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DRIVING AUTOMOTIVE INNOVATION AND FEDERAL POLICIES

FIELD HEARING

BEFORE THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION UNITED STATES SENATE

ONE HUNDRED FIFTEENTH CONGRESS

SECOND SESSION

JANUARY 24, 2018

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SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

ONE HUNDRED FIFTEENTH CONGRESS

SECOND SESSION

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DRIVING AUTOMOTIVE INNOVATION AND FEDERAL POLICIES

WEDNESDAY, JANUARY 24, 2018

U.S. SENATE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC.

The Committee met, pursuant to notice, at 10:02 a.m., Walter E. Washington Convention Center, 801 Mount Vernon Place, N.W., West Salon Room, Washington, D.C., Hon. John Thune, Chairman of the Committee, presiding.

Present: Senators Thune [presiding], Wicker, Inhofe, Lee, Heller, Young, Capito, Nelson, Blumenthal, Peters, and Hassan.

OPENING STATEMENT OF HON. JOHN THUNE, U.S. SENATOR FROM SOUTH DAKOTA

The CHAIRMAN. Good morning. One of the privileges of leading a committee with jurisdiction as broad as that of the Commerce Committee is that sometimes our work takes us off Capitol Hill and into the real world. In recent years, we have held field hearings in Alaska, New Hampshire, Nebraska, Florida, and, yes, South Dakota. While we have not traveled quite as far today, what we are here to discuss is no less important for all Americans, and it is great to be in a venue that will soon welcome scores of people excited about the future of the automobile.

The automobile industry is an essential part of America's economy, generating nearly $1 trillion of economic activity each year and supporting 7 million jobs across all 50 states. And this industry is not standing still. It is hard to believe, but the auto industry spends more on research and development of new technologies than the software and aerospace industries. Today's high-tech automobile has some 30,000 parts drawn from a global supply chain.

New technologies, such as automated vehicles, and new business models offering mobility as a service are poised to enable substantial growth. Key benefits include improved safety, new jobs, new transportation opportunities, and reduced congestion. Automated vehicles, or AVs, offer perhaps the largest potential gains in all of these areas.

More than 37,000 people lost their lives on U.S. roads in 2016, a troubling and unacceptable increase from the year before. According to the National Highway Traffic Safety Administration, or NHTSA, as many as 94 percent of those crashes were the result of human error. AVs, which cannot fall asleep, get distracted, or become impaired, could potentially save many thousands of lives every year.

AVs may also spur significant new economic activity. By one estimate, the wide adoption of AVs will spur a new passenger economy worth $7 trillion over the next few decades, and AVs will provide access to mobility to many Americans, such as the elderly and those with disabilities, some of whom may be unable to drive today.

If our country is to realize these benefits, policymakers must take a careful approach to these new technologies. We must allow innovation to thrive while also ensuring the technology is safe and reliable. We must also refrain from favoring one technology, business model, or type of company over another, so as to avoid locking in technology before innovation and market choices can take place.

The bipartisan AV START Act, which Senator Peters and I introduced, accomplishes these goals by building on the existing regulatory framework to prioritize safety through increased reporting and oversight, thus promoting public safety and building public confidence and trust.

At the same time, the AV START Act removes unintentional barriers to innovation in existing law and promotes a level playing field so that neither traditional automakers, tech giants, nor new startups are unfairly advantaged or disadvantaged.

If U.S. regulators are not able to foster safe testing and deployment of AV technology through modernizations like those in AV START, the rest of the world will not sit by. America currently leads the way in auto innovation, but many other countries, particularly China, are catching up. We all want America to remain competitive and see the benefits of new jobs and new economic growth.

The AV START Act is just that, a start. As AVs become more widespread, there will be tough policy and societal questions that we must all work together to answer. AV START contains formal processes to start answering some of these questions, such as those relating to data and how law enforcement will interact with AVs. This Committee will remain active and will build upon the strong foundation established by the AV START Act.

I want to thank Senator Peters, Ranking Member Nelson, and all the Members of the Committee for their great work on this landmark piece of legislation, and I look forward to seeing it pass the full Senate soon.

While AV technology is approaching quickly, the auto industry is innovating in other areas with immediate benefits. Advanced driver assistance systems, such as lanekeeping assist and automatic emergency braking are available in an increasing number of vehicles on the road today and are already saving lives. And new developments and fuel technologies, such as hybrid and all-electric vehicles and increased use of biofuels, such as ethanol, boost fuel efficiency and reduce pollution.

To explore these issues, we have a great panel of witnesses today representing organizations that are leading the way in many areas of automotive innovation. Mr. Luke Schneider, who is President of Audi Mobility U.S.; Mr. Mike Mansuetti, President of Robert Bosch North America; Mr. Tim Kentley-Klay, the CEO and Co-Founder of Zoox Inc.; and Dr. Randy Avent, who is President of Florida Polytechnic University. I want to thank all of you for being with us today, and I look forward to hearing your testimony.

And I will turn now to Senator Nelson for his opening remarks. Senator Nelson.

STATEMENT OF HON. BILL NELSON,
U.S. SENATOR FROM FLORIDA

Senator NELSON. Thank you, Mr. Chairman. Mr. Chairman, I was almost one of those traffic statistics this morning. Coming down one of the north-south streets, going the speed limit, suddenly, a car in the right lane to my front suddenly does a U-turn in the entire street right in front of us, to which we commented, if we were an automated vehicle and he was an automated vehicle, that would not have happened. So there was a demonstration for me early this morning.

I, like the Chairman, am very hopeful about the prospect of self-driving cars. I appreciate the efforts of Senator Peters, who has made this a signature issue. It is appropriate for him, because of being from Michigan, and he has been dogged in his pursuit of this legislation.

And I thank you, Mr. Chairman, that you have arranged to be down here at the auto show. It seems to have gotten a good bit of interest. I wonder how many are here for the hearing and how many are here really to go to the auto show. But your planning was enormously successful.

And I am very excited about my state of Florida's role in the development of autonomous technology. I am pleased that a part of our panel is Dr. Avent, who is the President of Florida Polytechnic University. The University is working in partnership with the Florida Department of Transportation to develop and operate a $42 million, 475-acre autonomous vehicle testing facility at their campus.

And I want to congratulate you for this achievement, Dr. Avent, and I am confident that your world-class facility will, in fact, play a vital role in the ongoing research that we are going to do.

This technology is advancing rapidly. Just two weeks ago, at the electronics show in Las Vegas, General Motors announced a plan to put fully autonomous vehicles without driver controls on public roads as early as 2019. Now whether or not that occurs depends on us and our legislation.

And General Motors is not alone. Countless other automakers, technology companies, and suppliers, are rolling out innovations that have the potential to completely transform our sense of mobility and, as the Chairman mentioned, to cut down, and as I experienced, on a lot of traffic accidents.

In addition, these vehicles may bring significant environmental benefits through reduced emissions; increased efficiency, productivity; the improved transportation opportunities for underserved communities, seniors and people with disabilities. While these benefits of self-driving vehicles are numerous, it is crucial that the Congress and the Federal Government exercise responsible oversight to ensure the safe development and deployment of these technologies.

So the AV START Act, which was passed unanimously by this Committee in October, is an important step. The bill enhances safety by requiring autonomous vehicle manufacturers to submit safety

evaluation reports to the Department of Transportation, and that is to demonstrate how they will address system safety, crashworthiness, and cybersecurity, among others. Additionally, this act reinforces the traditional existing roles played by Federal, State, and local governments pertaining to vehicle registration.

So I look forward to continuing to work with you and Senator Peters as this legislation advances.

[The prepared statement of Senator Nelson follows:]

PREPARED STATEMENT OF HON. BILL NELSON, U.S. SENATOR FROM FLORIDA

Thank you, Mr. Chairman, for holding this hearing.

I am very hopeful about the prospect of self-driving cars, and I appreciate the efforts of the chairman to arrange this event at the Washington Auto Show.

I am particularly excited about Florida's role in the development of autonomous technology and I am pleased to have the President of Florida Polytechnic University, Dr. Randy Avent, testify today.

The university is working in partnership with the Florida Department of Transportation to develop and operate a 42 million dollar, 475-acre autonomous vehicle testing facility in Polk County known as Suntrax. I would like to extend my congratulations to Florida Polytechnic for this achievement. I am confident this world-class facility will play a vital role in the ongoing research to improve autonomous technology and ultimately provide for the safe and efficient deployment of self-driving cars.

Autonomous technology is advancing rapidly. Just two weeks ago, at the Consumer Electronics Show in Las Vegas, Nevada, General Motors announced a plan to put fully autonomous vehicles—without driver controls—on public roads as early as 2019.

General Motors is not alone. Countless other automakers, technology companies, and suppliers are rolling out innovations that have the potential to completely transform our sense of mobility and, most importantly, save lives.

In addition, autonomous vehicles may bring significant environmental benefits through reduced emissions, increased efficiency and productivity, and improved transportation opportunities for underserved communities, seniors, and people with disabilities.

While the potential benefits of self-driving vehicles are numerous, it is crucial that Congress and the Federal Government exercise responsible oversight to ensure the safe development and deployment of these emerging technologies.

The AV START Act, which was passed unanimously by this committee last October, is an important step in the right direction.

The bill enhances safety by requiring autonomous vehicle manufacturers to submit safety evaluation reports to the Department of Transportation demonstrating how they address system safety, crashworthiness, and cybersecurity, among others.

Additionally, the AV START Act reinforces the traditional, existing roles played by the federal, state, and local governments pertaining to vehicle regulation.

I fully intend to continue working with Chairman Thune and Senator Peters to get this piece of legislation to the president's desk.

Thank you, Mr. Chairman, and I look forward to hearing from our witnesses.

The CHAIRMAN. Thank you, Senator Nelson.

And again, we want to welcome our panel. Thank you for being here. We will start on my left and your right with Dr. Randy Avent, who is President of Florida Polytechnic University in Lakeland, Florida; Mr. Tim Kentley-Klay, who is the CEO and Co-Founder of Zoox, Inc., from Menlo Park, California; Mr. Mike Mansuetti—I said that wrong the first time; my apologies, Mike—with Robert Bosch North America, Robert Bosch LLC in Northfield, Michigan; and Mr. Luke Schneider, who is President of Audi Mobility, located in the U.S. here in Austin, Texas.

So thank you all for being here. We look forward to hearing from you. If you confine your oral remarks as closely as possible to 5 minutes, we will make sure that all of your testimony gets included

in the written record, and it will maximize the opportunity that we have for members to ask questions.

So, Dr. Avent, please proceed. Welcome.

STATEMENT OF RANDY K. AVENT, PH.D., PRESIDENT, FLORIDA POLYTECHNIC UNIVERSITY

Dr. AVENT. Mr. Chairman, Ranking Member Senator Nelson, Members of the Committee, thank you for the opportunity to address you today on this very important topic. As many of you know, the vision of driverless cars has been around well over 50 years, but very little progress was made in that area until 2004 when DARPA created a prize competition called the DARPA Grand Challenge.

Since then, there has been exponential growth in the underlying AV technology that mirrors the development trajectories and other disruptive markets, like computing, networking, and DNA sequencing. Today, I would like to briefly touch on three dimensions of connected and autonomous vehicles: the market impact, the technical and regulatory challenges, and the potential role of the Federal Government.

As you all pointed out, numerous papers abound outlining the promises of autonomous vehicles. If developed and implemented correctly, the primary advantage of autonomous vehicles centers on significantly lowering driver-related deaths. As you pointed out, Senator Thune, last year alone, there were nearly 40,000 fatalities in the U.S. at a cost of over $410 billion, and more than 90 percent of those were due to human error.

But there are many secondary advantages that are also significantly important. For instance, autonomous vehicles can improve access for the elderly, children, and poor, and can make public transportation more effective by solving the last-mile problem. It can significantly increase the utilization of automobiles, which is less than 5 percent now. And with higher utilization of fewer cars, the capacity of our transportation infrastructure will naturally rise.

Beyond the transportation sector impact, core technologies underlying autonomy will impact other markets, such as agriculture, logistics, national defense, and manufacturing. In fact, it would be hard to find any technology with a more disruptive impact on both the U.S. and global economies then connected and autonomous vehicles.

I often say piston-powered vehicles driven by people and built by traditional car manufacturers may soon be replaced by interconnected computers on wheels scheduled and controlled by autonomous algorithms and developed by IT companies. U.S. car manufacturers will need to look more like IT companies, as they already are. Insurance markets, law enforcement, hotels, real estate, lawyers, auto repair, and health care will all be affected, just to name a few.

But while the promise of AV technology is noteworthy, there is still substantial barriers to its widespread adoption. For one, the AV technology core relies on what I call the sensor and signal processing chain, and there is still significant work that needs to be done on the edge cases to improve performance. A strong regulatory framework is paramount to safety and consumer acceptance,

but an overregulated market is likely to stifle innovation and give our global competitors an advantage.

To this end, we need a science-based, data-driven approach to create policies and legislation that is modeled after successful verification or certification approaches in other industries. This framework must integrate the full spectrum of testing approaches, ranging from digital simulation and hardware emulation, to closed-circuit and public open-road testing in urban areas.

Last, there will be a rapid shift in transportation technologies toward computer science, electrical engineering, and analytics, as the sensor and signal-processing chain matures, and vehicles interact with the civil infrastructure. Both the transportation industry and their regulatory partners will need to prepare for this shift.

States such as Florida have taken a leadership role in enabling this market. The Federal Government can have a very constructive role in enabling this transformative technology through research funding; through safety consortiums that investigate and provide factual data around AV accidents, much like the NTSB role in aviation accidents; and through creating quasi-governmental organizations, much like the Department of Energy's and the Department of Defense's federally funded research and development centers and university-affiliated research centers that conduct applied research and provide independent, unbiased technology expertise to the government.

Finally, Florida Poly is working with its partners to research solutions to these challenges. This includes a deep partnership with the Florida Turnpike Enterprises' world-class AV test track called SunTrax, and a partnership with the Orlando Smart City initiative that provides open-road testing in an urban setting. These two test complexes combined with Florida Poly's Advanced Mobility Institute focus on addressing many of these vexing challenges.

Thank you for your time today.

[The prepared statement of Dr. Avent follows:]

PREPARED STATEMENT OF RANDY K. AVENT, PH.D., PRESIDENT, FLORIDA POLYTECHNIC UNIVERSITY

Introduction

The Law of Accelerating Returns describes how technology is created and adopted. It states that technology is not created incrementally in a linear fashion; instead, it is relatively stable and changes little until there is an inflection point, after which it grows geometrically. The most prominent examples of the Law of Accelerating Returns are computing (*e.g.,* Moore's Law), communications (*e.g.,* Gilder's Law) and DNA sequencing (*e.g.,* $1000 genome). The Law of Accelerating Returns can also be used to describe the development of Connected and Autonomous Vehicles (CAV).

The concept of driverless vehicles has been around for over 50 years but little progress was made until the Defense Advanced Projects Agency (DARPA) received government approval for a cash-prize competition called the DARPA Grand Challenge. It's hard to argue that the DARPA Grand Challenge, and its subsequent Urban Challenge, were not inflection points for Connected and Autonomous Vehicles. Since these events, the pace of technology developments in this area has increased substantially leading to a significant disruption in many mobility-related markets. It is very likely that cars of the future will not be piston-powered vehicles driven by people; rather, they're more likely to be interconnected computers on wheels scheduled and controlled by autonomous algorithms and developed by IT companies. With a potential market of over $87B within 15 years, manufacturers are racing to grab their share of the market.

Benefits

Autonomous vehicle technology has the promise of solving many of today's transportation related problems. One of the most important benefits of CAV is its promise to significantly lower driving related deaths. Last year alone, there were over 40,000 fatalities in the U.S. at a cost of over $410B—and more than 90 percent of those fatalities were due to human error. With the potential for human error removed, self-driving cars will reduce instances of accidents caused by driver error, drunk driving or distracted drivers.

Autonomous Vehicles can also improve access for the elderly, children and poor and can make public transportation more effective by solving the "last mile" problem. Solving this last mile problem reduces or eliminates the difficulty of getting to and from light rail and other public transit modalities, leading to increased utilization of public transit systems and better mobility for large segments of the U.S. population.

Commuters may also save up to an hour every day. This savings of time will have many spin-off benefits from improved well-being to boosting the economy. According to the *2015 Urban Mobility Scorecard,* each year, Americans living in urban areas spend almost 7 billion hours in traffic, waste 3.1 billion gallons of fuel and lose around $160 billion due to traffic congestion. With CAV vehicles able to access up-to-the-minute data to help monitor traffic, as well as digital maps and other tools, they can determine the fastest, most efficient routes possible. Drive times between locations will be reduced as a result. All of this will result in less traffic, less congestion and less time and fuel waste. With the ability to optimize fuel consumption, new-age vehicles are also expected to reduce vehicle emissions by 60 percent.

Highway congestion can also be reduced with the implementation of platooning since high-tech sensors can react dramatically faster than humans, allowing the distance between vehicles to be drastically reduced. Therefore, vehicles will operate at higher speeds and require much less space between vehicles, leading to greater traffic throughputs. This will result in less traffic, improved efficiency in our highway systems and will reduce the need for future capital investments in our transportation infrastructure. Parking lots will also be affected since it is estimated that driverless cars can be parked with 15 percent less space.

Disruption in Markets

Predictions are that many markets will be affected as driverless cars become more numerous in societies around the globe.

The disruption has already started; autonomous cars will run the roads sooner than we expect. Joel Barbier points to numerous industries that are expected to change as a result. He states that "Business leaders in *all industries* can no longer take a "wait and see" approach. Companies must start being hyperaware by monitoring changes in their environment (which extends beyond what their competitors are doing); they must start making informed decisions and execute those decisions quickly to respond to the threat of autonomous vehicles. Further, company and government leaders must immediately address the impact on jobs and get serious about retraining efforts."

Some of the companies he identifies are obvious, such as auto manufacturing and auto repair. Others are less obvious. For instance, parking, law enforcement, insurance markets, real estate, hotels, media consumption, auto parts, lawyers and health care are just a few that will be impacted. And those are just some of the ones experts can think of. As with most disruptions, the biggest opportunities are ones that haven't yet been discovered.

Challenges

There are significant challenges ahead that need to be solved. Four major categories of challenges include (1) technological, (2) regulatory, (3) skills shift and (4) liability.

Automated Driver Assist Systems in many new vehicles have progressed, but fall short of enabling the sensor systems to guide a vehicle without human input. In addition, sensor development, improvements in data integration, data fusion and artificial intelligence are not yet robust enough to provide the safety of fully autonomous vehicles.

Decisions are still being debated regarding the regulatory environment around autonomous vehicles. Having the Federal Government responsible for vehicle safety, as is currently the case with existing vehicles, seems most workable. If each state is allowed to set its own safety standards, the resulting milieu will drastically complicate the testing and certification of driverless vehicles. Either way, regulatory policies for product testing and certification will need to be data-driven and science-based to avoid overburdening the industry with regulations that stifle innovation.

Chip manufacturers, software industry and defense are examples where this has been done well.

The move to autonomous vehicles will also cause a shift in the predominant skills necessary and the types of workers needed in the transportation industry and in their regulators. Currently, both fields are dominated by civil and mechanical engineers but will need to rapidly increase the percentage of computer science and electrical engineering professionals in the field.

The insurance industry is already beginning to struggle with the impact driverless vehicles will have on their industry—as are lawyers and Original Equipment Manufacturers (OEMs) as they wrestle with liability issues. Additionally, the number of traffic citations is expected to go down thereby reducing the amount of revenue available to those entities which currently benefit from driver-based vehicles.

CAV Technology Overview

The fundamental technology core in autonomy rest on a "sensor and signal processing chain" which roughly includes sensing, signal processing, networking, data fusion and artificial intelligence.

In this chain, sensors are responsible for perceiving an accurate description of the environment. Optical, microwave (radar) and lidar sensing each have advantages and disadvantages, and a robust sensing environment must use a combination of sensing modalities to best capture the environment. Signal processing provides the analysis, synthesis and modification of signals and is primarily responsible for separating the sensor signal from the environmental noise.

Networking allows both for coordination between vehicles, but it also provides a conduit for fusing disparate information to provide an improved model of the environment. Artificial Intelligence is the primary engine that takes this information and turns it into an action within the required response time.

This "signal processing chain" is used to provide different levels of decisions leading to autonomy. Currently, there are five levels of autonomy recognized.

Level 0: (now)—no automation and the driver is in complete control

Level 1: (now)—function-specific automation where the driver can easily regain control from the specific function

Level 2: (2013+)—combined function automation where driver is temporarily relieved of those driving functions; barely here now

Level 3: (2020+)—limited self-driving automation where the driver must be available to take over controls

Level 4: (2025+)—full self-driving automation where the driver is not expected to take control at any time

Role of Verification

There are many flavors of product testing, *e.g.,* certification, validation and verification, but all are designed to ensure the product meets specifications, fulfills its intended purpose and is safe to use. Most often, this process is performed by a third party that is unbiased and technically strong and involves repeated testing of a product to determine its selectivity, accuracy, repeatability, reproducibility and suitability. For CAV, testing should be done on pre-defined test scenarios that will stress all elements of the system. Pre-defined scenarios consist of predictable test cases, which the system will be subjected to on a regular basis, and unpredictable test cases. An example of a predictable test cases might include an autonomous vehicle picking up a passenger at an airport baggage claim. An unpredictable test case might include a white semi-tractor trailer pulling out in front of a car with a bright sun in the background. Unpredictable test cases are most often "six-sigma" events: They are rare, unpredictable and will have the most impact on ensuring CAV technology meets specification, fulfills its intended purpose and is safe for humans. To determine test cases, the Federal Government will need legislation that creates or delegates power to an organization that functions like the NTSB for aviation safety. This organization must gather data, analyze, document and report on all incidents across the country so that technology developers, manufacturers and independent testing can benefit from the lessons learned to create vehicles that are safe.

To do this, we suggest a holistic and systems oriented approach to testing based on four levels of testing. Each approach has advantages, and a robust test environment is useful only if it includes all approaches.

Digital simulation models the system and the environment for a given test scenario. Because it is a model-based simulation, it is inexpensive to repeat and the scenario can be easily controlled.

The primary disadvantage with digital simulation is that it is a model of both the system and the environment, and if the model is not correct, the results will also be incorrect.

Hardware-in-the-loop emulation simulates only the environment by creating a scenario and modeling the input to the system's sensors, *i.e.,* scenes are created much like a video game and played into the real CAV system. Because this approach only creates a model of the environment, it typically leads to a more robust test than simulation. Like simulation, testing can be easily controlled, is inexpensive to repeat and can easily be extended (*e.g.,* what if the white tractor trailer was blue, or what if it pulled out 5 secs earlier, . . .). Because this approach depends on a model of the environment, it may not always have the fidelity needed to absolutely verify functionality. For this reason, a closed-test complex is needed to do real testing and verify the results on both digital simulations and hardware-in-the-loop emulations.

A closed-test complex is a test track that ultimately provides a large and flexible theater where the autonomous vehicle and its actors are real. Test tracks lack both controllability and repeatability and are expensive, but they test real scenarios and are an important part of confirming functionality and developing models that support simulation and emulation.

Public open road testing is the testing of systems on real highways and in cities. This approach often results in multiple scenarios all happening in real-time. It is expensive to repeat, and it is impossible to control, but it most accurately reflects the real environment. Many companies are now using public open road testing as their only approach to developing fleets of CAV and this can be very dangerous. Open road testing is more applicable for demos than for testing since they are not controllable and will not exercise those rare events that happen only once in a million times.

Test Centers

The Federal Government can have a very constructive role in enabling this transformative technology through research funding, through safety consortiums that investigate and provide factual data around AV accidents and through creating quasi-governmental organizations much like the Department of Energy (DOE) and the Department of Defense's (DoD's) Federally Funded Research and Development Centers (FFRDCs) and University Affiliated Research Centers (UARCs) that conduct applied research and provide unbiased technology expertise to the government.

The Florida Turnpike Enterprise (FTE), Florida Polytechnic University (Florida Poly) and the Orlando Smart City are in a unique position to build a holistic test environment that could be used to provide certification of standards and national policies for CAV. As part of this holistic environment, Florida Poly is building the Advanced Mobility Institute which will provide digital simulation, Hardware-in-the-Loop emulation and layered services for the closed and open test grounds. FTE is building SunTrax, which provides an advanced state of the art closed facility test center for CAV. This test track represents an approximate $150M investment in a 400+ acre facility that provides complex test scenarios to users and can be easily reconfigured to adapt to evolving test cases. Both Florida Poly and FTE are members of the larger Orlando Smart Cities project that provides a testing platform on the public streets in the City of Orlando. The region also includes the University of South Florida's Center for Urban Transportation Research (CUTR), which focuses on transportation policy, regulations and standards.

Florida Poly is a new public STEM University with a focus on emerging technologies in computer science, electrical and computer engineering, mechanical engineering and data analytics. It has an applied research function modeled after DARPA, and it is focused on bridging the technology "Valley of Death" by translating fundamental research out of the University and into the market place. Florida Poly is developing deep expertise in technology development, testing and evaluation by modeling approaches used in mature industries like chip design and Defense to create a "science of CAV testing". The University is also developing educational programs in CAV with plans to offer distance education to professionals and executives in CAV with certifications. It is strategically located in Lakeland at the heart of Florida's High-Tech Corridor, which includes 23 counties and three fellow State University System public institutions. Lakeland is easily accessible from two of Florida's largest metropolitan areas, Tampa Bay and Orlando. They have combined populations of nine million people and nearly 70 percent of the state's high-tech companies, creating opportunities for industry, government and academic collaborations.

The CHAIRMAN. Thank you, Dr. Avent.

Mr. Kentley-Klay.

STATEMENT OF TIM KENTLEY-KLAY, CO-FOUNDER AND CEO, ZOOX

Mr. KENTLEY-KLAY. Chairman Thune, Ranking Member Nelson, Senators, thank you for the opportunity to testify before you today.

When I arrived in the U.S. from Australia just over 3 years ago, Zoox was but a dream, so it is, indeed, an honor to be here before you and among respected business leaders. Today, I will share with you our vision and the journey of Zoox; our perspective on the step-change safety opportunity offered by autonomous mobility; and, finally, the opportunity we have as a country to set the best policy foundation on which to build this technology and get it on the road.

My journey with autonomous mobility began in 2012 while in Melbourne, Australia, watching from afar what Google was doing, attempting to develop a self-driving car. My insight at the time was that such technology is about much more than incremental adaptation to the automobile. This technology, correctly understood, is going to transform how we move everyone and everything on this planet.

The belief we hold at Zoox is that AI and mobility will take us from the age of the automobile into the next mobility age, and we think that is the age of robotics—fully automated transportation. Thus, Zoox was founded to ask the question: What is the full realization of autonomy and mobility? Can we imagine that? And if we can, let's not build it in 10 years. Let's build it now.

At Zoox, we have gone from this founding vision to today augmenting cars that work as autonomous vehicles driving in downtown San Francisco. We are driving during the day. We are driving during the night, in heavy rain and fog. We are also driving autonomously on freeways. In short, Zoox is driving autonomously a complete set of urban road and weather features as we speak.

Beyond this, because we believe that the full realization of this technology is not retrofitted cars, we are also creating a vehicle from the ground up, without traditional controls, that is purpose-built for the needs of our cities today and tomorrow. This means shared, on-demand, zero-emission, safe, and wonderful mobility.

This represents a phenomenal effort by a highly interdisciplinary team that is fast-growing—over 375 at Zoox. Expertise ranges across fields of artificial intelligence with over 70 Ph.D.'s, product design, safety, vehicle engineering. The teams come from organizations such as Google, Tesla, Apple, Ferrari, NVIDIA, NASA, and NHTSA, and along with academic institutions, such as Stanford, MIT, Oxford, Princeton, and Carnegie Melon University.

The very real safety opportunity that autonomous mobility will offer drives our work every day at Zoox. Autonomous technology holds out the promise for a whole new safety paradigm, one that allows us to prevent crashes in the first place. The number of people we lost as a result of car crashes in 2016 went up despite our best efforts. That number represents nearly 2,000 more loved ones lost. In fact, car crashes are the leading cause of death of young people in this Nation. This should be unacceptable to us.

It is our view that only autonomous mobility offers the opportunity to make irrelevant the safety risks associated with driver impairment and error. We should act on that.

Finally, these paradigm shifts in both mobility and safety innovation, what then is the policy opportunity? First, it is important to recognize that we are in the midst of a great and global race. Other countries are sprinting to harness and deploy this technology.

And I know I certainly could not have started Zoox and scaled it as fast as I could with my cofounder and wonderful team anywhere else than in the United States of America. It welcomed me with open arms. I am grateful for that and keen to maintain our competitive edge here.

The signals we send to entrepreneurs and innovators through our regulatory system are vitally important to meet that end.

To date, the posture of both the Administration and Congress has been to create a level playing field to let the innovators innovate. This must continue. Your AV START Act, as well as the SELF-DRIVE Act, capture these principles and encourage innovation in a technology-neutral way without picking winners. The legislation making its way through Congress, in our view, is the right approach for this moment.

Finally, the Zoox journey is all about connecting people and places safely and in an environmentally conscious way, and with a sense of wonder. Autonomous mobility sits on the vanguard of possible. As innovators, we look forward to working with you, the regulators, to create with verve the next era in mobility.

Thank you.

[The prepared statement of Mr. Kentley-Klay follows:]

PREPARED STATEMENT OF TIM KENTLEY-KLAY, CO-FOUNDER AND CEO, ZOOX

Chairman Thune, Ranking Member Nelson, Senators:

Thank you for the opportunity to testify before you today. When I arrived in the U.S. from Australia just over three years ago, Zoox was but a dream, so it is indeed an honor to be here before you and among respected business leaders.

Today, I will share with you our vision and the journey we are on at Zoox; our perspective on the step-change safety opportunity offered by autonomous technology in mobility; and finally, the opportunity we have as a country to set the best policy foundation on which build this technology and get it on the road.

The Zoox Vision

My journey with autonomous mobility began in 2012, while in Melbourne, Australia, watching from afar what Google was doing: attempting to develop a "self-driving car."

My insight at the time was that such a technology is about much more than just incremental adaptation to the automobile. This technology, correctly understood, is going to transform how we move everyone and everything on this planet.

To understand what is about to happen, let's take a step back. The previous mobility age, before the automobile, was, of course, the horse and carriage. We were in that age for around 6,000 years. It was around 4000 BC that we domesticated the horse, put the axle on the wheel, and invented coach building. So what allowed the transition from that mobility age to the next?

Arguably, it was the invention of the internal combustion engine. We achieved a technology level on this planet where we could mechanize the horse's biomechanical power. The correct implementation of that invention was not to put the engine in the coach and keep the horse. People actually tried that, but it didn't work particularly well. The right application was to remove the horse—and change the architecture of the coach, quite radically, to get to a design such as the Model-T Ford in 1908. This transformation took us into the age of the automobile, an age we have been in for 130 years.

The belief we hold at Zoox is that A.I. in mobility will take us from the age of the automobile into the next mobility age. And we think that's the age of robotics—fully automated transportation. Thus, Zoox was founded to ask the questions: what

would the full realization of AI and mobility be? Can we imagine that? And if we can, let's build it not in ten years, but today.

At Zoox, we have gone from a founding vision three and a half years ago, to augmenting cars to work as autonomous vehicles driving in downtown San Francisco, during the day, during the night, and in heavy rain. We are also driving autonomously on highways. In short, Zoox is driving autonomously a complete set of urban road and weather features, today.

Beyond this, because we believe that the full realization of this technology is not retrofitted cars, we are also creating a vehicle from the ground-up—without traditional controls—that's purpose-built for the needs of our cities today and tomorrow.

This represents a phenomenal effort by a highly interdisciplinary and fast growing team of over 375, with expertise ranging across the fields of artificial intelligence, product design, safety, and vehicle engineering. The team comes from organizations such as Google, Tesla, Apple, Ferrari, NVIDIA, NASA, and NHTSA, along with academic institutions such as Stanford, MIT, Oxford, Princeton, and Carnegie Mellon.

The Safety Opportunity: Our Philosophy at Zoox

The very real safety opportunity that autonomous mobility will offer drives our work every day at Zoox. Autonomous technology holds out the promise of a whole new safety paradigm: One that allows us to both prevent crashes in the first place and protect occupants and vulnerable road users in superior ways if a crash does occur.

The number of people killed as a result of car crashes in 2016 went up 6 percent from the year prior. That number represents nearly two-thousand more loved ones lost. In fact, car crashes are the leading cause of death for young people in the U.S. This should be unacceptable to us: We should pursue autonomous technologies, which hold the potential to eliminate most crashes.

Indeed, in our view, it is only autonomous mobility that offers the real opportunity to make irrelevant the safety risks associated with driver impairment and error.

The Policy Opportunity

Finally, with these paradigm shifts in both mobility and safety innovation, what then is the policy opportunity? What is the government opportunity?

First, it is important to recognize that we are in the midst of a great race. Other countries are sprinting to harness and deploy this technology. And I know I certainly could not have started and scaled Zoox as fast as I have in any other country, and the United States has welcomed me with open arms. I am grateful for that, and keen to maintain our competitive edge here.

The signals we send to entrepreneurs and innovators through our regulatory system are vitally important to meet that end. To date—and this brings me to my second point—the posture of both the Administration and this Congress has been to create a level playing field to let the innovators innovate. That must continue. Your AV START Act, as well as the SELF DRIVE Act, capture these principles, assert the Federal Government's preemptive role over state legislation, and encourage innovation in a technology-neutral way, without picking winners. The legislation making its way through Congress, is in our view, the right approach for this moment.

Third, it is important to recognize that data-driven best practices must precede standard-setting. We are still in the very early stages of this paradigm shift, so it is important that responsible developers have the freedom to develop and generate the data needed for best practices and eventually relevant regulatory policies. I would note that this emerging industry has a strong safety record. In fact, there has been no injury caused by any fully autonomous vehicle developer to date. As such we should be encouraged to continue advancing our development while acting at all times responsibly.

Finally, the Zoox journey is all about connecting people and places, safely, in an environmentally conscious way, and with a sense of wonder. Autonomous mobility sits on the vanguard of possible. As the innovators, we look forward to working with the regulators to create, with verve, the next era in mobility.

Thank you.

The CHAIRMAN. Thank you, Mr. Kentley-Klay.

Mr. Mansuetti.

STATEMENT OF MICHAEL MANSUETTI, PRESIDENT, ROBERT BOSCH LLC

Mr. MANSUETTI. Chairman Thune, Ranking Member Nelson, Members of the Committee, thank you for the opportunity to testify before you today.

Robert Bosch founded the company in 1886 in Germany, and we established our first U.S. office in 1906. The Bosch companies in the U.S. today have now grown to encompass more than 18,000 associates in 25 states. Of our four business sectors, mobility solutions is the largest.

The U.S. remains at the forefront of Bosch's innovation efforts. We are actively testing automated vehicles in Michigan and in California. In 2017, Bosch announced the creation of a new center of competence for artificial intelligence, and Silicon Valley will serve as one of the three global sites for these efforts.

I appreciate the opportunity to share Bosch's view on the transformation of the auto industry. This hearing is taking place at a critical juncture in our history. We are witnessing a revolution in almost every aspect of the vehicle, from how we power our cars to how we handle and transition control of the overall vehicle, to the future role of the vehicle in the lives of individuals.

I deeply appreciate the efforts of Chairman Thune, Senator Peters, Ranking Member Nelson, and all of the Committee Members in sponsoring and passing the AV START Act. The Committee staff took great care to consider the issues that are impacting auto suppliers and to understand the complex role that we play as incubators and developers of automated driving systems.

Bosch further commends the Committee for including crash-avoidance technologies in the consumer education requirement from the AV START Act. We also express our appreciation to Senators Heller and Markey for their ongoing support of crash-avoidance technologies.

At Bosch, we have a vision for accident-free driving. We see the potential for automated vehicles and advanced driver-assistance systems to dramatically decrease vehicle-related injuries and fatalities. Making automated driving a reality calls for profound understanding of all vehicle systems. Bosch has this expertise, and we manufacture the key components, including radar, video, and ultrasonic sensors, brake-control systems, and electric power steering.

Automated driving will demand much more than just the fitment of more sensors and cameras. It will require a new vision for the electronic architecture and the safety-critical functions of the vehicle. To realize higher levels of automated driving, we need redundancy in safety-critical systems, such as braking and steering. Bosch is actively developing redundant braking solutions to support all levels of automation, and this redundancy is a critical element especially for Level 4 and Level 5 automated vehicles.

It is also important for Level 3 vehicles where a human driver is still necessary but safety-critical functions may be handled by the vehicle. As part of navigating this new landscape, Bosch is forging alliances. For example, in 2017, we announced a partnership with Daimler, which will focus on Level 4 and Level 5 automated vehicles.

Bosch is also cognizant of the tremendous need for consumer outreach. To bolster public understanding, Bosch has launched the Bosch Automated Mobility Academy to educate the public on how automated mobility can improve quality-of-life and explain how various advanced technologies will make the fully automated future possible.

The topic of cybersecurity is tightly intertwined with increasingly automated and connected vehicles, and it is a priority for Bosch. Bosch has worked for several years to develop robust and comprehensive solutions for our customers. We strongly support a layered approach to vehicle cybersecurity and have espoused this principle in the development of our own products and engagement with our customers.

We evaluate our customers' requirements in two ways, first by developing systems and technologies that can address risk based on the electronic architecture of the vehicles, and second by investing in future solutions that will be interwoven into vehicle design from the onset.

Understanding the importance of industry cooperation in addressing potential threats and developing best practices, Bosch joined the Auto ISAC in 2016.

As we look forward to these events, we cannot fail to address the demand for trained workers to fulfill the millions of jobs that will be needed to fuel the transformation. We clearly recognize the need to build and shape the manufacturing workforce of the future. To support this, Bosch maintains an apprenticeship program at several of our U.S. manufacturing facilities. In addition, our U.S. foundation, the Bosch Community Fund, provide grants to STEM-based educational programs and professional development for teachers.

So thank you again for the opportunity today. Bosch looks forward to continuing to work with each of you and the Committee as we continue to develop technologies that are truly invented for life.

Thank you, and I look forward to your questions.

[The prepared statement of Mr. Mansuetti follows:]

PREPARED STATEMENT OF MICHAEL MANSUETTI, PRESIDENT, ROBERT BOSCH LLC

Background

In North America, the Bosch group of companies ("Bosch Group") employ nearly 32,800 associates (with more than 18,000 in the U.S.) in more than 100 locations, as of December 31, 2016. In 2016, Bosch generated consolidated sales of $13.7 billion in the U.S., Canada and Mexico.

The Bosch Group is a leading global supplier of technology and services. The global group of companies employ roughly 390,000 associates worldwide (as of December 31, 2016) and generated sales of $80.9 billion in 2016. The operations are divided into four business sectors: Mobility Solutions, Industrial Technology, Consumer Goods, and Energy and Building Technology.

As leaders in IoT, Bosch offers innovative solutions for smart homes, smart cities, connected mobility, and connected industry. We use our expertise in sensor technology, software, and services, as well as our own IoT cloud, to offer customers connected, cross-domain solutions from a single source. Our strategic objective is to create solutions for a connected life, and to improve quality of life worldwide with products and services that are innovative and spark enthusiasm. In short, Bosch creates technology that is "Invented for life." The Bosch Group comprises Robert Bosch GmbH and the roughly 440 affiliates in some 60 countries. Bosch's global manufacturing, engineering, and sales network covers nearly every country in the world. The basis for Bosch's future growth is its innovative strength. At 120 locations across the globe, Bosch employs 59,000 associates in research and development.

Chairman Thune, Ranking Member Nelson, members of the Committee, thank you for the opportunity to testify before you today.

My name is Mike Mansuetti and I am the President of Bosch North America.

Robert Bosch founded the company in 1886, when he opened the "Workshop for Precision Mechanics and Electrical Engineering" in Stuttgart, Germany. From its inception, the company has focused on the importance of the international market and Mr. Bosch established his first U.S. office in New York City in 1906. The Bosch companies in the United States have now grown to encompass more than 18,000 associates with 25 active manufacturing sites across the country and three dedicated Research and Development Centers (Pittsburgh, PA; Palo Alto, CA; and Cambridge, MA). We maintain a significant presence in Michigan, South Carolina, Illinois, Florida, Wisconsin, California, Kentucky, and Minnesota. Bosch concluded its 2016 Fiscal Year with $13.7 billion in consolidated sales in North America. Bosch has four business sectors—Mobility Solutions, Industrial Technology, Consumer Goods, and Energy and Building Technology. Mobility Solutions is our largest sector, comprising approximately 60 percent of our business and representing 217,000 associates worldwide.

Bosch invested more than $450 million in North America in 2016. In 2016, Bosch opened an expanded technical center in Plymouth, Michigan, and relocated its Research and Technology Center within Pittsburgh. Moving forward, Bosch will invest $175 million in its Charleston, South Carolina plant to enhance its mobility solutions manufacturing activities at the facility. In December 2017, we were pleased to announce an additional $152 million of capital investment for our Anderson, SC manufacturing location to accommodate the expansion of our automotive electronics business and to retain additional associates at that site.

The United States remains at the forefront of Bosch's innovation efforts. We are actively testing Automated Vehicles in Michigan and in California, both on our own as a Tier One automotive supplier and in cooperation with our customers. In 2017, Bosch announced the creation of a new Center of Competence which will focus on Artificial Intelligence. Palo Alto, CA will serve as one of the three key global sites for these efforts. In support of our growth as an Internet of Things (IoT) company, Bosch founded the Chicago Connectory in May 2017. The Connectory serves as a community of entrepreneurially-minded innovators meant to foster cross-domain collaboration among corporate partners, startups and universities to drive the development of new IoT technologies. The Connectory also provides cutting-edge technology, expert programming, and mentorship from leading experts in IoT. In addition, Bosch offers technical resources, a small prototyping space, as well as mentorship from teams and leaders on topics in manufacturing, software engineering and commercialization. Part of the objective of the Connectory is to revolutionize the way we envision new products within Bosch and bring them to market.

I appreciate the opportunity to appear before you today and to share Bosch's perspective on the transformation of the automotive industry. This hearing is taking place at a critical juncture in our history as an industry. We are witnessing a revolution in almost every aspect of the vehicle, ranging from the method in which we power our cars, to how we handle and transition control of the overall vehicle and to the role that the vehicle of the future will play in the lives of individuals. I would also highlight the growing connection between the vehicle and the other aspects of our daily lives. Bosch is developing new applications that will enable consumers to manage their home, to safely engage in activities such as working and relaxing in the vehicle and to achieve time, economic and environmental efficiencies by avoiding congestion on the roads. I also wish to take this opportunity to express our deep appreciation for the efforts of Chairman Thune, Senator Peters, Ranking Member Nelson and all of the Committee members in sponsoring and passing the AV START Act (S. 1885). Your leadership in this critical area is greatly appreciated by Bosch. The Committee staff took great care to consider the issues that are impacting automotive suppliers and to understand the complex role that we play as incubators and developers of Automated Driving Systems (ADS), software and related components. We wish to acknowledge their hard work over the past year.

Automated Driving and Driver Assistance Systems

At Bosch, a driving motivation is safety. Above all, we see the potential for automated vehicles and for advanced driver assistance systems to dramatically decrease the numbers of vehicle-related injuries and fatalities, in the U.S. and across the globe. This is our primary driver as we seek to develop, refine and launch these new technologies into the market. We often speak of these advancements in a futuristic manner, but the reality is that automation is already providing tremendous benefits to vehicle drivers and occupants today. Bosch pioneered the active safety system Electronic Stability Control (ESC), also known as ESP, which is deployed in every

new passenger car sold in the U.S. In 2017, the National Highway Traffic Safety Administration (NHTSA) issued a report which found that more than 7,000 lives were saved by ESC during the 5 year period between 2011–2015.[1] The technology works by monitoring driver intent and vehicle direction and by automatically applying braking force as needed to prevent a loss of control. Most drivers are not even aware of its support as its activation is reflected solely in the momentary illumination of an indicator light on the dashboard.

As noted above, Bosch is heavily engaged in AV development and testing in the United States. Making automated driving a reality calls for profound understanding of all vehicle systems. Bosch has this expertise, and manufactures most of the key components itself—including radar, video, and ultrasonic sensors, brake control systems, electrical power-steering units, display instruments, and connectivity solutions inside and outside the vehicle. Bosch has more than 3,000 engineers around the world working to make automated driving a reality.

We are using our decades-long experience to ensure the safety of our components and ADS. Automated driving will demand much more than just the fitment of more sensors and cameras, it will require a new vision for the electronic architecture and safety-critical functions of the vehicle. The most highly automated systems available in the market today are classified as SAE Level 2. While the system is able to execute both steering and acceleration/deceleration under certain circumstances, the human driver is responsible for monitoring the driving environment and function as the backup to the system.

In order to realize higher levels of automated driving, we will need redundancy in safety-critical systems such as braking and steering. Bosch is actively developing and bringing to market redundant braking solutions to support all levels of automation. This redundancy is obviously a critical element for SAE Levels 4 and 5, but it will also be important for SAE Level 3 vehicles where a human driver is still necessary, but safety-critical functions may be handled by the vehicle under certain traffic or environmental conditions.

We are enabling redundant braking by replacing the vacuum brake booster with an intelligent electro-mechanical booster, the iBooster. A conventional brake system today comprises two actuators: a vacuum brake booster and ESC unit. In this system, in the unlikely situation that a failure occurs in the ESC unit, the human driver would act as the backup by depressing the brake pedal. The redundant brake system for automated driving is comprised of two actuators that are each able to decelerate the vehicle independent of the driver applying the brake pedal. Thus, even if a failure occurs in the brake system, either actuator (iBooster or ESC) is able to avoid wheel lock-up by modulating the brake pressure, which maintains the ability to steer during deceleration.

Redundant steering is also a key technology for automated driving and Bosch is leading in this area. In 2017, Bosch introduced its Electric Power Steering (EPS) system with fail-operational function. The system, which enables either a driver or automated driving system to make a safe stop in the rare case of a single failure, is a key requirement on the path to fully automated driving.

Bosch is forging new alliances, with both traditional partners and unique service providers, to address all of the key factors that will be necessary for automated driving. For example, in 2017, we announced a partnership with Daimler which will focus on Level 4 and Level 5 automated vehicles. In addition, on January 4, 2018, Bosch announced its intent to acquire a five percent stake in HERE Technologies, a global provider of digital mapping and location services. High-definition maps are a requirement for self-driving cars. These must be kept up-to-date with data from the vehicle's sensors and supplemented with real-time information on traffic conditions, congestion, construction sites, and accidents. Bosch's "road signature" uses information from the Bosch radar and video sensors in the vehicle to enrich and update high-definition maps. Consequently, Bosch and HERE are exploring opportunities to utilize road signature in the maintenance of HERE's map for automated vehicles. At the same time, Bosch will be continuing its work on the road signature with partners such as TomTom, AutoNavi, Baidu, NavInfo, and Increment P.

Bosch has built upon the foundational technology ESC, and our industry position as a leading manufacturer of micro-electro-mechanical systems (MEMS) and radar sensors, and mono-and stereo-vision cameras, to create a very broad portfolio of advanced crash avoidance systems that can help prevent an accident from occurring or minimize the severity of its impact. Our product list includes Automatic Emergency Braking, Lane Keeping Assist, Blind Spot Detection, Backover Avoidance Systems and Pedestrian and Rear Auto Braking systems. Bosch's Corporate Research

[1] DOT HS 812 391, March 2017, Estimating Lives Saved by Electronic Stability Control, 2011–2015.

and Technology Center estimates that Automatic Emergency Braking (City and Inter Urban) could address 35 percent of the accidents in the U.S. while Lane Keeping Assist and Lane Departure Warning (coupled with ESC) could address another 20 percent.[2] These are not ideas or visions yet to be realized; these are systems that can offer tangible, real world and life savings benefits to drivers and occupants right now. This Committee, and Congress as a whole, helped to advance the development of these technologies by supporting and funding the NHTSA Data Modernization Project. Recognizing the critical need for more comprehensive and robust real-world data concerning the actual causes of crashes in the U.S., the House and Senate directed NHTSA in 2012[3] to update its data collection efforts and provided funding to enable the incorporation of new collection sites, improved technology and enhanced data analysis. A deeper and more analytical understanding of the actual factors and aspects involved in real world crashes enables all of us to target those causes and to develop technology that provides a concrete benefit to consumers. This data is among the many elements that Bosch considers when determining where to invest its resources in creating future safety technologies.

Bosch commends the Committee for incorporating crash avoidance systems into the consumer education requirement that was approved as part of the AV START Act (S. 1885). We also wish to express our sincere appreciation to Senators Heller and Markey for the important work that they have done to call attention to crash avoidance technologies (Safety Through Informed Consumers Act of 2015[4]) and the need for their inclusion in the vehicle's star safety rating.

Bosch urges the Committee and NHTSA to re-energize and update the U.S. New Car Assessment Program (NCAP) or 5-star rating program. Highly automated vehicles will provide significant benefits and enable a new vision of mobility for millions of Americans; however, these vehicles may take years to reach high levels of market penetration. We project that conditionally automated Level 3 vehicles will be available to consumers this decade and Level 4 highly automated vehicles will be available in the beginning of the next decade. Since more than 37,400 individuals died in motor vehicle crashes in 2016, we must take immediate steps to help educate consumers on the options that are available today. Consequently, we respectfully recommend that the Committee examine the potential to incorporate crash avoidance technologies into the overall vehicle rating. A prior proposal to update NCAP, issued by NHTSA in December 2015, included not only several positive changes that would have boosted consumer awareness of new active safety systems, but also raised concerns relative to the significant adjustments that would be required in connection to the vehicle crashworthiness rating. We ask the Committee to re-examine the crash avoidance portion of the proposal, which generated notable support from relevant stakeholders such as leading vehicle manufacturers, the National Safety Council (NSC), the National Transportation Safety Board (NTSB), and the Insurance Institute for Highway Safety (IIHS).

I wish to note that Bosch supports the Federal Guidance for Automated Vehicles, which was released in September 2017. We commend NHTSA and the U.S. Department of Transportation (DOT) for all of their efforts and wish to acknowledge the significant investment of time and resources on the part of DOT leadership and the staff at NHTSA to create this framework. Bosch understands and supports the objectives of NHTSA in urging the release of a Voluntary Safety Self-Assessment (VSSA). Indeed, our company intends to release its own VSSA.

Consumer Education

Bosch is also cognizant of the tremendous need to conduct outreach to consumers and to engage in an active debate as to the benefits of these technologies, the manner in which the driver will be able to interact with them and to the proper expectations associated with such innovations.

Bosch's position on the need for improved consumer education is well known. We have urged NHTSA and the U.S. Department of Transportation for many years to include crash avoidance systems as a key component of the vehicle 5-star rating and to provide additional information to consumers through the Monroney Label.

Bosch strongly concurs with U.S. Transportation Secretary Chao that consumer education and awareness are critical enablers to the future success and adoption of ADS. In order to bolster public understanding, Bosch has launched the Bosch Auto-

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[2] Bosch Corporate Research analysis based on NHTSA Traffic Safety Facts 2015, DOT HS 812 384.

[3] DOT HS 812 128, March 2015, NHTSA's Review of the National Automotive Sampling System: Report to Congress.

[4] S. 1535, the Safety Through Informed Consumers Act of 2015. This legislation was approved in 2015 as part of the Fixing America's Surface Transportation (FAST) Act.

mated Mobility Academy to educate members of the public on how automated mobility can improve their quality of life and to explain how various advanced technologies and functions will make the fully automated future possible. The Academy also provides information on driver assistance technologies that provide safety and comfort benefits today and will serve as the building blocks to higher levels of automation.

You may access the Bosch Automated Mobility Academy at: *http://www.bosch-mobility-solutions.us/us/highlights/automated-mobility/amc/*

In addition to the Academy, Bosch remains committed to increasing consumer awareness through its partners and through demonstrations and presentations at dedicated industry and government events.

Cybersecurity

The topic of cybersecurity is tightly intertwined with the emergence of increasingly automated and connected vehicles and it is a priority for Bosch. Again, I commend the Members of this Committee and your staff for working so diligently to address this critical and complex issue. Bosch has been working for several years to develop robust and comprehensive solutions for our customers. Bosch strongly supports a layered approach to vehicle cybersecurity. We have espoused this principle in the development of our own products and in our engagement with customers.

We are addressing our customers' requirements in two ways: (1) developing systems and technologies that can address risks based on the electronic architecture of current vehicles, and (2) investing in future solutions that will be interwoven into the vehicle design from the ground up. Our current cybersecurity product portfolio ranges from security embedded in the hardware of our electronic products to sophisticated mechanisms which serve as a "wall" between external connectors to the vehicle and the safety-critical systems that govern the steering, braking and other functionalities.

Also, with the Bosch group of companies we have the leading team of security specialists in the automotive sector, ESCRYPT. It is an industry leader in securing over the air (OTA) updates of firmware and software, which are carried out in a similar manner as smartphone software updates. Users select a function on their smartphone or the infotainment system. The information is sent to the Cloud, which functions like an app store to provide the software and to start downloading it straight into the vehicle. Further, security updates can be distributed by such an infrastructure. Data transfer runs securely in the background while the car is being driven—and importantly the updates are only made when conditions are secure. According to Gartner Inc., 250 million cars around the world will be connected by 2020,[5] so this topic will continue to remain at the forefront as the industry advances.

In the future, Bosch sees the focus of automotive cybersecurity as intrusion detection and prevention. Bosch and ESCRYPT are actively developing components and systems to support OEMs in developing vehicles that are safe and secure. ESCRYPT's Intrusion Detection Prevention System enables continuous monitoring of attacks in the field and timely detection of attacks. The information is conveyed to a backend office through the cloud, enabling analysis by security analysts and forensic experts who can then develop an appropriate response. This could include a roll-out of countermeasures via security updates for the entire fleet in order to remedy the vulnerability.

Understanding the importance of industry cooperation and engagement in addressing potential threats and developing best practices, Bosch joined the Automotive Information Sharing and Analysis Center (Auto-ISAC) in 2016 and one of our associates presently serves as the Chair of the Supplier Affinity Group within the ISAC.

Bosch understands that the Committee has expressed interest in the topic of coordinated disclosure. Bosch has already established a process to enable effective communication with other Bosch entities and external parties, including researchers. In 2016, a Product Security Incident Response Team (Bosch PSIRT) was created to serve as the central point of contact for external security researchers, partners or customers to report security information related to Bosch products. The PSIRT interface provides a clear and accessible means for external parties to communicate and ensures that all submissions will be reviewed and considered. This mechanism enables an assessment of the validity of vulnerability notifications and allows for

[5] "Gartner Says By 2020, a Quarter Billion Connected Vehicles Will Enable New In-Vehicle Services and Automated Driving Capabilities," (Jan. 26, 2015). Press Release: *https://www.gartner.com/newsroom/id/2970017*

a quick and appropriate action. The Bosch PSIRT webpage further includes a list of existing Security Advisories.[6]

In addition, acknowledging security as an important element of the product-development process is a necessary step to ensure that security capabilities are properly implemented and that considered relative to all aspects of the vehicle life-cycle. Bosch has developed a security engineering process that is followed for all warranted present and future product development.

I also wish to note the importance of industry standards and of the active engagement by standard setting bodies across the world to develop appropriate standards in this area and, eventually, to harmonize their approach where possible. Bosch believes the industry standards will play a critical role in framing the future adoption and use of the technology. We are supporting these efforts and utilizing the recommended practices. For example, Bosch is actively participating in the ISO–SAE 21434 Road Vehicles Cybersecurity Engineering standardization process, which addresses the means of handling security topics in automotive product engineering.

Securing automobiles is a complex issue that requires both a comprehensive, strategic approach and a long-term commitment. We are devoted to developing tools and offering consulting to help the U.S. automotive industry with this important issue.

Artificial Intelligence

Bosch is advancing artificial intelligence. At the Bosch Connected World 2017 conference in Berlin, Bosch presented an onboard computer for automated vehicles. Thanks to artificial intelligence (AI), the computer can apply machine learning methods. The AI onboard computer is expected to guide self-driving cars through even complex traffic situations, or ones that are new to the car. Bosch's AI onboard computer can also recognize pedestrians or cyclists.

Bosch is also actively seeking ways to utilize AI to improve our existing products and operations, including in manufacturing where AI can scrutinize the effectiveness of our production so that products can be manufactured more quickly while maintaining exceptional levels of precision and quality. AI also has the potential to make our lives easier in many areas, whether its intelligent cars finding parking spaces, having the room temperature automatically adjusted to our needs, or protecting our homes against break-ins. We wish to acknowledge the leadership of Senator Cantwell, Senator Markey and Senator Young in introducing the Fundamentally Understanding the Usability and Realistic Evolution of Artificial Intelligence Act of 2017—or the "FUTURE of Artificial Intelligence Act."

Powertrain

Amongst the most dramatic challenges facing all of us in the industry is the design of the powertrain that will be needed for the future. Although much of the focus of the automated vehicle debate has been on the safety aspects and the engineering requirements, such as redundancy, fail-safe operational modes and human machine interface (HMI) needed to bring this objective to fruition, the reality is that automated vehicles will also change the needs of the powertrain.

Bosch is investing in the future by continuing to innovate new technologies that boost performance and efficiency and by investing in the many systems and advancements that we will be demanded by electric vehicles. At the North American International Auto Show (NAIAS) in Detroit last week, we featured our electric axle drive and our second generation 48-volt system (which provides improvements in fuel economy and performance). Bosch takes the challenge of the move to electric propulsion by offering a complete electric drive that is cost-attractive, performance based and helps saving battery capacity due to its very high system efficiency. The Bosch eAxle platform is designed to support the full range of passenger car and commercial vehicle segments.

Smart Cities

In assessing the landscape before us, Bosch also sees a shift in how consumers utilize their vehicles and the options that they expect in terms of mobility. One of the most notable challenges that we are facing as a global society is congestion and the difficulty associated with traffic management in our large cities. Urban traffic is predicted to triple by 2050. In the U.S., the average individual spends more than 40 hours a year stuck in traffic, wasting more than $120 billion in time and fuel. In order to prepare for the mobility scenario of the future, we have launched several smart city projects in countries around the world. Today, half of Bosch's 14 smart city projects include urban mobility solutions such as connected parking, automated driving, fleet management, multimodal transport, electromobility, and vehicle

[6] Bosch Product Security Incident Response Team website: *https://psirt.bosch.com/index.html*

connectivity (V2X and DSRC). After a successful pilot phase, Bosch intends to launch community-based parking in several U.S. cities this year. In places such as L.A., Miami, and Boston, the company will make real-time information about on-street parking available to car manufacturers. Drivers will be able to see on their navigation systems where there's a free space and drive directly to it. We have also announced a collaboration with Daimler to bring self-driving SAE Level 4 and Level 5 vehicles to city streets by the start of the next decade. This will open up new horizons in particular for people with limited mobility.

The Workforce of the Future

As we look forward to these advances and leaps within the industry, we cannot fail to address the demand for trained workers to fulfill the millions of jobs that will be needed to fuel the industry's transformation. Of Bosch's 390,000 associates worldwide, more than 20,000 are software engineers, nearly 20 percent of whom are working exclusively on the IoT.

Bosch recognizes the need to build and shape the manufacturing workforce for the future. As is the case with many of our partners in the industry, we encounter challenges in finding the right candidates for our open jobs and positions. Our strategy encompasses inspiring young minds and helping to generate an interest in science, technology, engineering and math ("STEM") and careers in manufacturing. The strategy includes hands-on training for students who are enrolled in technical colleges and universities.

Our investment also extends to our current associates. We provide access to a broad variety of training programs and skill-building initiatives to all of our team members. Bosch maintains several apprenticeship programs at its manufacturing facilities in the U.S. These programs enable students to receive hands-on training and gain valuable experience while working at a Bosch site. For example, the Bosch Rexroth plant in Fountain Inn, SC currently operates four U.S. Department of Labor-registered apprenticeship initiatives.

Many of the participants of the apprenticeship programs transition to a Skilled Associate position with Bosch at the conclusion of their training. Bosch Rexroth has an active partnership with the Greenville, SC Technical College. In March 2016, the Bosch Community Fund (BCF) provided $62,500 to the Greenville Tech Foundation in order to establish a hydraulics simulation lab at the Greenville Technical College Center for Manufacturing Innovation.

In addition to providing grants to support apprenticeship programs, the BCF also provides grants to fund educational programs focused on STEM, as well as manufacturing professional development for teachers. Last October the BCF awarded 7 grants totaling over $86,000 in the Owatonna, Minnesota community to support organizations and initiatives that provide students with robotics courses, career preparedness classes and manufacturing workshops. By investing in lab improvements, teacher training and enhancements in STEM and engineering curricula, the BCF is able to impact students' lives in the community and help to prepare the next generation for the workforce of the future. Since 2014, the BCF has awarded more than $308,000 to schools and organizations in the Owatonna area, and the BCF is engaged in many similar efforts across the country.

Bosch also supports both A World in Motion (AWIM) and First Robotics initiatives. Led by the Society of Automotive Engineers (SAE), AWIM works with children in kindergarten through 8th grade to bring science, technology, engineering and math education to life. Bosch volunteers work directly with children to complete challenges as a means to inspire them and build interest in STEM topics. Today, Bosch employees participating in AWIM are volunteering in nearly 80 classrooms located near seven Bosch North American facilities to bring STEM education to life. This not only gives us the opportunity to get involved in our communities, but also helps us develop our future scientists and engineers. The Bosch Community Fund also provides support to AWIM. Under the aegis of the First Robotics program, Bosch opens its doors to high school students and they are invited to work with Bosch engineers to design and build a robotic solution.

Conclusion

Thank you again for the opportunity to speak before the Committee. Bosch looks forward to continuing to work with each of you and with the Committee in the future. We would be pleased to provide additional technical information on any of these topics.

I welcome any questions you may have.

The CHAIRMAN. Thank you, Mr. Mansuetti.

Mr. Schneider.

STATEMENT OF LUKE SCHNEIDER, PRESIDENT, AUDI MOBILITY U.S.

Mr. SCHNEIDER. Chairman Thune, Ranking Member Nelson, and Members of the Committee, I appreciate the opportunity to testify today, and thank you on behalf of the automotive industry and developers of automated vehicles for your leadership in working to enact the AV START Act.

There is an urgency for the Senate to pass the AV START Act, because it will create for innovators a consistent, national regulatory framework for automated vehicles, and it is necessary to advance mobility solutions that will positively transform American cities, provide mobility to the elderly and the disabled, and ensure greater safety on our roads, a priority we share with your Committee and the Department of Transportation.

Passage of this legislation will allow us to realize the three transportation revolutions we so often talk about: shared mobility, electrification, and automated vehicles enhanced by digitalization, which some consider a fourth. Automation and digitalization are disruptive innovations, especially for automakers, and we are driving this new future as an industry. The clear societal opportunities in what the related technologies can offer is what is motivating us to rethink mobility in the most comprehensive way since the 1890s.

As the CEO of Silvercar, a disruptor in its own right, and the president of Audi Mobility U.S., I would like to share some insights into where this new frontier of automated, electric, and shared mobility as a service is headed.

While some skeptics fear job dislocation from disruptive innovations, the fact is that disruptors have created new categories of jobs that did not exist before. Existing sectors will continue to expand and transform, and a range of new jobs will be created for workers across all skill levels.

Audi is in the innovation business. Audi perfected all-wheel driving on racetracks, and then offered that technology across our fleet. We were the first to take Google Earth mobile in our navigation system before it was on phones. We implemented LED lighting before it became an industry standard. And as we enter what many call the "third wave" of the technological revolution, the auto industry finds itself at the center of it all.

There will be more industry innovation in the next decade than in the last century. The cost of batteries has gone down significantly while the number of sensors in the average vehicle has increased dramatically thanks to innovations in everything from capacity to size.

The way we want to access transportation through the use and even ownership of vehicles is fundamentally changing, along with the other major consumer categories in our lives.

Innovation will continue to be our legacy and our responsibility, but we will not be innovating just to sell more cars. We will be innovating to reduce fatalities, ease congestion, lessen emissions, and improve mobility for all.

The most important benefit of all this innovation is safety. The innovations I mentioned earlier all have one thing in common: safety. All-wheel drive excels in the worst conditions. Navigation systems tell people exactly where to go, so they spend less time on the

road even as they keep their eyes on it. Our lighting illuminates that road with the closest thing to daylight.

But here is the staggering reality. One and a quarter million people die on our roads every year globally, and human error is the number one cause. Vehicle automation promises to improve safety on our roads and reduce collisions by as much as 90 percent.

But maybe even more exciting, it can also deliver basic access that tens of millions of people currently do not have. The elderly and those with disabilities will be able to move with far greater freedom and efficiency. In America, nearly 16 million people 65 and older live in communities where public transportation is poor or nonexistent. Six million people with a disability have difficulty accessing transportation.

For Audi, that is why we are delivering Level 3 automation as well as working to develop highly automated vehicles that need no human driver at the wheel. Automated vehicles have the potential to reduce fuel use and carbon emissions, since they are likely to be EVs, shared, and drive more efficiently than humans. And fewer crashes means fewer traffic jams.

We want to work together to address the challenges facing cities and communities, like reducing fatalities, reducing congestion and pollution, maximizing scarce infrastructure dollars, and optimizing transportation flows. The new mobility options we are pursuing and the legislation you are working on will help us address this challenge.

Thank you.

[The prepared statement of Schneider follows:]

PREPARED STATEMENT OF LUKE SCHNEIDER, PRESIDENT, AUDI MOBILITY U.S.

Chairman Thune, Ranking Member Nelson, and members of the Committee, I appreciate the opportunity to testify today. Thank you on behalf of the automotive industry and developers of automated vehicles for your leadership in working to enact the AV START Act. There is an urgency for the Senate to pass the AV START Act because it will create for innovators a consistent national regulatory framework for automated vehicles necessary to advance the new mobility solutions that will positively transform American cities, provide mobility to the elderly and disabled, and ensure greater safety on our roads, a priority we share with your Committee and the Department of Transportation.

Passage of this legislation will allow us to realize the three transportation revolutions we so often talk about: shared mobility, electrification and automated vehicles, enhanced by digitalization.

Automation and digitalization are disruptive innovations, especially for automakers, and we are adapting to this new future. The clear societal opportunities and what their related technologies can offer is what is motivating us to rethink mobility in the most comprehensive way since the 1890s.

As the CEO of Silvercar, a disruptor in its own right (of the car rental business), and president of Audi Mobility U.S., I'd like to share some insights into where this new frontier of automated, electric, and shared mobility as a service is headed.

While some skeptics fear job dislocation from disruptive innovations, the fact is disruptors have created new categories of jobs that didn't exist before. Existing sectors will continue to expand and transform, and a range of new jobs will be created for workers across all skill levels.

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There will be more industry innovation in the next decade than the last century. The cost of batteries has gone down significantly, while the number of sensors in

the average vehicle has increased dramatically thanks to innovations in everything from capacity to size. The way we want to access transportation, through the use and even ownership of vehicles, is fundamentally changing along with the other major consumer categories in our lives.

Innovation will continue to be our legacy, and our responsibility. But we won't be innovating just to sell more cars. We'll be innovating to reduce fatalities, ease congestion, lessen emissions, and improve mobility for all.

The most important benefit of this innovation is safety. The innovations I mentioned earlier all have one thing in common: *Safety.* All-wheel drive excels in the worst conditions. Navigation systems tell people exactly where to go so they spend less time on the road even as they keep their eyes on it. Our lighting illuminates that road with the closest thing to daylight. But here's the staggering reality: 1.25 million people die on our roads every year globally. And human error is the number one cause. Vehicle automation promises to improve safety on our roads, and reduce collisions by as much as 90 percent.

But it can also deliver basic *access* that tens of millions of people currently don't have. The elderly and those with disabilities will be able to move with far greater freedom and efficiency. In America, nearly 16 million people 65 and older live in communities where public transportation is poor or nonexistent. Six million people with a disability have difficulty accessing transportation.

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We want to work together to address the challenges facing cities and communities like reducing fatalities, reducing congestion and pollution, maximizing scarce infrastructure dollars and optimizing transportation flows. The new mobility options we are pursuing and the legislation you are working on will help us address these challenges.

The CHAIRMAN. Thank you, Mr. Schneider.

We are going to have 5-minute rounds of questions here. We will try to keep this moving as much as we can. But again, thank you for being here. Thank you for your testimony.

I find this technology incredibly exciting, and I just look at the transformational impact it can have on our economy in terms of safety first and foremost, but second productivity, providing mobility for, as has been pointed out, communities of people that previously have not had access to it. And some of us up here have had the benefit, too, of being able to ride in some of these vehicles and see what is happening out there.

But I have a question for you, and I am going to make this a two- or three-prong question, so I can try to cover a lot of ground here. But there are skeptics out there, and I know that a lot of it has to do with Americans like to drive and it is a difficult transition to integrate AVs into a national fleet, but how do we, one, build consumer trust and confidence in this technology? Two, how do you address the concern that people have about negative impacts on the labor market, people who drive vehicles, for example, as a profession? And three, one of the other concerns that I have heard is, how do you address the issue of cybersecurity? That question comes up with regard to this technology as well.

So if you could speak to how we convince people this is a good thing, and we will come back. Those are at least three questions that I hear posed to me, and questions I would love to have you get an opportunity to answer. So feel free, whoever would like to take a stab at that.

Mr. MANSUETTI. Perhaps I will start. Thank you for those questions. We are also very concerned with those issues and have been working a lot to address those.

To your first question regarding building consumer trust, that was one of the big things that we see that we need to do and is a job of the automotive industry. That is why we started the Bosch Mobility Academy.

So when we talk to people and we talk to consumers about automated vehicles and are they ready to let go, many of them are not. They are ready to let go of certain functions; for example, parking. And we see parking as an early use case to help speed the adoption of automated vehicles, because who would not like to just get out, push a button, and have their car automatically valet parked or returned. And that helps to build the trust.

So we would be happy to talk more, and we have this academy to help educate consumers on that.

Regarding the labor impacts, I think we all stated that there will be quite a number of new jobs and new opportunities created. So on the manufacturing side, we continue to invest in apprentice programs and re-educating our workforce.

And I think with the new business models that emerge, we are going to see tremendous opportunities. As vehicles become more highly utilized, the increased opportunities for maintenance and cleaning and different things of this nature will arise from these new business models.

And cybersecurity is very important to us. So this all hinges on good, robust cybersecurity measures. We see cybersecurity kind of as a layered approach, if you think about it from an onion, starting at the basic silicon levels and building in technology and cybersecurity and the hardware and the connections, and then looking at the entire network from an intrusion detection system.

So those are some of the things that we are working on.

Mr. SCHNEIDER. I wanted to respond to that question with a few examples and a few instances in my personal experience.

The first is, one of the great things about the AV START Act is that it contemplates consumer education in the bill itself, that the Department of Transportation alongside individual OEMs and other industry players and industry associations all really need to conspire to do this together, so that the consuming public can become more comfortable with the concept of a car driving itself.

With respect to jobs, I can speak from personal experience there. We started a company, Silvercar, 5 years ago, created about 200 jobs in a very short period of time, all of which spanned a number of job categories. I think the big difference here is that the people employed in personal transportation are going to be working at some different things, not exactly the same things that they are working on today. That is fundamental to the nature of technology changing the way we move around. But we are optimistic about it because of the job classes and categorizations and the heavy technology orientation that they have had in companies like Silvercar.

And the last piece of this is really about security. This is always going to be a concern. And, frankly, I think from a safety and security perspective, very few industries are as regulated as the automotive industry. What we look at is the ability to separate systems

within cars, so that we do not impact driving systems or core systems, and we are still able to make use of the data that is generated by the use of these shared mobility systems to provide better and more efficient transportation.

Mr. KENTLEY-KLAY. Senator Thune, thank you for your three questions.

To address them briefly, in terms of adoption, there is always a bell curve with a new technology. You have your early adopters. You have the mainstream in the middle. And then you have your laggards at the end that may never adopt the technology. In the case of aviation, even though it is one of the safest modes of transportation, some people still refuse to fly. Ironically, though, they will drive, even though it is much more dangerous.

So I think the way to do this is you have to build trust with the community. This is happening today as developers develop this technology. There has been no injury by any developer of autonomous technology working in America yet from a vehicle that is driving itself. And yet, there has been many cases where the vehicles have been hit by human drivers.

So I think by limiting the geographic domain of deployment of the vehicles in the first instance to, say, downtown areas, in lower speeds, in good weather, we can win the public's trust and expand the technology over time.

In terms of the job space, people often talk about disruptive technology. I find that term a little bit myopic. I see us actually creating a constructive technology, correctly understood. For a new way to come into vogue in the mainstream, I think it has to be materially better than the incumbent.

So I think what we are actually creating is a new way of doing things better, and that will lead to new job creation. And this is always the way with technology.

If you look in America 100 years ago today, 40 percent of the workforce worked in agriculture. Today, it is less than 1 percent, but we do not have 40 percent unemployment as a consequence, because of a whole new set of economies and jobs that we have. Just as there are more people and more revenue from the automobile industry than the horse and carriage industry, there are going to be more people working and more revenue in autonomous mobility era as well.

So we see great opportunity here, and the challenge for society is, really, how do we reskill people to get the new job opportunities that will come from new technology?

Finally, in security, that requires perpetual vigilance. Cybersecurity is always going to be a threat. It is probably not the best to disclose in intimate ways what our countermeasures are at Zoox, but it is something we think a lot about and something we would be happy to chat about offline.

But one thing I would say is that it is important to understand the geometry of how these vehicles will work. In Zoox's case, we own and operate the vehicle, so a customer cannot buy it, and they cannot reverse engineer it in their garage to understand how to hack it or how it can work. To access the vehicle, you need to have a credit card and be part of a system, so we know who you are.

And then we are tracking the vehicle. We know where you are and what you are doing.

And then that vehicle is limited to the road network. The occupant in the vehicle has no capacity to take it off that road network as a bad actor.

So if you add all that up, I think it means the technology is actually quite secure, and it is really not a good area for a bad actor to try to do something that would be negative for society.

The CHAIRMAN. Senator Nelson.

Senator NELSON. Dr. Avent and Mr. Kentley-Klay, if you would, paint the picture, as a result of autonomous vehicles, what the downtown streets of New York City, Manhattan, look like in the future.

Dr. AVENT. Just to follow on the conversation previously, I think that there is no magic bullet for consumer trust, and it is going to have to be built incrementally, and probably is going to lag behind the technology. So I think this technology is going to be adopted maybe a little bit slower than what many are predicting.

But when it is adopted, I think that you will see interconnected computers that are scheduling each other. They are optimizing. They are adaptive. So downtown New York City will have vehicles on it. There probably will be fewer vehicles with more capacity because utilization of vehicles now is about 5 percent, and parking will change significantly. I think that you will see vehicles communicate to each other and interact with the environment, so much safer and more efficient transportation.

Senator NELSON. So will there be as much the need to purchase your own vehicle in the future, Mr. Kentley-Klay?

Mr. KENTLEY-KLAY. Senator Nelson, thank you for your question.

While people love driving cars, people do not like driving a car in gridlock. It is not a good use of our time. It is already clear in cities, and Manhattan is a great example, the average car ownership is 0.6 per household. Nationally in America, it is a little bit under two.

The demographics are quite clear, that young people see car ownership as a hassle. They have to park it. They have to do insurance. They had to do maintenance. They would much rather just have an on-demand model where they can pay for what they use. And when they are not using it, someone else is, which is a wonderful use of that product. It is getting high utilization.

To address your question before, in terms of, how does this change Manhattan? I mean, Manhattan is the crown jewel for this technology, in many ways. There are actually 13,000 Ubers, Lyfts, and taxis operating on the island at any one time.

In the opening stanzas of the technology, I think we are developing our technology to work in a mixed-mode environment. But beyond the launch of the technology, I think in the space of sort of 5 to 10 years, I think you will see cities creating disincentives for cars that pollute and that are human-driven to come into the most congested areas, and just to have autonomous mobility, and that will be transformational for the cities. You will reduce congestion. You will enhance the air quality within the city. You will be able to clean up the urban landscape. There is a lot of visual pollu-

tion from traffic lights, signposts, car parking. You will open up new lanes.

So I think, from an urban-planning point of view, the technology actually holds great promise to actually refresh and reinvent our most dense urban areas to be safer and more enjoyable.

Senator NELSON. Paint the picture of the future of travel from New York to Chicago, from Washington to Philadelphia. What is it going to look like? Anyone of you.

And then I want to ask you, Mr. Schneider, since you are one of the auto companies, I want you to tell me why is this not threatening the purchase of your automobiles?

Go ahead, paint the picture of this long-distance travel.

Mr. KENTLEY-KLAY. Well, I think it is going to be wonderful. Imagine the difference between a horse and carriage and the Model T Ford. That is an incredible transformation. And it is our belief that we are about to go through the same transformation in terms of the products that the general public will be able to access to enhance their ability to move across the country.

Senator NELSON. So is it that we are going to have high-speed, dedicated lanes that you are going to punch in that I want to go to Philadelphia or I want to go to Baltimore or New York or Boston? Is that what the future of long-distance travel is? Anybody?

Mr. KENTLEY-KLAY. I think you will see mixed-mode transportation. People will still fly and take trains, and they will drive cars. I think that technology will start in more dense urban areas first. But as it matures, it will lead to intercity travel, and it will be wonderful for people, because it will be safe. It will still work in a mixed-mode environment.

Senator NELSON. OK, Mr. Schneider, why are you not dealing yourself out of business?

Mr. SCHNEIDER. Well, this is a great question, and this is sort of at the heart of the matter.

So what is great about this is that we as an industry are beginning to speak in terms that are typically more associated with the technology in the high-tech sectors, and that is in the form of use cases. Some mixed-mode, multiple-use cases, whether you are trying to get from point to point in a city or from city to city, interurban, suburban, there are so many different use cases for personal transportation that to think a $10 trillion global industry is going to be solved by a single solution is really not realistic, from our view.

The way we look at this, and the reason why we as an automaker are excited about the future, is that in pretty much every other category that we consume—food, music, media, lodging—the consumer models either are changing or have changed. We buy things differently. We buy what we want. We pay for what we use. And we do it on our phone. And from our perspective, that concept of a consumer model where you are consuming this category of personal transportation is an entirely unexplored area, one that really marks the transformation of our industry.

So whether you use public transportation, which we believe will still be an available option to go from place to place, or use a private conveyance, which is automated or in some other way even highly automated, is an option.

The point is that getting from place to place will become a more efficient and a lower cost per passenger mile opportunity for people. We think that if you reduce that cost per passenger mile, then you will unlock demand for mobility. People view mobility and moving around as a basic need today, not a luxury or something like that, and that is exciting, because if you really believe that, and you are looking at the people who can create the assets that move people from place to place, fundamentally, that is what we do.

So if the way we offer those up to the consuming public is different, just a different consumer model, then that is our obligation, to figure out how to serve them what they need.

The CHAIRMAN. Senator Wicker.

STATEMENT OF HON. ROGER F. WICKER,
U.S. SENATOR FROM MISSISSIPPI

Senator WICKER. Gentlemen, clearly, we need automated microphones at this hearing.

[Laughter.]

Senator WICKER. Mr. Kentley-Klay, you said the AV START Act and the SELF-DRIVE Act are the right approaches. Mr. Schneider, you said there is an urgency to passing the AV START Act.

So let me ask you, Mr. Mansuetti, have you looked at this legislation? And do you advocate the passage of it?

Mr. MANSUETTI. Yes, we support it. We appreciate the work that has been done, and it provides a clear and certain framework moving forward, so we very much support it and look forward to the passage.

Senator WICKER. Doctor, we have taken a vote up here, and we cannot seem to get up a majority for how to pronounce your name, so would you help us?

Dr. AVENT. Yes, sir, it is Avent, just like what air comes out of.

Senator WICKER. Just like the dairy in Oxford, Mississippi. OK.

What do you think about this legislation? Is there an urgency to getting this done? And if we get it done, how soon will we see the fruits of it?

Dr. AVENT. I actually have not read it in its entirety, so I will pass on that question.

Senator WICKER. OK, and that is fair enough. Let me ask you, then, who wants to talk about HOT CARS? Three of you have advocated the passage of this legislation. The AV bill contains the hot car provision, which I helped co-sponsor.

There were approximately 755 child vehicular heatstroke fatalities in the United States between 1990 and 2015. We have heard concerns about the costs of this, but we have also heard that, with the development of sensors to detect the presence of other vehicles, we might as well go ahead and spend the extra $30 to $50 to incorporate heat-detection sensors in the backseats of vehicles.

So let me start with you, Mr. Schneider, because you already have the Audi MMI connect App for smart phones with this level of precise sensing and mobile connectivity. Can that be a way to jumpstart the provision and save the lives of children in the backseats?

And then other people might want to comment on this.

Mr. SCHNEIDER. Sure. I appreciate the opportunity to respond to that.

The ability to save lives in vehicles, regardless of how those lives are lost, is a priority for Audi. So the ability to use smart phone technology or wireless or anything, really, to improve the safety of vehicles, is in our best interest. So this is yet one other example, I think, of how we have shown a commitment to safety and how we believe that the passage of this bill and the ability to greater connect cars, both to terrestrial and in other locations, is important.

Senator WICKER. How close is Audi to this capability?

Mr. SCHNEIDER. I cannot speak to that directly, but I can definitely give you a response after the hearing.

Senator WICKER. Anyone else want to comment? Mr. Kentley-Klay?

Mr. KENTLEY-KLAY. Senator Wicker, thank you for your question. I think it is important to understand there are two directions this technology will develop. The first is automobiles that are sold to customers, they will have increasingly automated functions. And I cannot speak to hot cars in that category. The category that Zoox is developing is we do not sell the car. We own and operate the vehicle in a city, and customers pay per minute, per mile.

In that case, our vehicle is designed to be deployed for up to 16 hours. We expect a utilization rate of 50 percent to 60 percent, so we would condition the cabin throughout its deployment environment. It is never parked for a long period of time in a car park and getting hot. So the ability for that issue to be eradicated with our architecture is, I would say, complete.

Senator WICKER. Mr. Mansuetti?

Mr. MANSUETTI. As we develop sensors for interior occupancy sensing and also driver monitoring, these technologies can also be used to do just that, to detect occupants in the car and also sense the temperature and provide a warning, so those are things we are looking at actively as we develop this technology.

Senator WICKER. It seems like we ought to be able to do it without much cost.

We have heard questions about infrastructure in New York, and we have heard questions about cross-country trips. We hope Congress is about to get a recommendation from the administration about an infrastructure bill. What do we need to include in infrastructure legislation that could facilitate the development of autonomous vehicles?

Mr. SCHNEIDER. That is another great question, and one where I think we have to take this initiative in the right perspective. So while many would like to think that tomorrow we are going to see autonomous vehicles connected and taking us where we want to go, the reality is that this will be a longer term, more of an evolution than a revolution.

So specifically, what we need in an infrastructure bill today is not something, I do not think, anybody can comment on specifically. But what we do need is the ability to put more vehicles on the road, to test them, to understand where the pinch points are, where the safety compromises might be, and to be able to very accurately and clearly communicate that to an administration and a

legislature that has the ability to enact and improve those conditions.

The CHAIRMAN. Thank you, Senator Wicker.

Senator Peters.

STATEMENT OF HON. GARY PETERS,
U.S. SENATOR FROM MICHIGAN

Senator PETERS. Thank you, Mr. Chairman. I want to thank Chairman Thune and Ranking Member Nelson for hosting this meeting.

I will say this is the best-attended Committee meeting I have been to since I have been a Member of this Committee, so maybe we need to have more meetings here at the auto show, Mr. Chairman, or just have more hearings about an incredibly exciting topic.

It is really a pleasure to be here with the industry.

And, Senator Thune, thank you so much for your leadership on this bill. I think we all saw his passion in his opening comments. And I enjoy working with him because he is a no-nonsense Senator. You can tell that by the fact that he asked the three big questions right out of the box, like no-nonsense, let's get right to the core of this.

And that is what you have done all along. Thank you, Mr. Chairman.

And, Senator Nelson, thank you for being there every step of the way as well and working with all of us to make this a reality.

And I agree, this technology is transformative. You can call it disruptive or creative. It is all of those things. In fact, I believe it is the biggest thing to happen to the auto industry since the first car came off of the assembly line, and we all know that was a pretty big deal for the auto industry to have an assembly line. And this will be equally as big, and it is happening faster than I think the public realizes.

Given the fact that General Motors, as Senator Nelson mentioned, has already announced for 2019 to have these cars. The Ford Motor Company is going to have a self-driving car off their assembly line, they have announced, by 2021. Other companies are making similar claims.

I was just at the Detroit auto show last week, which is an incredible show, and they were featuring a number of self-driving cars, including the Ford Motor self-driving car that they are working on and testing in Ann Arbor, Michigan, that delivers pizzas, Domino's pizzas, to your door, which is innovative and just one example of all the things that are going to happen as a result of this.

But in order for that to happen, and this topic has already been brought up about consumer trust, we are certainly aware of that. You have to win trust because this is a new thing for consumers, that they have to feel comfortable. That can be a potential limiting factor to it.

So the legislation before us, the AV START Act, actually creates a requirement that the Department of Transportation work with both industry and other government agencies to advance responsible consumer education. Central to that, in my mind, is to make sure consumers understand what these cars can and cannot do, particularly before we get to Level 4 and 5. There is always an

issue related to the car may not do everything you think it is, and you will expect it can, and then something bad will happen as a result of that.

If those kinds of accidents occur, we can expect to have significant consumer pushback on this technology, if we are not doing it right or we are not doing it in a way that fully informs consumers.

So my question to you, this is required in the legislation, is how will your companies, or some ideas of how we will accomplish that to make sure that, before anybody gets in that car, they understand what this car can or cannot do? Given that requirement in this bill, how will you react to it? Anyone can start.

Dr. AVENT. I may differ a little bit from some of the other panelists in that I think open-city testing alone is not the right option. It is only one piece of a very thorough and integrated approach to testing.

The problem with open-city testing is that your events aren't controllable. They are real world, which is a great thing and something that needs to be done, but you cannot control events, and it is hard sometimes to observe them, and it is certainly hard to repeat them.

So I think you need a holistic approach, an integrated approach, to testing to build the trust. That includes everything from simulation and emulation, where you can really control and run lots of test cases, to closed-track testing, where you can focus on those edge cases.

For instance, like Senator Nelson said today, when someone makes a U-turn out in the middle of the road, that is a six sigma event that happens once in a million times, unfortunately, but there will be lots of those cases. For instance, the Tesla that was in the automobile accident where a white truck pulled out in front of it, and the sun was just in the perfect location that it could not see it, the sensor could not see it, and it ran into it.

There will be a vehicle that is going down the road in Kentucky that has potholes on it, no lanes on it, and a horse will run out in front of it. Those are the rare events that you are not going to be able to get in-city exclusively, so you have to build an infrastructure that allows you to test all those cases and really characterize when it works, and when it does not work.

And for those cases where it does not work, what can we do to improve that? I think that is going to take a little bit of time to do that.

Senator PETERS. Anyone else?

Mr. MANSUETTI. Thank you, Senator Peters. I would say, as I mentioned before, this awareness and education of the consumer, we have a duty as an industry to do this, and I would liken it to when we introduced electronic stability control. We were early innovators in ABS. This is a foundational element of automated driving. We really undertook, together with the insurance industry and other industries, to educate the public on how to use this particular safety system and what is happening when it is in use.

So I think we have to continue to demonstrate through good use cases—I mentioned before the example of parking—that people can become familiar in a safe environment and begin to trust the overall technology. I think that is happening as we introduce some of

these safety features in the vehicles today, like automatic emergency braking or lane departure warning or adaptive cruise control. So I think people will become more familiar.

And as more technology is available on the road, we will continue to build that consumer trust.

Senator PETERS. Dr. Avent, if I may just ask a quick question, because you brought up the point of having not just city testing but testing in other environments, including proving grounds. Of course, you are one of the automated vehicle proving grounds that has been designated. We have one in Michigan. I see Mr. Maddox here from the American Center for Mobility.

How are these proving grounds operating? How do you feel where we are with them, how important they are? And what can we do in Congress to make your work and the other nine proving grounds work more efficiently?

Dr. AVENT. I think they are emerging, and they are evolving over time as the technology evolves, and they are being responsive to how the technology is going. I think they are a critical part. Like I said, one of the big advantages of these test grounds is that you can control the events and you can experiment with it, so you can take those fringe test cases that technology really is not quite mature for and you can experiment around them and really understand when and where this technology works.

As you mentioned, there are 10 sites across the Nation that have been chosen as testing grounds, and all of them are going to have a little bit different expertise, so I do not think there is a winner-take-all approach to it. I think you need multiple people doing different things and integrating it all together.

I think that these test grounds can provide a valuable interface to the government to help with regulations, because it can provide data and a science-based approach to what regulations need to be and what ones do not need to be. I think many of them are attached to universities, which I think is a great thing, because universities are independent. They are unbiased. They do not have anything in this market, and they can provide real, true advice.

Senator PETERS. Thank you.

The CHAIRMAN. Thank you, Senator Peters. And by the way, thanks for your great work on this and continued work trying to get this cleared through the Senate.

Next up is Senator Heller.

STATEMENT OF HON. DEAN HELLER, U.S. SENATOR FROM NEVADA

Senator HELLER. Mr. Chairman, thank you for this work. I want to thank our panelists for being here. Clearly, with the size of the crowd we have here today, there is a tremendous amount of interest in this technology.

I am kind of proud that Nevada has been one of the leaders in driverless technology. We were the very first state to pass autonomous vehicle legislation in 2011 that paved the way for testing. And last year, Nevada also passed a full implementation of autonomous vehicles for personal and commercial use, and we now have autonomous trucks and buses that are testing on our roads.

So in Nevada, we have nearly a half million seniors. We have about 275,000 disabled individuals. We also have 300,000 veterans. I think my father-in-law and my father fall in all three of those categories. But needless to say, for these individuals, this technology will bring them, I think, greater independence and greater mobility.

Having said all that, my experience in this, without telling you my age, everybody younger than me loves this technology. Everybody that is older, they are a little worried about this technology. So we have a lot of work to do.

But I do believe that there is a real opportunity. I know that most people on this panel have probably, at one time or another, had an opportunity to be in an autonomous vehicle. In fact, 20 years ago, I was at CES, and they had the latest and greatest piece of equipment, and that was a hydrogen vehicle that could go about 60 miles on a tank of gas at 30 miles an hour and cost $1 million. Here we are 20 years later, Tesla has Model 3, and it is $35,000 and will go 500 miles, and it will go 80 miles an hour. So it is amazing how much things have changed in the last 20 years.

In fact, last year at CES, I was in an Audi with Delphi technology and was able to drive seven miles on the freeway, get off the freeway, in an autonomous vehicle. There was somebody in the driver's seat, but their hands were off the wheel and were off the brakes and the gas pedal. It is just fascinating to see just what has happened in the last 20 years.

Mr. Kentley-Klay, you talked a little about the future. I know Senator Nelson talked about 20 years from now. It sounds like to me that the equipment and the technology that you are offering, it sounds like, 20 years from now, no one will own a vehicle.

Mr. KENTLEY-KLAY. Senator Heller, thank you for your question. I think it was in 1908 that the Model T Ford shipped. How long did it take before the coach builders were out of business? If you look back historically, it was around 2 decades.

I think with the safety case in this technology and how quickly we can advance it, well within 2 decades, I think everyone will be driving automated vehicles or using shared automated mobility, because that is what we need to do to make the roads safe.

Senator HELLER. Talking rural vehicles or rural areas, I am part of that 1 percent of those farmers you were mentioning. We had 303 vehicular deaths last year in Nevada. More than half of them happened in the rural portions of the state.

What kind of testing is being done out in the rural portions? Even though it is less than 20 percent of the population, rural America, it still has an above average vehicular death rate.

What are we going to do for—Dr. Avent talked about animals. How are we going to ensure that, in the rural portions, where these accidents do occur, that they are being tested?

Mr. KENTLEY-KLAY. I am reminded of the Arthur C. Clarke quote, "Any sufficiently advanced technology is indistinguishable from magic." This is a really new technology. To people in rural areas or in cities, it might look like magic, but to developers, this is advanced technology. And we understand what we are building and how it works.

In fact, the way our vehicles are engineered, we do not have to understand that it is a horse or a squirrel or a person to know that there is something there and we need to stop. And so we can engineer the vehicles that understand abstractly what is happening geometrically in the environment to get the requisite safety we need, and what we really need to do is take the public, everyone in America, on the journey of how this technology works so that they can understand it, to get the assurance that they need that it is safe.

Senator HELLER. Let me ask you one more question really quickly before I run out of time, and that is, why was it advantageous for you to go from Australia to the United States to do your work here as opposed to your own home country?

Mr. KENTLEY-KLAY. Thank you for the question. I think the intersection of creativity, capital, and computer science in America is unprecedented. And to create the technology that we do, we need the engineering depth of talent that is in this country that we can access to scale. We need investors that are brave enough to invest in such an advanced technology. And we need the connections that are in this country, because it is integrated, to bring the right set of peoples together, even working with you today, to make this technology a reality.

The CHAIRMAN. Thank you, Senator Heller.

Next up is Senator Hassan.

STATEMENT OF HON. MAGGIE HASSAN,
U.S. SENATOR FROM NEW HAMPSHIRE

Senator HASSAN. Thank you, Mr. Chair and Ranking Member Nelson.

Thank you to all of the witnesses for being here and for the work you are doing. This is, indeed, very exciting technology and really represents the potential for enormous innovation in all aspects of American life and global life, actually. So thank you for the work you are doing.

I wanted to drill down on a couple things. I happen to be the mom of a 29-year-old young man with very severe disabilities, so much of what you talk about is very exciting for those of us who live in a world in which we have a family member with a disability. But it is also a reminder that people who do not have disabilities often think they know what solutions are for people who experience disabilities, and they forget to talk to people who actually experience disabilities, example being, "Yes, Mrs. Hassan, the entryway is accessible for your son in a wheelchair," to find that there is a little, tiny lift without the adequate turning radius to get a particular kind of wheelchair in and out, right?

So can you all just talk to me about what interactions you are having with people who might represent the disability community to really understand and drill down on what the different populations within that community will need?

Mr. SCHNEIDER. This is an immensely important topic, and it is one in a very recent personal experience I came to understand in a much more profound way of someone with a disability and the challenges associated with getting into and out of a vehicle to do some very simple things.

The reality is that automated vehicles hold the potential for greater self-sufficiency and the ability to provide a basic level of mobility for persons with disabilities that does not exist there today. And the way we think about that is really the way we think about engineering almost any system, which is to understand that customer's journey, to try to think through the very specific moments that matter and the points of considerable duress that are undergone, and to really understand and factor into our engineering models the many differences faced by people with disabilities, because disabilities are not all the same. There is a wide, wide variety.

Our work with ADA compliance and with other regulations has given us as an industry a very deep respect for the need to provide mobility and transportation for all. And this is yet another case where it is a very exciting moment in time.

Senator HASSAN. Thank you.

Anybody else just briefly, because I do have a couple other questions?

The second question, shifting to some of the concerns I hear from consumers and constituents is, because of the technological innovations that drive AV, you all will have an awful lot of consumer data available to you. So the question is, what information will be collected on consumers who purchase AVs? What is the industry doing to protect the data from being sold and shared without the consumer's consent? And how easily can consumers access and change what data is collected and shared about them?

Anybody?

Mr. MANSUETTI. Maybe I will start. Consumer data, and especially security and privacy, is very important, so we believe that, first and foremost, we need to protect this data. We also need to have consent to use the data.

As to the extent of what data will be collected and how it will be shared and how it will be used, I think that continues to develop as these business models develop. But for us, in developing the technology, it is first and foremost how we protect this data and data security.

Senator HASSAN. Anybody else?

All right, last question, which we probably cannot handle in 48 seconds, and I will submit it in writing, but I am a former Governor, and I am sitting here listening to all the things that State and local governments are going to need to be thinking about to accommodate and help launch this technology, everything from, what kind of roads do we build, right? Where do we build them? How do we deal with the reality that there are bad actors out there who would like to try to infiltrate the systems—the software systems that run this technology? This becomes critical infrastructure. How are we going to partner and deal with that?

How are we going to deal with job training for the next generation and for the people who are today going to be displaced by this technology?

And last, there is always that question in rural America, which is, how do we get out this new technology and infrastructure to that last mile where population, or in my case, in New Hampshire, the last two-thirds of my state—it isn't the last. It is the first to

everybody who lives in my north country. But two-thirds of my state is populated by 52,000 people. And so how are we going to leverage what we need to leverage and get this technology out to the least densely populated places in our country so that everybody has the freedom and the economic advantage that this technology poses?

We will submit that in writing, and I look forward to working with you guys on that.

The CHAIRMAN. Thank you, Senator Hassan. We will make sure we get that responded to.

Senator Inhofe is up next.

STATEMENT OF HON. JIM INHOFE,
U.S. SENATOR FROM OKLAHOMA

Senator INHOFE. Thank you, Mr. Chairman.

First of all, every time you ask for a yes or no answer, you do not get a yes or no answer, so I am going to test you guys. I have two questions I am going to ask and listen very carefully.

First of all, I want to say, Mr. Kentley-Klay, you are the only one in your opening statement that used a couple of phrases that I like to use, one being "level playing field," and the other, "government without picking winners."

So here is the first question. Since we are at the auto show, I want to highlight an issue that is of concern to me and perhaps to others who are here today, which we do not talk much about, the fact that Federal policy is stacked against liquid fuels. This year's auto show is debuting the most electric vehicles ever. But electric vehicles do not even make up 1 percent of the Nation's auto sales, and auto manufacturers are producing more and more of them, of course. Why?

As Merrill Matthews, a scholar at the Institute for Policy Innovation, puts it, "carmakers are building cars and trucks the government wants their consumers to have, and that means electrical vehicles."

In 1975, Congress created a law to help with the fuel shortage situation by establishing the Corporate Average Fuel Economy, or CAFE standards. We no longer have a fuel shortage issue, but that did not stop the Obama Administration and California from ensuring standards kept increasing beyond the technology, what you can do to force their electric car fantasies on the rest of us.

But consumers want trucks and SUVs. They make up two-thirds of the vehicles sold. Yet these vehicles do not help automakers meet current DOT and EPA regulations, so they make more and more electrics to lower the overall mileage at a significant loss.

Additionally, taxpayers are on the hook for up to $7,500 per electric or hybrid vehicle sold today in the form of tax credits. When Hong Kong ended their tax credit, the sales dropped significantly, which goes to show you that people want to make their own decisions. So as electric vehicles are forced onto the U.S. consumer, the liquid fuel industry, and I am talking about oil and gas and ethanol, will be wondering why their government abandoned them in pursuit of the California dream.

The Federal Government should not be in the business of dictating to consumers what type of cars they should have or creating winners and losers.

So question number one, do you believe the Federal Government should be in the business of dictating to consumers what types of cars they should have and creating winners and losers?

Let's start with you, Mr. Klay. Yes or no?

Mr. KENTLEY-KLAY. No.

Senator INHOFE. Very good. How about you, Doctor?

Dr. AVENT. No.

Mr. MANSUETTI. So the question is of the government picking winners and losers, that was your main question? No.

Mr. SCHNEIDER. Do we have time?

Senator INHOFE. Yes, go ahead.

Mr. SCHNEIDER. On the issue of level playing fields and the government picking winners and losers, we believe the consumers should have the choice.

Senator INHOFE. Good for you. All of you, I am proud of you.

Now the last question is, the promise of automatic vehicle technology will impact all the users of our Nation's highways and transportation system.

You highlight, and this would be to you, again, starting Mr. Klay, you highlight in your testimony the strong safety benefits that come with more autonomous vehicles on the road. Do you believe that these benefits can be or should be realized by all motor vehicles, including trucks which are driving on the roads today? Yes or no?

Mr. KENTLEY-KLAY. Thank you for the question. I believe this technology will expand to all modes of technology and transportation.

Senator INHOFE. Yes or no? That is yes.

OK, go ahead, the rest of you, please.

Dr. AVENT. I do not think that it has to be done, but I think it certainly could be an advantage.

Senator INHOFE. OK, your answer, Mr. Mansuetti?

Mr. MANSUETTI. Yes, this can be helpful.

Senator INHOFE. Thank you.

Mr. Schneider?

Mr. SCHNEIDER. I agree.

Senator INHOFE. OK.

Dr. Avent, what justifies the exceptions of not having this apply to trucks, in your mind?

Dr. AVENT. I do not think there is an exception. I think that, again, it can be market-motivated. But I think that the technology certainly can help that industry tremendously.

Senator INHOFE. That is good. Good answer.

Thank you, Mr. Chairman.

The CHAIRMAN. Thank you, Senator Inhofe.

Senator Lee is up next.

STATEMENT OF HON. MIKE LEE,
U.S. SENATOR FROM UTAH

Senator LEE. Thanks very much to each of you for being here and for answering your questions. We are on the precipice of a

groundbreaking technological revolution, one that combines computing power with telecommunications abilities, sensing abilities, so as to really change the way the American people interact with their means of transportation. And it has the power, simultaneously, to make us healthier, to make us safer.

One of the things that I worry about in this circumstance is that the only thing that can stop this technological revolution from taking place and from improving the lives of 330 Americans is the government itself.

I worry, for example, about the push that some are seeming to desire, to depart from our traditional regulatory processes and to add an additional layer here, specifically for you, specifically for this technology. I shudder at the thought of what the government might have done had premarket approval been a prerequisite for starting some of the technologies that brought the Internet to life for the American people, or if premarket approval had stifled any of the number of innovations that make the lives of the American people better from day-to-day.

So Mr. Kentley-Klay, I would like to start with you and ask you a question regarding how regulations like NHTSA premarket approval might stifle innovation in this industry from your perspective?

Mr. KENTLEY-KLAY. Senator, thank you for your question. I do not know that NHTSA actually has a regulation out for premarket approval, but our view is that, with a new technology, you definitely do not want to stifle it. At the same time, we need to deploy it in a safe and risk-managed way. And the right way to do that is exactly what we are doing here today, having informed conversation so that all stakeholders understand the politics of what is being created and making the right judgment calls about how to bring it into reality.

Senator LEE. And it is not in your interests, it is not your desire to make an unsafe vehicle, correct?

Mr. KENTLEY-KLAY. Absolutely not. I mean, I would say that, today, in the states of Michigan and Florida and I think Arizona as well, you legally could drive a vehicle with no one sitting behind the wheel, but no developer is doing that because they are making the judgment themselves that the technology is not ready.

Senator LEE. Right. And if you did make that judgment call and you went for it, people would not drive that vehicle, people would not purchase that vehicle, people would not buy stock in the company, people would not invest in that company.

Mr. KENTLEY-KLAY. It would be incredibly counterproductive to spend years and billions of dollars developing the technology to release it prematurely and have people lose confidence in the technology.

Senator LEE. By the same token, you are not asking for a regulation-free environment. You are not asking for the government to stay out of this entirely and to pretend as if this were the Wild West in which there are no rules?

Mr. KENTLEY-KLAY. Absolutely not. We are asking for an informed conversation to, in a risk-managed way, deploy the technology in a way that expedites its benefits.

Senator LEE. Aren't there, in fact, some safety-related risks that could result in the wake of and precisely because of an overly aggressive Federal Government regulatory regime?

Mr. KENTLEY-KLAY. That is a potential outcome, yes.

Senator LEE. In other words, isn't there a very real risk with an emerging technology like this one that the government sets a standard, and that standard could become at once the floor and the ceiling, thus stifling innovation?

Mr. KENTLEY-KLAY. I think standards should be set based on data, and we do not quite have the data yet. So if we set standards before we fully understand what we are creating, we could stifle innovation.

Senator LEE. Just about two weeks ago, Secretary Elaine Chao, the head of the U.S. Department of Transportation, made an announcement that the Department of Transportation would be seeking public input across the transportation industry to "identify barriers to innovation and shape initiatives."

I would like to ask each of you, in the moment we have remaining, in just a few seconds, tell me what you think the biggest barriers to innovation are?

We will start with you, Dr. Avent.

Dr. AVENT. I do think the application of all existing regulatory policies is not best—because it is completely different, and it is a new frontier, and we have to be careful of taking existing policies and regulating based on those.

Senator LEE. Mr. Kentley-Klay?

Mr. KENTLEY-KLAY. I would commend Senator Thune and Senator Nelson on their opening remarks. I think you guys get it. As a new entrant into this new era of mobility, the biggest barrier to innovation would be an incumbent trying to make it difficult for us to deploy the technology when we actually know what we are doing.

Senator LEE. To drive out would-be competitors.

Mr. KENTLEY-KLAY. That is right.

Senator LEE. Mr. Mansuetti?

Mr. MANSUETTI. We must be careful not to overregulate here, and that is why we are in such strong support of the AV START bill. I think you guys are doing exactly the right thing that allows us to continue to innovate iteratively on these technologies and bring them to market as safely and quickly as we can.

Senator LEE. Well-said. I tend to agree.

Mr. Schneider?

Mr. SCHNEIDER. I think you said it in your opening comments. There is a confluence of technological changes happening, and to properly regulate this so that that does not prohibit innovation while maintaining the safety that we all require.

Senator LEE. Thank you very much. I see my time has expired.

Thank you, Mr. Chairman.

The CHAIRMAN. Thank you, Senator Lee.

Senator Capito.

STATEMENT OF HON. SHELLEY MOORE CAPITO,
U.S. SENATOR FROM WEST VIRGINIA

Senator CAPITO. Thank you, Mr. Chairman, Ranking Member. And I thank all of you. It has been a very interesting hearing.

I wanted to touch on a subject that I think Mr. Mansuetti mentioned in his opening statement, and that is the workforce issues here. I would imagine, at this point, with the innovation that is going forward, it is pretty highly technically advanced degrees, engineering and computer science types of innovationists that have gotten us to this point. But for the workforce of tomorrow to meet the challenges of the AV technology, you mentioned apprenticeships. You mentioned grants for STEM and then professional development for teachers.

I am wondering how you think this will impact the jobs of the future, because we have heard a little bit about how it is going to impact the jobs of the future in a negative way, in the development and in the training. And I also would like to just remind everybody that, in the STEM fields, women and minorities are very underrepresented, and it is important that we spur that next generation into what I think is going to be a very exciting field.

So, Mr. Mansuetti?

Mr. MANSUETTI. I think, first, when you look at the current state we are in when we are developing the technology, the technology is very exciting, and we are being able to attract a lot more of these STEM candidates into things like autonomous driving. If you look at the automotive industry, that has been kind of stigmatized as, "Do I want to go into the automotive industry?" which was once seen as perhaps dying.

So now we are seeing a lot of excitement generated and being able to attract those candidates to work on the exciting new technology.

I think, in the future, as we discussed, the jobs will be changing in mobility. So when we look at just a simple case with the auto itself, whether it is a car that we have today, an electrified vehicle, or maybe even a shared taxi, with the increased utilization, there is going to be more and different types of maintenance functions, for example.

So we will see new opportunities opening up along all these different lines of how the technology is deployed, and then in these use cases, as we go to a shared mobility.

So I think the importance is to continue to train the workforce, educate them in these new opportunities, and be ready for the new jobs of the future.

Senator CAPITO. Dr. Avent, do you have a comment on that?

Dr. AVENT. Yes, I think exactly the same thing. Certainly, the technology relevant in this is going to be around new fields, around machine intelligence, around artificial intelligence, which is computer-science-based. Certainly, there is going to be a lot of sensor developments related to this that are going to have to take place. So technology around STEM, and particularly what we called core STEM, which is the engineering, mathematical, and physical sciences, are going to be very relevant.

Senator CAPITO. The opportunities are going to be all up and down the scale here. It is not just going to be at the high end, probably where it is now on the development portion.

Dr. AVENT. On the development portion, but also, they are going to have to be maintained. They are going to have to be improved. So really all up and down the scales.

Senator CAPITO. My second question involves partners. We talked about some partnerships, but I am curious to know, it is going to change the face of the highway in terms of road signs and indicators, so that the car can pick up indicators rather than the human eye picking up indicators.

I am wondering what kind of partnerships you have with road builders and State DOTs and local transportation authorities?

Mr. Kentley-Klay?

Dr. Avent, did you have a response to that?

Dr. AVENT. In the case of Florida Polytechnic University, we have a partnership with the Florida Turnpike Enterprise, which is a part of the Florida Department of Transportation, and we are working hand-in-hand with them on exactly those types of things, and experimenting on a closed-loop test track.

Senator CAPITO. So, Mr. Kentley-Klay, you are already doing this. So what kind of coordination do you have with your local transportation authority, sign makers, all those things?

Mr. KENTLEY-KLAY. Senator, thank you for your question. This overlaps a little bit with the previous question about infrastructure and spending, and should that be deployed in the area of autonomous vehicles.

Our view is that we are developing the technology to work with infrastructure as-is. We do not require new signs, new lane markings, or anything like that for the technology to be introduced into the market and scale. We think if we had that dependency, it would cripple our ability to bring the technology into the marketplace.

There is various talk of technologies where traffic lights can talk to vehicles, or vehicles can talk to other vehicles or pedestrians. They are interesting, in theory, but the problem with those technologies is, if you are actually dependent on them, if there is a fault, then the system will fault. So we are developing our systems in a way that they are robust without dependencies on any sort of infrastructure changes.

Senator CAPITO. That is good to hear. Thank you.

Mr. Mansuetti, did you have an additional comment?

Mr. MANSUETTI. With regard to partnerships, we are doing a lot with cities around the country, especially in this area of smart city development, so we are involved a lot within their department of transportations and what they are doing on the mobility front in cities. So that has been very interesting.

The CHAIRMAN. Thank you, Senator Moore.

Senator Young.

STATEMENT OF HON. TODD YOUNG,
U.S. SENATOR FROM INDIANA

Senator YOUNG. Thank you, Chairman. This has been a very interesting hearing. There are a lot of reasons for optimism and outright excitement moving forward as these technologies develop.

I think the thing perhaps I am most excited about are the potential changes to the quality-of-life of a disabled person, of an elderly person, of someone who happens to be site-impaired. It is going to give them a new sense of independence, to be more mobile, improve their quality-of-life. You can see them integrating into the workforce more.

Mr. Kentley-Klay, you talk about this in your testimony, how there have been previous mobility ages, I think as you referred to them, and how AI is going to bring on a new mobility age.

Could you unpack this concept, this new mobility age a bit for us, please? And just try to paint a picture of how the lives of our disabled and elderly Americans might change as this technology evolves.

Mr. KENTLEY-KLAY. Certainly, Senator. Thank you for your question.

The pace of change is accelerating. The previous mobility age was, of course, the horse and carriage. It was actually around 4000 B.C. that we domesticated the horse and put the axle on the wheel, and that gave us coach building, and that was a huge change for society on that day because we could move goods at a much more expeditious rate.

That was 6,000 years ago. It looks like we are about to leave the automobile age, which we have been in for around 130 years, so it is a much, much more compressed time span, and go to the age of fully automated transportation, which is coming. There is no unobtainium that needs to be created to create this technology. We understand what we need to do, and it is now just a lot of elbow grease to make it ready for commercial operation.

So the change is happening. And we are excited, as many people have commented, that this technology will increase access. Our mission statement is connecting people and places, and that is people without qualification, and that is what we want to enhance.

Senator YOUNG. Does anyone have anything to add?

Dr. Avent?

Dr. AVENT. Thank you. I think if you look at a lot of industries, they start off as a craftsman model. Then over time, they become more efficient by becoming software-managed industries.

I think in the case of transportation, it is still a craftsman model. We teach a driver how to drive. They get behind the wheel. This is the natural progression of that industry, to move over to a much more software-managed industry. They become much more efficient. As part of that, we do not to teach people how to drive. It will improve access to a lot of people that generally do not get that.

Senator YOUNG. Mr. Mansuetti, let me turn to discussing something others have touched down, the workforce of the future. I know that Bosch at least appears to have thought pretty creatively about this, from the manufacturing professional development programs to STEM to apprenticeship programs. Continued career and technical education we know will be needed to alleviate any short-

fall in the workforce and make sure that workers have the skillset required to fill the jobs of the future in this space.

Could you discuss what role you see moving forward for government, particularly the Federal Government, but maybe government generally, in making sure that companies like yours will have access to the skilled workforce that they need?

Mr. MANSUETTI. I think that is going to be very important in the future. As we look today, there is a shortage of skilled workers, so we need to continue to expose and be able to train and qualify the workforce of the future. I think that requires a partnership between State and local and Federal officials, as well as industry.

We kind of need to look at the K-through-graduate education model and getting those things to work together. Many times, we see that there are disconnects when you go through certain education systems. So we are trying to partner not only with universities but also, for example, where we are working, where we are heavily involved in manufacturing, for example, in the Southeast, working together with states, with the State universities, the technical colleges, the universities, to ensure that the right training is being applied and that we are training people at the right time in the right skills that we need.

So we have a very good partnership, and we need to continue that.

Senator YOUNG. And from a policymaker's standpoint, I see one of the challenges being trying to work with you to determine what skills are generalized that are needed across the economy, which skills are specifically needed for this emerging sector, if you will, of the economy, and then which skills are firm-specific and ought to be invested in by companies like Bosch, for example.

I guess the last thing I would add, Mr. Chairman, I just want to commend those who are responsible for drafting this legislation, for working with all the stakeholders. I understand principled compromises are required to end up where we are today, and I have high confidence this is going to become law, and I will be supportive.

I still do lament, and I want to be on public record of lamenting the fact that we have limited this to passenger vehicles and not incorporated trucks into this legislation. I think we could save a lot of lives and improve a lot of lives if we were to broaden the scope of it.

But with that said, I will end on an optimistic note and thank you once again for being here.

Thanks for holding this hearing, Mr. Chairman.

The CHAIRMAN. Thank you, Senator Young. And that view you articulated on trucks is one that I share, and I hope that, at some point, we can get that aspect of this important debate addressed.

Senator Blumenthal.

STATEMENT OF HON. RICHARD BLUMENTHAL, U.S. SENATOR FROM CONNECTICUT

Senator BLUMENTHAL. Thanks, Mr. Chairman.

I want to begin on an optimistic note and thank this excellent panel for giving us a view of the future with this exciting, won-

drous technology that will give us a brave new world in automobiles and perhaps beyond automobiles in transit in general.

And I want to avoid appearing to be an automotive Neanderthal or Luddite, but simply express a couple of reservations about potential irrational exuberance when safety is at stake.

I want to avoid creating another generation of cars that may be unsafe at any speed, and we know from our experience that the simplest of devices in automobiles right now—ignition switches that malfunction, or safety bags that are killers, as a number of my colleagues know—can potentially pose great dangers.

Right now, collision-avoidance technologies, such as automatic emergency braking, have been proven. They are available. They offer substantial safety benefits. And they have been recommended by the Federal Government, by safety authorities, by consumer advocates.

And in fact, Mr. Mansuetti, 73 percent of Audis sold last year had AEB systems, so Audi is doing way better than many of your colleagues, because they sell only about 19 percent, according to 2017 model statistics. I assume you would agree that making collision avoidance systems standard should be a top priority for 2019?

Mr. MANSUETTI. Yes, from a Bosch perspective, we certainly agree. But speaking to Audi, I do not want to talk for you.

Senator BLUMENTHAL. I am sorry. Mr. Schneider?

Mr. SCHNEIDER. Absolutely. Look, our record on implementing safety-related automotive devices, like automatic emergency braking, I think is pretty well-documented, and we do support the further infusion of that technology into our fleet.

Senator BLUMENTHAL. So that something as simple as AV technology, and I know, Mr. Mansuetti, you produce it, so you would agree, can help save lives.

GM has said it is going to be manufacturing autonomous vehicles without steering wheels or peddles by 2019, but Nissan's R&D Chief has said, "We will always need a human in the loop."

At CES earlier this month, as you know, Mr. Kentley-Klay, Phantom Auto demonstrated how a car in Los Angeles can be remotely controlled by a human operator in Mountain View, California. I understand that your company has a patent on this kind of teleoperation technology, so my question to you is, what kind of fallback system would you envision perhaps making use of this technology or a similar technology in the vehicles that will be under your control?

Mr. KENTLEY-KLAY. Thank you, Senator. That is a great question.

I think the headline is that this technology fully realized is going to be incredibly safe to the point we are going to look back to the age of the automobile and say, wow, we were super-reckless, allowing that carnage on our roads. And I think you are going to have society having that judgment call within 5 to 10 years.

How do we achieve that endpoint? Not to get too deeply into the technical details, but our vehicles are engineered with three computers. There is a main AI computer. There is a backup computer behind that, and a backup computer behind that, and they are on different power buses.

So if there is a hardware fault or a software fault, our vehicle has special hardware that is designed to stop itself in its lane. It will not go out of its lane and go into what we call a minimal risk condition.

This is taking techniques used in aerospace. They are proved to be very space safe. In fact, I do not think there has been a fatality in aviation in America in the past 8 years, and these airplanes are all flown by triplex fly by-wire computer systems.

So again, I think it is partly a public education campaign, but we are very confident that we can engineer these vehicles to be robust and safe.

Senator BLUMENTHAL. So you would view teleoperation as having a role in the future of your vehicles?

Mr. KENTLEY-KLAY. Yes. I think when your model is to have autonomous vehicles deployed as a for-hire service in cities, you are still going to need a command center in that city that has human-in-the-loop oversight of the fleet, both to deal with vehicles if they have an issue but also to deal with customers if they need help as well, and that is part of our model.

Senator BLUMENTHAL. Thank you.

My time has expired. I have more questions, but maybe we will have a second round.

The CHAIRMAN. Thank you, Senator Blumenthal.

Yes, if you want to ask another question, go ahead. We have a little bit of time, if these guys do not mind, and if anybody else has any final questions on the panel, too, we can use this as wrap-up.

Senator BLUMENTHAL. Thanks, Mr. Chairman.

Dr. Avent, on this issue of teleoperation, what role do you think that teleoperations should have in anticipating or dealing with unexpected or unpredictable events. In your testimony, you talk about the importance of testing autonomous vehicles against the rare, unpredictable six sigma events to make sure that they are safe for humans. Do you envision teleoperation as having a role?

Dr. AVENT. By teleoperation, do you mean remote control——

Senator BLUMENTHAL. Exactly.

Dr. AVENT.—where you have a user somewhere else, not in the vehicle?

I think that may be a wrong path to go. It could be an interim, but I think that it is more appropriate to go from having a driver in the vehicle over to fully autonomous.

I think the military certainly has experimented and done a lot in teleoperation with UAVs and drones and all, and they work, and they are safe. But I think that it does not meet the full benefit of going to autonomous vehicles.

Senator BLUMENTHAL. And let me ask all of you, having taken GM's statement that we will have AVs on the road by 2019, how soon, in your view, will be have Level 5, safe, autonomous vehicles? Maybe you can just go down the line and get a prediction, in terms of years from now.

Dr. AVENT. I think there is a common thing that says technology is overrated in the near term and underrated in the long term. I think that it is going to be longer than probably many technologists believe. I think a big part of that is going to be the adoption of it

and the trust, more so than the technology itself. But I would say 10 years, if I was a betting person.

Senator BLUMENTHAL. Ten years.

Mr. Kentley-Klay?

Mr. KENTLEY-KLAY. I think there is a shallow ramp for this technology into early adoption and then mass adoption. I think around 2020, you will see fully automated vehicles that are on-demand working in confined geo-fenced areas in certain locations. As the technologies improve, that is going to expand.

Senator BLUMENTHAL. But that is a more confined area ——

Mr. KENTLEY-KLAY. That is right.

Senator BLUMENTHAL.—in 3 years and then being consistent with——

Mr. KENTLEY-KLAY. Two to 3 years.

Senator BLUMENTHAL. Mr. Mansuetti?

Mr. MANSUETTI. At Bosch, we agree with that, with Mr. Kentley-Klay. We see by the end of the decade, 2020, we will see these use cases emerge in limited areas. In the next decade, increasingly more rollout of the technology. And by the end of the next decade, I think you will start to see fully autonomous Level 5 vehicles in all cases.

Mr. SCHNEIDER. I think, in general, we would agree with that timeframe. But again, just to reiterate, this is going to be an evolution, and the full benefits of autonomous vehicles really come from not just a single-use case or even a handful of use cases. It comes from a preponderance of those use cases.

So over the next decade, we are going to see these enter the full one by one, but certainly, in the near term, we will have some pretty serious progress.

Senator BLUMENTHAL. I just want to close with a final question, recognizing the reservations that have been expressed about the overinvolvement of government and premarket approval, as one of my colleagues said. Nobody is for overregulation or overinvolvement by government, but sometimes standards are necessary, and enforcement of these standards are critically important to saving lives.

And, Mr. Kentley-Klay, you say in your testimony, I think you would all agree, that standards should be data-based. They should be driven by real facts from the real world.

So my question I think, finally, to the panel is, how do we make sure that the government is receiving the kind of data it needs to make smart decisions about how to protect consumers? Anybody who wants to volunteer is welcome.

Mr. MANSUETTI. I mean, we see the technology with automated vehicles, no one can do it alone, so it takes a coalition, a collaboration, and a partnership, and that includes the government. So we will continue to collaborate openly.

And where you need information, we are very helpful to provide that, so that we make good, sound decisions, we do not overregulate, and we provide this framework that allows us to move forward in the future to bring this technology to life, which everyone wants as quickly and as safely as possible.

Senator BLUMENTHAL. Mr. Avent?

Dr. AVENT. I agree with that. There is not going to be one industry or one type of person who is going to solve this problem. It is going to take a collection of lots of people. So I think consortiums, everyone working together in developing the technologies and testing them is very important.

Senator BLUMENTHAL. And you would all agree, I assume, that government does have a role to play in protecting safety?

And in fact, in developing this technology, the reference was made earlier to the Internet. In fact, the Internet was the result of a partnership, a continuing partnership over many decades of private industry, academia, and the government, principally the military, as is demonstrated very dramatically and powerfully by a book called "The Innovators" written by Walter Isaacson.

Anybody who has any question about that partnership should read the book, and I think it provides a useful template, perhaps for this new technology.

Thank you, Mr. Chairman.

The CHAIRMAN. Thank you, Senator Blumenthal. We have in our bill safety-reporting requirements that address a lot of those concerns that you have voiced today. And I am hoping the panel has been influential in getting you to vote for the bill eventually when the time comes.

I think Senator Peters has a question.

Senator PETERS. Thank you, Mr. Chairman. And you are right. We have thought long and hard about making sure that safety is first and foremost in this legislation, making sure that we are trying to find that middle ground to allow innovation to flourish but also being careful about making sure these vehicles meet standards before they get out onto the road. The proving grounds, as you talked about as well, which we need to have more government involvement as well to make sure you have the resources to fully test these vehicles.

We will collect those data as time goes on. And there will be a lot of data collected, and it will get better and better.

We have to get to the point, Mr. Kentley-Klay, where you said that we deal with roughly 40,000 deaths on the highway and hundreds of thousands of debilitating injuries. We are on the verge of making major progress to eliminate nearly all of those when you take out the human factor—the human error factor. So that is a major motivator for me, and I think most of the folks on the Committee, to get to that point.

The question that I had—and you can comment on that if you like, as you are pushing the button. Before you do that, though, a question that came up a little bit dealt with the power plant. We talked about a lot of factors related to this technology, but one thing that I have heard, and I want the panel to comment on, does this mean we are moving to electric power plants?

My understanding is that this technology works best with an electric power plant as opposed to an internal combustion engine. Are we seeing a change in the as well?

Mr. Schneider, you may be first, given the work that you are doing with your company, and any others who would jump in.

And if that is the case, we have had a number of questions related to infrastructure, et cetera. That will lead to a lot of other

issues as to how we make sure we have the infrastructure to support those electric vehicles that are on the road.

Sir?

Mr. SCHNEIDER. Certainly, that is an outstanding question, and one of those things at Audi that we think of as one of three major technological changes that are driving the industry. In addition to mobility and autonomous vehicles is electrification.

So yes, indeed, power plants are moving to the electric variety, whether those are battery-operated or use other technologies to do that is I think an industry question in the longer term. However, the infrastructure of a vehicle is moving to an electrical one as a whole.

And as a guy who started his career as a powertrain engineer designing engines at Ford, I tell you that it has moved and accelerated even just over the past decade, so I would expect it to continue.

Mr. MANSUETTI. For us, we see the future of mobility as automated, connected, and electrified. So electrification will play a large role in the future of autonomous vehicles.

And to your specific question, yes, some of the things are much more easily realized in electrical vehicle architecture for this new technology.

Mr. KENTLEY-KLAY. Getting around cities on roads kind of sucks today. This technology is going to make it awesome, so we should all work together and just make it happen. Zoox is pure electric.

On top of the 40,000 fatalities in America alone in 2016, and millions actually going to hospital, there is a study from MIT that came out that said around 50,000 people in the U.S. died up to a decade early because of pollution from mobility. The United Nations also forecasted in 2050, 75 percent of the world population is going to live in mega-city-like environments. So to get longevity of life, we really want to have zero-emission mobility in our most dense urban environments.

Dr. AVENT. I will defer to the panelists, because they are actually developing a lot of this technology. But as an academic, I do not think that the coupling of the technology is neither a necessary nor a sufficient condition. I think you can do autonomy on internal combustion engines. But I do think electrification is an incredible opportunity that we should take advantage of.

The CHAIRMAN. Senator Peters, thank you.

Senator Nelson.

Senator NELSON. Mr. Chairman, for the record, I would like to insert a statement of Advocates for Highway and Auto Safety as part of our record.

The CHAIRMAN. Without objection.

[The information referred to follows:]

PREPARED STATEMENT OF CATHERINE CHASE, PRESIDENT,
ADVOCATES FOR HIGHWAY AND AUTO SAFETY

Introduction

Advocates for Highway and Auto Safety (Advocates) is a coalition of public health, safety, and consumer organizations, insurers and insurance agents that promotes highway and auto safety through the adoption of Federal and state laws, policies and regulations. Advocates is unique both in its board composition and its mission

of advancing safer vehicles, safer drivers and safer roads. We respectfully request that this statement be included in the hearing record.

Motor Vehicle Deaths are Climbing

According to the Federal Government, each year motor vehicle crashes kill tens of thousands of people and injure millions more at a cost to society of over $800 billion.[i] Unfortunately, deaths resulting from motor vehicle crashes have been on the rise. According to the latest statistics from the National Highway Traffic Safety Administration (NHTSA), 37,461 people were killed on our Nation's roads in 2016. This is an increase of over five percent from 2015.[ii] This follows a seven percent increase from 2014 to 2015.[iii] Preliminary figures for the first six months of 2017 show no significant change.[iv]

Advocates firmly believes that automated vehicle (AV) technology has the potential to make significant and lasting reductions in this mortality and morbidity toll. However, the process created in the AV START Act will allow untested and unproven AVs to be sold to the public without appropriate independent or governmental oversight to provide necessary protections to both those in the AVs and those sharing the roads with them.[v] In addition, the AV START Act will potentially allow the sale of hundreds of thousands of AVs that are exempt from existing federal motor vehicle safety standards (FMVSS). In fact, longstanding Federal law was recently amended to allow for an unlimited number of vehicles that are not in compliance with FMVSS to be tested on public roads,[vi] despite opposition from consumer, public health and safety organizations.[vii] This was a massive increase from the previous limit of 2,500 vehicles for most manufacturers.[viii] Therefore, AVs can already be sold to the public as long as they are in compliance with FMVSS, and AV manufacturers can already put an unlimited number of AVs that are not required to comply with FMVSS on public roads for testing purposes. The AV START Act "takes a wrong turn" by allowing for the sale of potentially millions of AVs to the public without minimum safety standards, without necessary consumer information so that the public understands their capabilities and limitations, and without cybersecurity standards to protect against hackers.

Instead of creating an unchecked, wide-open path for the entry of AVs exempt from safety standards into the marketplace, academic facilities and testing grounds should be utilized as the proper venues for evaluating AV technology. Research centers, such as those already established in Michigan and Florida, among others, should serve as the incubators for this unchartered technology. In fact, a number of automakers themselves readily admit that AV technology is still in its infancy. As Bryan Salesky, the Chief Executive Officer of Argo AI, a company partnering with Ford on the development of AV technology recently noted:

> *We're still very much in the early days of making self-driving cars a reality. Those who think fully self-driving vehicles will be ubiquitous on city streets months from now or even in a few years are not well connected to the state of the art or committed to the safe deployment of the technology. For those of us who have been working on the technology for a long time, we're going to tell you the issue is still really hard, as the systems are as complex as ever.*[ix]

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[i] The Economic and Societal Impact of Motor Vehicle Crashes, 2010 (Revised), HS 812 013, U.S. DOT, NHTSA (May 2015 (Revised)), available at *http://www-nrd.nhtsa.dot.gov/Pubs/812013.pdf.* (NHTSA Cost of Motor Vehicle Crashes Report).

[ii] Traffic Safety Facts Research Note, 2016 Fatal Motor Vehicle Crashes: Overview, NHTSA, Oct. 2017, DOT HS 812 456.

[iii] National Center for Statistics and Analysis, 2015 motor vehicle crashes: Overview, Report No. DOT HS 812 318, National Highway Traffic Safety Administration (Aug. 2016).

[iv] National Safety Council, NSC Motor Vehicle Fatality Estimates (June 2017).

[v] S. 1885, American Vision for Safer Transportation through Advancement of Revolutionary Technologies Act, 115th Congress, 1st Session (2017).

[vi] Fixing America's Surface Transportation Act, Sec. 24404, Pub. L. 114–94 (2015).

[vii] Examining Ways to Improve Vehicle and Roadway Safety: Hearing Before Energy and Commerce Committee, Subcommittee on Commerce, Manufacturing and Trade, 114th Cong. (Oct. 21, 2015) (Statement of Joan Claybrook).

[viii] 49 U.S.C. § 30113.

[ix] Bryan Salesky, *A Decade after DARPA: Our View on the State of the Art in Self-Driving Cars* (Oct. 16, 2017), available at: *https://medium.com/self-driven/a-decade-after-darpa-our-view-on-the-state-of-the-art-in-self-driving-cars-3e8698e6afe8.*

Additionally, Gill Pratt, chief executive officer of Toyota Research Institute, stated, *"It's a mistake to say that the finish line is coming up very soon. Things are changing rapidly, but this will be a long journey."*[x]

Whether it is children's toys, new medication or innovative vehicle technologies, radically different products should first be assessed in a controlled environment instead of allowing widespread public distribution in order to determine whether they are safe or have unintended consequences. The AV START Act, which could govern AVs for years to come, fails to include several critical and commonsense protections that will help to ensure the safe development and deployment of this technology.

Advocates Has Consistently Promoted Advanced Technologies in Vehicles to Save Lives and Prevent Injuries

Advocates has always enthusiastically championed vehicle safety technology and for good reason. It is one of the most effective strategies for preventing deaths and injuries. NHTSA has estimated that since 1960, over 600,000 lives have been saved by motor vehicle safety technologies.[xi] In 1991, Advocates led the coalition that supported bipartisan legislation sponsored by former Senators John Danforth (R–MO) and Richard Bryan (D–NV) that included airbag technology in the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991.[xii] As a result, by 1997, every new car sold in the United States was equipped with a front seat airbag and the lives saved have been significant. In fact, airbags save over 2,000 lives annually,[xiii] and have saved an estimated 44,869 lives since 1987, according to NHTSA.[xiv]

Advocates continued to build on this success by supporting additional lifesaving technologies as standard equipment in all vehicles in other legislation and regulatory proposals. These efforts include: tire pressure monitoring systems;[xv] rear outboard 3-point seat belts;[xvi] electronic stability control;[xvii] rear seat belt reminder systems;[xviii] rear view cameras;[xix] brake transmission interlocks;[xx] seat belts on motorcoaches;[xxi] electronic logging devices;[xxii] and, crash avoidance systems such as automatic emergency braking.[xxiii] These safety advances have saved hundreds of thousands of lives and many have been accomplished because of the bipartisan leadership of the Members of the Senate Commerce, Science, and Transportation Committee.

NHTSA Has a Statutory Duty to the Public to Ensure the Safety of Autonomous Vehicles

Over fifty years ago, Congress passed the National Traffic and Motor Vehicle Safety Act of 1966 because of concerns about the death and injury toll on our highways.[xxiv] The law required the Federal Government to establish minimum vehicle safety performance (not design) standards to protect the public against "unreasonable risk of accidents occurring as a result of the design, construction or performance of motor vehicles."[xxv] While motor vehicles have changed dramatically since

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[x] David Welch and Gabrielle Coppola, Don't Worry, Petrolheads. Driverless Cars Are Still Years Away, Bloomberg News (Jan, 9, 2018), available at: *https://www.bloomberg.com/news/articles/2018–01–09/toyota-to-hyundai-say-pump-brakes-on-hopes-of-robo-car-s-arrival.*

[xi] Lives Saved by Vehicle Safety Technologies and Associated Federal Motor Vehicle Safety Standards, 1960 to 2012, DOT HS 812 069 (NHTSA, 2015); See also, NHTSA AV Policy, Executive Summary, p. 5 endnote 1.

[xii] Pub. L. 102–240 (Dec. 18, 1991).

[xiii] National Center for Statistics and Analysis, Lives Saved in 2015 by Restraint Use and Minimum-Drinking-Age Laws, National Highway Traffic Safety Administration, Report No. DOT HS 812 319 (Aug. 2016).

[xiv] Traffic Safety Facts 2015, Lives Saved by Restraint Use, and Additional Lives that Would Have been Saved at 100 Percent Seat Belt and Motorcycle Helmet Use, 1975–2015, DOT HS 812 384, NHTSA (2017).

[xv] Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act, Pub. L. 106–414 (Nov. 1, 2000).

[xvi] Anton's Law, Pub. L. 107–318 (Dec. 4, 2002).

[xvii] Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA–LU), Pub. L. 109–59 (Aug. 10, 2005).

[xviii] *Id.*

[xix] Cameron Gulbransen Kids Transportation Safety Act of 2007, Pub. L. 110–189 (Feb. 28, 2008).

[xx] *Id.*

[xxi] Moving Ahead for Progress in the 21st Century (MAP–21) Act, Pub. L. 112–141 (Jan. 3, 2012).

[xxii] *Id.*

[xxiii] 80 FR 62487 (Oct. 16, 2015).

[xxiv] Pub. L. 89–563 (Sept. 9, 1966).

[xxv] Title 49, U.S.C. Sec. 30102.

that time and will continue to do so in the future, the underlying premise of this prescient law and NHTSA's safety mission have not.

Unfortunately, recently NHTSA has chosen to issue only "voluntary guidelines" for the development of AVs.[xxvi] Voluntary guidelines are not enforceable because they are not legally binding, and, therefore, are inadequate to ensure safety and protect the public. Manufacturers may unilaterally choose to deviate from the guidelines or ignore them entirely at any time and for any reason including internal corporate priorities such as cost or marketing considerations. In addition, some entities may choose to follow the guidelines while others may not, creating a dangerous and unreliable patchwork of safety protection. Consumers and NHTSA also have no legal recourse against a manufacturer's failure to follow the guidelines. NHTSA cannot bring an enforcement action, force a statutory recall, or even influence a voluntary recall for failure to abide by the guidelines.

Opinion polls already show strong public skepticism and reticence about AVs and those doubts are warranted. Over the last few years, automakers have hidden from the American public and regulators safety defects that have led to numerous unacceptable and unnecessary deaths and injuries as well as the recall of tens of millions of vehicles.[xxvii] Consumer acceptance of AV technology is critical to its success and to fully realizing the lifesaving potential of AVs. Advocates recently commissioned a CARAVAN public opinion poll that revealed intense apprehension regarding the widespread deployment of AVs. In fact, two-thirds of respondents (64 percent) expressed concern about sharing the roads with driverless cars.[xxviii] Moreover, a recent study conducted by the Massachusetts Institute of Technology garnered similar results. Only 13 percent of those polled reported that they would be comfortable with vehicle "features that completely relieve the driver of all control for the entire drive."[xxix] In addition, 59 percent of respondents reported that the maximum level of automation that they would be comfortable with were "features that actively help the driver, while the driver remains in control."[xxx] Similarly, in a national survey commissioned by Kelley Blue, 80 percent of those polled believed that people should always have the option to drive themselves, and nearly one in three respondents said they would never buy a Level 5 (entirely automatic) vehicle.[xxxi] Furthermore, a poll by the Pew Research Center found a majority of U.S. adults would not want to ride in a driverless car (56 percent).[xxxii] The reluctance and hesitation of the public to embrace AVs will not be overcome unless the development of the technology is transparent and AV failures are not widespread.

As with any segment of American society, people with disabilities have varying needs. While AVs may be part of the answer to increasing mobility for people with disabilities, it is certainly not the only solution, and it is by no means "one size fits all." AVs will help some people but provide little or no assistance to others based on their circumstances. The cost of a vehicle retrofit or utilizing a taxi or ride-sharing company on a regular basis remains out of reach for many people with disabilities. Installing an automated system in a vehicle or removing the driver from an automated ride sharing service does not necessarily reduce or eliminate cost barriers that inhibit mobility. Moreover, there is no guarantee that the current designs of automobiles that do not easily allow for a ramp or lift system to be integrated into the body of the vehicle, or for a wheelchair to be stored safely in the trunk or passenger area, will be changed once AVs are introduced. The AV START Act allows for potentially catastrophic scenarios in which hundreds of thousands of cars could be allowed to operate that do not meet Federal safety standards, including those that provide occupant protection. Allowing AVs that do not meet critical Federal safety standards puts all roadway users at risk, but poses particular problems for people with disabilities who may be especially vulnerable when AVs are involved in a crash, do not function as intended, or have a defect.

[xxvi] NHTSA, Automated Driving Systems 2.0: A Vision for Safety (Sep. 12, 2017).

[xxvii] United States Department of Transportation, NHTSA, Docket No. NHTSA–2015–0055, Coordinated Remedy Program Proceeding; NHTSA, safercar.gov, Vehicle Owners, Consumer Alert: GM Ignition Switch Recall Information; *U.S. v. Volkswagen,* Case. No. 16–CR–20394 (E.D. Mich.).

[xxviii] Advocates for Highway and Auto Safety, *CARAVAN Public Opinion Poll: Driverless Cars* (Jan. 12, 2018).

[xxix] H. Abraham, B. Reimer, B. Seppelt, C. Fitzgerald, B. Mehler & J. Coughlin, *Consumer Interest in Automation: Preliminary Observations Exploring a Year's Change,* Massachusetts Institute of Technology, AgeLab, White Paper (2017–2), p. 6 (May 2017).

[xxx] *Id.*

[xxxi] Kelley Blue Book, Future Autonomous Vehicle Driver Study (Sept. 2016).

[xxxii] Pew Research Center, Automation in Everyday Life (Oct. 2017).

Federal Oversight is Essential if Autonomous Vehicles Are to Ensure Public Safety

The AV START Act unnecessarily eviscerates the current Federal regulatory scheme that has been in place for decades to ensure the safety of motor vehicles traveling on American roads. AV technology can be expeditiously developed while not jeopardizing public safety. In order to achieve that end, several provisions of the AV START Act should be revised or deleted.

Section 6 of the AV START Act will allow millions of vehicles to be sold to the public that are exempt from existing critical safety standards, the FMVSS. Providing broad statutory exemptions from the FMVSS for AVs is both unnecessary and unwise. As mentioned above, there is already a statutory process in place for manufacturers to seek an exemption from the FMVSS which Congress amended only three years ago. Section 24404 of the Fixing America's Surface Transportation (FAST) Act[xxxiii] permits auto manufacturers to test or evaluate an unlimited number of vehicles exempt from one or more of the FMVSS. Exempt vehicles under this provision may not be sold or resold to the public. Furthermore, the exemption provision in current law, 49 USC Section 30113(a), provides that manufacturers may receive an exemption from compliance with the FMVSS for the sale of 2,500 vehicles to be sold in the United States in any 12-month period. There has simply been no demonstrable evidence presented that the development and deployment of AVs requires that an untold number of AVs should be exempt from such critical Federal safety standards that are essential to protecting public safety.

Furthermore, the legislation currently contains no prohibition on AVs receiving an exemption from crashworthiness or occupant protection standards which protect the vehicle's passengers. Such exemptions can diminish the level of occupant protection that has been established through years of research under the existing regulations. For example, removing the steering wheel should not eliminate the requirement to protect the occupant from injury using safety systems such as airbags. Prohibiting such exemptions will in no way inhibit the development of AV technology but will ensure that passengers of AVs are properly protected in a crash.

Advocates supports the provision in Section 6 of the AV START Act that requires NHTSA to evaluate the safety performance of the AVs which have been granted an exemption(s) before an additional or greater number of vehicles may be granted a subsequent set of exemptions. However, the time period before the total number of vehicles that are exempt from the FMVSS should be lengthened from 12 months to 24 months, at a minimum. This will allow for NHTSA to gather the data it needs to make an accurate assessment of the AVs that have already been granted exemptions.

Finally, Section 7 of the AV START Act drastically alters current Federal law which prohibits manufacturers from rendering safety systems, such as the brakes and brake pedal, inoperable. This provision is a dangerous change in settled law because it would allow automakers to turn off safety systems while the AV is being driven by the computer. This could unnecessarily dilute safety at the discretion of the manufacturer and sets a precedent of Congress allowing manufacturers to circumvent many of the existing safety standards. Currently, automakers cannot turn off safety systems without government oversight. As such, Section 7 should be removed entirely.

Recommendations:

- *Reduce the number of AVs that will be permitted to be exempt from critical Federal safety standards. Increase the time period after granting an exemption from 12 to a minimum of 24 months so that NHTSA has an opportunity to collect enough data to make accurate safety assessments before permitting more exempt AVs to be sold.*
- *Prohibit any and all exemptions from Federal safety standards that will diminish the level of occupant protection currently provided by the FMVSS.*
- *Eliminate the provision that permits manufacturers to unilaterally disable critical safety systems while the vehicle is operating in autonomous mode.*

The Development of Autonomous Vehicles Must Be Transparent or Public Confidence in the Technology Will Suffer

The development and deployment of AVs as well as NHTSA's role in regulating this technology must be open and transparent. Section 9 of the AV START Act requires manufacturers of AVs and AV technology to submit to NHTSA a Safety Evaluation Report (SER) that details the development of the technology and its expected

[xxxiii] Pub. L. 112–141 (Dec. 4, 2015), codified at 49 USC § 30112(b)(10).

performance in real world conditions. While Advocates support that this submission be mandatory, this provision only directs manufacturers to "describe" their AV systems. This language should be revised to require that sufficient information and data are included in the SER to ensure that NHTSA can properly assess the safety performance of the technology. In the absence of such a legislative directive, manufacturers will continue to submit slick marketing brochures such as those recently released by two manufacturers[xxxiv] instead of providing data and documentation that will allow the public and NHTSA to accurately evaluate the safety of the technology. Advocates supports two important provisions in Section 9 of the AV START Act which require the SERs to be promptly made available to the public and which subject manufacturers who knowingly and willfully submit false information in the SER to the civil penalty provisions of 49 U.S.C. § 30165.

The AV START Act should ensure that consumers are given essential information about an AV. While the requirement in Section 12 of the bill calls for a rulemaking on consumer information, it could be years before a final rule is issued. Every manufacturer should be required to provide each consumer with information about the capabilities, limitations and exemptions from safety standards for all vehicles sold in the U.S. at the time of sale. This information should be made available to consumers from day one, even before NHTSA issues a rule. Therefore, the agency should be required to issue an Interim Final Rule immediately requiring such information be provided to consumers. Additionally, it would be useful for consumers and researchers to be able to automatically identify AVs by vehicle identification number (VIN).

NHTSA should also be required to establish a publicly-available AV database with basic safety information for consumers and for use in safety research. The database would be similar to the safercar.gov website that NHTSA maintains to inform the public about safety recalls applicable to their vehicle. The AV database would enable consumers to enter their VIN to obtain critical information about their AV such as the level of automation, any exemptions granted by NHTSA from the FMVSS, and the operational design domain which includes limitations and capabilities of each autonomous driving system with which a vehicle is equipped. Such a database will be critical for consumers who purchase AVs, especially used vehicles that are not required to have a consumer sticker (Monroney label) on the window and may be missing an owner's manual. According to Edmonds, there were 38.5 million used cars sold in 2016.[xxxv] The database would also allow NHTSA and other research groups to perform independent evaluation of the comparative safety performance of AV systems, and identify poorly performing and unsafe autonomous driving systems, as well as those that provide greater safety performance.

Additionally, data sharing among manufacturers is essential to improve overall safety among AVs. Data and information about known flaws or problems encountered during development and while in use must be shared among manufacturers and with NHTSA and the public to ensure that all AV systems are learning about problems in real time and can benefit from the experience of other AV systems. This type of collaborative development is already taking place in the industry with the creation of the Automotive Information Sharing and Analysis Center (ISAC). Data sharing will expedite solutions to unusual or unique safety problems and ensure they are readily identified and corrected. Yet, the AV START Act does not require that the critical safety data generated by AVs will be shared or even provided to NHTSA. It is essential that the legislation require all crashes involving AVs be reported immediately to NHTSA by manufacturers. The Early Warning Reporting of crashes requires manufacturers to submit a very small portion of this information, but all crashes involving AVs should be fully reported.

Section 10 of the AV START Act establishes a technical advisory committee that will make recommendations to the Secretary of the U.S. Department of Transportation (Secretary) on the safety standards that should be issued for AVs. Advisory committees, which may be useful in limited circumstances, are unacceptable substitutes for the agency fulfilling its statutory mission and issuing safety standards through public rulemakings. These committees often escape public scrutiny especially when the advisory committee is not subject to the Federal Advisory Committee Act (FACA),[xxxvi] as is the case with the advisory committee established under the AV START Act. In addition, the representation on these committees is often not fairly balanced and as such the committees are incapable of providing accurate and unbiased recommendations to the Secretary. Moreover, these committees are often

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[xxxiv] Waymo, *Waymo Safety Report: On the Road to Fully Self-Driving* (Oct. 2017); General Motors, *2018 Self-Driving Safety Report* (Jan. 2018).

[xxxv] Edmunds, *Used Vehicle Market Report,* Executive Summary (Feb. 2017).

[xxxvi] Pub.L. 92–463 (1972).

a significant drain on agency staff time and already sparse funding. Instead of establishing an advisory committee, the AV START Act should authorize NHTSA to receive the funding it so badly needs to hire the experts it must have to properly regulate AVs and fulfill the agency's statutory mission.

Recommendations:

- *Ensure that manufacturers are required to include sufficient data and documentation in the SER to ensure that NHTSA has enough information to accurately assess the technology.*
- *Provide consumers with critical information about the capabilities and limitations of AVs. Direct NHTSA to immediately require information at the point of sale and in the vehicle's owner manual.*
- *Direct NHTSA to establish a publicly-available AV database with basic safety information for consumers and for use in safety research.*
- *Require manufacturers to report all crashes involving an AV to NHTSA.*

Commonsense Safeguards Must be in Place to Ensure the Safety of Autonomous Vehicles

Without essential changes and additions to AV START Act, this legislation will needlessly put all road users at risk. The additional improvements outlined below will in no way inhibit or even slow the development and deployment of AVs. Rather, these commonsense recommendations will ensure public safety and industry accountability.

Include Level 2 AVs

The AV START Act does not include Society of Automotive Engineers (SAE) Level 2 AVs, like the Tesla Model S which was involved in the 2016 fatal crash in Florida.[xxxvii] During a September 12, 2017, hearing on the crash conducted by the National Transportation Safety Board (NTSB), deadly failures of Tesla's Level 2 Autopilot system were readily identified.[xxxviii] NTSB found that similar problems also exist in other Level 2 AVs across many manufacturers.[xxxix] In the near term, Level 2 AVs will likely comprise the majority of the passenger vehicle AV fleet. Proper safeguards to curb Tesla-like failures must be put in place. At a minimum, Level 2 AVs should be covered by the SER safety assessment reporting, consumer information disclosure and cybersecurity provisions in the AV START Act.

Require Cybersecurity Standards

A failure to adequately secure AV systems and to protect against cyber-attacks could endanger AV passengers, non-AV motorists, pedestrians, bicyclists and other vulnerable roadway users. It could also clog roads, stop the movement of goods and hinder the responses of emergency vehicles. Problem areas could include subjects such as global position system (GPS) signal loss or degradation, spoofing, and offline and real time hacking of single vehicles or fleets of vehicles. The real possibility of a malevolent computer hack impacting hundreds or thousands of AVs, perhaps whole model runs, makes strong cybersecurity protections a crucial element of AV design. Yet, Section 14 of the AV START Act merely requires manufacturers to have a cybersecurity plan in place with no minimum standards of protection or effectiveness. Instead, the legislation should require NHTSA to establish a minimum performance standard to ensure cybersecurity protections are required for all AVs levels 2–5. Considering the recent record of high-profile cyber-attacks,[xl] allowing manufacturers merely to have a cybersecurity plan in place is grossly inadequate to ensure that AVs are protected against potentially catastrophic cyber-attacks and breaches.[xli]

Provide Standards to Prevent Driver Distraction

In AVs that require a human to take control from the AV system (Levels 2 and 3), the automated driving system must keep the driver engaged in the driving task. Research demonstrates that even for a driver who is alert and performing the dynamic driving task, there is a delay in reaction time between observing a safety

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[xxxvii] National Transportation Safety Board, *Collision Between a Car Operating With Automated Vehicle Control Systems and a Tractor-Semitrailer Truck Near Williston, Florida,* Report No.: NTSB/HAR–17/02 (Sep. 12, 2017) (NTSB Tesla Crash Report).

[xxxviii] *Id.*

[xxxix] *Id.*

[xl] Stacy Cowley, Equifax Breach Exposed Data From 2.5 Million More People Than First Disclosed, N.Y. Times, Oct. 3, 2017 at B2.

[xli] Chester Dawson, The Dangers of the Hackable Car, Wall St. J, Sep. 17, 2017.

problem and taking appropriate action.[xlii] For a driver who is disengaged from the driving task during autonomous operation of a vehicle, that delay will be longer because the driver must first understand the situation, then take control of the vehicle before taking appropriate action. The failure of the automated driving system to keep the driver engaged in the driving task during the trip was identified as a problem by the NTSB Tesla crash investigation. The NTSB found that the Tesla Autopilot facilitated the driver's inattention and overreliance on the system, which ultimately contributed to his death.[xliii] The Autopilot was active for 37 minutes of the 41 minute trip and of the 37 minutes the system detected the hands on the steering wheel only 7 times for a total of 25 seconds.[xliv] The NTSB also found that these problems are widespread across manufacturers with similar systems.[xlv] The AV START Act fails to address this critical safety problem, yet technology to discern distraction and provide alerts is already available, and NHTSA should be directed to establish a minimum performance standard to ensure driver engagement throughout the trip.

Provide for Standards to Protect the Electronics that Power Safety Systems

Motor vehicles and motor vehicle equipment are powered and run by highly complex electronic systems and will become even more so with the introduction of autonomous driving systems. Similar to the Federal Aviation Administration (FAA) requirements to protect the electronics in aircraft,[xlvi] NHTSA should require minimum performance standards for the electronics in all motor vehicles, particularly AVs. Also, interference from non-safety systems can affect the electronics that power critical safety systems if they share the same wiring and circuits. For example, in one reported instance a vehicle model lost power to its dashboard lights when an MP3 player was plugged in and used.[xlvii] Minimum performance requirements are essential to ensure the electronics that power and operate safety and autonomous driving systems function properly. Performance requirements are also needed to make certain these systems are not compromised by non-safety features that share the same electronics. However, the AV START Act fails to direct NHTSA to develop and issue performance standards for the electronics systems of modern motor vehicles as the FAA does for aircraft which, like AV cars, are highly dependent on electronic systems.

Require an AV "Vision Test" to Ensure Operating Safety

In order for an AV to properly interact with its surrounding environment, it must not only detect other vehicles and roadway infrastructure but also other participants using our Nation's transportation systems such as pedestrians, bicyclists, construction workers in work zones, first responders providing assistance after crashes, and law enforcement officers directing traffic. A failure to properly detect and react to any of these could have tragic results. AVs and automated driving systems must be subject to objective testing to ensure that they properly detect other road users, as well as pavement markings and infrastructure, can correctly identify the type of object that has been detected, and can then also respond properly and safely. Therefore, the AV START Act should direct the Secretary to initiate a rulemaking proceeding to require automated driving systems, including SAE Level 2 automated driving systems, to meet a minimum performance standard for detecting and reacting to the AV's driving environment.

Provide NHTSA with Additional Authority to Counter Widespread Safety Problems

Regulating AVs presents unique challenges for NHTSA, and those issues warrant the agency being given additional tools to protect against potentially catastrophic defects. Flaws or viruses in computer software of AVs could adversely affect thousands of vehicles simultaneously. The agency, therefore, should be given imminent hazard authority in order to expedite the grounding of vehicles that the agency has identified as having a potentially dangerous, widespread software problem or cybersecurity threat that could lead to inordinate crashes, deaths and injuries. Also, because of the potential serious nature of any software problem that could imperil safety in thousands of vehicles, the ability to levy criminal penalties is essential. Criminal penalties will deter manufacturers and suppliers from willfully permitting

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[xlii] Human Factors, Koppa, R.J., FHWA, Ch.3, Sec. 3.2.1 Perception-Response Time.
[xliii] NTSB Tesla Crash Report.
[xliv] *Id.*
[xlv] *Id.*
[xlvi] 14 CFR 25.1309.
[xlvii] General Motors, LLC, Receipt of Petition for Decision of Inconsequential Noncompliance, NHTSA, 79 FR 10226, Feb. 24, 2014.

the sale of AV systems with flawed software operating systems that could pose a danger to human life in the event of a crash.

Recommendations:

- *Amend the AV START Act to apply critical safety provisions to Level 2 AVs as these vehicles will likely comprise the majority of the passenger vehicle AV fleet in the early years of deployment.*
- *Direct NHTSA to issue safety standards addressing critical safety issues involving AVs including cybersecurity, driver engagement, electronics systems and the ability to detect objects in its driving environment.*
- *Provide additional legal authority to NHTSA to enable the agency to effectively respond to crises and protect public safety.*

NHTSA Needs Additional Resources

The unacceptable level of motor vehicle crashes, fatalities and injuries combined with the demands being placed on NHTSA with regard to AV technology necessitates an increase in agency funding. While the FAST Act did provide some additional resources, the agency budget is still inadequate to manage the myriad of challenges facing the agency. Today, 95 percent of transportation-related fatalities, and 99 percent of transportation injuries, involve motor vehicles on our streets and highways.[xlviii] Yet, NHTSA receives only one percent of the overall U.S. Department of Transportation (DOT) budget.[xlix] NHTSA will face even greater challenges in the future as AVs continue to develop and are introduced into the market. For NHTSA to exercise proper oversight over AVs, and even just comply with the current requirements in the AV START Act, the agency will need to hire more staff with technical expertise.

Moreover, in light of the fact that motor vehicle crashes impose a comprehensive cost on society of $836 billion, $242 billion of which is direct economic costs such as lost productivity, medical costs and property damage, it is imperative to provide adequate resources to advance serious measures to combat a serious problem.[l] The AV START Act requires NHTSA to take on new significant responsibilities such as: reviewing SERs filed by manufacturers; evaluating and making determinations on potentially numerous requests for thousands of exemptions from the FMVSS within 180 days of receipt; amending and issuing safety standards; and, supporting advisory committees.

In order to efficiently execute all of these tasks, an office dedicated to AV safety should be established within NHTSA. Safety should not be compromised and progress should not be slowed because the agency does not have adequate technical expertise, organization and funding to oversee the development and deployment of AVs.

Recommendation:

- *NHTSA must be given additional funding and a new dedicated office to AVs should be created to meet demands being placed on the agency with regard to the advent of AV technology.*

States Must Not be Preempted from Acting to Protect their Citizens Especially in Light of NHTSA's Failure to Regulate Automated Vehicles to Date

Advocates agrees with the statutory mission of NHTSA to regulate the design and performance of motor vehicles to ensure public safety which, in modern day terms, includes AVs and automated driving system technology. However, in the absence of comprehensive Federal standards and regulations to govern the AV rules of the road, the states have every legal right, indeed a duty to their citizens, to fill the regulatory vacuum with state developed proposals and solutions for ensuring public safety. NHTSA, by issuing only guidelines, has left the field of AV safety open to the states to fulfill their traditional role of protecting the health and welfare of their citizens. As the National Conference of State Legislatures (NCSL) noted in its comments to NHTSA's first set of guidelines issued in September 2016, "Without any indication on forthcoming Federal regulations regarding the safe operation of HAVs, states may be forced to fill the gap in order to ensure the safety of public road-

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[xlviii] National Transportation Statistics 2015, U.S. DOT, RITA, BTS, Tables 2–1, and 2–2 (2017).

[xlix] Budget Highlights Fiscal Year 2018, U.S. DOT.

[l] NHTSA Cost of Motor Vehicle Crashes Report.

ways."[li] Moreover, the Pennsylvania Department of Transportation stated in its comments to the same guidelines:

Yes, there should be consistent treatment of highly automated vehicles nationwide. However, where the adoption of 'safety standards' being applied to highly automated vehicle testing is totally voluntary (as opposed to self-certifying as against a regulatory framework in the FMCSS) [sic], what level of comfort does that give to the states and their citizens that their transportation and law enforcement agencies are properly discharging their duty to ensure that highly automated vehicles are in fact safe?[lii]

Recommendation:

- *Until NHTSA issues comprehensive standards and regulations to govern AVs, states must not be precluded from enacting state developed solutions to protect their citizens.*

Conclusion

Autonomous vehicles have the potential to address the unacceptable annual death and injury toll and associated costs reaching billions of dollars. As the Senate takes the first step to creating national policy on AVs with potentially long-lasting consequences, it is critically important that the AV START Act include provisions that advance this life-saving technology in as safe and expeditious manner as possible. However, this technology cannot reach its full safety potential without critical safeguards put in place by Congress. Currently the process the bill creates for AV deployment is flawed, and Advocates has put forth 12 recommendations which we urge the Senate to consider moving forward. We believe the role of our Nation's experts in academia to provide the needed testing and proving grounds, as opposed to exposing other highway users on public roads, is essential to both make sure the AVs are safe as well as to build confidence in a currently skeptical public. In conclusion, the current "hands off" approach to hands free driving renders our Nation rudderless at a time in our Nation's transportation history when leadership is needed more than ever. Advocates urges an immediate course correction to ensure the safe development and deployment of AVs.

Senator NELSON. And I would like to conclude my remarks and questions by asking Dr. Avent what is going to be the impact of this new kind of quickly developing technology upon our educational system?

And I ask the question since my experience is informed by what happened to the whole educational system as a result of the space program. Going to the Moon in the Apollo program created a whole generation of engineers, mathematicians, scientists, and technologists. What do we see going forward here?

Dr. AVENT. That is a good point, sir. Once I heard that the amount of money that we spent on the entire space program, we saved in communications within 6 months. And this was when I was in college, which was a long, long time ago, and I am sure the statistics are much more compelling now.

Certainly, this is a big market. As we talked about, it is going to be a disruptive market. It is going to be a change and far-reaching into a lot of industries, but also into a lot of end applications. As I pointed out in my testimony, not just public transportation but agriculture. And it will be pervasive.

And the technology involved in this will be new technology that needs to be developed. Artificial intelligence has been around for many years, but it still needs to evolve a lot and to grow. So I think that we are going to see a new generation of engineers. I think we

[li] William T. Pound, Executive Director, National Conference of State Legislatures, *Public Comments on Federal Automated Vehicles Policy,* Docket No.: NHTSA–2016–0090 (Nov. 21, 2016).

[lii] Leslie R. Richards, Secretary of Transportation, Commonwealth of Pennsylvania, *Letter to Secretary Foxx and Administrator Rosekind,* Docket No.: NHTSA–2016–0090 (Nov. 21, 2016).

will see much more focus on electrical engineering, on computer science, on data analytics, machine learning, those types of technologies. And I think the market will pull from the universities and really create many more people going into those areas.

The CHAIRMAN. Thank you, Senator Nelson.

I have just one last sort of quick question. One is, because a lot has been talked about today, and as we have looked at this issue, the stakeholder community, obviously, highlights, emphasizes, the fact that this is going to save a lot of lives. My question, very directly, is, do you think the safety in terms of lifesaving result of automated vehicles as advertised by the industry will be realized? Are the lives saved as a result of this technology consistent with what the reality is?

Mr. SCHNEIDER. I can say that I am more than optimistic that we will realize the benefits that we are even just laying out today. I do not think that there has ever been a moment in the history of the industry where we were on the verge of such a profound improvement both in safety, lost productivity, and just the benefits of living in our cities and the quality of our air and everything that goes with it.

So from that perspective, I think that I am absolutely optimistic that this is going to happen.

The CHAIRMAN. Thanks.

Mr. MANSUETTI. We share that feeling as well. This is revolutionary technology that will dramatically improve the quality of all of our lives. And with safety, absolutely, we will make tremendous progress with this technology.

Mr. KENTLEY-KLAY. Yes.

The CHAIRMAN. Good.

Mr. KENTLEY-KLAY. Beyond that, these vehicles have pervasive, 360-degree perception with no blind spots, and they are always watching. Having been developing this technology now for 3 years full-time, I and my team are absolutely convinced that it will deliver on its safety promise and then some.

Dr. AVENT. Even when you account for the once-in-a-million events, which are the rare cases, when you divide 40,000 by 1 million, it is pretty close to zero. So yes, I do agree, it is going to make an incredible impact.

The CHAIRMAN. So one quick follow-up question. I agree with that. I think when you get out there into the future and the quality of those predictions in terms of lives saved I think will be realized. But I think for a lot of people, it is looking at this transitional period, and I will use as an example Senator Nelson's example this morning of the car that made a U-turn in front of him, and in a perfectly autonomous world, the autonomous vehicles would have detected that and reacted accordingly and prevented an accident.

But what happens when you have a driver in one vehicle, an autonomous vehicle operating next to it? In the transitional period, when you have drivers on the road and autonomous vehicles on the road, what happens in those types of situations? I am just curious as to what your thoughts are about what the safety features might be if a human reacts the wrong way to an autonomous vehicle?

Mr. KENTLEY-KLAY. So, Senator, and anyone on the panel would be welcome to come visit Zoox in San Francisco and see for yourself

exactly how it would respond in those situations. Driving in complex downtown environments, we actually face those scenarios every hour.

Now is not the time to go into the technical reasons about how we solve that, but we have the methods in place to handle those situations.

The CHAIRMAN. OK.

All right, one more, Senator Blumenthal. Now you really have to vote for the bill.

[Laughter.]

Senator BLUMENTHAL. I withdraw my question.

[Laughter.]

Senator BLUMENTHAL. I expect I will vote for a bill.

In the meantime, in the time that we are waiting, whether it is 3 years or 10 years, for the deployment of this technology on a widespread, perhaps universal scale, would everyone here agree that safety mechanisms like collision avoidance technology, automatic braking systems, should be fully deployed, and that Audi's example should be followed by the rest of the industry?

I will spare you an answer, Mr. Schneider.

Mr. MANSUETTI. Absolutely.

Dr. AVENT. Absolutely.

Mr. KENTLEY-KLAY. As we are developing a 100 percent autonomous vehicle, we already have those systems in place in our architecture. Yes.

The CHAIRMAN. Before we close out, I want to ask unanimous consent to place in the record testimony from NXP Semiconductors concerning connected vehicles and cybersecurity, as well as testimony submitted from Honda regarding innovation in the changing automotive industry. We will include those, without objection.

[The information referred to follows:]

NXP SEMICONDUCTORS USA, INC.
Austin, TX, January 24, 2016

Chairman Thune, Ranking Member Nelson, and members of the Committee,

Thank you for the opportunity to share insights from the forefront of mobility. As the world's largest automotive semiconductor company employing 7,000 Americans, NXP plays an active role in the transformation of the most fundamental of all American relationships: the driver's connection to his or her car. Every era of innovation in our vehicles has placed key car attributes in the spotlight: horsepower, sleek design, and enhanced efficiency have all taken center stage at one time or another. We believe that when scholars write this decade's transport history they will view it as the era powered by automotive semiconductors, an era that witnessed the enablement of a vehicle's ability to sense, think, and act. We are honored to take you on a behind the scenes tour of the coming age.

America's roads and vehicles constitute the lifeblood of the Nation's commerce, the basis of its storied freedom of movement, and a core part of its pioneering identity. Despite these positive transport attributes there are also negative consequences including road fatalities, air pollution, and heavy traffic. The latter alone takes its toll across the globe with 1.3 million lives lost every year to road accidents (more than 30,000 in the U.S. alone). According to research by the U.S. Department of Energy (DOE), electrified automated cars could reduce energy consumption by as much as 90 percent. With today's technology, we are well positioned to take on traffic flow, road safety, and the environmental challenges presented by a growing worldwide vehicle fleet. In all of these areas, the expanded deployment of semiconductors will play a significant role in bringing about massive improvements.

The role of automotive semiconductors

An understanding of the role of technology in the future of smart mobility requires a grasp of some basic terminology:

- *Dedicated Short-Range Communications,* or DSRC, is a two-way short to medium-range wireless communications capability adhering to the IEEE 802.11p standard that permits very high data transmission critical in communications-based active safety applications. The Federal Communications Commission allocated 75 MHz of spectrum in the 5.9 GHz band for use by intelligent transportation systems vehicle safety and mobility applications.
- V2V stands for *vehicle-to-vehicle communications.* The data exchange occurs via radio signals designated as DSRC, and occur nearly instantaneously between vehicles without the need for operator intervention. Vehicles exchange information on speed, trajectory, etc., signaling the driver via a *human-machine interface* (HMI—a visual display, audio alert, haptic—such as steering wheel vibration—feedback system, or some combination of these) with regard to road conditions, environmental hazards, traffic signal timing, and more.
- V2I stands for *vehicle-to-infrastructure communications.* Vehicles equipped with *on-board* units, radios capable of communicating with intelligent roadside infrastructure and relaying information to the driver via the HMI, are V2I-enabled.
- V2X is a catch-all term covering *vehicle-to-everything* communications. Ideally, all new production vehicles would be equipped with DSRC equipment capable of communicating with dense deployments of intelligent roadside infrastructure linked in turn to municipal and regional traffic management centers. Numerous pilot deployments are planned and/or underway to further demonstrate the massive increases in safety and efficiency to be realized by wide implementation.

Advanced Driver Assistance Systems (ADAS) are the foundation of increasingly automated cars. NXP masters the full complexity of self-driving technology, offering silicon-based solutions that span a range from SAE Levels 1–5. Our solutions help ensure that every journey will be safe, secure, and enjoyable.

The concept of the car has morphed into a securely connected, self-driving robot with the capacity to sense the environment, think, and act autonomously. In addition to having a powerful "brain", an automated vehicle must be capable of receiving sensory inputs, and turning associated "thoughts" into actions. To make precise, safety-related decisions, an array of complementary sensor technologies needs to draw a high-precision digital map of the car's environment and accurately detect objects. As autonomous cars are expected to generate +1GB of data per minute, cars need to securely process multiple streams of information with flawless intelligence. Just like the human body, strong reflexes will be required in addition to the central brain to meet this challenge. At the same time, automated cars need smart actuators to generate power, put the car in motion, and regulate systems. NXP covers the complete self-driving portfolio with solutions that sense, think and act.

- Sensing: Our radar, secure V2X, and vision technologies act as a vehicle's state-of-the-art eyes and ears. An estimated 50 percent of all car radar modules shipped in 2017 rely on NXP processing and front-end technology to make life safer for drivers and passengers. NXP's vision processors deliver the performance and features to power critical driving functions such as pedestrian detection, lane keeping, traffic sign recognition, collision avoidance, and blind spot monitoring.
- Thinking: Holistic intelligence across all architecture domains enables reliable decision-making. Sensor fusion at high performance and low power is at its core. NXP's pioneering sensor fusion solutions enable autonomous vehicles to coordinate input from numerous sensors throughout the car to make decisions. The NXP BlueBox™ platform fuses these disparate data streams to create 360° awareness around the vehicle.
- Acting: We offer a range of smart actuators—including motor control, power/battery management, intelligent amplifiers, and LED drivers.

A semiconductor company's insights into the automotive space may seem like an unusual vantage point until you consider how vital electronics have become to automotive architectures. In fact, 90 percent of innovation in the automotive sector now comes from electronics. Electronics are also at the center of the three most important automotive megatrends; autonomy, connectivity, and electrification.

Today's cars are safer, more efficient, and smarter than ever before, and semiconductors are a big part of the reason why. The vehicles rolling from assembly

lines are more like robots on wheels, and the very high degree of electronic sophistication is largely due to semiconductor technology. As this trend toward electronification continues, semiconductor companies will continue to play a significant role in vehicle design.

How do you build a safe, self-driving car, securely connected to a new scheme of smart mobility services? By utilizing a domain-based architecture which intelligently groups together the functions that let cars sense, think, and act—and eventually to fully replacing the human driver. This helps manage complexity and separate concerns related to security, upgradability, and functional safety. The domain-based architecture is connected by an internal network and secure central gateway that acts as the "glue" to hold everything together, enabling reliable and efficient communication. NXP's portfolio covers every area of the connected car's domains which is why car makers look to us to for our insights into the future of mobility.

Vehicle to Everything (V2X): a closer look

Car-to-car communication is attracting significant attention because it promises to drastically reduce road fatalities, improve mobility and enable a high-level of vehicle automation.

Supporting safety critical applications is at the core of car-to-car communication, and for years, the technology of choice for V2X has been the IEEE802.11p standard. Recently, a new standard addressing V2X applications has started evolving under the umbrella of 3GPP, whose focus is mobile broadband standardization. Because the safety of millions of road users will depend on the performance of these technologies, it is important to compare them.

There are several relevant facts to consider when comparing IEEE802.11p to LTE–V2X:

- IEEE802.11p is ready now, LTE–V2X is not. Today, IEEE802.11p-based products are available on the market from multiple silicon chip vendors. Some Tier1s (companies providing components such as seats, electronic modules, windows, etc. directly to the automotive OEMs) have complete solutions available. In contrast, there is no LTE–V2X product available in the market today, and it will most likely take several years before a complete solution will be ready and tested. The promised 5G version of V2X will have an even longer time horizon;
- IEEE802.11p is already installed in cars on the road. An end-user can buy a vehicle (*e.g.,* Cadillac) equipped with IEEE802.11p technology today;
- IEEE802.11p mass deployment could begin soon. Volkswagen, one of the largest car manufacturers worldwide, publicly announced that from 2019 onwards, they will equip their first model series with IEEE802.11p technology.

The cellular community is advocating that V2X implementations should wait for cellular technology to be ready and tested, and disregard the investments and field tests done to validate IEEE802.11p for safety critical applications. More concretely, the cellular community claims that LTE–V2X offers:

- A strong cellular eco-system which leverages years of experience in providing paid-services and a mature technology available worldwide. This is a valid argument, but it refers to entertainment services in a cellular-based technology. The communication between a device and a base-station is fundamentally different from the device-to-device communication in a dynamic environment;
- Twofold better performance. However, it is IEEE802.11p which outperforms LTE-V2X in important V2V use cases;
- Minor added cost. This is questionable as the support of safety critical applications strongly indicates the need to separate those from the entertainment SW and HW. Therefore, LTE–V2X will likely be physically separated from the cellular modem;
- A roadmap of evolution and future proof technology due to the continuous effort in improving the technology via the well-tested mechanism of the 3GPP meetings. While this might be true, introducing an updated standard every 12 to 15 months does not guarantee that older vehicles will be able to communicate with newer ones. This is in contrast with the need of creating a stable and universal international standard to enable the success of V2X technology.

The proposed LTE–V2X technology is a derivative of the cellular uplink technology that maintains similarity with the current LTE systems: frame structure, sub-carrier spacing, clock accuracy requirements and the concept of a resource block, to mention a few. These properties were not made to fit the vehicular use cases,

but rather are inherited from existing cellular technology. Consequently, LTE–V2X struggles to meet the specific application requirements of car-to-car communications.

Technically, LTE–V2X suffers when there is no network to support the communications. It has stringent synchronization requirements, it cannot properly receive messages from nearby and closed-by transmitters, and it is limited in its maximum range. Furthermore, it proposes a resource allocation scheme that does not properly handle messages with variable size and a multiple user access mechanism that is not well suited for broadcasting messages or for handling collisions of messages. The heavyweight design of LTE–V2X translates into a higher overhead.

Commercially, LTE–V2X cannot leverage the presence of the standard LTE modem in the car. Different safety requirements and technology needs strongly suggest that the safety critical domain of LTE–V2X will be separated from the entertainment domain of the standard LTE modem. The stringent synchronization requirements could significantly increase the costs in the LTE–V2X hardware.

Strategically, LTE–V2X might not be the best technology for safety critical applications as its fast development cycle does not match the automotive development cycle. The 3GPP community has already started working on a new version of LTE–V2X while the current version has not been tested in the field yet. The next generation of IEEE802.11p is also being considered to capitalize on the experience of multiple large-scale field trials to test safety critical applications.

Our conclusion is that IEEE802.11p technology is ideal for safety critical applications that must be supported in the absence of a network. If the cellular infrastructure is available, LTE–V2X is a valid alternative and offers a more mature eco-system for entertainment services. The win-win situation would be to focus on the strongest points of each technology and work together to provide the best car-to-car communication solution, continue deploying IEEE802.11p for safety critical applications and ensure that the upcoming LTE–V2X technology can coexist.

Security: a fundamental necessity for the future of advanced mobility

As we have said before, cars are morphing from smart machines to self-driving robots on wheels. A big part of this transformation depends on the car's ability to draw from real-time data about its surroundings using wireless technologies like V2X communications, GPS and radar. This external wireless input is needed to be able to instantaneously assess the current context of the vehicle and continually plan the autonomous trajectory. This external wireless input presents security challenges because it increases the ways that hackers can attack cars.

Another critical factor is that soon the driver will be missing—we are removing the computing, rationalizing and double-checking functions of the human being—and replacing these with smart machine computing performance, mimicking what the driver does naturally.

Right now, there is a shift in the way we think about security. Systems engineers are focusing on the basics—applying fundamental security to the critical areas including the interfaces that connect the vehicle to the external world, gateways, which separate safety critical systems from other car and infotainment systems and networks that provide secure communication between control units (there can be over 150 of these control units in a vehicle). But in addition to these measures, we can see advancement in three ways—(1) security management, especially the delegation of aspects of security to *e.g.,* a rental car company or a delivery company; (2) Over-The-Air software updates to be able to update any software in the vehicle at any time (there will be 200–300 million lines of code in a car soon), seamlessly, to patch vulnerabilities real time, and (3) further protection and monitoring against the increasingly intelligent and devious hacker—against wireless and physical attacks. A core aspect of this is the Secure Element (SE), a tamper-resistant platform (typically a one-chip secure microcontroller) capable of securely hosting applications and their confidential and cryptographic data (*e.g.,* key management) in accordance with the rules and security requirements set forth by a set of well-identified trusted authorities.

The attached White Paper, "A Multi-Layer Vehicle Security Framework", provides additional insights into securing connected vehicles and creating a safer, more efficient mobility future.

Conclusion

We hope that the Committee takes three key points from the foregoing message:

- In addition to electrified automated cars helping to prospectively reduce energy consumption by as much as 90 percent, today's technology—if more widely deployed—could bring about a radical reduction in traffic fatalities and minor accidents alike. In all of these areas, the expanded deployment of semiconductors will play a significant role in bringing about massive improvements.

- In terms of cars communicating with each other, IEEE802.11p technology is ideal for safety critical applications that must be supported in the absence of a network. When and where the cellular infrastructure is available, LTE–V2X is a valid alternative and offers a more mature eco-system for entertainment services. The win-win situation would be to focus on the strongest points of each technology and work together to provide the best car-to-car communication solution, continue deploying IEEE802.11p for safety critical applications and ensure that the upcoming LTE–V2X technology can coexist.
- No innovative solutions will succeed without designing in security. NXP advocates for a multi-layered, "4+1" layer security framework as only a holistic approach to securing the complete vehicle architecture of a connected car can succeed. A secure element must serve as a tamper-proof trust anchor, engaging with physically and electrically isolated networks using a central gateway with a firewall. The remaining layers ideally consist of secure networks with the bus monitoring and cryptographic capabilities of a secure transceiver or microcontroller for message authentication, secure processing on the microcontrollers, with trusted software running in a protected environment, and of course, the "+1" layer—the secure car access solution.

We at NXP are proud that our innovations—many of which have their origins in the United States—are driving a more secure, smarter mobility future. We hope that the foregoing information is of value to the committee, and look forward to receiving and responding to any comments or questions that members of the committee may have.

Respectfully,

LARS REGER,
Senior Vice President and
Chief Technology Officer—Automotive,
NXP Semiconductors.

About NXP

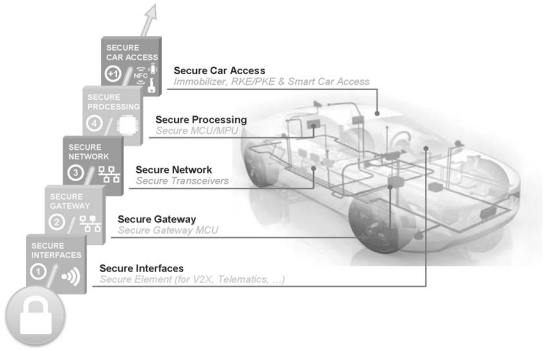
NXP Semiconductors N.V. enables secure connections and infrastructure for a smarter world, advancing solutions that make lives easier, better and safer. As the world leader in secure connectivity solutions for embedded applications, NXP is driving innovation in the secure connected vehicle, end-to-end security & privacy, and smart connected solutions markets. Built on more than 60 years of combined experience and expertise, the company has 45,000 employees in more than 35 countries. Built on a 50-year legacy with Motorola and Philips, NXP has design, research and development, manufacturing and sales operations in the United States, where we employ nearly 7,000 people. NXP owns and operates three wafer fabrication facilities in the US, two of which are in Austin with a third facility in Chandler, Arizona. The representative products of these fabs include microcontrollers (MCUs) and microprocessors (MPUs), power management devices, RF transceivers and amplifiers, and sensors. Find out more at www.nxp.com.

A Multi-Layer Vehicle Security Framework

Whitepaper

Authors:

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BU Automotive
NXP Semiconductors



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Introduction

Vehicles are going through a rapid evolution: many mechanical systems are being (or have already been) replaced by electrical systems, leading to highly computerized vehicles. In addition, connectivity is being added for reasons of safety and convenience. But with that comes a security risk.

Until recently, cars have been isolated from their environment and from the internet. The only exception was the interface for vehicle diagnostics, but because this port is a wired interface within the vehicle, it could rely on the physical protection offered by the vehicle itself. As such, remote and scalable attacks, i.e. attacks that can be mounted from anywhere within the internet, did not play a role.

But that situation is rapidly changing. Now most modern cars allow smartphones to be paired via Bluetooth with the car radio for hands-free phone calls or to play music. And many modern cars are wirelessly connected to the internet, for example to enable additional services in the car and to provide for some limited remote control of the car, e.g. remote unlocking and starting. Aftermarket connected insurance and remote diagnostic dongles on the OBD port bring a new connected risk too, unforeseen in the original vehicle design. To improve safety, these cars will also be equipped with telematics based emergency assistance (e.g. eCall) and V2X communication technologies for accident prevention. This results in the fully connected car summarized in Figure 1 below.

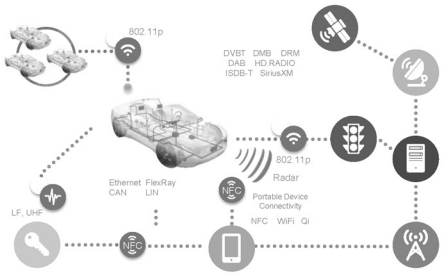


Figure 1: The interfaces of the connected car

The hacks of 2015

The hacks of 2015 reached the popular press [1][2][3], and caused some of the biggest vehicle recalls in history [4]. For the first time, the public started to understand the need for increased in-vehicle security. US politicians felt the need to get involved [5] and most recently the FBI have decided the risk is so high, they have even issued warnings to the public [6]. And recent surveys show that such steps may not be superfluous [7].

But the events of last year has also shown the world that different OEMs had different security levels in place already, and different speeds of solving the issue. As the vehicle OEMs reacted, NXP put together a framework, consisting of 4 security layers that lead to a highly secure vehicle network. Whatever their starting point, this framework will guide our customers to a quick and cost effective step function increase in security, using NXP products.

From a physical hack to a remote attack

Most security hacks, whether targeted at cars or consumer goods like smartphones, consist of linking up a number of smaller vulnerabilities. In the first stage, a hacker identifies weaknesses in the design and/or implementation of a device – often using physical attacks (reverse engineering). The next step is exploitation, in which the hacker links up a number of these vulnerabilities, which may ultimately lead to a remote and scalable attack. The Jeep hack of 2015 is a great example of this: after (physical) reverse engineering of the vehicle, they linked up weaknesses in the external network, the TCU and the programming interface of a device on the CAN network, allowing them to take full control over the vehicle. An attack that affects a complete vehicle fleet is the worst case scenario, but the Jeep hack showed us all that it is, currently, very realistic.

How to secure a vehicle

The Connected Car and the presence of hackers are now parts of life – hence security must be an integral part of the design of the Connected Car, as security is as weak as the weakest link. Vehicle security is a big topic, but we can break it down into manageable chunks.

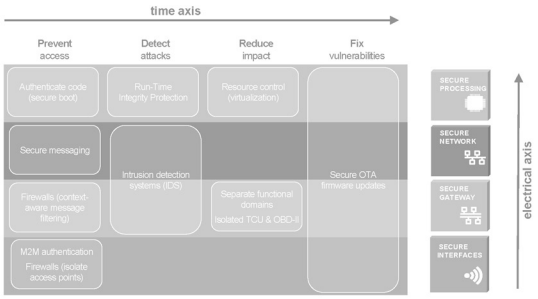


Figure 2: Breaking down the topic of vehicle network security

We can break it down on two different axes – a time axis, and an electrical axis:

The time axis

Security needs to be designed into the vehicle architecture from the very start and it must furthermore be maintained throughout the vehicle's entire lifecycle. Contrary to common belief, security is much more than prevention only. To secure a vehicle, one must:

- **Prevent access**, e.g. using machine-to-machine authentication and gateway firewalls, to ensure that hackers cannot access and tamper with the (safety critical) nodes in the vehicle
- **Detect intruders**, e.g. secure boot of the controller, to validate that the software is (and remains) genuine and trusted
- **Reduce impact** of any determined intruders who did manage to gain access, e.g. by isolating the network domains, to prevent that a compromised infotainment unit in one domain can be used to control e.g. the brakes in another domain
- **Fix vulnerabilities**, e.g. enable full vehicle OTA update capability through the secure gateway, to fix vulnerabilities before they can be exploited (at large scale) by hackers

We can look at the IT industry for guidance to solve the problem of vehicle security. The key point is defence in depth – never rely on just one line of defence, but assume that has been breached, to reveal another layer of defence. Then assume that has been breached to reveal another layer, etc.

There is for example a common myth that adopting a system of individual unique secret keys for every vehicle is sufficient, but that assumes the perfect impenetrable system, and one of those hasn't been designed yet. Unique keys alone are not sufficient to protect the vehicle. At best, they prevent scaling of the attack to other vehicles.

NXP's 4+1 security framework

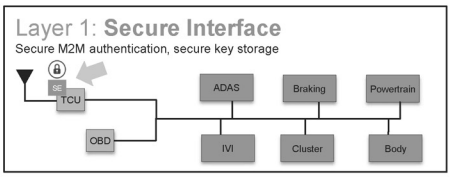
A secure vehicle architecture follows the same principles, summarized in the 4 layers of security that together provide the right level of protection:

- **Secure interfaces,** which connect the vehicle to the external world
- **Secure gateway**, which provides domain isolation (separating interfaces, infotainment, safety-critical systems etc.)
- **Secure network**, that provides secure communication between control units (ECUs)
- **Secure processing,** on the various control units that implement all the features of the connected car

These four generic layers are complemented by an additional layer, comprising the various car access and immobiliser solutions.

Let's look more closely at these layers:

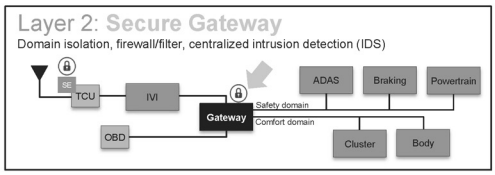
Layer 1 – Secure Interface



A common network today is completely unprotected. If a hacker gets access to the telematics control unit (TCU) or on-board diagnostics (OBD) port, he can then send spoofed CAN messages and hence control safety critical items, like brakes.

To secure the Connected Car, first of all, the communication channels needs to be protected against data theft, e.g. by encrypting the data, and against manipulation, e.g. by authenticating the messages that are exchanged to protect their authenticity and integrity.
The first layer of protection adds security to the TCU, by attaching a Secure Element for maximum security. Secure elements are dedicated security microcontrollers with advanced cryptographic accelerators and proven advanced physical and electrical attack resistance – more commonly used in ePassports, bank cards and mobile phones – that can be used to establish an end-to-end secure channel to the external world, e.g. using TLS over a regular cellular or WiFi connection. They also act as an ultra-secure vault for keys and certificates.

Layer 2 – Secure Gateway



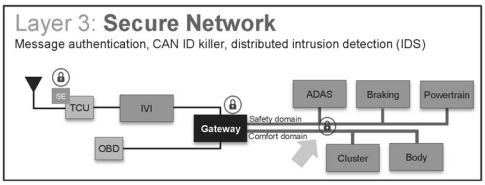
As was observed in the Jeep hack, once the hackers were on the network, they could send messages anywhere. This can be blocked by the presence of a central gateway ECU. This separates the TCU and OBD from the network and breaks up the vehicle network into functional domains, with the gateway firewall deciding what nodes can legitimately communicate with what other nodes

In the Tesla Model S hack of 2015, the protection offered by the gateway was highlighted by Marc Rogers as a key security feature for modern vehicles [3]. Where in the Jeep hack [1], Miller & Valasek could switch off brakes remotely because the Jeep did not have a gateway and associated domain isolation, in the Tesla hack, the worst they could do was sound the horn!

The first true gateway was introduced into some high-end vehicles 8 years ago. Since then, as the amount of data being transferred between ECUs in the vehicle has significantly increased, the gateway functionality has become more complex, and also more common place in our vehicles. In its current form, the central gateway provides many functions, linking data and signals from the various nodes around the vehicle, converting the plethora of automotive communication protocols.

From a security view point, apart from isolation, its most important function is the firewall that separates the external interfaces from the safety-critical inner vehicle network. The gateway engine is a contextually aware routing function that determines, by a number of increasingly sophisticated checks, which messages are currently legitimate, and hence will be passed through the gateway onto the destination.

Layer 3 – Secure Network



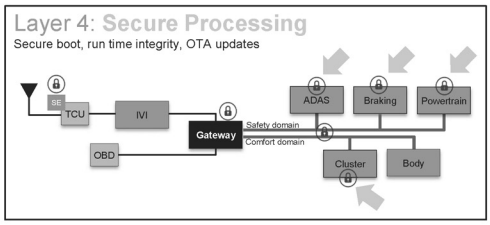
So with the network now split into domains, the attack surface of the architecture is significantly reduced. But the sub-network is still vulnerable to attacks, such as message manipulation. Layer 3 protects this sub-domain by doing 4 things:

1. adding a message authentication scheme – each message is extended with a cryptographic code to guarantee an authentic sender and also that it was received unaltered.
2. encryption – data & identity theft can be avoided by encrypting the messages that are exchanged between different ECUs inside the vehicle
3. intrusion detection – pattern recognition and rules checking to detect anomalies in the network traffic and to block malicious packets before they can even reach the microcontroller, including message rate limiting mechanisms to prevent denial-of-service attacks
4. ECU level validation – the authenticity of ECUs in the network can be verified regularly (e.g. on engine start and periodically afterwards)

These features can be enabled by security subsystems (including cryptographic accelerators) that are integrated in the microcontroller. However, it is impossible for OEMs and Tier-1s to apply a security upgrade to all existing microcontrollers and their software from one vehicle model to another. The associated cost for validation and verification of the modified hardware and software would simply be too high.

An network-centric security solution is proposed as an alternative, cost-effective upgrade path. By implementing such security features at the network level, inside the transceiver, security can be retrofit to existing networks with existing ECUs, while significantly reducing the amount of ECU software re-development.

Layer 4 – Secure Processing



And finally, we need to ensure the software running on the processor is genuine and trusted, and has not been altered in any way. To achieve that, modern microcontrollers feature secure boot and real-time integrity checking schemes to guarantee the code image is authentic, trusted and unaltered. On top, mechanisms for controlled lock-down of the MCU and ECU through manufacturing are employed to lock out debug and serial download features, which would be invaluable to hackers

On top of that, a secure software upgrade mechanism is needed. Modern vehicles already feature around 40 microcontrollers (high end can be over 100) and 100 million lines of code (i.e. more than modern PCs and smartphones), and those numbers will only increase over time. That represents huge software complexity. Such complex systems *cannot* be bug free, so vulnerabilities *will* be found after the vehicle enters the road. But when a bug or security vulnerability is detected, the OEM needs to have the ability to quickly, seamlessly and of course securely, update the vehicle software, preferably without the need to visit the garage. The ability to perform OTA (Over-the-air) software updates for *every* ECU in the vehicle is now demanded, and is justified by the number and cost of vehicle recalls in the last few years.

Layer +1 – Secure Car Access

Secure car access is the traditional side of vehicle security, covering immobiliser and car access solutions. Innovations in this area include new features like remote lock & unlock, passive start, remote vehicle monitoring and car access via NFC or BTLE using a smart phone or wearable device.

Which layers to apply, and in which order?

The 4 generic layers are presented here as logical sequential 4 steps, however depending on the OEM architecture, it may be that layer 4 is instigated prior to layer 3, or indeed layer 1 is the last to be implemented relying on the security of an applications processor in the TCU, without the secure element. Decisions like that would need to be driven by individual vehicle threat analysis.

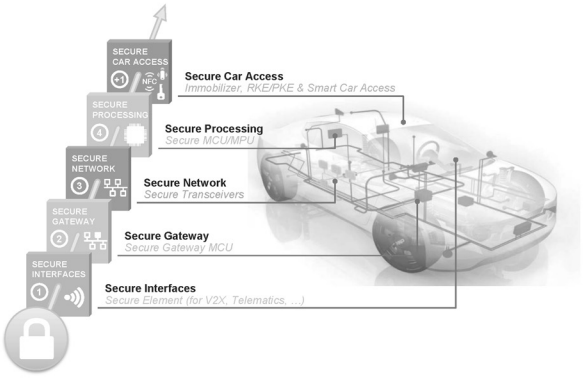
Conclusions

We are in a new era of vehicle complexity and connectivity. But that has also brought a new era of ingenuity and resourcefulness of car hackers. However, the security of the vehicle electrical architecture is vital to ensure the safety of the vehicle occupants so we need to respond to this threat.

NXP has devised a multi-layered approach, that we call our 4+1 layer security framework which provides a holistic approach, for securing the complete vehicle architecture. This builds on our automotive heritage, with deep and wide automotive application knowledge (in-vehicle networking, ADAS, infotainment, body, powertrain, etc) and leverages innovation from our market leading smartcard products used in secure applications like banking, ePassports etc.

This framework applies a defense-in-depth strategy, assuming that a determined hacker can get access through individual layers. These layers of protections are:

- **secure interfaces**, using a secure element as a tamper-proof trust anchor,
- physically & electrically isolated networks using a **central gateway** with firewall
- **secure networks** with the bus monitoring and cryptographic capabilities of a secure transceiver or microcontroller for message authentication,
- **secure processing** on the microcontrollers, with trusted software running in a protected environment.
- And of course, the "+1" layer – the **secure car access** solutions



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About the authors

After graduating from the University of Glasgow, Andy Birnie had various roles in product & technology development, but is currently Systems Engineering Manager for Automotive Microcontrollers and Processors within NXP. In this role Andy is responsible for working with Tier1s and OEMs to understand market trends and customer demands, to define the next generation of microcontrollers and security solutions, keeping NXP at the forefront of automotive electronics systems technology. Andy sits on the OPEN Alliance steering group, pushing adoption of Ethernet into automotive, and was a founder member of the AESIN (Automotive Electronic Systems Innovation Network) consortium in the UK.

Timo van Roermund is security architect in NXP's business unit Automotive with deep expertise in applied security for embedded devices, such as Vehicle-to-X communication systems, in-vehicle networks, Internet-of-Things appliances, mobile phones and wearable devices. His external contributions include for example his membership of the programme committee of the Cyber Secure Car conference and his active contribution to the ITS (V2X) security standards via the Car-2-Car Communication Consortium's working group Security, the ETSI TC-ITS working group Security and the IEEE 1609 working group. Timo received the MSc degree in Computer Science and Engineering from the Eindhoven University of Technology.

About NXP

NXP Semiconductors N.V. (NASDAQ:NXPI) enables secure connections and infrastructure for a smarter world, advancing solutions that make lives easier, better and safer. As the world leader in secure connectivity solutions for embedded applications, NXP is driving innovation in the secure connected vehicle, end-to-end security & privacy and smart connected solutions markets. Built on more than 60 years of combined experience and expertise, the company has 45,000 employees in more than 35 countries. Find out more at www.nxp.com.

HONDA NORTH AMERICA, INC.
Washington, DC, January 24, 2018

Hon. JOHN THUNE, Chairman,
U.S. Senate Committee on Commerce, Science, and Transportation,
Washington, DC.

Hon. BILL NELSON, Ranking Member,
U.S. Senate Committee on Commerce, Science, and Transportation,
Washington, DC.

Dear Chairman Thune and Ranking Member Nelson,

Thank you for this opportunity to share Honda North America, Inc.'s (Honda) views on the "Driving Automotive Innovation and Federal Policies" hearing. Honda has been investing and manufacturing in the U.S. for more than 40 years. This includes 12 manufacturing plants which have enjoyed $3.4 billion in investments in the past four years alone and produce passenger vehicles, power equipment, and power sports products. Honda has also purchased $27 billion in parts and materials from 610 U.S. suppliers. Our 14 R&D facilities have researched, designed, and developed 29 Honda and Acura car and light truck models since 1991. The U.S. also hosts the global headquarters for HondaJet. Honda directly employs 30,000 Americans and in more than 50 years in the U.S. has never laid off a permanent associate.

As our automotive products evolve, so too must our business models. One example of that evolution is the creation of one of Honda's North American research and development business units, Honda R&D Innovations, Inc. based in Silicon Valley. This open innovation-focused business unit has established two programs that serve as catalysts to discover and experiment with new technologies and business concepts for Honda products: Honda Xcelerator and Honda Developer Studio.

Honda Xcelerator is Honda's open innovation program designed to facilitate collaboration between technology startups across all funding stages who share Honda's vision to transform the mobility experience. The program easily engages innovators in an open and friendly environment, offering funding for rapid prototyping, a collaborative workspace, and pairing with Honda mentors. Innovators also have access to Honda vehicles and vehicle data to develop, test, and refine their prototype. Honda Xcelerator currently works with technology incubators around the world, including partnerships with MassChallenge (Boston, Mass.), Creative Destruction Lab (Toronto, Canada), Drive (Tel Aviv, Israel) and equity crowd funding platform OurCrowd (Jerusalem, Israel). This list is expected to continue to grow.

In 2017, Honda Xcelerator showcased its startup collaborations with partners LEIA 3D and VocalZoom. In partnership with LEIA 3D, Honda developed a driver's display meter using nano technology that can provide three-dimensional images, switching seamlessly between different viewing angles for warnings and driver-assistive systems. Honda also partnered with VocalZoom to apply VocalZoom's optical microphone technology to improve voice interaction inside the vehicle.

Honda Developer Studio connects innovators with Honda engineers to quickly get their applications ready for the road. Like Honda Xcelerator, Honda Developer Studio also provides access to vehicles so that innovators can experience real-time results and vehicle feedback as the applications are being built. For example, Honda is collaborating with Visa on an in-vehicle payment technology that enables users to make payments, such as at a gas station or parking facility, from inside their cars. We envision a world where consumers can effortlessly make everyday purchases from the car . This connected car project is an early step in Honda's work regarding electronic commerce in the age of the Internet of Things. We've developed a proof-of-concept experience and will have more information on future commercial plans as we receive the test results.

Additionally, Honda and DreamWorks Animation have partnered on a platform that leverages a ConnectedTravel software development kit, vehicle data, and virtual reality (VR) technology. The platform can be used to rapidly create in-vehicle entertainment experience for passengers through a location context-aware application. The technology uses VR goggles to display information such as restaurant guides or to advance a game in sync with the movement of the car.

Honda Innovations is proactively searching for the next great technology to benefit our products and, ultimately, our customers. Our open innovation platform provides the best method to modify these technologies for Honda products and be able to bring them to the market relatively quickly. Honda stands ready to work with anyone who has an idea to make our products work better for our customers.

The CHAIRMAN. I would say to the members of our panel, if you could, and if members of our panel here could get questions in, we would like to get those responded to, turned around to complete the record in 2 weeks, so if there are written questions that come in response to this hearing, do your best to get those back to us, the answers back to us, as quickly as possible. It would be greatly appreciated.

And I want to thank the crowd for being here today. It is good participation from our audience.

How about we give all these folks a hand this morning?

[Applause.]

The CHAIRMAN. Thanks again to our panel. Thanks to all of you for being here. And this hearing is adjourned.

[Whereupon, at 12:03 p.m., the hearing was adjourned.]

A P P E N D I X

TRANSPORTATION RESEARCH CENTER INC.
East Liberty, OH, February 7, 2018

Hon. JOHN THUNE,
Chairman,
Senate Committee on Commerce,
Science, and Transportation,
United States Senate,
Washington, DC.

Hon. BILL NELSON,
Ranking Member,
Senate Committee on Commerce,
Science, and Transportation,
United States Senate,
Washington, DC.

Dear Chairman Thune and Ranking Member Nelson:

Thank you for the opportunity to share the Transportation Research Center Inc.'s (TRC) perspective following the Senate Commerce, Science, and Transportation Committee's field hearing on Driving Automotive Innovation and Federal Policies held Wednesday, January 24, 2018.

TRC along with The Ohio State University (OSU) were among the first to begin testing automated vehicles in the 1970s. TRC's connected and automated vehicle (CV/AV) research, testing, and deployment has continued, in conjunction with the National Highway Traffic Safety Administration's (NHTSA) vehicle research and test center located at TRC, in developing objective test procedures for various applications of connected vehicle technology and functional testing for automated vehicles by procuring and verifying next generation testing capabilities for automated vehicles.

We are the Nation's leading independent automotive proving ground, and the only industry, non-for-profit, government, and university-affiliated research facility in the U.S. TRC employs over 450 people and has served more than 1000 customers, including virtually every OEM and numerous tier 1 suppliers. TRC's campus encompasses 4,500 acres, a 7.5-mile high-speed track, and operates 24/7, 359 days a year. We hope both of you will visit us soon. Last year we were honored to host Secretary Elaine Chao, Senator Rob Portman, and several Members of Congress, including the Chairman of the House Transportation and Infrastructure Subcommittee on Highways and Transit, Sam Graves.

During the hearing, the U.S. DOT's 10 federally-designated autonomous vehicle proving grounds were referenced. We would like to share with the Committee that we are actively involved in developing a "Community of Practice" for conducting AV testing with California, Florida, Michigan, North Carolina, Pennsylvania, Texas, and Wisconsin, to name a few.

TRC currently supports emerging active safety and advanced driving assistance systems technology development to enable CV and AV testing of automation systems. Our customers trust in TRC for a comprehensive, holistic approach to not only testing automated systems, but the vehicles themselves. Critical testing and validation such as dynamic and durability testing, performance, and mileage accumulation still need to be performed, even on automated vehicles.

TRC's commitment to automated vehicle technology and safety continues over the next five years with significant public-private partnership (P3) funding for Phase One of our 540-acre Smart Mobility Advanced Research and Test (SMART) Center. This $45 million expenditure, which does not include Federal funding, will contain a flexible platform, mega intersection, urban network, and control center specifically dedicated to testing autonomous technologies and vehicles. Our facility will offer customers a confidential, controlled, repeatable environment to test their AV technologies.

TRC's SMART Center will be the world's largest, contained within an independent proving ground. Once controlled testing is complete OEMs, innovators, and start-ups will be able take their products onto the open road for real world testing along the U.S. Rt. 33 Smart Mobility Corridor connected to TRC's facility. Funding for this corridor was made possible because of a U.S. DOT Advanced Transportation and

Congestion Management Technologies Deployment Initiative (ATCMTD) grant. The State of Ohio, local communities, OSU, and TRC joined forces to match Federal dollars to implement smart infrastructure technology to solve congestion issues. This corridor also leads to the connected vehicle pilot in Marysville, Ohio and to Smart Columbus, where we have the only federally-designated smart city in the country.

With capital investment in upwards of $100 million, decades of experience within the automotive industry, and hundreds of customers, TRC is pleased to provide leadership, partnership, and expertise to industry and government as it embarks on the next generation of transportation innovation.

Chairman Thune and Ranking Member Nelson, thank you for your leadership and commitment to the safe deployment of automated vehicles onto the public roads. We appreciate the opportunity to express our views around this important policy conversation.

Sincerely,

BRETT ROUBINEK,
President and Chief Executive Officer,
Transportation Research Center Inc.

Cc: Senator Sherrod Brown
Senator Rob Portman

PREPARED STATEMENT OF NED FINKLE, VICE PRESIDENT, EXTERNAL RELATIONS, NVIDIA

Chairman Thune, Ranking Member Nelson, Senators:

NVIDIA had the great honor to testify last summer in front of your committee and discuss how we are helping to pave the way for self-driving vehicles. I believe all parties at the hearing shared the excitement of the improved safety and increased access that autonomous vehicles will soon bring to our roads. After watching last month's hearing with speakers from Audi Mobility U.S., Robert Bosch, and Zoox, we're thrilled to see that these companies are continuing to build momentum toward an autonomous vehicle future that closely aligns with NVIDIA's goals.

During last summer's hearing, NVIDIA detailed our technology and our ecosystem, highlighting that the NVIDIA DRIVE artificial intelligence computing platform was in use by more than 225 automotive companies worldwide. Now, seven months later, we have grown that network to over 320 OEMs, tier 1 suppliers, startups, and research institutions, including companies such as Audi, Volvo, Mercedes-Benz, Bosch, and PACCAR trucks. Also included are over 150 startup companies that are using the NVIDIA DRIVE platform to innovate in autonomous technology in such areas as HD mapping, simulation, sensor technology, or even reinventing the entire mobility ecosystem, like Zoox is proposing.

At the beginning of 2018, NVIDIA further strengthened its ecosystem of partners and its technology offerings with a series of announcements at the Consumer Electronics Show. Our DRIVE Xavier, the world's first autonomous machine processor, is being delivered to customers this quarter. Capable of calculating 30 trillion operations per second, while only consuming 30 watts, it is targeted to bring Level 3 and 4 autonomy to production vehicles in the next couple of years. We also announced at CES our DRIVE Pegasus AI computing platform, which delivers 320 trillion operations per second—the compute horsepower needed for Level 5 robotaxis. DRIVE Pegasus takes the performance of a trunk full of PCs, and sizes it down in an auto-grade form factor the size of a license plate. Our customers will have Pegasus in hand for R&D by mid-2018, which aligns with the 2020 time-frame stated today on when speakers believe Level 5 vehicles will be available.

We also revealed new partners: Uber is using NVIDIA technology to power its fleet of self-driving cars and trucks; Volkswagen will infuse AI into its future vehicle lineup; and Aurora, founded by three self-driving technology pioneers, is utilizing NVIDIA technology to create a new Level 4 and 5 self-driving hardware platform.

Last month's testimony spoke to the need for simulation, in addition to physical proving grounds. Through the power of our GPUs, NVIDIA can simulate potentially hazardous situations that are too dangerous to perform in the real world, and use these techniques to train AI software before putting a vehicle in the real world. Through AI technology, we can simulate driving 300,000 miles in five hours, and cover every paved road in the United States in just two days.

But in-vehicle technology is useless for transportation services unless it is of the strictest automotive grade. NVIDIA DRIVE is the first functionally safe AI self-driving platform that can operate even when faults are detected. Certified to the inter-

national safety standards of ISO 26262, safety certified ASIL–D makes DRIVE a holistic safety platform.

The speakers expressed the need for consortiums to come together so companies can provide the data the Senate and House need to better rollout legislation. We couldn't agree more. NVIDIA would like to let the U.S. Senate Committee on Commerce, Science, and Transportation know that we are at your service and are always available to provide insight on why AI is the key to unlocking the challenge and promise of self-driving cars, including, most importantly, creating a safer, more productive, and less congested world.

Thank you.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MAGGIE HASSAN TO RANDY K. AVENT, PH.D.

Question 1. As a former Governor, I recognize that there are ways that state and local governments can work to accommodate and help launch this technology, as well as ensure that it is safe and appropriately regulated. That is particularly important when we recognize that there are bad actors out there that would like to try and infiltrate the technology systems that run these cars. What should states and localities be thinking about in terms of a regulatory infrastructure that will allow this technology to flourish in a safe manner?

Answer. There are two unique factors I believe will drive the regulation of this technology at the Federal level, more than at the state level. First, it is a very complex capability that involves integration of multiple advanced technologies in sensing, signal processing, machine learning, Artificial Intelligence (perception, reasoning, . . .) and mobile communications. This complexity will require significant resources in test centers and test configurations—and deep technical expertise in specialized areas. Second, with the estimated market value well in the billions, there will be a rush to market before the technology is fully mature. In fact, we have already seen that and some of the results have been fatal.

To make this technology safe for all conditions (everyday conditions as well as rare events), I believe we will rely heavily on the national test centers. These centers are best equipped to study and characterize the extended operating conditions (*e.g.,* someone walking out behind a car at night, a white tractor trailer pulling in front of the car when the sun is positioned such that it blinds the sensors,. . .). These centers should have strong ties to universities (most of them do) because universities are uniquely postured to provide unbiased technical expertise. It is for this reason, I suggested imitating the defense (and energy) FFRDC or UARC programs. Lastly, regulations should be developed in a data-driven framework so as not to overburden and slow down adoption of the technology.

States can have an active role in this technology by working with the test centers to make sure their unique geographic conditions are represented in the test scenarios. They should also supply data from state run investigations into accidents so that vehicles can mature much like the airline industry has over the years. States can also help speed adoption through infrastructure projects like dedicated limited access lanes, similar to bike lanes, for the last mile. Well-marked road networks will help provide guidance for the algorithms, and new civil infrastructure projects should consider that vehicles will soon begin communicating with signage, stoplights and each other.

Question 2. My state is very sparsely populated especially in the North. There is always a question in rural America, of how we will get this technology off the ground and make sure rural communities aren't left behind. How are we going to leverage what we need to leverage, and get this technology out to the least densely populated places in our country, so that everybody has the freedom and economic advantage that this technology poses?

Answer. Rural areas are likely to poise certain challenges for the vehicles that need to be addressed as the technology is developed and tested. First, these vehicles are safer when they are slower because they have more time to react. At first glance, one may think this improves safety in rural areas, but many rural areas have winding roads with limited visibility; and in the case of northern New Hampshire, mountainous terrain that can affect communications between vehicles through obscuration. Roads in rural areas may also be more challenging for these vehicles because they may be narrower and may have less defined markings, making it more difficult for the algorithms to detect road boundaries. These problems are likely not insurmountable but need to be addressed through research, development and testing to make this technology safe for all.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MAGGIE HASSAN TO TIM KENTLEY-KLAY

Question 1. As a former Governor, I recognize that there are ways that state and local governments can work to accommodate and help launch this technology, as well as ensure that it is safe and appropriately regulated. That is particularly important when we recognize that there are bad actors out there that would like to try and infiltrate the technology systems that run these cars. What should states and localities be thinking about in terms of a regulatory infrastructure that will allow this technology to flourish in a safe manner?

Answer. Thank you for the question. As this technology comes to market, states and localities should consider ways to encourage interaction between developers of this technology and state and local law enforcement and first responder communities. The model that exists in California is useful for others. In California, the DMV has promulgated rules for autonomous vehicle (AV) developers to generate a law enforcement interaction plan, to share that plan with the California Highway Patrol, and also to notify local authorities.

Question 2. My state is very sparsely populated especially in the North. There is always a question in rural America, of how we will get this technology off the ground and make sure rural communities aren't left behind. How are we going to leverage what we need to leverage, and get this technology out to the least densely populated places in our country, so that everybody has the freedom and economic advantage that this technology poses?

Answer. This is a very good question. It is important that everyone enjoy the safety, mobility, and sustainability opportunities that AV technology can bring to the market. The deployment of fully autonomous vehicles across the U.S. will not happen overnight, and the initial vehicle costs are likely to high to sell to individual consumers. Over time, however, the availability of the technology is expected to expand across the country. Additionally, Level 2 and Level 3 (ADAS) autonomous systems will likely be available for individually owned vehicles that are sold in rural areas. Even just in the past few years, semiautonomous ADAS technologies have made driving safer. It is important to know that there are different business models to bring automated and semi-automated technologies to market. Zoox's particular model focuses on deployment in dense areas. But the technology that companies like Zoox are developing through cutting-edge R&D will make automotive travel safer, period, throughout different geographical regions, both urban and rural.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MAGGIE HASSAN TO MICHAEL MANSUETTI

Question 1. As a former Governor, I recognize that there are ways that state and local governments can work to accommodate and help launch this technology, as well as ensure that it is safe and appropriately regulated. That is particularly important when we recognize that there are bad actors out there that would like to try and infiltrate the technology systems that run these cars. What should states and localities be thinking about in terms of a regulatory infrastructure that will allow this technology to flourish in a safe manner?

Answer. Bosch agrees that cybersecurity is an issue of great importance. Automakers and suppliers are actively working together to advance the cybersecurity state of the art and to define best practices to secure vehicle systems. Coalitions such as the Auto-ISAC promote entities to work together at an industry level, which helps to coordinate and develop standard procedures and protocols. Through the Auto-ISAC, members can report incidents, exploits, threats and vulnerabilities from testing, consumer reports or security research, which encourages industry-wide sharing and maturity.

Bosch strongly supports a layered approach to vehicle cybersecurity, in alignment with the approach encouraged by NHTSA in its 2016 Cybersecurity Best Practices. Further, Bosch is committed to providing products that meet or exceed industry guidelines to minimize cybersecurity threats. With the Bosch group of companies we have a leading team of security specialists in the automotive sector, ESCRYPT, which has enabled us to design a layered approach to enable intrusion detection and mitigate against cyber-attacks during the entire lifecycle of a vehicle. The core layer protects the integrity of each individual ECU (electronic control unit) with secure updates and defined privileges. The second layer focuses on the in-vehicle network by protecting the integrity of critical signals. For example, Bosch uses AUTOSAR-standardization to support authentic communication between different vehicle systems. The third layer focuses on securing the E/E (electric/electronic) architecture

by protecting and separating domains. Lastly, the fourth layer includes vehicle firewalls and security standards for communication and external interfaces. When protecting against external attacks, this is the first line of defense, which protects the safety and integrity of the vehicle and privacy of the driver.

Bosch supports a framework that allows the industry to continue to adapt to rapidly changing technology and ever-evolving threats. The automotive industry has been proactive in continuing to develop a robust cybersecurity system to protect users. Bosch supports the efforts of NHTSA, which has encouraged entities to develop layered cybersecurity protections for vehicles to minimize risks to safety. Bosch has maintained an open dialogue with NHTSA concerning this topic and our technology. We also supported the two NHTSA cybersecurity workshops, which were convened in 2016 and 2018 to help encourage and enable an information exchange between various government agencies and the industry. We believe that additional interaction between the industry and other interested stakeholders could help to create a greater understanding and awareness of this complex subject.

Question 2. My state is very sparsely populated especially in the North. There is always a question in rural America, of how we will get this technology off the ground and make sure rural communities aren't left behind. How are we going to leverage what we need to leverage, and get this technology out to the least densely populated places in our country, so that everybody has the freedom and economic advantage that this technology poses?

Answer. Automated driving functions have the ability to save lives in all types of communities. NHTSA's March 2018 Traffic Safety Facts report stated that 90 percent of all car accidents are caused by human error. Vehicle automation will continue to increase levels of safety for all road users.

Bosch believes that vehicle automation will likely first benefit drivers in rural communities by increasing safety through Level 1 and Level 2 automated systems (as defined by SAE J3016). Essentially, these categories include Advanced Driver Assistance Systems (ADAS) which support the driver but do not take control of the vehicle. According to NHTSA, 33.4 percent of all police-reported crashes in the U.S. in 2015 involved a rear-end collision with another vehicle as the first harmful event in the crash. ADAS technologies, such as forward collision warning and automatic emergency braking, can aid drivers in avoiding these collisions in both urban and rural environments. Similarly, partially automated driving functions, such as highway assist, can support drivers on highways and well-developed state and Federal roads by taking over the vehicle's longitudinal and lateral guidance. As one example, this can help drivers to maintain safety when driving in certain stressful and/or monotonous situations. Bosch has a long-term commitment to helping to make these technologies more affordable so that, in turn, they can penetrate into a greater portion of the overall vehicle fleet and to more lower-cost models. This commitment led Bosch to introduce a medium range radar in 2013, which offers carmakers an additional option when deploying driver assistance technologies. Bosch continues to believe that an update of the U.S. New Car Assessment Program (also known as the Vehicle 5-Star Rating) to include driver assistance systems would enable a more widespread understanding and adoption of these technologies in the U.S.

Furthermore, Bosch is working to develop highly automated vehicle technologies for urban environments and foresee that, as automated vehicle technology matures, it may become available to a wider group of communities. Greater penetration rates of highly automated vehicle functions could allow this technology to reach even the least densely populated areas in our country.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MAGGIE HASSAN TO LUKE SCHNEIDER

Question 1. As a former Governor, I recognize that there are ways that state and local governments can work to accommodate and help launch this technology, as well as ensure that it is safe and appropriately regulated. That is particularly important when we recognize that there are bad actors out there that would like to try and infiltrate the technology systems that run these cars. What should states and localities be thinking about in terms of a regulatory infrastructure that will allow this technology to flourish in a safe manner?

Answer. NHTSA has the regulatory authority over the design, construction and performance of motor vehicle safety and to mitigate risks of harm, including risks that may arise in connection with ADSs. The U.S. Department of Transportation restated NHTSA's enforcement authority with respect to ADSs in *A Vision for Safety 2.0* and clarified and delineated Federal and State regulatory authority. I would note that NHTSA has shown it will move aggressively to investigate any AV inci-

dents. One of NHTSA's main recommendations to States that want to encourage ADS adoption was to review their existing laws and regulations for language that might create unintended barriers to ADS operation.

That said, some of the most useful things States and localities can be doing to facilitate optimal conditions for automated vehicles would be to ensure that infrastructure is in good repair, such as roads and lane markings. Cities and localities should also be planning today for mobility needs soon to come, such as pick up and drop off zones, truly connected street signals and charging station infrastructure.

Question 2. My state is very sparsely populated especially in the North. There is always a question in rural America, of how we will get this technology off the ground and make sure rural communities aren't left behind. How are we going to leverage what we need to leverage, and get this technology out to the least densely populated places in our country, so that everybody has the freedom and economic advantage that this technology poses?

Answer. Fortunately, much of the life-saving ADAS technologies known as SAE Levels 1 and 2 automation are available in today's vehicles such as lane departure warning and automatic emergency braking. These systems help keep passengers safer on rural roads where the percentage of crashes are higher based on vehicles miles traveled.

Future mobility transportation services in rural areas could include automated shuttles in partnership with hospitals or health care centers or on demand shared mobility services for elderly individuals who are no longer driving, allowing them to retain their mobility and age in place.

It is interesting to note that providing mobility access to older persons in rural districts is a primary motivation for exploring this technology in Japan and for its automakers and technology companies. In the U.S. the focus has been more on serving urban and suburban districts, however different use cases will be pursued across the board and there are many compelling aspects of rural use.

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