Legal Aspects of Autonomous Driving

The need for a legal infrastructure that permits autonomous driving in public to maximize safety and consumer benefit.

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1 Introduction

Autonomous driving and autonomous vehicles are currently one of the most intensively researched and publicly followed technologies in the automotive realm. This technology could dramatically improve safety, efficiency, and mobility by taking the driver out of the loop and relying on vehicles to navigate themselves through traffic.

In order to accomplish the vision of autonomous driving, many technical challenges need still to be solved. The automotive industry appears up to the task. But there are also many non-technical challenges to be considered on the path toward a vision of autonomous vehicles, with legal challenges being among the most critical.

As automobiles are becoming more and more self-reliant in making mission-critical driving decisions, public policies, tort law, and technical standards need to be revisited to prepare courts and the public for the new realities of traffic with autonomous vehicles. This short paper will assess the current situation, give an outlook of the technical evolution, and propose first steps in the legal realm.

2 Status of Driver Assistance Systems and Autonomous Driving

Driver assistance systems and autonomous vehicles have been proposed since the 1940s and seriously researched since the 1960s. Highly developed computing and sensing performance since the 1980s have lead to autonomous research vehicles, and now a variety of driver assistance systems in production.

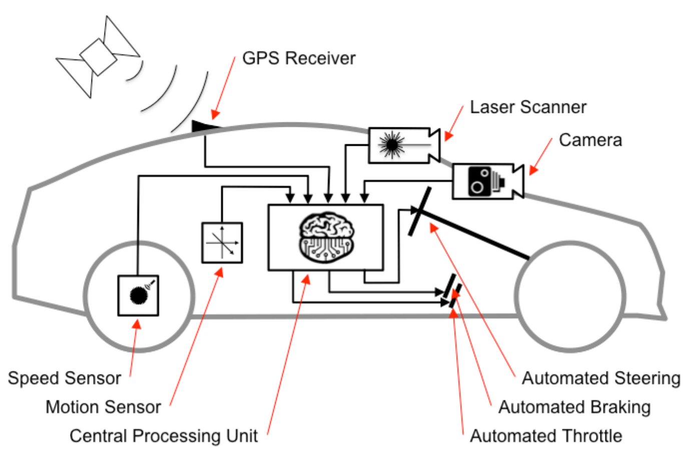

Figure 1: Basic layout of driver assistance systems (simplified concept of full lateral and longitudinal control)

These driver assistance systems help the driver navigate the vehicle through specific traffic situations (e.g., highway cruising, changing lanes, driving at night, parking). The basic layout of those systems (Figure 1) typically includes sensors—such as cameras, laser, radar, or GPS—that detect the environment and location of the vehicle, as well as computer algorithms that process sensor data, detect obstacles, categorize situations, plan path, and drive actuators. As a result, the system can drive, brake, and steer the vehicle, or at least provide warnings or other salient information to the driver.

The different levels of system integration can be defined as follows:

Warning and Information
- Passive system helps driver to maneuver the vehicle in certain situations
  Examples: Navigation System, Park Distance Information, Lane Departure Warning

Assisted Driving
- Specific driving task(s) automated for specific use case(s)
  Examples: Adaptive Cruise Control, Heading Control, Lane Change Assistance

Automated Driving
- All driving tasks automated for specific use case(s)
  Example: Automated highway, Automated Parking

Autonomous Driving
- All driving tasks automated for all use cases
  Example: Autonomous vehicles (“unlimited” coverage)

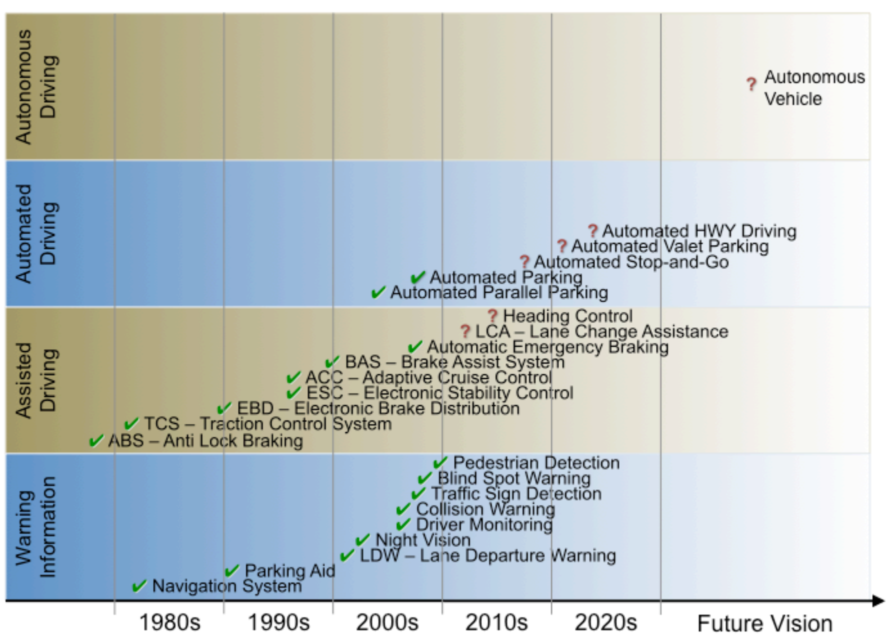

Figure 2: Classification and history of driver assistance systems (author’s depiction, source: Wikipedia)

Figure 2 provides a timeline of known and anticipated autonomous vehicle features. One milestone in advanced driver assistance systems was the introduction of “Adaptive Cruise Control” (ACC) in the late 1990s. ACC uses radar or laser sensors to detect the distance to vehicles ahead and adapts the set speed of the cruise control if the distance is getting too short. Once the lane is clear again or traffic speeds up, the vehicle accelerates again to resume the set speed.

Since this milestone, other systems have been introduced such as automated emergency breaking (radar / laser / camera sensor detect objects and perform breaking if accident is unavoidable) or pedestrian detection (cameras identify humans in path and alert driver). But to date it remains challenging to classify the specific traffic situation (e.g., "merging", "passing", "curve") and specific objects (e.g., "pedestrian", "cyclist", "cargo box", "traffic sign") so that further research on sensors, algorithms, and others is necessary to improve the detection and interpretation of the vehicle's environment.

Academia and industry are presently engaged in extensive research and development programs to address remaining challenges and to further advance driver assistance technologies. The long-term vision is that the driver can choose to drive the vehicle in the traditional sense or have the vehicle navigate autonomously through traffic. Besides the technology aspects of this field, questions regarding consumer acceptance, financial profitability, and legal challenges remain.

3 Challenges of Individual Mobility and Motivation for Autonomous Driving

The automobile is at a crossroads. We face enormous challenges around safety, efficiency, and mobility. Autonomous vehicles and vehicles features have the potential vastly to improve the quality of personal and commercial transportation in each of these key areas.

3.1 Safety

Car crashes have been called a "major epidemic."[1] Recent statistics show that 34,000 people were killed in motor vehicle traffic crashes in the United States in 2009.[2] The number worldwide is about 1.2 million.[3] Driver error is by far (95%) the most common factor implicated in vehicle accidents (followed by road / weather condition 2.5%, technical failure 2.5%).[4] The broad introduction of mobile communication devices may worsen this already bad situation: a recent study shows that the risk of a crash or near-crash due to dialing on a cell phone is 3-6 times higher compared to the non-distracted situation (the risk of an accident due to texting is up to 23 times higher)[5].

Addressing driver error as the primary factor leading to accidents and casualties would make traffic much safer. While education, communication, and enforcement can help,

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[1] Traffic Crashes Take Their Toll on America's Rural Roads, U.S. DOT / National Highway Traffic Safety Administration, December 2006
[2] Early estimate of motor vehicle traffic fatalities in 2009, NHTSA, Washington, DC, 2010
[3] National Highway Traffic Safety Administration, "2007 Traffic Safety Annual Assessment – Highlights", Washington, DC, 2008
[4] National motor vehicle crash causation survey, NHTSA, Washington, DC, 2008
[5] New data from VTTI provides insight into cell phone use and driver distraction, Virginia Tech Transportation Institute, Blacksburg, VA, 2009

direct drivers assistance may be the most promising tool. There is clear evidence that driver assistance systems and, eventually, complete vehicle autonomy, can significantly reduce property damage, injuries, and casualties.

3.2 Efficiency

Another recent and significant statistic: the impact of traffic congestion in the United States leads to unproductive time of about 36 hours for the average commuter each year, which in addition totals in 2.8 billion gallons of fuel unnecessarily burnt and a financial loss of $87.2 billion per year in the United States in 2007.[6] While these numbers show that traffic is an additional burden on the business schedule of the working population, it also documents a sizable (and potentially avoidable) portion of the emission problems that needs to be attributed to the transportation sector (the 2.8 billion gallons of fuel represent about 2% of the entire transportation sector in the U.S.).

Autonomous driving technology can help to harmonize traffic flow by controlling individual automobiles more precisely through anticipation and inter-vehicle collaboration. Of course, coordinating traffic in this way will present challenges to privacy and autonomy. Any standard or plan must proceed carefully and take these and other factors into account. But ultimately, vehicles can be controlled most efficiently where the overall traffic situation can be examined. This usually incorporates data that an individual driver could not comprehend (e.g., platooning of multiple vehicles by means of multiple layer traffic control).

Estimates show that an efficient cruise control alone could improve fuel savings by 7%[7] in addition to the gain in travel time through a smoother traffic flow. Other experiments show that the effect of vehicle convoying / platooning can take advantage of aerodynamic drag reduction which can lead to another fuel saving in the order of 10-20%[8]. In order to take advantage of those benefits, vehicles need to be controlled by autonomous driving / driver assistance systems, which eliminate the inefficiencies of human drivers by navigating vehicles more precisely and collaboratively in traffic.

3.3 Mobility

Yet another recent study showed that one-half of after-school trips made by 15-year-olds are made by private automobile; for 18-year-olds, this ratio increases to three-fourths.[9] U.S. adolescents are clearly dependent on the automobile for basic freedom of movement. Acquiring a driver's license is a defining moment in the life of young people which suddenly enables them to live their lives more actively and socially, but which also leads to a higher danger in their lives due to risk of accidents. Autonomous driving technology could help tremendously with the transition between "not driving" and

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[6] Schrank, David, and Tim Lomax. 2009. "The 2009 Urban Mobility Report." Texas Transportation Institute, Texas A&M University System, College Station, TX (September).

[7] P. Reed, M. Hudson, "What Really Saves Gas? And How Much?", http://www.edmunds.com/advice/fueleconomy/ articles/106842/article.html (2005)

[8] "Vehicle Platooning and Automated Highways", PATH Program, University of California (1998)

[9] Clifton, K. J., Independent mobility among teenagers: An exploration of travel to after-school activities, University of Iowa, 2003

"driving" adolescents as when, for instance, 15 year-olds experience the benefits of individual and independent mobility earlier while being shuttled by an autonomous car without affecting the schedule of their guardians. Autonomous driving / driver assistance systems can also help novice drivers to acquire the driving skills necessary to become a safe and experienced driver at a much lower risk of accidents.

Importantly, autonomous driving technology can help elderly or disabled citizens keep an active lifestyle such as running daily errands and maintaining their social relationships. Elderly drivers reportedly tend to avoid particular driving situations (at night, in poor weather, on highways) and drive less overall.[10] Individuals experiencing lower levels of cognitive and visual function due to disability also generally drive less.[11] Autonomous driving technology can help those drivers master difficult traffic situations while keeping them and others safe.

4 Legal Challenges of Autonomous Driving

The traditional approach to traffic litigation assumes the cause of an accident to be a human or technical failure, environmental conditions, or some combination thereof. Considerations become more complex in the case of an autonomous vehicle. As the vehicle navigates itself through traffic, it makes "mission-critical" decisions, which, in a narrow range of circumstances, can and will contribute to accidents. Such an event cannot necessarily be classified as a technical failure, however, the same way as, for instance, a damaged tire.

This presents an arguably novel situation wherein artificial intelligence acts on behalf of a human with life or death consequences. It is unclear how courts, regulators, and the public will react to accidents involving robotic cars. Overreaction is a clear danger, even could it be shown that a transition to autonomous vehicles leads to far fewer traffic-related deaths over all.

Mitigating this issue will require, at a minimum, research and education. Examples of how to prepare the courts and the public for autonomous vehicles include:
- Pilot fleet communities with statistical comparisons
- Extensive beta testing with "limited autonomy"
- Mock trials and focus groups
- Special insurance policies for autonomous vehicles
- Mandatory data recorders for autonomous vehicles

[10] West, C.G.; Gildengorin, G.; Haegerstrom-Portnoy, G.; Lott, L.A.; Schneck, M.E.; and Brabyn, J.A., Vision and driving self-restriction in older adults. *Journal of the American Geriatrics Society 51:1348-55, 2003*

[11] Stutts, J., Do older drivers with visual and cognitive impairments drive less? *Journal of the American Geriatrics Society 46:854-61., 1998*

5 A Partnership Between Academia, Industry, Government to Establish Policies for Autonomous Driving

5.1 Partnership Between Academia, Industry, Government

Single organizations or institutions cannot solve the challenges of individual mobility. Nor can it be resolved by reference to a single discipline. In the end, interested entities within industry, academia, and government need to work together, especially when addressing interdisciplinary topics in an emerging field. Academia in particular, with its focus on research and its relative neutrality, is well-positioned to take a leadership role.

5.2 Research at the Intersection of Engineering, Law, Economics, Humanities

The interdisciplinary character of autonomous driving requires research in a variety of different fields to establish policies and a common understanding of benefits, identify and address challenges, and educate future experts in the field. The following is a brief overview of the diverse research and education landscape:

- The engineering field is researching in great detail what existing technology can fulfill in terms of autonomous driving and take over driving tasks from humans. These topics address to a large extent the fields of computer vision, probabilistic computing, situation recognition, and decision-making. In addition, fail-safe strategies and safety concepts need to be devised, to account for system failure and potential misuse.

- As described in great length throughout this document, the pubic policy and legal fields need to conduct in depth studies of tort, liability, and standards for autonomous driving to pursue a path toward public deployment. As the current legal situation generally assumes that a human is in control of a vehicle, this paradigm needs to be adapted when considering vehicles are making driving-relevant decisions autonomously. The research in this field should seek analogies from other sectors (autonomous aircraft, robotic systems in industry and consumer products, autonomous agents) and apply practices to public roads. It is expected that a set of policies can be established to create the necessary legal framework that allows for safe and worthwhile innovation in this field.

- A plain consideration of monetary effort per vehicle and infrastructure compared to the monetary benefits through fewer accidents and fewer resources dissipated can give a first indication in that direction. However, considerations of economic aspects need to go deeper and take into account how much consumers would be willing to spend for a certain technology that also provides intangible benefits of extended mobility or freedom. A comparison with other automotive innovations would be very helpful to evaluate which specific functionality of autonomous driving consumers would be attracted by and therefore be willing to pay for. Only in this context it will be possible to assess if the cost of autonomous driving (which is expected to be significant) can be compensated by the tangible benefits outlined in the beginning, but also by rather intangible aspects such as consumer satisfaction.

- This last consideration also touches on the human aspects of autonomous driving. In this field, research is necessary to explore how the interaction of humans and the vehicle change when the vehicle navigates autonomously through traffic, especially if "traffic" still includes a large number of human-driven (= non-autonomous) vehicles. Assuming that this technology (especially at the beginning) might not be able to cover absolutely all traffic situations and that some degree of human intervention might be necessary, hand-over scenarios between human and vehicle need to be researched, i.e. how humans get prompted to take over control in certain situations. Essentially this will define the companionship between human and vehicle. It needs to be considered to what extent humans might feel that their individual freedom increases or is being compromised. Individuals would feel unsafe if a certain level of trust is not reached in the companionship with the car. It becomes clear that the role of the human in such an automobile and the individual driving experience will be very different in such a scenario, which needs to be addressed in the human factors research in great detail.

6 Proposal for an Interdisciplinary Program in Law and Engineering of Autonomous Driving

6.1 Program Scope

The Law School and School of Engineering at Stanford University are currently contemplating a program to explore the legal and policy aspects of autonomous vehicle systems. The collaboration between the Stanford Law School Center for Internet and Society (CIS) and the Center for Automotive Research at Stanford (CARS) will help pave the way toward safe and efficient autonomous driving through close study of the engineering, legal, and policy hurdles to its realization.

The program will consist initially of a dedicated research fellow with an interdisciplinary background and small advisory board of veteran lawyers and engineers. The output of the program in the first two years will include:

- Database of relevant legal and engineering developments to provide essential information on the topic of autonomous driving to academia, industry, government;
- Report to Congress and other policy-makers to address necessary actions;
- Communications strategy to educate the public about autonomous driving;
- Landmark conference to initiate a dialogue between engineering and legal experts.

6.2 Program Benefits

The program will determine which legal and policy issues impede greater autonomy in vehicles systems and make suggestions for reform. It will have chronicle advancements in vehicle system autonomy and relevant developments in the law. And it will convene major stakeholders to discuss the best way to proceed with vehicle autonomy quickly and safely. The project will be a resource not only to lawmakers, but also to lawyers and companies involved in litigation, and to journalists seeking to cover industry developments.

In the absence of this or a comparable program, autonomous vehicles systems would proceed with less confidence. Should there be a set back—in the form of high profile litigation or other incident—many in industry, policy, and law will have to ramp up on difficult issues at an uncomfortably fast pace. Moreover, journalists seeking to cover autonomous vehicles will not have the program and its fellow and advisory committee as a resource. This would make it harder to assess a certain situation without the right facts and context. Finally, policy makers and judges would not be as familiar with the issues and may react to events without adequate consideration. It is assumed that this could delay realization of safe, efficient autonomous vehicles systems, at least in the United States.

7 Summary

Autonomous driving has great potential to improve public safety, efficiency, and mobility. While several steps toward that vision have already been undertaken with a variety of driver assistance systems, the legal and policy situation remain unclear. This field requires broad support in public, government, and industry. Accordingly, this paper proposed that academia lead an initiative to study the field, recommend actions, and initiate public communication on the subject. As outlined, centers within the Law School and School of Engineering at Stanford University are exploring a new program with the objective to help pave the way toward safe and efficient autonomous driving through close study of the engineering, legal, and public policy fields. The program will initially be framed for two years with the expectation to establish an expert database, a report to congress, a communications plan, and a landmark conference to summarize the findings and define further necessary milestones toward autonomous driving.

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