Challenges in Autonomous Vehicle Development

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Abstract

We are in the brink of the next disruptive technology in the automobile revolution. The autonomous vehicles will have the direct impact on our society and the way we move and live. The autonomy means "autos" (self) and "nomos (rule). The definition of autonomy is the ability of an individual to make a rational, uninfluenced decision. The autonomous vehicle must follow the principles of autonomy like humans, making fair decisions at all situations. To navigate to a given destination based on passenger provided instructions, autonomous vehicle must observe, understand, model, infer, and predict behavior of the surrounds like, weather, animals, debris, follow the traffic rules and signals, and the humans inside and outside the car and finally make a split-second decision. The social, economic, ethical, human behavior, urban and suburban landscape, insurance, legal and liability, and ethnographical effects are enormous. These aspects must be considered for the development of the autonomous vehicle. This paper would examine the challenges in developing autonomous vehicle.

Keywords:
Autonomous, Social, Ethics, SAE, Smart technology

1. Introduction

World Health Organization (WHO, 2018) Global status report on road safety 2018, highlights that the number of annual road traffic deaths has reached 1.35 million. Road traffic injuries are now the leading killer of people aged 5-29 years. The burden is disproportionately borne by pedestrians, cyclists and motorcyclists, in particular those living in developing countries. The report suggests that the price paid for mobility is too high, especially because proven measures exist. Drastic action is needed to put these measures in place to meet any future global target that might be set and save lives. An increase in average speed is directly related both to the likelihood of a crash occurring and to the severity of the consequences of the crash. For example, every 1% increase in mean speed produces a 4% increase in the fatal crash risk and a 3% increase in the serious crash risk. The death risk for pedestrians hit by car fronts rises rapidly (4.5 times from 50 km/h to 65 km/h). In car-to-car side impacts the fatality risk for car occupants is 85% at 65 km/h.

Allied Market research report (Jadhav, 2018) projects that the global autonomous vehicle market size would be $54.23B in 2019 and increase to $556.67B by 2026. The AV uses artificial intelligent (AI), light detection and ranging (LiDAR) and RADAR sensing technology. Navigant Research report (Abuelsamid, 2019) ranked GM Cruise, Waymo and Ford Autonomous vehicle as the top three vehicle manufacturers leading the autonomous vehicle revolution. The research states that Waymo and GM Cruise are neck and neck in the race to secure autonomous-vehicle leadership, with scores of 86.7 and 86.6 points, respectively. The score is based on 10 factors: vision; go-to-market strategy; partners; production strategy; technology; sales, marketing and distribution; product capability; product quality and reliability; product portfolio; and staying power.

Ford's approach to developing Self-driving vehicles (Ford, 2018) report states that the growth of autonomous vehicles causing a shift from individual ownership to the use of shared mobility such as ride-sharing services. Most infrastructure is built to meet the needs of the individual use of vehicle. Most of the vehicle sit ideal in the parking lot about 95% of the time. As a result of this, as much as 30% of the prime real estate in the city centers are devoted to just parking alone. Autonomous vehicles are one of the solutions to address this concern. Ford Motor Company has created Ford Autonomous Vehicles LLC, a new organization charged with accelerating its AV business to capitalize on market opportunities. National Highway Transportation Safety Administration (NHTSA, 2019) adopted the SAE J3016 standard for autonomous vehicle level of automation as defined per the Table 1 and Figure 1 below:

Table 1. SAE J3016 Definition of Autonomous Vehicle

LEVELS OF AUTOMATION	WHO DOES WHAT, WHEN
Level 0	The human driver does all the driving. (**No automation**)
Level 1	An advanced driver assistance system (ADAS) on the vehicle can sometimes assist the human drive with either steering or braking/accelerating, but not both simultaneously. (**Driver Assistance**)
Level 2	An advanced driver assistance system (ADAS) on the vehicle can itself actually control both steering and braking/accelerating simultaneously under some circumstances. The human driver must continue to pay full attention ("monitor the driving environment") at all times and perform the rest of the driving task. (**Partial Automation**)
Level 3	An Automated Driving System (ADS) on the vehicle can itself perform all aspects of the driving task under some circumstances. In those circumstances, the human driver must be ready to take back control at any time when the ADS request the human driver to do so. In all other circumstances, the human driver performs the driving task. (**Conditional Automation**)
Level 4	An Automated Driving System (ADS) on the vehicle can itself perform all driving tasks and monitor the driving environment – essentially, do all the driving – in certain circumstances. The human need not pay attention in those circumstances. (**High Automation**)
Level 5	An Automated Driving System (ADS) on the vehicle can do all the driving in all circumstances. The human occupants are just passengers and need never be involved in driving. (**Full Automation**)

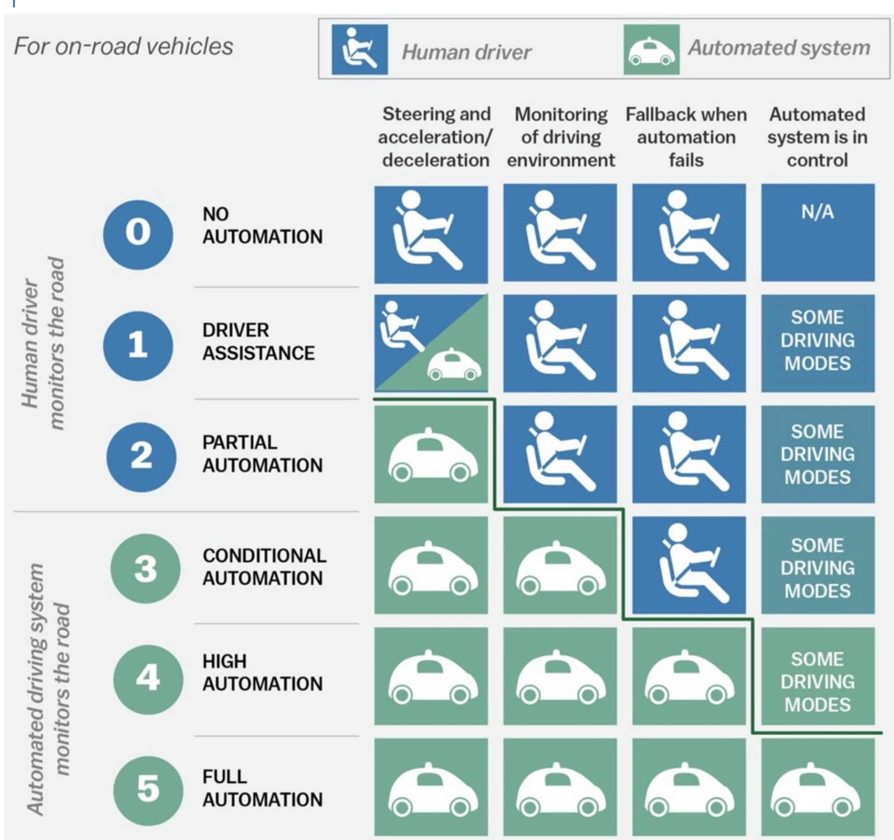


Figure 1. SAE J3016 Graphical Representation of Autonomous Vehicle

This paper will highlight the challenges in developing the autonomous vehicle technology. Per NHTSA a safe vehicle must be able to achieve four performance goals: Avoid crashes, protect occupants, obey traffic laws and norms, complete intended travel mission. Also, AV developers must address a question that can an autonomous vehicle behave ethically.

The outline of this paper consists of several sections. In Section1: the introduction, Section 2: the literature review, Section 3: technical challenges, Section 4: human factors, ethics and social challenges, section 5: legal and liability challenges, and Section 6: the summary and discussion are presented.

2. Literature Review

There are lot of literature available on autonomous vehicle technology. The Autonomous Vehicles Readiness Index (AVRI) is a tool to help measure 25 countries' level of preparedness for AV. It is composite score that combines 25 individual measures from a range of sources into a single score. The score main focuses are: Policy and Legislation, Technology and Innovation, Infrastructure, and Consumer acceptance. The top 25 countries that are ready for autonomous vehicles are listed by KPMG (2019). The Netherlands leads the list followed by Singapore, Norway and the United States.

This Navigant Research Leaderboard examined the strategy and execution of 20 leading automated driving system companies. These companies were rated on 10 criteria: vision; go-to market strategy; partners; production strategy; technology; sales, marketing, and distribution; product capability; product quality and reliability; product portfolio; and staying power. The top 10 auto companies that are ready to a lunch an AV were listed by the Navigant Research. The top of the list is Waymo, followed by GM, and Ford Autonomous Vehicles (Abuelsamid, 2019)

The application of state -of -the art embedded system programming, software engineering, data processing, distributed computing, computer vision and deep learning techniques to the collection and analysis of large-scale naturalistic driving data in the MIT-AVT study by Fridman et al. (2017) seeks to break new ground in offering insights in to how human and AV interact in the rapidly changing transportation system.

Du et al. (2017) proposed a LIDAR and vision fusion system for car detection through the deep learning framework. It consists of three major parts. The first part generates seed proposals for potential car locations in the image by taking LIDAR point cloud into account. The second part refines the location of the proposal boxes by exploring multi-layer information in the proposal network and the last part carries out the final detection task through a detection network which shares part of the layers with the proposal network. The evaluation shows that the proposed framework is able to generate high quality proposal boxes more efficiently (77.6% average recall) and detect the car at the state-of-the-art accuracy (89.4% average precision). With further optimization of the framework structure, it has great potentials to be implemented onto the autonomous vehicle.

Bimbraw (2015) presented a detailed chronology of Autonomous cars: Past, present and future a review of the developments in the last century, the present scenario and the expected future of autonomous vehicle technology. Various semi-autonomous features introduced in modern cars such as lane keeping, automatic braking and adaptive cruise control are based on vision and embedded systems. Extensive network guided systems in conjunction with vision guided features will be used in autonomous vehicles. It is predicted that most companies will launch fully autonomous vehicles by the advent of next decade. The future of autonomous vehicles is an ambitious era of safe and comfortable transportation.

Gao et al. (2018) presented an object classification method for vision and light detection and ranging (LIDAR) fusion of autonomous vehicles in the environment. This method is based on convolutional neural network (CNN) and image up sampling theory. By creating a point cloud of LIDAR data up sampling and converting into pixel-level depth information, depth information is connected with Red Green Blue data and fed into a deep CNN. The proposed method can obtain informative feature representation for object classification in autonomous vehicle environment using the integrated vision and LIDAR data. This method is also adopted to guarantee both object classification accuracy and minimal loss. Experimental results are presented and show the effectiveness and efficiency of object classification strategies.

Brummelen et al. (2018) presented a comprehensive review of the state-of-the-art AV perception technology available today. It provides up-to-date information about the advantages, disadvantages, limits, and ideal applications of specific AV sensors; autonomous features; and localization and mapping methods implemented in AV research. This useful information is to gain a greater understanding of the current AV solution landscape and to guide experienced researchers towards further research and development. Perception and Automotive Sensors focus on the sensors themselves, whereas Localization and Mapping focus on how the vehicle perceives where it is on the road, providing context for the use of the automotive sensors. By improving on current state-of-the-art perception systems, AVs will become more robust, reliable, safe, and accessible, ultimately providing greater efficiency, mobility, and safety benefits to the public.

3. Technical Challenges

There are 5 levels of automation as defined by SAE standard J3016. This SAE Recommended Practice describes motor vehicle driving automation systems that perform part or all of the dynamic driving task (DDT) on a sustained basis. It provides a taxonomy with detailed definitions for six levels of driving automation, ranging from no driving automation (level 0) to full driving automation (level 5), in the context of motor vehicles and their operation on roadways.

The levels of driving automation are defined by the specific task performed by the DDT and/or DDT fallback. “Role” in this context refers to the expected role of a given primary driver, based on the design of the driving automation system in question and not necessarily to the actual performance of a given primary driver. For example, a driver who fails to monitor the roadway during engagement of a level 1 adaptive cruise control (ACC) system still has the role of driver, even while s/he is neglecting it.

Active safety systems, such as electronic stability control and automated emergency braking, and certain types of driver assistance systems, such as lane keeping assistance, are excluded from the scope of this driving automation taxonomy because they do not perform part or all of the DDT on a sustained basis and, rather, merely provide momentary intervention during potentially hazardous situations. Due to the momentary nature of the actions of active safety systems, their intervention does not change or eliminate the role of the driver in performing part or all of the DDT, and thus are not considered to be driving automation. It should, however, be noted that crash avoidance features, including intervention-type active safety systems, may be included in vehicles equipped with driving automation systems at any level. For Automated Driving System (ADS) features (i.e., levels 3-5) that perform the complete DDT, crash avoidance capability is part of ADS functionality (NHTSA, 2019).

Currently available Driver Assistance Technologies are: Rear Automatic Backing Up & Parking, Rear Cross Traffic Alert, Traffic Jam Assist, Highway Pilot, Adaptive Cruise Control, Forward Collison warning, Automatic Emergency Braking, Pedestrian Automatic Emergency Braking, Adaptive Lighting, Lane departure warning, Lane Keeping Assist, Blind Spot Detection, Lane Centering Assist (NHTSA, 2019).

Currently, most autonomous cars could be driven by level 2 features, such as lane keeping system and automated braking technology. Level 3 automation requires reliable sensor quality. Autonomous vehicles function similar to robots, following a “sense-plan-act” design (Ref. Figure 2). Sensors interpret data, such as lane markings on the road and nearby objects, use the data to determine a plan, and then act accordingly. AV’s would respond even better than human drivers to an event such as a child running into the street- sensors could perfectly calculate the child’s and the car trajectory to determine exactly how much to swerve and brake. Today’s sensor technology uses Light Detection and Ranging (LIDAR) systems which are limited by range (unable to work in long distances) and reflectivity (poor reflection off of some materials, susceptibility to glare). RADAR systems are limited by inability to detect non-metallic objects (i.e. pedestrians). Other types of sensors that are effective at near ranges (1-10 meters). AVs are quite capable of navigating on predetermined routes under favorable weather conditions- with GPS coordinates for the course’s road segments and stop signs- but sensor technology needs to be enhanced (SAE, 2018).

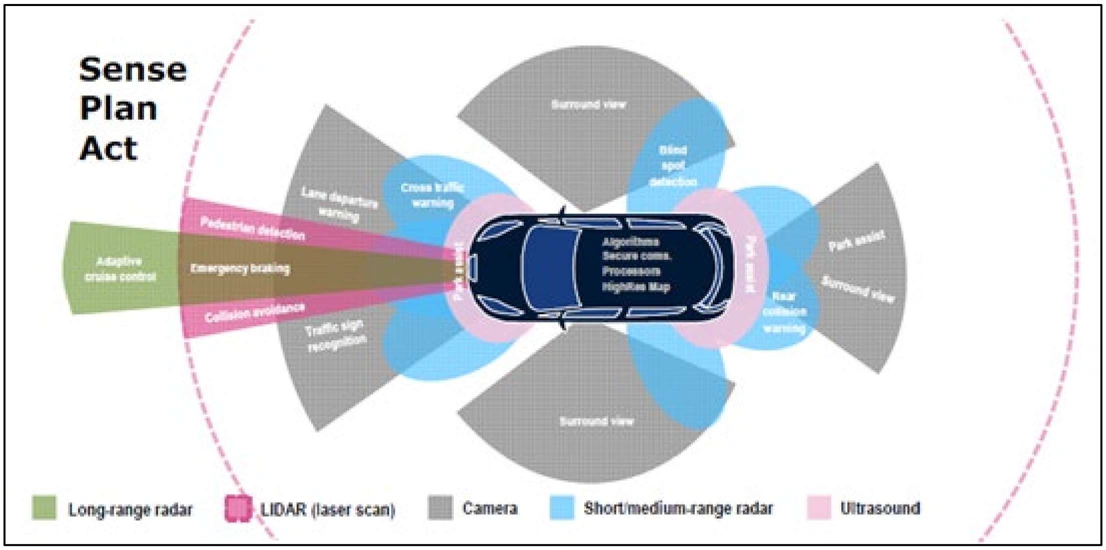
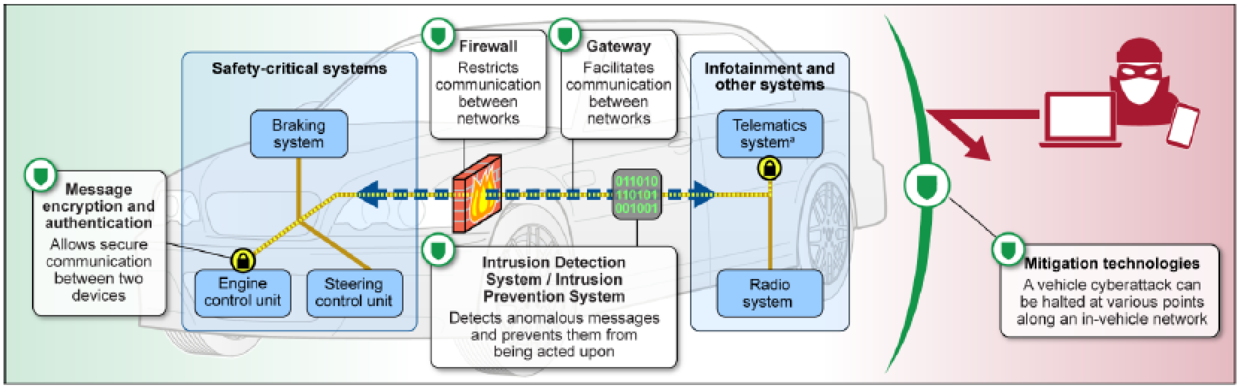


Figure 2. Technologies that allow vehicles to sense-plan-act in response to the dynamic driving environment (Parrish, 2015)

Vehicle-to-vehicle (V2V) communication enables vehicles to wirelessly exchange information about their speed, location, and heading. The technology behind V2V communication allows vehicles to broadcast and receive omni-directional messages (up to 10 times per second), creating a 360-degree "awareness" of other vehicles in proximity. Vehicles equipped with appropriate software (or safety applications) can use the messages from surrounding vehicles to determine potential crash threats as they develop. The technology can then employ visual, tactile, and audible alerts—or, a combination of these alerts—to warn drivers. These alerts allow drivers the ability to take action to avoid crashes. These V2V communication messages have a range of more than 300 meters and can detect dangers obscured by traffic, terrain, or weather. V2V communication extends and enhances currently available crash avoidance systems that use radars and cameras to detect collision threats. This new technology doesn't just help drivers survive a crash—it helps them avoid the crash altogether.

Vehicles that could use V2V communication technology range from cars and trucks to buses and motorcycles. Even bicycles and pedestrians may one day leverage V2V communication technology to enhance their visibility to motorists. Additionally, vehicle information communicated does not identify the driver or vehicle, and technical controls are available to deter vehicle tracking and tampering with the system. The use and integration of Vehicle-to-Everything (V2X) communications technologies into the transportation environment, which have the potential to improve motor vehicle safety and efficiency as well as support cooperative vehicle automation concepts. V2X use 5.9Ghz spectrum for transportation safety communications. vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-pedestrian (V2P) communications, collectively referred to as "V2X" communications (NHTSA, 2014).

Cybersecurity threats can endanger critical infrastructure. Transportation systems that depend on digital infrastructure are at risk when they do not prioritize maintaining security, modernizing systems to reduce vulnerabilities, and implementing enhancements to increase the resiliency of digital infrastructure. To mitigate potential threads, ADS should include strong security and functional testing of the technology, people, and processes. Vehicle's Cybersecurity-Mitigation Technologies in-vehicle network is shown in Figure 3.



Source: GAO analysis of stakeholder information. | GAO-16-350

Figure 3. Vehicle's Cybersecurity-Mitigation Technologies in-vehicle network

Litman (2019) in his Implications for transport Planning report stated that operating a vehicle on public roads is complex due to the frequency of interactions with other, often-unpredictable objects including vehicles, pedestrians, cyclists, animals and potholes. Because of these interactions, AVs will require orders of magnitude more complex software than aircraft (Figure 4). Producing such software is challenging and costly and ensuring that it never fails is virtually impossible. There will almost certainly be system failures, including some that cause severe accidents.

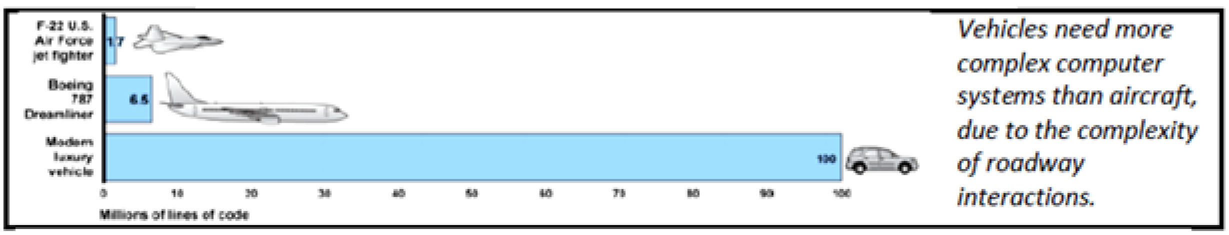


Figure 4. Aircraft and Autonomous vehicle software code compared (GAO 2016)

Current technology status is that the automobiles are operating using Level 2 and somewhat Level 3 technology. This driving habit is not 100% safe since, vehicle is always still requiring immediate driver attention. The roadways, roadway marking, sign boards, weather, hazardous conditions, public acceptance, pessimistic behavior towards modern technology, cybersecurity, legal and liability issues creating roadblocks for the Level 4 and Level 5 progress. Once, the vehicle is fully automated, the real benefit will be enormous in terms of economy, driver and pedestrian safety, productivity, parking space, leisure, less crash, insurance, and most of all less dependence on oil and improved environmental sustainability.

4. Human Factors, Ethics and Social Challenges

Ohn-Bar and Trivedi (2016) presented a compressive review of the humans in the AVs. The paper highlighted the understanding, modelling and predicting the human behaviour in the AVs based on three domains: (1) inside the vehicle, (2) around the vehicle, and (3) inside surrounding vehicles.

The Moral Machine, an online experimental platform designed by Awad et al. (2018) to explore the moral dilemmas faced by the autonomous vehicles. This platform gathered 40 million decisions in ten languages from millions of people in 233 countries and territories. First, they summarized global moral preferences. Second, documented individual variations in preferences, based on respondents' demographics. Third, cross-cultural ethical variation, and uncover three major clusters of countries. Fourth, these differences correlate with modern institutions and deep cultural traits. The results are shown in Figure 5.

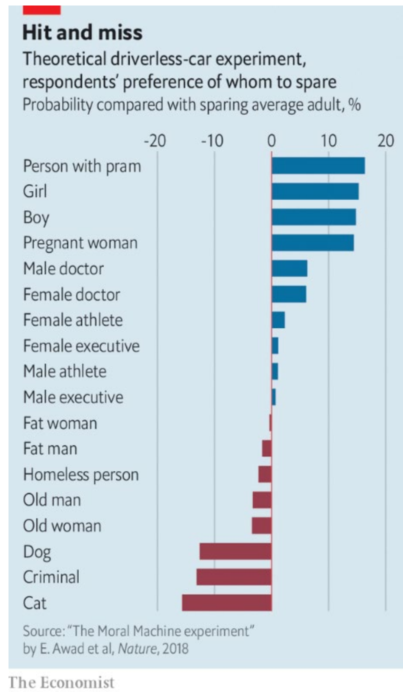


Figure 5. Hit and Miss: Theoretical AV experiment (Awad, 2018)

Level 2 and Level 3 Automated Vehicle driving should be (1) functionally safe and electronically reliable, (2) operationally intuitive for drivers under diverse driving conditions (3) compatible with driver abilities and expectations (4) supportive of improved safety by reducing driver error (5) operational only to the extent granted by the driver and always deferent to the driver and (6) secure from malicious external control and tampering. Addressing human factors questions is central for accomplishing these goals. A key element of vehicle automation is the driver-vehicle interface (DVI). The DVI refers to the vehicular displays that present information to the driver, and controls that facilitate the driver's control of the vehicle as a whole as well as the status of various vehicle components and subsystems. DVI be designed in a manner consistent with driver limitations, capabilities, and expectations. The human interface should inform the driver the current automation mode and status, message characteristics, visual interface, auditory interface, Haptic interface, and driver inputs (Ni and Leung, 2015).

Recognizing that the movement of cars on the road involves inherently social action. Vinkhuyzen and Cefkin (2016) led the research for the development of autonomous vehicles (AVs) that engage with pedestrians, bicyclists, and other cars in a socially acceptable manner. The expected results that can be implemented into algorithms, resulting in a challenge to our social science perspective: How to translate what are observably social practices into implementable algorithms when road use practices are so often contingent on the particulars of a situation, and these situations defy easy categorization and generalization? This case study explored how to proceed cross-disciplinary engagements. A particular challenge is the limitations of the technology in making observational distinctions that socially acceptable driving necessitates. Significant successes were achieved, including the identification of road use practices that are translatable into AV software and the development of a concept, called the **Intention Indicator**, for how the AV might communicate with other road users. Continued investigation required on road use to uncover and describe the ways in which the social interpretation of the world can enhance the design and behavior of AVs.

Authors have studied six different human behavior vs AV scenarios on the roadways and intersections. Aside from the technical challenges, there are the social considerations of a location. For a car driving down the street, for instance, an area where children are playing by the side of the road changes the sense of location for a driver significantly. We might expect that an AV take such social considerations into account when it drives down the road, yet that necessitates that the AV has a concept of what "playing children" are—that it is able to recognize not only children, but also their behavior as playing—and that it could adjust its driving style dynamically. (The same street without playing children does not require a similar level of caution).

Maurer et al. (2016) The AV be able to operate responsibly on the roads; AVs will need to replicate- or do better than – the human decision-making process. The decision-making process require a sense of ethics, and this is very difficult capability to reduce into algorithms for a computer follow.

A simple scenario that illustrates the need for ethics in autonomous cars (Lin, 2014). Imagine in some distant future, autonomous car encounters this terrible choice: it must either swerve left and strike an eight-year old girl or swerve right and strike an 80-year old grandmother. Given the car's velocity, either victim would surely be killed on impact. If the driver does not swerve, both victims will be struck and killed; so, there is good reason to think that AV ought to swerve one way or another. But what would be the ethically correct decision? Ethics must be considered when programming a self-driving car, because no one can be discriminated because of their age. The United States offer equal protection to all persons, as stipulated in the fourteenth amendment of its constitution.

If the autonomous car were most interested in protecting its own occupants, then it would make sense to choose a collision with the lightest object possible (the girl).

If the choice were between two vehicles, then the car should be programmed to prefer striking a lighter vehicle (such as a Mini Cooper or motorcycle) than a heavier one (such as a sports utility vehicle (SUV) or truck) in an adjacent lane.

Suppose a person is driving an autonomous car in manual mode; driver is in control. Either intentionally or not driver could be inattentive about to run over and kill five pedestrians. Car's crash-avoidance system detects the possible accident and activates, forcibly taking control of the car from driver's hands. To avoid this disaster, it swerves in the only direction it can, to the right. But on the right is a single pedestrian who is unfortunately killed. Was this the right decision for AV to make?

A consequentialist would say yes: it is better that only one person dies than five. But a non-consequentialist might appeal to a moral distinction between killing and letting die, and this matters to OEMs for liability reasons. If the car does not wrestle control from the human driver, then it (and the OEM) would perhaps not be responsible for the deaths of the five pedestrians while you were driving the car; it is merely letting those victims die. But if the car does take control and make a decision that results in the death of a person, then it (and the OEM) becomes responsible for killing a person.

AV programming development is only one of many areas to reflect upon, as society begins to adopt autonomous driving technologies. Assigning legal and moral responsibility for crashes is a much-discussed topic today for AV development.

5. Legal and Insurance Challenges

Autonomous vehicles will be a disruptive technology. In addition to liberating humans from the task of driving, the technology will cause a migration from private car ownership to commercial car-sharing services, alter the dynamics and underlying infrastructures of urban and suburban living, and -most importantly- substantially reduce the carnage on our roadways.

If the liability is not handled correctly by policymakers, AV technology will face major setbacks. Highly automated vehicle liability may have unique set of challenges. Liability can be broken into two parts- tort liability concerning drivers and insurers and manufacturer liability concerning manufacturers and tech companies. It is important to understand the current state of tort liability and how drivers and insurers are affected as AV technology advances. Currently, insurance companies set rate for the driver and the traditional car based on age, miles driven per year, etc. If the AV accidents are due to the quality of the AV software, it might be handled like airplane schemes. As more features become automated, the blame will shift from drivers to manufacturers. This could deter car companies from further integrating higher levels of AV technology into their cars. Defects could be due to manufacturing, design and inadequate instructions or lack of warning. Design defects could face a no-win situation for the car companies.
A good liability scheme should not deter companies from integrating technology for social good out of fear of liability, and but it should not incentivize them to intentionally deliver unsafe cars (Ni and Leung, 2015).

Ownership: If the AV is owned by a driver, occupant might think that his/her life is more important than others. The occupant arguably should bear more or all of the risk, since he or she is the one introducing the machine into public spaces. If a person is riding a public AV, then the liability might transfer to the AV manufacturer.

Insurance: The ultra-safe AVs that can avoid most or all accidents will mean that many insurance companies will go bankrupt, since there would be no or very little risk to insure against. Mega-accidents might occur as AVs are networked together and vulnerable to wireless hacking. What can the insurance industry do to protect itself while not getting in the way of the technology, which holds immense benefits? If under attack, whether a hijacking or ordinary break-in, what should the AV do: speed away, alert the police, remain at the crime scene to preserve evidence, or maybe defend itself?

Travel Break: AV might be diverted by insidious advertising schemes that may allow third-party advertisers to have some influence on the autonomous car's route selection, e.g., steering the car past their businesses.

Road Announce: If the AVs drive too conservatively, they may become a traffic hazard or trigger road-rage in human drivers with less patience. If the crash-avoidance system of an AV is well known, then other human drivers may be tempted to "game" it, e.g., by cutting in front of it, knowing that the automated car will slow down or swerve to avoid an accident.

No more DUI Arrest: If those cars can safely drive us home in a fully-auto mode, that may encourage a culture of more alcohol consumption, since we won't need to worry so much about drunk-driving.

The larger challenge, though, isn't just about thinking through ethical dilemmas. It's also about setting accurate expectations with users and the general public who might find themselves surprised in bad ways by autonomous cars; and expectations matter for market acceptance and adoption. Whatever answer to an ethical dilemma that industry might lean towards will not be satisfying to everyone. Ethics and expectations are challenges common to all automotive manufacturers and tier-one suppliers who want to play in this emerging field, not just particular companies.

Automated cars promise great benefits and unintended effects that are difficult to predict, and the technology is coming either way. Change is inescapable and not necessarily a bad thing in itself. But major disruptions and new harms should be anticipated and avoided where possible. That is the role of ethics in innovation policy: it can pave the way for a better future while enabling beneficial technologies. Without looking at ethics, we are driving with one eye closed.

6. Summary and Discussion

Bahrani Fard and Brugeman (2019) study findings show that several factors can affect the industry's progress in the coming decades, including:

Technology readiness: Safe and efficient operation of emerging mobility technologies relies on the availability and functionality of enabling technologies. Need to explore in key functioning areas such as human-machine interactions.
Infrastructure: The existing infrastructure must be updated and enhanced to be able to respond to the expansion of intelligent mobility technologies. However, unclear regulations, technology failures, or state and local budget constraints may discourage intelligent transportation systems.
Industry collaborations: Cross-sector communication and stakeholder collaboration are needed to reduce technology production costs. Also, industry collaborations with lawmakers can facilitate the process of AV supporting regulations.
Regulations and policies: Lagging regulations and unclear standards can curb technological progress as investors always seek to secure their investments by predicting industry trends.
Social acceptance: The value of the technology relative to its cost coupled with safety and security concerns determine consumers' willingness to pay for new mobility technologies. Public education can be beneficial in improving the popularity of intelligent transportation technologies.

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Biography

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