Self-Driving Cars: How Modern Automobiles Will Change Your Life

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Term Paper

Engineering Management 52 – Technical and Managerial Communications

Tufts University

Medford, Massachusetts

April 13, 2020

EXECUTIVE SUMMARY

This paper was written as a term paper for Professor Amy Hirschfeld's spring 2020 Technical and Managerial Communications class at Tufts University. The purpose of this paper is to illustrate that you should support the advancement of self-driving cars because the technology is designed to optimize safety and would greatly benefit society.

Within this paper, I seek to address three main topics to further understand the impacts of self-driving cars: hardware, software and control protocols, and current applications. I begin by examining the sensors commonly deployed in autonomous cars and their functions, as well as explain how machine learning is used in control systems to make decisions and determine the motion of the car. I then go on to outline how self-driving cars are currently developed and tested. Finally, I list the benefits that self-driving cars will have on the future and the challenges that could set back their widespread use.

My goal in writing this piece is to help readers consider how engineers and computer scientists apply innovative technology to increase the level of automation seen within self-driving cars. These mechanical designers use a suite of sensors and methods, ranging from lidar to GPS, to solve two broad problems: what is the cars position on the road and where are surrounding objects? While each sensor serves an individual purpose, sensors with similar functionality are often used as substitutes for each other. Because these control systems need to make timely decisions, with no room for failure, onboard computers use machine learning to analyze sensor data rapidly and identify important patterns.

Currently, hundreds of companies, ranging from corporations to start-ups, are racing to develop completely autonomous cars. Already, many of them have released semi-autonomous cars to the public. To thoroughly test and gradually introduce the technology to the public, developers drive higher-level autonomous vehicles on pre-determined tracks, where every inch of the roads are digitally scanned and edge cases are uncommon. Despite challenges like overcoming high costs and winning the public's trust of the technology, companies are determined to deliver the technology swiftly because of the potential benefits. Autonomous transportation could radically reduce the number of annual car accidents, cut down on auto-emissions, and provide safe opportunities for people incapable of driving themselves.

I believe that people should be informed about self-driving cars and see how the onboard technology enables autonomy in order to make an informed decision on whether they would use autonomous transportation. Because of notable potential benefits, the self-driving car industry is growing rapidly and the inevitable introduction of autonomous vehicles to the public will undoubtedly change our lives.

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List of Definitions

Acceleration	the change in velocity over time. Its sign (positive or negative) based on the direction.
Accelerometer	a sensor that measures the linear acceleration of an object.
Accuracy	samples in a dataset have recorded values that are close to the actual value.
Actuator	a part of a machine that is responsible for moving or triggering a mechanism. Requires a controlling signal and power source.
Algorithm	a process or set of rules to follow in making calculations, particularly for computers.
GPS	Global Positioning System
Gyroscope	a sensor that measures rotational velocity and position.
IMU	Inertial Measurement Unit, a sensor that measures linear and rotational motion.
Lidar	Light Detection and Ranging, a remote sensing method that uses light pulses to detect the shape and distance of objects surrounding the sensor.
Localization	the process of determining an exact location of an object.
Neural Network	a series of algorithms used to identify patterns and trends in data. The structure of the algorithms mimics the human brain.
Precision	samples in a dataset have consistent recorded values with low variation.
Radar	Radio Detection and Ranging, a remote sensing method that uses radio waves to detect the distance of objects surrounding the sensor.
Redundancy	the inclusion of extra components in a system to use as backups.
Sensor	a device that uses technology to measure an observable physical quality and produce data about that quality.
Speed	the magnitude of velocity, not based on direction
State Matrix	a matrix used in control theory to describe the current value of physical characteristics of a system.
Velocity	the change in position over time. Its sign (positive or negative) based on the direction.

1.0 Introduction

1.1 Purpose

I wrote this paper for Professor Amy Hirschfeld's Technical and Managerial Communications class at Tufts University, with the intended purpose of demonstrating the complexity and life-altering potential of self-driving cars. Through this explanation and analysis, my goal is that readers understand the technology at hand and how self-driving cars are developed today. Moreover, I am hopeful the reader will come to see how innovative technology and testing will make self-driving cars trustworthy to the general public. Scientists are currently predicting that the public will regularly use self-driving cars in the next decade. Therefore, it is vital to craft an informed opinion about self-driving cars now, as the decision to support autonomous transportation will soon be upon us.

1.2 Scope

I begin by discussing the different levels of autonomy to give the reader context for standards of self-driving cars. I give an overview of the technology used in self-driving cars, and categorize the technology into two parts: hardware and software. In reference to hardware, I discuss lidar, the most exciting type of sensor used for object detection. I also explain other remote sensing technology like radar, ultrasonic sensors, and cameras. In reference to software, I give the readers context about the machine learning algorithms and control procedures for self-driving cars and tackle how companies test cars on pre-built digital maps. I move on to present the reader with current applications of self-driving cars. To conclude the paper, I discuss the possible benefits and drawbacks that autonomous vehicles will have on the future.

To give the reader a broader idea of how self-driving cars work, I do not go into immense depth about how the cars are made or how every sensor works. I also do not discuss the social aspects of self-driving cars in depth; specifically, public perception, ethics, and governmental regulation. You should also recognize that there are many companies and laboratories developing self-driving cars and there is a diversity of solutions to many of the problems that self-driving cars must solve. As a result, self-driving cars do not always have the same onboard technology and are not tested in the same ways.

1.3 Background Information

1.3.1 The Levels of Autonomy in Self-Driving Cars

Engineers use the levels of autonomy to classify how much control a driver has over a self-driving car or any automated form of transportation. As the levels of autonomy increase, the driver has less control of the car. With innovations in sensing and processing data, cars with higher levels of automation are on the market. Most cars feature some type of cruise control, an example of Level 1 automation. Some cars on the market have level 2 automation, meaning drivers can take their hands off the wheel while the car makes turns on the highway and parks itself. Self-driving cars at Level 3 and above can function with little intervention from the driver and are only available in regulated areas. Each level of autonomy is shown in Figure 1 (Hetch 2018)[*].

[*] See List of References

2.0 Technology of Self-Driving Cars

2.1 Hardware in Autonomous Vehicles

2.1.1 What is Lidar?

Self-driving cars use many different types of sensors to interpret their surroundings, but lidar may be the most exciting. Lidar is a method for detecting objects and mapping 3-D environments using laser pulses. Although typical microwave radar has a longer range than most lidar, radar has a much weaker resolution than lidar (Hetch 2018). Scientists use lidar for many different 3-D mapping applications, such as mapping the ocean floor and searching for drone landing sites. Lidar sensors generate 3-D point clouds of data that give detailed position and velocity information about objects close to the car. Sensors can produce millions of data points per second, which allows for higher resolution than normal microwave radar. Although it works better at shorter distances, new lidar technology can reliably detect objects around 200 meters away (Hetch 2018). While there are some drawbacks to lidar, like high cost and limited range, engineers are working on lowering the cost of production and increasing range capabilities. Developers are improving lidar quickly because, unlike other methods, lidar provides enough detailed data to accurately find the location of the car and detect oncoming obstacles.

2.1.2 Radar, Cameras, and other Sensors used in Self-Driving Cars

Self-driving cars feature a suite of sensors that accomplish the task of identifying where the vehicle is and what objects are around the car. The most common sensors in automated vehicles are cameras, microwave radar, ultrasonic sensors, GPS receivers, and inertial measurement units (IMUs). Some of these sensors have the same function to make sure there is redundant data. As a result, inaccurate data from one sensor can be verified with data from another.

To determine the exact location of the cars, designers outfit self-driving cars with GPS receivers and IMUs. According to Surden and Williams' "How A Self Driving Car Works", self-driving cars use GPS to "gain a rough approximation of their location, detecting the current road and direction", and then use other sensors like lidar and IMUs to "determine physical placement on the detected road within a few centimeters of actual location" (Surden, Williams 2016). While broader GPS data helps self-driving cars navigate road paths and directions, the more precise physical location data gives the control system a sense of which lane the car is in and how the car should navigate in different upcoming traffic situations.

In addition to lidar, engineers use microwave radar, ultrasonic sensors, and cameras to detect obstacles. Figure 2 below compares the detection ranges and purposes for different object detection sensors (Babak 2017). Microwave radar works by sending out microwave rays from a hub and measuring the time it takes for the rays to bounce back to a receiver. As the range increases, the resolution of radar becomes much lower than that of lidar. Radar can be used as a backup sensor for lidar, or a replacement for radar in cheaper systems (Tsyktor 2019). Ultrasonic sensors, which are currently used in Tesla cars for nearby object detection, work similarly to radar and lidar but send out sound pulses instead of light or microwave rays. These sensors perform best at detecting objects within several meters of the car. Also, ultrasonic sensors are the least expensive remote detection sensors and are currently used in assisted parking systems (Hetch 2018).

Cameras are often used to add more redundancy to object detection. While color data provided by cameras can be very valuable for detecting specific objects on the road like road signs, they are limited by the slower speed of image analysis and dependence on external light. Although each of the sensors has distinct advantages and drawbacks, many of the sensors have the same function to establish redundancy in the system. Because the failure of sensors could have fatal consequences, engineers ensure that if one sensor fails to see an obstacle or provides faulty location data, another sensor will provide the correct data. The hardware on self-driving cars continues to improve, and overlapping data helps engineers decrease the failure rate of cars.

2.2 Control and Software Systems in Autonomous Vehicles

2.2.1 Pre-built Maps for Autonomous Vehicles

To make autonomous travel safe and controlled, companies test the capabilities of their cars on pre-determined tracks or previously scanned maps. Specialized mapping vehicles use lidar and cameras to scan curb elevations, significant traffic features, and lines on the road (Surden, Williams 2016). Engineers use the collected data to generate maps that resemble Google Maps Street View. These maps must contain more information than normal GPS maps because normal maps lack the precision needed for navigating a self-driving car. Map specialists examine the prebuilt annotated maps for errors and add in lane markings, intersections, lane paths, and traffic signs. With predetermined information about a car’s surroundings and actuating signals, the vehicle’s control system can compare and verify live data from sensors. Onboard computers process and compare live data to digital maps to make control decisions and improve reliability. The live data is also used to update the pre-built maps that may be slightly out of date.

2.2.2 Protocols for Automated Driving

The control system for self-driving cars, like many other robots, uses systematic procedures and computer programming to identify the safest path for the car. Designers generally control the car in three main steps: sense, plan, act. In the sensing phase, the control system receives data from the sensors that I previously discussed. On-board computers rapidly process the data to determine the current state of the car. Embedded software processes the state matrix and images from cameras to make decisions on how the car should act. The control system has high-level algorithms dedicated to making driving strategy decisions, and low-level algorithms to adjust steering, throttle, and braking (Babak 2017).

Additionally, the algorithms are split into longitudinal and lateral control. Longitudinal control determines how a car moves forward and backward in the lane, whereas lateral control determines how the car changes lanes and turns. The speed and acceleration data of the host vehicle and surrounding vehicles is important for determining how the car should move forward and backward, while traffic signals processed by cameras or pre-built maps trigger the car to brake or slow down (Babak 2017). Lidar, radar, and video cameras provide the longitudinal controls with redundant information to allow for smooth, reliable acceleration and deceleration.

Lateral control systems respond to neighboring cars, handle lane changing, and make smooth and accurate turns. For example, engineers study how the car should optimize lane changing for transition time and passenger comfort (Babak 2017). Pre-built maps and cameras are used to detect necessary turns or lane shifts. Additionally, the distance and speed data from ultrasonic and lidar sensors identify objects to either side of the car.

2.2.3 Using Machine Learning with Automated Vehicles

For onboard computing systems to process data quickly, engineers use advanced machine learning algorithms in the control system. Although machine learning is a broad term, I am referring specifically to algorithms that have been iteratively trained to identify patterns, features or trends using some set of given inputs. The algorithms can be trained by a person, or automatically by recursive algorithms, telling the algorithm if it reached the correct solution. Algorithms perform better when they are better trained.

To process images quickly, programmers implement pattern recognition algorithms. These algorithms identify features like object borders and significant lines in the image, as well as filter out outlying datapoints. By filtering the data, engineers reduce the size of the data set so it can be processed faster. The reduced image is passed through clustering algorithms, which find inherent structures in the data to organize it into groups of other common data points (Gupta 2018). Once data has been classified as a certain state, it can be passed through decision matrix algorithms. Decision matrix algorithms analyze relationships between datasets to determine the actions that the control system will trigger.

All these algorithms can be written as neural networks. In the case of the DAVE-2 system designed by members of the NVIDIA Corporation, a convolutional neural network was used to process data from a front-facing camera and steer a self-driving car (Bojarski 2016).

Without machine learning, control systems could not automatically process images in the car’s surroundings, or rapidly act on crucial state data. Heavily trained neural networks and algorithms continue to improve in today’s golden age of computer science and make it possible for cars to act safely without the need for human intervention.

3.0 Implementation of Self-Driving Cars

3.1 Current Applications of Self-Driving Cars

3.1.1 Models and Simulations of Autonomous Cars

Because self-driving car companies have high costs for development and no room for error, they will often model their self-driving car systems in simulations before testing them in the real world. All parts of the system can be tested in computer simulations. However, engineers might examine the control system more closely because sensors are tested better in a physical environment. To test out the neural network used to control a self-driving car, NVIDIA ran a simulation where they fed their control system a video feed that would change its angle based on steering feedback. The block diagram for the simulation is shown in Figure 3. (Bojarski 2016)

3.1.2 Closed System Self-Driving Cars

Another safe way of testing out self-driving car technology is to use pre-built digital maps to drive shuttles or cars on a pre-determined course. I had the chance to visit Optimus Ride in the Seaport District of Boston and witnessed self-driving shuttles driving people on a set track from their offices to a nearby T stop. Autonomous car companies have received permission from the government and privately-owned spaces to employ Level 4 technology on campus shuttles and employee buses (Kaslikowski 2019). These cars will often still have a driver in the driver's seat as a backup to the system.

Although today's technology is advanced enough to handle Level 4 automation, companies are patiently demonstrating success and reliability in more controlled systems so that the general public can see the amazing capabilities of these cars. Waymo has generated buzz for having publicly available automated shuttles, but they are only available in Phoenix, which has consistent, clear weather. The shuttle service in Phoenix is only run in a pre-defined area that is constantly mapped (Kaslikowski 2019).

3.1.3 Assisted Driving

Assisted driving is the most used type of automation used in today's cars. Assisted driving can range from simple tasks like automatic parking to hands-off cruise control driving on the highway. Tesla recently released a software update to its cars to enable assisted cruise control, low speed road maneuvers, and assisted parking (Fagella 2020). Cadillac's Super Cruise system does not have functionality for low speed maneuvers or parking, but it does allow for completely hands-free highway driving, as opposed to Tesla's system which suggests that the user should keep their hands on the wheel (Kaslikowski 2019).

3.2 Predictions for Future Implementation

3.2.1 Possible Benefits for the Future

After explaining how the technology of self-driving cars enables Level 3 and 4 autonomy reliably, I want to discuss some of the problems that automated cars will continue to solve in the future. Pollution, automobile accidents, and traffic congestion are problems that affect us every day and are becoming worse as more cars are being used and produced.

The interconnectivity and responsive sensors on self-driving cars can help solve all these problems. According to Daniel Howard's report "Public Perceptions of Self-Driving Cars", communication between cars could eliminate 81% of police-reported traffic accidents (Howard 2013). Although some people may not feel comfortable giving up control to a self-driving car, automation systems on these cars could save thousands of lives lost yearly to drunk driving, texting and driving, and other unnecessary causes for automobile accidents. As one might imagine, coordination between cars would make roadways much more organized. Platooning, or deploying cars on the highway in tight lines, has been shown to cut down traffic congestion and use aerodynamics to save fuel for cars in the back of the platoon (Howard 2013). Similar to cyclists in the Tour de France lining up behind one another to conserve energy, cars would be able to cut down fuel consumption by up to 25%.

From a social perspective, self-driving cars will address the issue of transportation equity. If companies like Uber use self-driving cars or self-driving cars become available for public use, costs for ridesharing would decrease and enable people to travel that can't afford a car themselves. Furthermore, people that can't drive themselves would be able to benefit from autonomous driving services, like aging populations, children under the legal driving age, and people with disabilities.

Altogether, the opportunities for transportation safety, efficiency, and equity are compelling. These benefits have motivated engineers to develop faster processing, more reliable sensors, and bring universal self-driving in the next decade.

3.2.2 Possible Issues for the Future

Although the technology to fully implement Level 5 autonomous vehicles is not yet available, the greatest challenges facing the self-driving car industry are winning over the general public's trust, reducing costs, and establishing government regulation for the self-driving car industry. In Daniel Howard's study about the public perception of self-driving cars, he surveyed a random population in Berkeley, California about the most and least attractive elements of self-driving cars. Figure 4 exhibits the survey's responses (Howard 2013). The most attractive elements listed by participants in the survey were safety, amenities and convenience, while the least attractive elements listed were lack of control, liability, and cost.

I believe that although citizens might be worried about giving up vehicle control right now, it takes time and testing for passengers to trust new types of transportation. If you are concerned about the lack of human control in their vehicle, you should keep in mind that these systems are being painstakingly designed and tested by human engineers to have no room for error. Companies are also solving the problem of high development costs and will be able to lower costs as the industry gains more traction. Because companies are thoroughly testing self-driving cars, I believe people will want to use self-driving cars once they see several years of successful autonomy in pre-determined track applications.

4.0 Conclusions

Self-driving cars are complex systems optimized for safety and reliability. Each of the sensors involved serves a unique purpose, but are also designed to serve as backups for other sensors. Research and advancements in machine learning enable engineers to process sensor data faster and implement fast decision-making in the control systems. Many companies are currently developing self-driving cars and have already achieved high-level autonomy. I recommend that the public should use self-driving cars. While you may feel uncomfortable about using one now, I urge you to consider the benefits and large-scale efforts put into developing user safe technology and be willing to support the development of reliable self-driving cars.

5.0 Figures

Fig. 1 Levels of Autonomy from “Lidar for Self-Driving Cars (Hetch 2018)

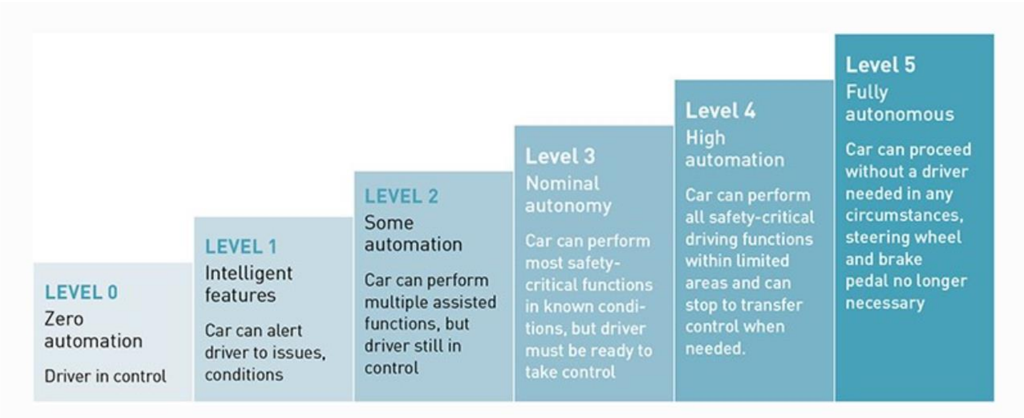


Figure 2. Sensors on Self-Driving Car and their Functionality (Babak 2017, Figure 4)

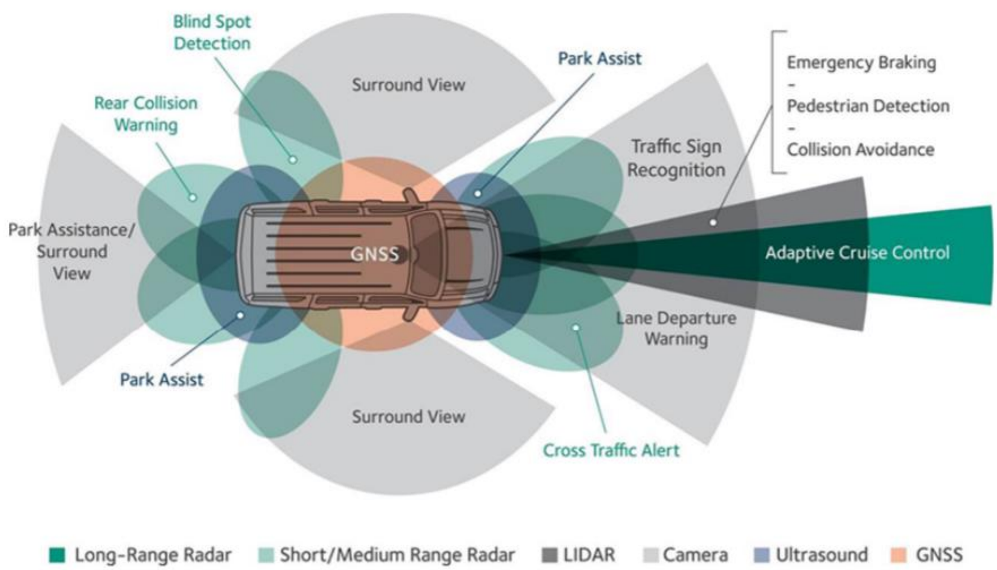


Figure 3. Block Diagram of Convolutional Neural Network in simulated controls test (Bojarski 2016)

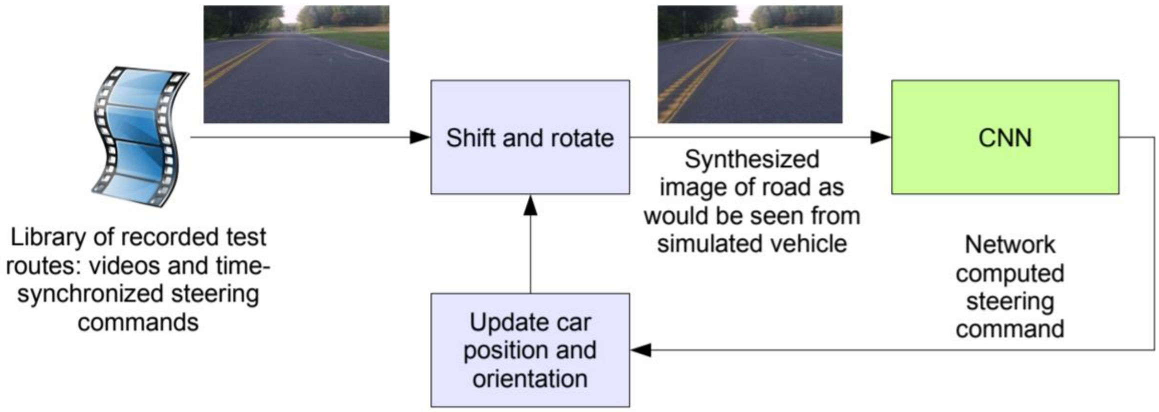
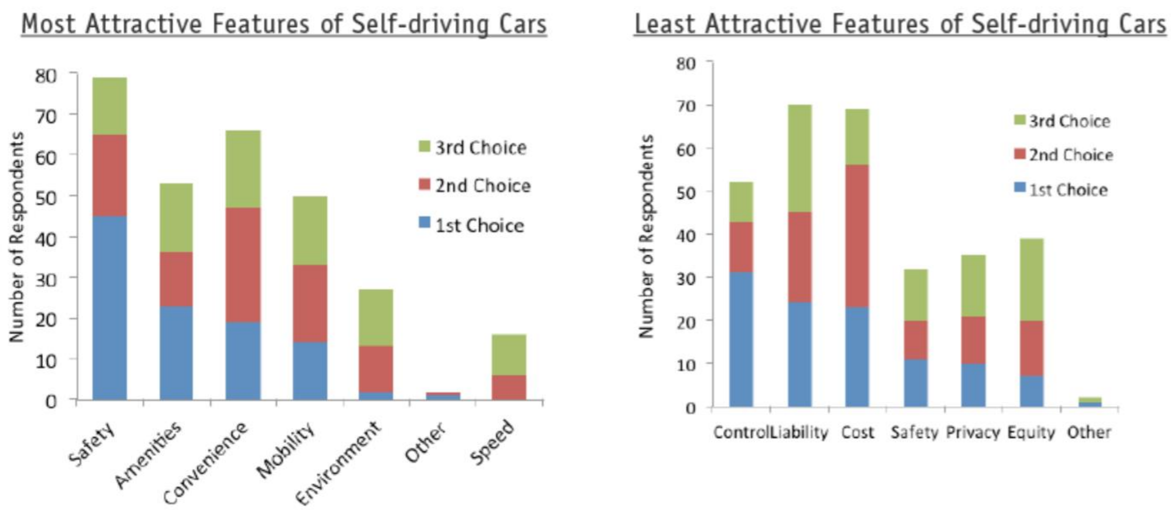


Figure 4. Most Attractive vs. Least Attractive Features of Self-Driving Cars (Howard 2014)



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