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"Promises and Perils: The Potential of Automobile Technologies"

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Introduction

Thank you Chairwoman Schakowsky, Ranking Member Bilirakis and Members of the Committee for this opportunity to testify before you on a topic vital to American competitiveness and our quality of life—ensuring the safe and responsible development of self-driving vehicle technology. My name is Raj Rajkumar. I speak to you as an academic researcher and educator who has devoted nearly two decades to advancing the frontiers of autonomous vehicle (AV) technology. I have worked closely with industry partners like General Motors and government at the federal, state and local levels. I am also an entrepreneur who founded a successful AV software company and experienced firsthand the potential of this technology to contribute to economic development.

The title of this hearing is on target[1]. As with most transformative inventions, AV innovations will be accompanied by large-scale economic opportunities, immense social benefits and notable perils. As my testimony will highlight, these perils include

(a) not advancing innovation that will ensure the safety of this technology, and

(b) falling behind in a global technology race that will define competitiveness in the massive transportation industry and beyond.

My remarks will focus on three areas.

- First, I will briefly review the growth of this quintessentially American invention.

[1] In 2019, I had given a talk titled “Self-Driving Vehicles: The Promise, Peril and Challenges” at a workshop on AVs (http://www.ipam.ucla.edu/programs/workshops/autonomous-vehicles/.)

- Secondly, I will review the emerging technology and AV market trends, and how these developments offer insights on the policy considerations the Committee is seeking to explore and address.
- Finally, I will highlight some broad principles that may contribute to ensuring that America and American communities, citizens and workers realize the full potential of the safe deployment of self-driving technology.

A Brief History of the Technology and Passion Shaping the Development of AV Technology

The vision for autonomous vehicles has its roots in a 1939 World's Fair GM Futurama[2] where engineers had envisioned vehicles that could drive themselves even before digital computers as we know them today were born. Early-stage research efforts soon followed, including a presentation by the Pittsburgh-based Westinghouse[3] company in 1959 of a radar system on car bumpers that would utilize dots and dashes built into the interstate highway system to enable self-driving. Focused research efforts began with National Science Foundation and Department of Transportation programs in the 1980's. Carnegie Mellon's first-generation autonomous vehicle, Terregator, emerged from these efforts in 1983. A small mobile robot, the Terregator could only travel at a speed of less than one mile an hour but could sense its surroundings and drive around obstacles.

Over the next few decades, investments across eight federal agencies advanced various components of the technology. New programs in the Department of Defense, National Aeronautics and Space Administration, and the Department of Energy, along with the National Science Foundation and The Department of Transportation were key to developing foundational vision, sensing, computing, planning and control technology innovations. These programs, along with critical concurrent advances in computing and recently in machine learning, advanced the frontier.

Scientists like me who were drawn to the pursuit of this technology share a passion for the mission to save lives and reduce the vast human and economic toll of automotive crashes. When vehicles can drive themselves, transportation deserts can be eliminated and personal independence will be bestowed to elderly and differently-abled individuals currently facing barriers to full participation in the economy and society.

Like prior revolutionary advances, AV technology has had to overcome the peaks and valleys of hype and disillusionment. The critical inflection point that demonstrated practical feasibility of the technology was triggered by DARPA about 15 years ago. The DARPA Grand Challenges held in 2004, 2005 and 2007 enabled self-driving technology to move from university labs to early-stage commercial development. In the years following the historic 2007 DARPA Urban Grand Challenge, industry and venture investments of more than 10 billion dollars globally have

[2] https://www.thetruthaboutcars.com/2014/05/autonomy-and-the-1939-worlds-fair/
[3] https://slate.com/culture/2009/06/1959-when-america-first-met-the-microchip.html

accelerated both innovation and the potential for commercial applications. The pace of innovation has been dramatic but slower than had been anticipated by some.

Our Carnegie Mellon vehicle that won the 2007 DARPA Urban Grand Challenge utilized the entire rear portion of the vehicle for its computing system and had an entire grid of sensing and vision equipment on its rooftop. Today's self-driving test vehicles resemble traditional passenger vehicles. The computing capability of current AVs is over a million times greater than that of our 2007 vehicle.

Underlying this history of innovation are the best American traditions of collaboration and partnership among government, industry, academia and the communities across America that joined in incubating this technology. It has been a partnership focused on transformative technology innovations targeting important societal challenges. As we plan ahead to address the challenges and opportunities of the next phase of AV development and to chart the path to deployment, the full might of the American innovation ecosystem must be brought to bear.

A Brief Review of the Technology, Industry Growth and the Global Race

AV technology involves a complex "stack" of technologies. Its hardware components include a variety of computing, sensing and communications equipment. Multiple software layers that generate the seemingly incredible driving capabilities utilize both algorithmic and AI approaches, which make thousands of decisions per second.

The continued development of AV technology is dependent upon both separate and integrated advances in each of these layers of the stack. Self-driving applications also depend upon and contribute to advances in computing, software, communications and AI in fields ranging from health care to manufacturing. Hence, it is important to regard self-driving technology not simply as a revolution only in transportation, but as a vital component of a web of breakthroughs that will span and shape much of the U.S. economy in the future.

Self-driving vehicles are also part of a convergence of technologies that involves the synergy between breakthroughs in AV technology, electrification and connectivity. My research has demonstrated that Connected and Autonomous Vehicle (CAV) technologies will support the scaling of electric vehicles as well as greener applications in passenger rail, freight rail and shipping.

Similarly, the safety of AVs will be greatly enhanced by the deployment of 5G and future generations of wireless technology, while also extending the reach of this technology to realize the potential for significant energy and efficiency improvements. The opportunity to integrate AV technologies with smart infrastructure and smart building applications will be transformative in meeting the climate challenge while enabling a range of new services and industries. We must therefore continue to invest in and support pilot deployments of edge computing (which provides compute power right at the devices rather than in the cloud or other centralized location), and Vehicle to Everything (V2X) connectivity technologies that enable self-driving vehicles to communicate with virtually all travelers and elements of the infrastructure around them. We must keep a broader vision of this technology convergence in mind as we shape the policies for the safe deployment of self-driving vehicles. The estimates of the vast market impact of the technology reflect this potential.

The long-term market size for autonomous transportation is estimated to be $7 trillion per year[4]. This massive market comprises a diverse set of market segments and companies. There are over 250 US companies in the industry including automakers, and providers of critical component technologies and services. The industry ranges from household names to tech start-ups providing hardware components, software tools for testing, as well as mapping and vision technologies. During the pandemic, core AV route-planning software was put to work in Pittsburgh to facilitate the delivery of meals to home-bound students. The reach of the AV industry has also shattered the bi-coastal concentration that dominates most major emerging technology sectors. Nodes of AV innovation span the heartland from over 2,000 jobs in Pittsburgh to centers in Ohio, Michigan, the Southwest and the South. Currently, more than 1,400 vehicles are being tested by 86 companies in 36 states.

The large AV market is composed of the following distinct segments:

- Robotaxis: a fleet of vehicles without any human operator, possibly without a steering wheel, gas and brake pedals and used to provide dedicated or shared rides;
- Passenger vehicles: individually-owned consumer vehicles that drive themselves in well-tested domains which become larger over time;
- Road-worthy delivery robots: vehicles that drive on public roads but carry only goods and no passengers for delivery;
- Personal delivery devices: vehicles that move at pedestrian speeds on sidewalks to deliver food and medicine within a community (such as a neighborhood or campus);
- Long-haul trucks: Semi-trailers that are a backbone of the nation’s economy and;
- Public transit: vehicles that can be used selectively to supplement existing mass transportation.

[4] The Verge, “Intel predicts a $7 Trillion self-driving future”, June 2017, https://www.theverge.com/2017/6/1/15725516/intel-7-trillion-dollar-self-driving-autonomous-cars.

The diversity of the above market segments also highlights how central the technology will be in shaping the future of a comprehensive transportation system that can better meet the needs of individuals, communities, industry and government. Self-driving ground vehicles can coordinate with autonomous system breakthroughs in drones to revolutionize agriculture as well as personal transportation, the shipment of goods and even health-care services.

The enormous market potential for AVs has understandably sparked a global technology race. After the ground-breaking 2007 DARPA Urban Challenge, China in particular initiated a sequence of similar annual competitions. Chinese teams learned to literally crawl first, walk next and now are surging ahead in the ongoing technology marathon. China is also deftly seeking to apply its significant leadership in 5G technologies to self-driving vehicles. Unless we undertake quick and corrective actions, China can secure a dominant position in both of these important economic sectors.

China's ability to catch-up with our advances has been aided in part by their relatively lax regulatory environment. While we should not aim to mirror their regulatory model, we must recognize what is at stake in the overall race and seek to out-innovate them in the core technologies that will ultimately enable the safe deployment of AV technology. In short, unless we act, leadership in a technology that we created and nurtured could slip to China, which is very aggressive in terms of investments and deployment-friendly policies.

The Road Ahead – Recommendations for Navigating the Perils and Ensuring the Ability to Realize the Promise

It is imperative that we commit soon to an all-of-nation initiative to ensure AV technology does not join the list of innovations which are invented in the US but end up generating jobs and wealth only far beyond our shores. The following five major pillars would form the foundation of this national commitment.

1. Advance a New Generation of Collaborative Research

The rapid growth of commercial investment over the last decade may lead one to a presumption that federal research investment is no longer needed to advance the technology and the industry. That is unfortunately not the case. Driving safely under a wide spectrum of weather, lighting, road and traffic conditions is the most complex activity that most adults engage in on a regular basis. Consequently, AVs are not yet a part of our daily lives. Critical investments in basic research to (a) verify, validate and demonstrate the safety of complex cyber-physical systems and AV technologies,, (b) enable connectivity, and (c) design smart infrastructure are vital to the ability to win this global race. Moreover, as has been demonstrated in sectors such as communications and health care—continued progress on the technological frontier is also essential to support progress on sound regulations. Security violations can also potentially lead to major loss of life, property and trust as hackers can cause physical damage. While industry participants deeply recognize the need to keep vehicles safe, targeted research programs to enhance cyber-security and cyber-physical security are sorely needed.

A recent and ongoing USDOT program to launch the Automated Driving Systems Demonstration grants is a positive first step. We should reinvigorate the coordinated multi-agency research framework that made the U.S. the early leader in AV technology and focus on opportunities for synergistic developments in AVs, EVs and connectivity breakthroughs to advance overall U.S. competitiveness. It will also be critical to continue support for research in cybersecurity and data management techniques.

2. Accelerate Investment and Deployment in the Advanced Infrastructure of the Future

A core basic research agenda also requires a complementary commitment to investments in smart physical infrastructure, 5G, edge computing and V2X communications technologies. As Congress and the Administration move forward to place broadband connectivity at the heart of the nation's infrastructure agenda, initiatives to support V2X testbeds across the nation would make a vital contribution to accelerating innovation and improving safety. These testbeds will enable safe driving under different weather conditions, lighting conditions, geographical terrains and construction zones. The testbeds can also advance self-driving applications to other innovations in infrastructure and building technologies. Specific testbeds can be developed to bridge between urban, suburban and rural needs.

3. Actively Engage on Workforce Issues

An all-of-nation commitment must certainly include a central focus on job and workforce needs. As witnessed in other industries, the introduction of AV technology is likely to transform the nature of jobs and improve safety. Drivers of transit vehicles and semi-trucks do much more than driving alone, and it is likely that their roles and responsibilities will expand, as partial automation is eased into operations over time.

Importantly, these are not issues that can be "thrown over the transom" to be resolved after technology deployment. Breakthroughs this transformative necessitate social innovation along with technological advances.

Labor organizations should be engaged directly in university research advancing the technology frontier. Carnegie Mellon University is in the early stages of a potential model for such collaboration with a project bringing together the perspectives of transit unions to the development of autonomous transit technology. Such collaborations will help inform training and safety requirements, and enable new job creation opportunities while bringing the perspective of the worker---whose domain expertise on safety and operations is incredibly valuable—to the research enterprise.

In addition, we need to accelerate collaborations among research institutions, industry, community colleges and community STEM education programs to shape a more inclusive research and industry workforce. The USDOT-funded National University Transportation Center based at Carnegie Mellon has launched Women and Diversity in Transportation Fellowship Programs, partnered with the Pennsylvania Rural Robotics Initiative to expand K-12 STEM engagement, and has been training Community College of Allegheny County students in AI and AV technology. Its new executive education and certificate program called “Managing AI in Transportation” also builds new career pathways at the forefront of emerging job opportunities.

Based on past experiences in other industries, all intentional actions to bring workforce development and workers to the table must also recognize the following: Given the global race to develop AV technology and broaden the reach of the technology from transportation to manufacturing, agriculture and the overall national logistics infrastructure, well-meaning efforts that might seem to preserve some jobs in the near term can cost our nation many more over time. If the technology cannot be developed here, it will happen elsewhere. If the technology cannot be deployed here, it will be deployed elsewhere.

4. Diligently Manage the Transition from Driver Assist Features to Automated Driving Systems

Recent model-year automobiles have a wealth of driver assist features including lane departure warning, lane keeping/following, blind zone alert, automated emergency braking and cross-traffic alert. Such driver assist features however require the vehicle operator to be paying attention at all times. Since human attention tends to fade when active driving engagement is absent, robust driver monitoring mechanisms are highly desirable. These driver monitoring and assist functions can also be enhanced to detect whether a driver is drowsy and/or impaired. Unnecessary fatalities and injuries can be therefore minimized. NHTSA and other enforcement agencies must both educate the public about the deep chasm between advanced driver assistance systems and full autonomy, while ensuring that vendors do not oversell functions and/or use misleading labels.

5. Recognize the Need for a Regulatory Policy Framework that Advances Safety and Accelerated Innovation

In the early days of automobiles, some states required individuals to walk ahead of cars to warn pedestrians. Breakthrough technologies always create a need to align our goals for safety and innovation. Recognizing that continued research can help mitigate regulatory challenges, the following recommendations are offered as general principles for the next phase of regulatory policy for AVs:

- <u>Safety is paramount</u>: safety will be enhanced by creating a clear and uniform national approach to on-road testing. This national framework must incentivize and enhance industry investment in advances that address critical safety needs by harnessing market forces that align deployment with safety;

- Recognize the distinctions between AV market segments: The regulatory framework should not seek to create a single approach for all the various self-driving market segments. The regulatory approach should explicitly take into account the distinct elements and nature of different application segments[5];

- Be adaptive and agile: Given the rapid technological advances, the regulatory framework should not be set in stone - a well-defined path is needed to continually adapt to the evolving needs for real-world testing and deployment, and the conditions for fully autonomous vehicle testing;

- Encourage collaboration: The federal government should continue to support testing and deployment collaborations—such as that being implemented by government authorities, industry and academic partners in the Smart Belt Coalition comprising the states of Michigan, Ohio and Pennsylvania to facilitate advancing specific applications and foster the engagement of transportation officials with rapid technological advances; and

- Create a national roundtable: While enabling testing and collaboration, the federal government should regularly bring together industry, state and local transportation officials, the academic research community and labor organizations together to foster greater dialogue and information sharing.

Conclusion

The emergence of AV technology is an exemplary American innovation success story. Support for basic research by Congress and multiple administrations across several decades combined with close collaboration among academia, startups and major companies and supportive communities has brought a technology within reach that was once science fiction. However, significant, but addressable technical and policy challenges remain. Continued collaboration and innovation will be vital.

Autonomous vehicles are poised to create large-scale economic opportunities and yield an array of social benefits. We must avoid the potential peril of not encouraging innovation that will achieve safer roads. Most critically, unless we take rapid and concerted action, we can end up ceding global leadership in a technology we invented here to other countries with an established edge in complementary technologies like 5G.   AV regulations must be clear, uniform, and adaptive. And the federal government must encourage private-public-academic collaboration, and convene regular national roundtables of all stakeholders.

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[5] As an example, exemption caps need not be a hammer to use across all AV market segments. Vehicles with a licensed operator inside can be regulated differently.