passengers to be protected. “40,000 people die on U.S. roads every year,” and this is a clear challenge that motivates Zoox to improve safety and work to reduce deaths on U.S. roads. (A New Bar for Safety, n.d.).

Since 2018 and every three years after, Zoox has released information targeting several ideals and standards towards their number one priority: safety. Three volumes of information have been released about safety innovations and building cars with a focus on safety. In the first volume, Zoox expresses the belief that by designing AVs, there will be a “safety paradigm shift: from reactive to proactive safety.” Not only does Zoox mention the technology and computer architecture that allows them to demonstrate improving safety but also mentions the important attributes of cybersecurity and data security practices they are adopting and establishing such as constantly checking and updating software to be the latest and with the least number of vulnerabilities. Managing their relationship with law enforcement by addressing measures that

need to be taken during a situation between the AV and the police was also mentioned as an important goal. Lastly and most importantly, Zoox wants to let the public know that their vehicles are accessible to all people, and the AV industry will help people with disabilities have more freedom and protection. Overall, Zoox's main goals are to have “safer streets,” “fewer cars,” and “less pollution,” in the U.S. Zoox's safety reports show that they continue to develop accessibility and spread their contributions to more locations (Levinson & Evans, n.d.).

The Public: A Discussion on Opinions, Challenges, and Solutions

As a disclaimer for this project, ambiguity, assumptions, and lost connections have prevented some goals from being achieved. This is mainly because there has not been consistent data specifically geared towards Zoox, so for the main analysis and discussion of the project, important information about the public’s eye on AVs will relate to the entire industry. Luckily though, there are many studies discussed in this section that emphasize using data from the largest sources of AV testing, and Zoox is usually a top three company in the United States for the number of vehicles on the road that are solely autonomous. The information gathered will not only be informative but may also influence others wanting to be transparent with the idea of AVs and see how much development a company has made in the industry and its reputation in society.

Since 2016, the National Highway Traffic Safety Administration (NHTSA) has published guidelines for automated driving systems, outlining specific safety measures that manufacturers should adopt, including privacy, ethical considerations, registration, and data sharing. These guidelines have been updated four times, with the most recent version published in January 2020, reflecting changes in the AV industry. Zoox, a major player in AV development, explicitly aligns

its safety guidelines with NHTSA recommendations, demonstrating a commitment to meeting U.S. government safety standards (Automated Driving Systems | NHTSA, n.d.).

However, current regulatory structures remain inadequate in addressing the unique challenges posed by AVs. Traditional safety models designed for human drivers struggle to adapt to the complexities of machine learning and automated decision-making. One study argued that a proactive regulatory approach, including pre-market approval, continuous monitoring, and mandatory reporting, is needed to create a comprehensive safety framework (Wansley, 2024).

Network latency during teleoperations remains a critical technical challenge. Zoox's TeleGuidance allows human operators to intervene in complex scenarios, but latency issues can delay real-time perception, decision-making, and vehicle control, thus compromising safety. Another study investigated this technology in similar companies and highlighted strategies to mitigate these delays, such as improving communication and infrastructure and developing more efficient data processing techniques. Enhancing teleoperation reliability is essential for the safety and performance of AVs, particularly during training and testing phases (Kamtam et al., 2024).

Ethical decision-making in AVs raises significant moral and social questions. Another study proposed that AVs should follow ethical principles based on public consensus when faced with moral dilemmas like the classic trolley problem. Their study identified key factors influencing decision-making, including the number of injuries, the presence of children, the majority opinion, and the legal consequences of actions. The study suggests that prioritizing the protection of law-abiding individuals and children could guide AV algorithms in real-world scenarios. Incorporating these ethical principles into AI models and safety protocols could align AV behavior with societal values (Li et al., 2022).

To define public consensus in this context, most people believe that AVs should behave the same way as human drivers. The actions of human drivers are usually based on logical standpoints, such as driving based on the law, and on emotional standpoints, such as showing common courtesy. Naturally, having an AV break the law is being addressed by AV companies, but for an AV to display common courtesy to humans or other AVs, there needs to be more research on this topic. No one wants to see a reckless AV, so one approach to be considered is conducting surveys with the public on their thoughts on AV behaviors on the roads.

Public perception of AVs is shaped by various stakeholders, including the government, industry, and the public. Another source found that Congress focuses more on traditional car industry issues than AVs, and there is limited attention on driver responsibility and AV technologies. Public administrations and agencies discuss car safety more frequently, but the technological and ethical challenges of AVs remain secondary topics. Engineers and developers engage more deeply with AV technologies, but ethical programming remains a challenge as responsibility shifts from human drivers to technology. The paper suggests that policymakers and industry leaders are reacting to technological changes rather than shaping them proactively, which can be a serious problem for the industry in the near future (Schuelke-Leech et al., 2019).

The impact of AVs on professional drivers is also a key concern. Another study explored how AVs affect the well-being of truck drivers and rideshare drivers, such as Uber and Lyft. Safety in complex driving conditions, such as bad weather and pedestrian interactions, was a primary concern. Job loss and reskilling emerged as significant anxieties, with drivers worried about reduced job satisfaction and the loss of human intuition in decision-making if AVs replace human drivers. Greater transparency from employers about how AV adoption will affect the workforce is essential to addressing these concerns (Dubljević et al., 2023).

Accident data involving AVs offer insight into their performance and challenges. Another study analyzed real-world crash data and found that most AV-related incidents are low-severity rear-end collisions, often caused by human drivers misjudging AV behavior. AVs tend to drive more cautiously and strictly follow traffic rules, which can create conflicts with aggressive or inattentive human drivers (Ghorai et al., 2024). Improving AV interaction with human-driven vehicles and transitioning to a predominantly autonomous traffic environment could reduce crash rates. Another source supported these findings, noting that low visibility, complex intersections, and poor weather conditions contribute to higher crash rates, and head-on and angular collisions tend to be more severe. This research highlights the need to enhance AV navigation in high-risk environments to help support the public by decreasing accidents (Kohanpour et al., 2024).

Pedestrian safety in AV environments remains a significant challenge. Another study proposed a Smart Pole Interaction Unit (SPIU) to enhance pedestrian safety by facilitating real-time communication between AVs and pedestrians. The SPIU would process data from multiple sensors to detect pedestrians and alert AVs to avoid collisions. Integrating such systems into urban infrastructure could improve AV performance in mixed-traffic environments and reduce pedestrian-related accidents (Chauhan et al., 2023).

Liability and responsibility in AV-related incidents present complex legal challenges. Another source examined the uncertainty surrounding liability when control is shared or entirely managed by an AV system. Liability could rest with the operator, manufacturer, or both, depending on the extent of automation and the nature of the incident. Jurisdictions have begun adapting DUI laws to account for passengers in AVs, but ambiguity remains. Legal systems face difficulties in assessing fault when AV algorithms are involved, highlighting the need for clearer liability models and updated legal frameworks (Gurney, 2015).

Cybersecurity is another critical area of concern for AVs. AVs are highly interconnected through electronic control units (ECUs), third-party software, and external networks, making them vulnerable to hacking. Another paper defined hacking as unauthorized access to vehicle systems for retrieving driver data or manipulating functionality. The NHTSA recommends layered security models, including firewall protection, system segmentation, and manual override mechanisms, to mitigate these threats. Over-the-air updates for cybersecurity issues also have become an industry standard, reducing the need for physical recalls. However, enhancing encryption, data protection, and threat-sharing frameworks remain essential for securing AV networks (Kennedy, 2017).

Privacy challenges are closely linked to cybersecurity risks and are also an area of concern. Another study identified three primary privacy concerns: autonomy privacy (control over personal choices), information privacy (data protection), and surveillance privacy (monitoring of travel behavior). AVs collect vast amounts of data, including passenger identities, travel routes, and sensor-detected information. Misuse of this data could deter public adoption of AVs. Potential solutions found in the paper include improved encryption, stricter data retention policies, and greater transparency about data usage. Clear regulatory standards on data ownership and transmission are essential to building public trust in the technology (Collingwood, 2017).

State-level AV policies vary significantly across the U.S., and another source identified four key regulatory elements: human operator requirements, driver override capabilities, data capture during disengagements and crashes, and safety incident reporting. Most states address only one or two of these elements. Twenty-seven states require AV insurance, fourteen states impose penalties for safety violations, and eight states have laws addressing disability accommodations. Greater consistency in state policies, particularly in data collection and safety

reporting, could enhance AV performance and accountability across jurisdictions (Ehsani et al., 2022).

Overall, AVs present a complex relationship of technological, legal, and ethical challenges. While significant progress has been made in AV safety, regulatory frameworks, and public acceptance, gaps remain in liability, privacy, and human-machine interaction. Enhancing real-time decision-making, improving pedestrian safety, and establishing clearer liability standards will be crucial in advancing AV technology and fostering public trust. By aligning technological development with ethical principles, improving regulatory consistency, and addressing public concerns, the AV industry can create a safer and more equitable autonomous transportation ecosystem.

Analysis and Conclusion

AVs are at a challenging point in their development as they need to continue to grow in order to become sustainable entities. Robust perception using detection, classification, localization, and mapping is crucial for AVs to enhance road safety. By using a variety of sensors like cameras, lidar, and radar, AV companies like Zoox could achieve better detection, handle adverse conditions, and decrease driving errors (Van Brummelen et al., 2018).

Ethical considerations should be a priority for companies developing AVs. Companies are constantly addressing a wide range of ethical issues in their reports, especially Zoox. Safety and cybersecurity continue to be primary concerns, and dealing with moral dilemmas is essential. Human oversight, liability, and design modifications are still a struggle in the industry, but academic discussions and industry practices can lead to a more comprehensive understanding of the ethical challenges of autonomous driving (Martinho et al., 2021).

The project was intended to investigate specific areas of Zoox, and from further research, these areas are inconclusive but also inspiring. One area is "working on advancing autonomous driving technology with a major goal of increasing road safety and comfort of motorized transport" (Geißlinger, 2021). Some of the major ethical considerations for AVs are technical safety, human agency, inclusiveness, and societal well-being. (Geißlinger, 2021). Another is the foundational practice of how AVs navigate in urban environments like, for example, creating an image-based localization, which "given a database of views of city street scenes tagged by GPS locations, the system computes the GPS location of a novel query view" (Zhang & Kosecka, 2006). Another point is with a collision risk assessment: "a new risk assessment methodology that integrates a network-level collision estimate with a vehicle-based risk estimate in real-time" (Katrakazas et al., 2019). The last key point is on the discussion of AV regulation in the United States government. The current implications of AVs at the federal, state, and local levels need to address initiatives, executive orders, legislation, and policy frameworks, and most importantly, the Society of Automotive Engineers' self-driving autonomy levels are important criteria to look into within the government. (Hemphill, 2020).

Finally, the trolley problem originally mentioned should be discussed. Of course, Zoox has many resources that can prevent a problem from happening, but the only question that needs to be addressed is whether the public will trust these resources and how other companies are handling them. Once technology is more readily available and easier understood by the public, ethical scenarios may not be as serious and more manageable.

Based on this research, many holes have been filled, but more work is still needed to be done. Through the development of standard computer hardware components and the study of machine learning applications in vehicles, the aim is to deepen an understanding of the

automotive industry's current innovations and future challenges. Ultimately, there are goals to apply these insights to, and there needs to be support for the responsible and effective integration of self-driving technology into society. Autonomous vehicles are the future, and there are many exciting things to come on the horizon.

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