Testimony of
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Subcommittee on Highways and Transit

Hearing on

How Autonomous Vehicles Will Shape
the Future of Surface Transportation

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Chairman Petri, Ranking Member Holmes Norton, and members of the Committee, I appreciate this opportunity to testify before you on automated vehicles and the implications for the future of surface transportation.

The future of the automobile is extremely bright. Increasingly, a car's capabilities are determined more by its electronics than by its mechanics. This is bringing countless innovations that improve driver comfort, provide useful information and entertainment, and, most importantly, advance safety.

As I have stated in prior testimony before Congress, safety is the National Highway Traffic Safety Administration's (NHTSA) top priority. Our programs are all designed to reduce crashes resulting in deaths and injuries. According to estimates, there were 33,561 fatalities on America's roadways in 2012. This represents an increase of about 3.3 percent as compared to the 32,367 fatalities that occurred in 2011. If these projections are realized, 2012 will be the first year with a year-to-year increase in fatalities since 2005. In addition to the devastation that these crashes cause to families, the economic costs to society reach into the hundreds of billions of dollars. Automated vehicles can potentially help reduce these numbers significantly.

Before getting into automated vehicles, I would like to highlight some of the work the agency has done to improve vehicle occupant survivability, primarily by advancing the vehicle's crashworthiness. Through technologies such as seat belts and air bags, occupants are more likely to survive a crash than they were 20 or 30 years ago. The agency will continue working on improvements to crashworthiness exemplified by recent final rules on roof strength and preventing occupants from being ejected in crashes. Our current research efforts are aimed at developing improvements to our child safety standards; a new frontal crash test for adults, the elderly, and pedestrians; advancing batteries and other alternative fuel research; and improving our understanding of crash injury and impact mechanisms through advanced biomechanics to develop future crash test dummies and models.

Advanced Braking Technologies. At the same time, there are exciting prospects for improving roadway safety through new crash avoidance technologies. Recognizing the promise these technologies hold, the agency has been aggressively pursuing many of the emerging technologies that are now deployed on new vehicles. We believe advanced technologies, such as electronic stability control, can mitigate a crash or even prevent it from occurring in the first place.

To that end, I am pleased to highlight the "Significant and Seamless" initiative that we recently announced. Significant and Seamless aims to address the areas in highway safety where the industry can fast-track existing technology. One major component of the initiative is Forward Collision Avoidance and Mitigation, which is a sensor-based vehicle technology that could detect an imminent forward crash with another vehicle or pedestrian. In 2012, one-third of all police reported crashes involved a rear-end collision with another vehicle as the first harmful event in the crash. The system would alert the driver to take corrective action or automatically apply the brakes to assist in preventing or reducing the severity of the crash.

I believe that the agency's work on crash avoidance research is the foundation for automated vehicles. We are actively evaluating the newest technologies that incorporate active braking in addition to warning drivers to avoid crashes. In particular, NHTSA is focusing its efforts on dynamic braking and crash-imminent braking systems. Such technologies employ radar, camera, lidar or the fusion of these technologies to detect and track vehicles or objects in the forward path and activate the brakes if the driver fails to do so or supplement the driver's braking to avoid or mitigate collisions. We are also evaluating whether enhancements to these systems could be robust enough to detect and avoid pedestrian impacts. The agency estimates that these technologies could impact approximately 900,000 rear-end (vehicle to vehicle) and 29,000 pedestrian crashes each year and thus offer the potential for substantially reducing property damage, injuries, and fatalities associated with motor vehicle crashes. NHTSA is currently evaluating system performance in a variety of crash scenarios and under controlled test conditions to develop new ways in estimating the real world benefits these advanced systems could provide. We sought public comments on our initial findings in 2011 and have now conducted additional analyses and research in response to those comments. Based on its research, the agency has enough data to make an agency decision this year as to pathways to advance market penetration into the rest of the fleet.

Vehicle-to-Vehicle Communications. NHTSA, along with the Research and Innovative Technology Administration (RITA), and the Federal Highway Administration, have greatly accelerated our efforts to initiate and complete research on vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) platforms designed to increase driver situational awareness and reduce and mitigate crashes. We believe V2V technology will complement and ultimately merge with the advanced braking systems and other crash avoidance technologies that we are currently evaluating to shape the future of motor vehicle safety. V2V will give drivers information needed to make safe decisions on the road that cameras and radars just cannot provide. This added capability not only offers the potential to enhance effectiveness of current production crash avoidance systems, but also enables more complex crash scenarios, such as those occurring at intersections, to be addressed. We currently estimate V2V could potentially address about 80 percent of crashes involving non-impaired drivers once the entire vehicle fleet is equipped with V2V technology. This leading-edge technology also holds the potential for improving mobility and benefitting the environment by connecting vehicles not just with each other, but also with road infrastructure.

The V2V program has been developed around Digital Short-Range Communications (DSRC) technology that operates on Federal Communications Commission licensed spectrum. Located in the 5.9 GHz band, the physical characteristics of this spectrum is able to support data from a number of safety applications that require nearly instantaneous information relay. Since this spectrum was first allocated, the Department has conducted significant research developing the concept, supporting consensus standards both in the U.S. and with other Nations, and working with the auto manufacturers on coordinated V2V technology development. The Federal Communications Commission is considering making portions of the 5GHz spectrum, including the 5.9GHz spectrum that DSRC relies on, available to accommodate growing data transmissions from unlicensed devices, such as Wi-Fi. I recognize the FCC will look at "harmful interference" as part of its consideration and would like to note that, in order to provide a reliable and trusted public safety service, current DSRC enabled safety devices require instant availability to the medium to meet safety requirements. In other words, a DSRC transmitter needs to be able to transmit whenever it senses the requirement to transmit, so that the basic safety message is immediately shared with recipients in real time to be useful. Thus, DOT would initially define "harmful interference" with safety as anything that prevents or delays access to the desired channel, or otherwise pre-empts the applications from providing its life safety capability.

For passenger vehicles, we have established a collaborative research effort with a consortium of automobile manufacturers to facilitate the development and are exploring possible deployment of models for V2V communication safety systems. The project is completing the development and testing of several safety applications, addressing interoperability issues, and evaluating safety benefits for a limited set of applications. We started by holding driver acceptance clinics across the country between August 2011 and January 2012. The evaluation included more than 700 drivers who experienced crash warnings while driving vehicles. The feedback from drivers was overwhelmingly positive, with over 90 percent expressing a desire for such a system in their personal vehicles.

This past August, the Department completed the Connected Vehicle Safety Pilot Model Deployment in Ann Arbor, MI. The Model Deployment encompassed various types of vehicles that included a mix of integrated, retrofitted, and aftermarket vehicle safety systems. This program demonstrated V2V and V2I safety applications, interoperability, and scalability in a data rich environment and provided real-world field data that we are using to develop a better understanding of the operational policy issues associated with V2V and V2I deployment. The safety pilot program enlisted approximately 3,000 specially equipped vehicles to operate in day-to-day driving and provided an opportunity to collect the first-of-its-kind real world data that cannot be duplicated in a laboratory setting. It represents the largest test ever of connected vehicles in a real-world environment. Given the potential of this transformative technology, we have accelerated our efforts. NHTSA is using the results from the Safety Pilot and other studies to decide this year whether to further advance the technology through regulatory action, additional research, or a combination of both. We expect to issue decisions on light duty vehicles this year, followed by a decision on heavy-duty vehicles in 2014.

The Federal Highway Administration (FHWA) has actively conducted research in support of developing a cooperative vehicle-highway system that enables vehicle automation. This work includes studying the impacts of platooning commercial vehicles through Cooperative Adaptive Cruise Control, or CACC. CACC will allow significant reductions in the headway between connected-automated vehicles with improved safety at highway speeds, greater use of existing lane capacity, and improvements in fuel economy (up to 20 percent savings). FHWA's other efforts include working with public agencies and vehicle manufacturers to better understand how a connected infrastructure system, including roads, sensors, and traffic control devices, can interact with and support automated or partially automated vehicles. And the FHWA provides the conduit by which the opportunities and challenges of vehicle-highway automation will be coordinated with State Departments of Transportation and local and Tribal agencies.

Automated Vehicles. Recently, traditional and non-traditional auto companies have unveiled research projects to develop what some call "autonomous" (self-driving) vehicles that can perform certain driving functions automatically. These companies identify safety as one of the compelling factors favoring automation. To accomplish the most sophisticated self-driving applications, they envision a system of cameras, radar, lidar, vehicle-to-vehicle communications and other sensors integrated with sophisticated algorithms that can monitor the road in an increasingly wide variety of roadway, weather, and traffic scenarios. Such systems have greater awareness and can more rapidly and reliably make decisions than the average driver. Not surprisingly, this vision has captured the Nation's attention. What was once previously thought of as science fiction and decades away from reality may now appear to be just around the corner, particularly as some of these companies are touting that they will have a commercially available vehicle in the next five years.

Vehicle manufacturers have already begun to offer, and in some cases, such as Electronic Stability Control, NHTSA has already regulated what we call single function automated systems. Manufacturers continue to develop these systems and are now combining functionalities to achieve higher levels of automation. Some vehicle manufacturers indicate that consumers will see some of these more advanced combined systems in the U.S. in the next few years but full self-driving is several years away. NHTSA has been actively involved in researching the near term technologies because we already believe many of them hold great safety promise. For example, NHTSA is engaged in research to evaluate the effectiveness of currently available automated braking systems in avoiding or mitigating crashes. As part of this research, the agency is partnering with a broad set of stakeholders to develop test procedures and to evaluate the technologies and methods to assess their potential safety benefits, as previously mentioned.

NHTSA conceives of these many and varied innovations as three distinct streams of technological change and development that are occurring simultaneously — (1) in-vehicle crash avoidance systems that provide warnings and/or limited automated control of safety functions; (2) crash avoidance systems enhanced by V2V communications; and (3) self-driving vehicles.

The confluence of these three streams of innovation has created a fair amount of confusion in making distinctions between different concepts and in finding commonly understood category descriptions. NHTSA finds that it is helpful to think of these emerging technologies as part of a continuum of vehicle control automation. The continuum, discussed below, runs from vehicles with no active control systems all the way to full automation and self-driving. While NHTSA is conducting research along the entire automation continuum, our emphasis initially is on determining whether those crash avoidance and mitigation technologies that are currently available (or soon to be available) are not only safe, but may also be effective in reducing crashes. Because these same technologies are the building blocks that may one day lead to a driverless vehicle, we have also begun research focused on safety principles that may apply to even higher levels of automation, such as driver behavior in the context of highly automated vehicle safety systems.

NHTSA has proposed definitions for five levels of automation to allow for clarity in discussing this topic with manufacturers, policymakers, and other stakeholders. The definitions cover the complete range of vehicle automation, ranging from vehicles that do not have any of their control systems automated (level 0) through fully automated vehicles (level 4).

Level 0—No Automation. At the initial Level 0, the driver is in complete control of the primary vehicle controls (steering, brake, and throttle) at all times, and is solely responsible for monitoring the roadway and for safe operation of all vehicle controls. Vehicles that have certain driver support or convenience systems, but do not have control authority over steering, braking, or throttle, would still be considered Level 0 vehicles. Examples include systems that provide only warnings (e.g., forward collision warning, lane departure warning, blind spot monitoring) as well as systems providing automated secondary controls such as wipers, headlights, turn signals, hazard lights, etc. Although a vehicle with V2V warning technology alone would be considered Level 0, that technology could significantly augment, and could be necessary to fully implement, many of the technologies described below. Furthermore, it would be capable of providing warnings in several scenarios where sensors and cameras cannot (e.g., vehicles approaching each other at intersections).

Level 1—Function Specific Automation. Level 1 automation involves one specific control function that is automated (note: a Level 1 vehicle may feature multiple automated functions, but they operate independently from each other). The driver still maintains overall control, and is solely responsible for safe operation, but can choose to cede limited authority over a primary control. Examples of Level 1 automation include:

- adaptive cruise control, where the driver sets a specific speed and does not have to continue pressing the accelerator;
- electronic stability control, where the vehicle automatically reduces power to the wheels and/or applies brakes when cornering too aggressively; or
- dynamic brake assist, where the vehicle automatically provides additional braking power if it senses that the driver's braking input is insufficient to avoid a collision.

The vehicle may have multiple capabilities combining individual driver support and crash avoidance technologies, but it does not replace driver vigilance and does not assume driving responsibility from the driver. The vehicle's automated system may assist or augment the driver in operating one of the primary controls—either steering or braking/throttle controls (but not both). As a result, there is no combination of vehicle control systems working in unison that enables the driver to be disengaged from physically operating the vehicle by taking hands off the steering wheel *and* feet off the pedals at the same time.

Level 2—Combined Function Automation. Level 2 automation involves at least two primary control functions designed to work together to relieve the driver of control of those functions. Level 2 automated vehicles share authority allowing the driver to cede active primary control in certain limited driving situations. Combining adaptive cruise control with lane keeping assistance would be an example of Level 2 automation.[1] The driver is still responsible for monitoring the roadway and is expected to be available for control at all times and on short notice. The system can relinquish control with no advance warning and the driver must be ready to take control of the vehicle safely. The major distinction between Level 1 and Level 2 is that, at level 2, in the specific operating conditions for which the system is designed, the driver can disengage from physically operating the vehicle by taking hands off the steering wheel *and* feet off the pedals at the same time.

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[1] Adaptive cruise control utilizes sensors (often radar) to automatically adjust speed to maintain a safe distance from vehicles ahead. Lane keeping systems will automatically take steps (through steering adjustments) to keep the vehicle in its lane if sensors detect that the vehicle will depart from the lane.

Level 3—Limited Self-Driving Automation. Level 3 automation enables the driver to cede full control of all steering, brake, and throttle functions to the vehicle. The driver is expected to be available for occasional control, but with a comfortable transition time that will enable the driver to regain situational awareness. The vehicle is designed to ensure safe operation during the automated driving mode, observing all rules of the road. An example would be an automated or self-driving car that can determine when the system is no longer able to support automation, such as entering a construction area. At this point, the vehicle signals the driver to reengage the driving task. The major distinction between Level 2 and Level 3 is that, at Level 3, the vehicle is designed so that the driver is not expected to constantly monitor the roadway while driving and provides sufficient time for the driver to reengage in driving.

Level 4—Full Self-Driving Automation. The vehicle is designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip. Such a design anticipates that the driver will provide destination or navigation input, but is not expected to be available for control at any point during the drive. This includes both occupied and unoccupied vehicles. By design, safe operation rests solely on the automated vehicle system.

By ensuring that our research plan includes the entire automation continuum, the agency strives to remain knowledgeable about the full range of potential benefits and risks of increasing vehicle automation. The agency's work on automated vehicles is designed to—

- address safety questions about driver engagement and re-engagement across levels of automation;
- evaluate concepts of operation and development of system requirements; and
- provide guidelines for automated sensing and control.

As we continue our work on Level 1 automation and our efforts to calculate the safety benefits that those single-function systems may offer in the near term, we have begun new research on Levels 2–4. NHTSA is working cooperatively with other DOT agencies on this research, given its relevance to the intermodal Intelligent Transportation Systems program. We are also engaged in a broader policy development process across the Executive Branch. For our part, we have identified three key areas for preliminary research—(1) human factors and the human-vehicle interface; (2) initial system performance requirements; and (3) electronic control system safety. NHTSA's research will inform policy decisions, assist in developing an overall set of requirements and standards for automated vehicles, identify any additional areas that require examination, and build a comprehensive knowledge base for the agency as automated system technologies progress.

Recommendations for State Actions Concerning Self-driving Vehicles. Several states have enacted legislation expressly authorizing operation of "autonomous" vehicles within their borders under certain conditions. Generally, these laws seem to contemplate Levels 3 and 4. We offer these recommendations to state drafters of legislation and regulations governing the licensing, testing, and operation of self-driving vehicles on public roads in order to encourage the safe development and implementation of automated vehicle technology, which holds the potential for significant long-term safety benefits. In general, we believe that states are well suited to address issues such as licensing, driver training, and conditions for operation related to specific types of vehicles. However, in light of NHTSA's relative expertise and national regulatory authority over vehicle safety, and given the quickly changing technologies involved, we are concerned about whether state regulation of the automated vehicle technologies (as opposed to their operators or operations) is feasible or advisable. Such regulation at this time may stifle innovation needed to improve safety and reliability. Should states adopt standards for the regulation of automated vehicle technologies, NHTSA will need to evaluate their relationship to Federal Motor Vehicle Safety Standards. Moreover, we do not recommend at this time that states permit operation of self-driving vehicles for purposes other than testing.

While the agency does not believe that self-driving vehicles are currently ready to be driven on public roads for purposes other than testing, I would like to emphasize that we are encouraged by innovations in automated driving and their potential to transform our roadways. For states interested in enacting legislation to support self-driving vehicles, NHTSA recommends that states—

(1) Ensure that the driver understands how to operate a self-driving vehicle safely through a driver-licensing program.
(2) Ensure that on-road testing of self-driving vehicles minimizes risks to other road users. This includes certifying that the vehicle has already operated for a certain number of miles in self-driving mode without incident prior to testing the vehicle on public roads.
(3) Limit testing operations to roadway, traffic, and environmental conditions suitable for the capabilities of the test self-driving vehicles. We encourage states to consider appropriate limitations on the conditions in which a vehicle may be operated in self-driving mode.
(4) Establish reporting requirements to monitor the performance of self-driving technology during testing.
(5) Ensure that the process for transitioning from self-driving mode to driver control is safe, simple, and timely.
(6) Ensure that test vehicles have the capability to detect, record, and inform the driver that the automated systems have malfunctioned.
(7) Ensure that installation and operation of any self-driving vehicle technology does not disable any Federally required safety features or systems. Federal law prohibits making inoperative any Federally required safety system and the installation of self-driving technologies should not degrade the performance of any of those Federally required systems or the overall safety of the vehicle.
(8) Ensure that self-driving vehicles record information about the status of the automated control technologies in the event of a crash or loss of vehicle control.

NHTSA does not recommend that states authorize the operation of self-driving vehicles (Levels 3 - 4) for purposes other than testing at this time. We believe that there are technological and human factor issues that must be addressed before self-driving vehicles can be made widely available. Self-driving vehicle technology is not yet at the stage of sophistication or demonstrated safety capability that it should be authorized for general driving purposes. As innovation in this area continues and the maturity of self-driving technology increases, we will reconsider our present position on this issue.

Driver Vehicle Interfaces for Warning Systems and Automated Vehicles. Recognizing the risks of driver distraction, vehicle warning systems introduce a new set of challenges to the driver. Many current crash avoidance systems provide a warning to the driver, expecting the driver to take appropriate action (engage the brake or steer) to avoid a crash. In order to determine if regulations or standardization is needed, there are several issues we need to understand better, such as: will the driver understand the warning systems when they activate given the variety in the vehicle fleet, will the driver become startled if the vehicle intervenes to avoid a crash, or is there a better way to warn the driver?

We are conducting extensive human factors research with the goal of developing requirements for the driver-vehicle interface for automated vehicles. The objective is to ensure that drivers can safely and seamlessly transition between automated and non-automated vehicle operation, and that any additional information relevant to safe operation is effectively communicated. The research will primarily focus on Level 2 and 3 systems. As new automated driving concepts emerge, we will evaluate the need for driver training in automated systems. Additionally, NHTSA will be developing test and evaluation tools (simulators, test vehicles, etc.) to evaluate driver and system performance for various automated vehicle concepts.

As a first step toward completing research on these issues, the agency is evaluating emerging Level 2 and Level 3 system concepts to answer fundamental human factors questions. The evaluation will examine how drivers react and perform in these types of automated vehicles. In addition, we will consider driver vehicle interface concepts that may be needed to ensure that drivers safely transition between automated driving and manual operation of the vehicle. Ultimately, we want to improve motor vehicle safety by defining the requirements for automation in normal driving that are (1) operationally intuitive for drivers under diverse driving conditions; (2) compatible with driver abilities and expectations; (3) supportive of improving safety by reducing driver error; (4) operational only to the extent granted by the driver and always deferent to the driver; and (5) secure from malicious external control and tampering. Through this research, we hope to develop recommendations for specific requirements needed for the driver-vehicle interface to allow safe operation and transition between automated and non-automated vehicle operation.

As you can see, the promise of advanced vehicles that can avoid crashes is extremely bright. While there are certainly risks with any emerging technology, I firmly believe that, when this risk is properly identified, understood, and mitigated, we can minimize it and fully reap the potential benefits. There are a lot of exciting innovations coming, and NHTSA is working hard, as it has done in the past and will continue to do in the future, to ensure that all vehicles on the Nation's roadways are safe and reliable. I thank you again for this opportunity to testify, and I am happy to take questions.