



Testimony on Autonomous Vehicles before
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Alain L. Kornhauser, PhD

Professor, Operations Research & Financial Engineering.

Director, Transportation Program

Faculty Chair, Princeton Autonomous Vehicle Engineering (PAVE)

Princeton University

Board Chair, [Advanced Transit Association](#)¹ (ATRA)

Founding Chair, [Coalition for Automated Road Transportation Safety \(CARTS\)](#)²

Former Vice-Chair of the NJ Commission on Science & Technology

Thank you very much for inviting me to testify about Autonomous Vehicles or what I call SmartDrivingCars (trucks & buses too).

Just a little bit of background about me. I have been teaching and researching issues about automated transportation since 1971, more than 45 years. Beginning with something called Personal Rapid Transit, which was going to save cities by providing on-demand 24/7 automated mobility for everyone. With my students, we contemplated and designed systems composing of 10,000 stations using 10,000 miles of guideway that could serve essentially everyone in New Jersey. Only problem: to build the slim overhead guideways that interconnected those stations would cost a quarter trillion dollars or so. I also participated in Automated Highway studies in the 70s, 80s and 90s. Those efforts were focused on building new roadways that would exclusively serve automated cars and trucks. However, it eventually became obvious that those concepts weren't going anywhere because NJ DoT would never build an Automated Highway until General Motors built and sold many automated cars. And GM would never build or have a chance of selling automated cars until NJ DoT built the automated roads that would unlock the benefits of the automated cars. Again, getting started was impossible.

I then had the great pleasure of leading the Princeton University entries in the [2005 DARPA Grand Challenge and 2007 DARPA Urban Challenge](#)³ that focused on the development and demonstration of automated driving technology; driverless cars using roads just like anybody else without needing anything special nor disrupting anyone. The success of those Challenges almost 15 years ago made it clear to many of us that the way to use automation to deliver safe, affordable, environmentally respectful, on-demand, ubiquitous, 24/7, mobility for all, was to focus on putting sufficient intelligence in each car, truck or bus such that it could drive safely and use the roads that we already have on a shared basis without disrupting the existing users of those roads. This allowed us to focus our attention,

¹ <http://www.advancedtransit.org/>

² https://www.princeton.edu/~alaink/CARTS/CARTS_Mission_Vision_Statement.pdf

³ https://en.wikipedia.org/wiki/DARPA_Grand_Challenge

ingenuity and money on creating that intelligence in just a single, or a handful, of vehicles. Once working on those few vehicles, we could simply replicate what works. That intelligence involves software, whose replication costs are essentially zero, and hardware (processors and sensors) that scale really well so that in-volume replication costs become very inexpensive. Viral adoption would surely follow. And one of the reasons why we are here today is that it is happening. Consider the evolution of Waymo, the division of Alphabet/Google who many consider the leading innovator of driverless car technology.

[Waymo began in 2009](#)⁴ by assembling some of the talent from the DARPA Challenges and began developing and evolving their automated driving technology to work on just a couple of Priuses that they purchased from the local Lexus dealer. Then a couple of years later went back to the Lexus dealer and got about 20 Lexies in order to continue to improve its automated driving technology stack. Then a couple of years later built about 200 Fireflies, two seat cars without any pedals, nor a steering wheel, to further improve and extend the scope of their evolving driverless technology. Then a couple of years later ordered 2,000 Chrysler Pacificas to get serious about really improving their technology to the point that it can actually deliver on-demand ride-hailing mobility (Uber/Lyft-like services) to normal people in an “[early rider program](#)”⁵ in Chandler Arizona, a suburb of Phoenix. Then on March 27 of this year obtained an [option to purchase 20,000 Jaguars](#)⁶ and the at the end of May placed an option to buy another [62,000 Chrysler Pacificas](#)⁷, apparently in a move to provide safe, affordable, environmentally respectful, on-demand, ubiquitous, 24/7, mobility in many test markets around the country, my conjecture.

This history of converting normal road vehicles to safe automated road vehicles by Waymo has been growing at an exponential rate of 10x every 2 years since their inception in 2009. At this growth rate, it implies that in 2020 Waymo will order 200,000 and in 2022, 2 million new cars to make driverless. Given that these vehicles have been designed to deliver safe, affordable mobility on demand, their fundamental business case necessitates that they be used as extensively as possible, each and every day. Consequently, these vehicles will be managed and operated as a fleet to serve as many as possible trip makers throughout the 24 hour day. A rule of thumb is that each car could serve about 50 person trips per day at a cost of about 25 cents per passenger mile or about half of [AAA's estimated costs](#)⁸ of using your own car.

These driverless cars can be productive throughout each day serving the general public. It will be a long time before any of these driverless cars will be sold into private hands where they'd end up sitting around unused in driveways and parking lots rather than providing quality-of-life enhancing mobility to everyone, especially the most mobility disadvantaged.

Let me make sure that we are all clear about what I have been talking about. That is Driverless Cars (which could also be moving goods or moving groups of people in buses where and when the demand warranted.). To date, Waymo is the ONLY company in the world that has operated a car on any normal public roadway without a driver or attendant in the car, much as we currently use elevators, They did it for the first time in 2015, giving a short ride in a Driverless Firefly in Austin Texas to [Steve Mahan](#)⁹, who is legally blind. It wasn't until [November of 2017](#)¹⁰ that they did it again to members of their early rider

⁴ <https://techcrunch.com/2010/10/09/google-automated-cars/>

⁵ <http://fortune.com/2018/03/13/waymo-driverless-minivans-phoenix/>

⁶ <http://www.latimes.com/business/autos/la-fi-hy-waymo-jaguar-20180327-story.html>

⁷ <https://www.theverge.com/2018/5/31/17412908/waymo-chrysler-pacifica-minivan-self-driving-fleet>

⁸ <https://newsroom.aaa.com/auto/your-driving-costs/>

⁹ https://www.youtube.com/watch?v=X_d3MCKlvG8

¹⁰ <http://fortune.com/2017/11/07/google-waymo-phoenix-self-driving-car/>

program [in Chandler, AZ](#)¹¹. Waymo has announced that they will launch commercial driverless ride-hailing services in Chandler [by the end of this year](#)¹².

Driverless is the ultimate opportunity in the use of automated driving technology to improve mobility. It has the opportunity to provide “safe, affordable, environmentally respectful, on-demand, ubiquitous, 24/7, mobility for “all”” as part of a centrally managed fleet. Less capable levels of automation what I term “Safe-Driving Cars” and “Self-Driving Cars” can deliver valuable, but more limited, public benefits.

Safe-driving Cars, as the name clearly implies, uses sensors and intelligence to keep a car from crashing and staying in its lane of travel. These technologies are focused on going beyond crash mitigation, focused on having drivers and passengers survive crashes using seat belts, air bags and crash attenuating designs, to actually intervening at the right time to automatically apply brakes and/or control the steering wheel so as to **not** crash into something ahead or drift out of the lane. This continuous monitoring and automatic intervention in the driving environment is focused on correcting driver errors or mis-behavior that all too often lead to crashes. These technologies such as Automated Emergency Braking are really extensions of technologies that already exist, such as [anti-lock brakes](#), or are mandated, such as [electronic stability control](#), in all new cars.

Automated Emergency Braking is intended not let cars crash into objects in the lane ahead. Even though there is a large variation in the performance of these systems that are currently on the market they can and are helping reduce some collisions. I contend that they would become even better and more new car customers would buy them if the insurance industry was able to properly reward its customers that could most benefit from these technologies. If the heavily regulated insurance industry was given the freedom to appropriately discount premiums and the ability to educate and steer its insurance customers to acquire the crash avoiding technologies and reduce their insurance claims. Insurance companies could really promote crash avoidance thus reducing their LOSS, improving their profitability and reducing insurance expenses to the Safe-driving car owner.

Self-driving Cars. As the name clearly implies these cars are able to drive themselves, but can't do it well enough to drive without a driver or attendant in the car; else they'd be called Driverless. So, while you may be able to take your hands off the steering wheel or feet off the pedals, a normal licensed and capable driver needs to be paying attention to the road ahead and be prepared to take over whenever the automated system encounters a driving situation that it can't handle. Self-driving cars having [Tesla's AutoPilot](#)¹³ or [GM's SuperCruise](#)¹⁴ or [Volvo's Pilot Assist](#)¹⁵ or [Mercede's Distronic Plus](#)¹⁶, or [Subaru's EyeSight](#)¹⁷ are available today. These systems focus on providing comfort and convenience to the driver by letting the driver take his/her hands off the wheel and feet off the pedals, but **absolutely** require that the driver remain aware of what is happening and prepared to take over and avoid a crash. Unfortunately, car makers, in their enthusiasm to sell these features, aren't necessarily clear that the technology that they're selling you may not be good enough for you to really relax and certainly is NOT good enough to enable you to even think about having another adult beverage or allowing you to really text and certainly NOT enabling you to doze off while it drives.

As I've mentioned, these systems are already on the market and are being used on New Jersey roads as we speak. That barn door is open; however, there are a couple of ways the legislature could be helpful.

¹¹ <https://youtu.be/aaOB-ErYq6Y>

¹² <https://www.theverge.com/2018/8/21/17762326/waymo-self-driving-ride-hail-fleet-management>

¹³ <https://www.tesla.com/autopilot>

¹⁴ <https://www.cadillac.com/world-of-cadillac/innovation/super-cruise>

¹⁵ <https://www.youtube.com/watch?v=ECivk7SgPDK>

¹⁶ <http://www.silverstarny.com/blog/what-is-mercedes-benz-distronic-plus-with-steering-assist/>

¹⁷ <https://www.cars.com/articles/subaru-expands-eyesight-as-new-study-shows-effectiveness-1420700145788/>

1. One is by incentivizing NJ DoT to improve the stripping on all New Jersey roads and improving the readability of all signs. Since all of the automated lane keeping systems on the market today use computer vision to determine the location of the lane edges, having easy to see lane edges on all streets, especially those most heavily traveled, as well as good stop lines, pedestrian crossings and turn lane markings would help every one of us to better see these markings, and enable each of these self-driving systems work better. I don't want to suggest that good lane markings and good readable signs haven't been a high priority of New Jersey's road maintenance program, but maybe not so much. Thank goodness that these Self-driving systems don't need nor have they been designed to use fancy electronic gizmos. They just need good paint and good signs, just like each of us need to drive more safely.
2. A 2nd system that would substantially improve the throughput of what is the world's most efficient bus transit corridor, exclusive bus lane, the XBL, leading from the NJ Turnpike to the Lincoln Tunnel and the PABT (Port Authority Bus Terminal). That would be to retrofit "off-the-shelf" intelligent cruise control, as exists in all of the aforementioned Self-driving car systems, into each of the transit buses that are authorized to use the XBL each morning. This a fleet of approximately 3,000 buses. As operated today, the XBL has a maximum practical throughput of approximately 700 buses per hour. What limits the throughput is the large disparity in the separation between buses as they traverse the XBL. Any of the intelligent cruise control systems in any of the self driving cars on the market today could safely deliver a 50% increase in capacity of that facility. This amounts to an increase of almost 20,000 one-seat rides in the peak hour into mid-town Manhattan from NJ's Park & Ride lots. This capacity increase is essentially equivalent to the number of seats that the new rail tunnels would provide. [I first proposed this to NJ Transit and the Port Authority more than 20 years ago](#)¹⁸. Given that the automated technology is off-the-shelf, cost of such a retrofit couldn't possibly be greater than \$20k/bus, or \$60 Million to do the 3,000 buses. The Port Authority might finally be taking a close look at this. Help from the NJ Legislature might actually push this over the top and make it a reality.

Let's get back to the 3rd kind of SmartDrivingCars, **Driverless**, which is really the focus of much of the proposed legislation. Driverless is the technology that has the biggest opportunity to improve the quality of life of many New Jersians, create jobs and substantially improve New Jersey's economy. The [9 million New](#)¹⁹ [Jersians](#) take more than 30 million vehicle trips on a typical day, more than 90% of which are taken in automobiles or light duty trucks. New Jersey's public road system affords those having access to an automobile a superior quality of life being able to go anywhere at any time at essentially zero marginal costs. However, the Census claims that in Mercer County alone, there are over [15,000 households](#)²⁰ representing about 27,000 residents²¹ that don't have access to one of these vehicles. Most are very poor, many are seniors. Their lack of mobility to get to jobs, health care, training and recreation greatly restricts their quality of life. For example, in 2014, Amazon opened a fulfillment center in Matrix Business Park in Robbinsville New Jersey, a high tech warehouse that currently employs over 2,500 people. While the facility is located at the nexus of major interstate roads, it is not located within walking distance of housing and is not served by NJ Transit. To help out, the [Greater Mercer Transportation Management Association](#)²² (TMA), established a shuttle, the "Z line" to take employees from the Hamilton Market Place (HMP), served by three (3) bus lines²³. However, except for those folks living within walking distance of HMP, this is not a one-seat ride to work. In fact if one lives in Ewing,

¹⁸ [https://www.princeton.edu/~alaink/CARTS/XBLupdated proposalPignataro_1995.pdf](https://www.princeton.edu/~alaink/CARTS/XBLupdated%20proposalPignataro_1995.pdf)

¹⁹ <http://worldpopulationreview.com/states/new-jersey-population/>

²⁰ <https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=bkmk>

²¹ <https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=bkmk>

²² <http://gmtma.org/contact-us/>

²³ NJT 601,606, 613

one needs to catch an NJT bus at about 5:30 am to arrive at the Amazon facility just in time to start on the 7am shift, while by car or by Uber or Lyft, one can do it in about 30 minutes. If, instead, one had Waymo-styled driverless service available, 30 minute ride could be offered affordably and with enhanced vehicle management, pairing those who can share rides, thus making each person trip more affordable, more energy efficient and more environmentally responsible while providing a personal auto-like level-of-service. These vehicles, would then be available to affordably serve on-demand mobility needs to healthcare, learning, shopping, dining, and recreation to the young, the old, the poor and anyone else throughout the entire day. Even more efficient shuttle services between more concentrated locations such as between remote parking and the passenger terminal at Trenton-Mercer airport or between remote athletic facilities, classrooms and dormitories at Princeton University. These concentrated driverless shuttle services could readily be expanded to the West Trenton train station or even the Amtrak/NJ Transit station in the airport scenario and to low income and senior housing locations in Princeton.

What is needed to deliver these services is the creation of what I would like to term as a “win-win welcoming environment” between the private sector fleet management companies that would provide the driverless mobility services and the public sector entities that represent those that would use the services as well as those residents that live along the public roads that these vehicles would use to deliver the services. In return for the welcoming to use the so designated network of public roadways by the fleet operator(s), a “common carrier obligation” would be embraced by the fleet operator. That obligation might/should include the commitment to offer safe on-demand high-quality shared ride services on a **priority basis** to the most mobility disadvantaged household living and needing to travel within the defined network of public roadways within a defined geo-fenced area. Instead of remaining idle, the fleet could then serve anyone else needing to travel within the defined area. Such a service could start with but a few vehicles, say 10, operating within a limited geo-graphic area, that might reach across Mercer County but authorized to use only streets for which the neighbors would welcome these vehicles on their streets and gaining the opportunity to be a customer of the afforded mobility. If successful the system could readily grow to 100, then 1,000 and so on as deemed appropriate.

The legislation creating the public-private partnership relationship that would create both the “welcoming environment” and the “common carrier obligation” go well beyond the current proposed legislation. It may well require the creation of the mechanisms that would ensure the delivery of the rights and responsibilities of the neighborhood and community associations as well as the reporting requirements that ensure safety and the diligent delivery of the priority services by the fleet operator

All of this presupposes that Driverless vehicles are operated and managed by substantive entities that have demonstrated an ability to deliver on the “common carriage obligation” and have demonstrated the ability to maintain the safety of the driverless technology. Until driverless vehicles become common place, it would be prudent for New Jersey to prohibit driverless operation without an attendant ready to take over unless the entity that tells that vehicle where to go and what roads to use to get there has agreed to the “common carriage obligation”. Else the vehicle is a Self-driving vehicle that NJ legislation should require that a licensed driver be in the driver’s seat, alert and ready to take over the driving function should that become necessary.

I’ve said little about the movement of goods, but, of course, there is a substantial opportunity to move goods locally using driverless vehicles, especially if those vehicles perform those deliveries in the wee hours of the morning when our streets are essentially totally unused and no children are chasing balls into any of them. Between the hours of 1am and 5 am, deliveries of packages, mail etc. could readily be accomplished efficiently and safely. Creating legislation that would encourage such operation is, of course, very desirable.

Again, thank you for your attention to my comments. I fully encourage you to do whatever you can to have New Jersey play a leading role in the evolution and deployment of these most valuable technologies. I'd be pleased to answer any of your questions.