Testimony of
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Hearing on

The Road Ahead:
Advanced Vehicle Technology and Its Implications

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Chairman Rockefeller, Ranking Member Thune, and members of the Committee, I appreciate this opportunity to testify before you on what, in my slightly biased opinion, is an extremely exciting subject—the future of the automobile.

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 many times 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 early estimates, there were over 34,000 fatalities on America's roadways in 2012. This represents an increase of about 5.3 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. The advanced safety technologies we are discussing today can help reduce these numbers significantly.

Crashworthiness to Crash Avoidance. We have done a lot 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.

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 these technologies can mitigate a crash or even prevent it from occurring in the first place. For example, because of the agency's research on electronic stability control (ESC), we issued a rule requiring that technology on all new light vehicles since model year 2011 be equipped with ESC to help drivers maintain control of their vehicle in conditions where they might otherwise lose control. Other technologies such as forward crash warning and lane departure warning, both of which help drivers avoid dangerous crash scenarios, are being recognized in NHTSA's vehicle rating program (the New Car Assessment Program, known as NCAP) to help educate the public about the life saving potential that they hold. We continue to evaluate even more advanced technologies that are becoming available as options in production vehicles today. For example, some of these technologies are able to sense an impending crash and either apply the brakes for the drivers if they fail to do so, or are smart enough to know when the driver is not applying enough braking force and supplement the braking force to avoid or mitigate the collision.

NHTSA believes it has the capabilities—and the responsibility—to estimate the effectiveness of these crash avoidance systems, without waiting for years of crash data, in order to make regulatory decisions sooner and save more lives. Without a doubt, the potential for emerging technologies to transform cars and improve safety is breathtaking.

Auto manufacturers are equipping cars with lasers, cameras, radars, and various sensors that enable features unimaginable a few years ago. NHTSA has been studying and evaluating many of the building block technologies that will enable innovations, and this is just the beginning. The automotive technologies that we see are rapidly evolving, and NHTSA is working to understand the potential benefits as well as identify new challenges that they will bring to drivers.

The Transportation Research Board (TRB) published a report last year titled *The Safety Challenge and Promise of Automotive Electronics: Insights from Unintended Acceleration*.[1] In this report, the TRB found that "electronics systems have become critical to the functioning of the modern automobile" and that these systems are interconnected with one another. These interconnected electronics systems are creating opportunities to improve vehicle safety and reliability, but are also creating new and different safety and cybersecurity risks. Furthermore, these electronics systems present new human factors challenges for system design and vehicle-level integration. I am happy to report on our efforts to address these challenges.

Crash Avoidance Research. For the past several years NHTSA has been engaged in research related to many types of crash avoidance systems, including both those that warn the driver to take appropriate action and those that automatically affect a vehicle control function. Much of our early effort was focused on system performance and finding new ways to estimate the effectiveness of these systems. That research led the agency to mandate ESC and incorporate systems like forward collision warning and lane departure warning as a recommended technology into the NCAP program. We recommend that consumers look for these particular technologies when a manufacturer demonstrates the technology on its vehicle meets the NCAP performance specification. We are also considering adding additional advanced crash avoidance technology to the current list as a way to (1) inform the consumer and (2) enable the market to pull these emerging technologies into the mainstream. Our most recent analysis indicates that consumers do find the information helpful and manufacturers are increasing the availability of these technologies on new vehicles. We recently published a notice seeking public input on what new technologies should be included in the program and we plan to make a decision on the next advanced technology in FY 2013. Using a more naturalistic setting, our research is now evaluating how our earlier estimates for the benefits of the collision warning systems compare with the learning and improvements that manufacturers have made over the years to these systems. We also hope to learn how drivers are using these systems in their everyday driving.

NHTSA is also 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

[1] www.nap.edu/catalog.php?record_id=13342

avoid or mitigate collisions. We are also evaluating whether enhancements to these systems could be robust enough to detect and avoid pedestrian impacts. 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. We will complete our work to inform an agency decision later this year.

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 technology also holds great promise 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, this spectrum is uniquely capable of supporting 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.

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. This project is developing several safety applications, addressing interoperability issues, and evaluating safety benefits. 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.

Last August, Secretary LaHood launched the Connected Vehicle Safety Pilot Model Deployment in Ann Arbor, MI. The Model Deployment encompasses various types of vehicles that include a mix of integrated, retrofitted, and aftermarket vehicle safety systems. This program is demonstrating V2V and V2I safety applications, interoperability, and scalability in a data rich environment and provides real-world field data that can be used to develop a better understanding of the operational policy issues associated with V2V and V2I deployment. The safety pilot program enlists approximately 3,000 specially equipped vehicles to operate in day-to-day driving and provides 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. The data are collected on a routine schedule and our researchers are already digging into it. Given the potential of this transformative technology, we have accelerated our efforts. NHTSA will use 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.

Vehicle Cybersecurity. As the TRB noted, "electronics systems have become critical to the functioning of the modern automobile." Over the past several decades, the vehicle has evolved from primarily relying on mechanical systems to one with an increasing reliance on computing power and electronics. And with this evolution comes increased challenges, primarily in the areas of system reliability and cybersecurity—the latter growing more critical as vehicles are increasingly more connected to a wide variety of products. Whether the entry point into the vehicle is the Internet, aftermarket devices, USB ports, or mobile phones, these new portals bring new challenges.

NHTSA recognizes this challenge and the growing potential for remotely compromising vehicle security through software and the increased onboard communications services. NHTSA has generally regulated through performance standards developed for specific vehicle systems or sub-systems to address a specific type of safety risk (e.g., frontal collision). However, with electronic systems assuming safety critical roles in nearly all vehicle controls, we are facing the need to develop general requirements for electronic control systems to ensure their reliability and security.

To address this new frontier, NHTSA established within the Office of Vehicle Safety Research the Electronics Systems Safety Research Division that will focus on these efforts. To support the new division, we have requested $2 million in our Fiscal Year 2014 budget proposal for vehicle electronics and emerging technologies research. This division provides NHTSA with a focal point that combines vehicle electronics and automotive engineering to address electronics and software technologies and their implications to vehicle safety. The funding would begin initial research focused on evaluating the safety of electronic control systems in five key areas—(1) functional safety design; (2) fail-safe strategies; (3) software reliability; (4) diagnostic and notification strategies; and (5) human factors considerations. Additionally, we will need to quantify and assess risk for both single vehicle and connected vehicle systems. We will examine and apply appropriate lessons learned from other industries, such as aviation and medical industries, where loss of life is the overriding concern in electronic system failures. We will identify and evaluate potential solutions and countermeasures and consider the need for additional standards or regulations. This will involve collaborating with a variety of stakeholders including the National Institute of Standards and Technology, the White House Office of Science and Technology Policy, the Department of Homeland Security, the Department of Defense, and many private industries.

The division is also focusing on issues related to cybersecurity. Because we recognize their importance in developing safety-critical systems, NHTSA will build off relevant voluntary industry standards and evaluate what manufacturers are already doing. We have initiated cybersecurity research, with the goal of developing a preliminary baseline set of threats and how those threats could be addressed in the vehicle environment. This work will complement and support the agency research to develop performance requirements for automated vehicles.

For the V2V program, our research is evaluating a layered approach to cybersecurity. Such an approach, if deployed, would provide defense-in-depth, managing threats to ensure that the driver cannot lose control and that the overall system cannot be corrupted to send faulty data. In partnership with the auto companies and other stakeholders we have developed a conceptual framework for V2V security. We are also developing countermeasures to prevent these security credentials from being stolen or duplicated. Additionally, we are developing protocols to support a V2V security system that is designed to share data about nefarious behavior and take appropriate action.

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. They envision a system of cameras, radar, lidar, and other sensors integrated with sophisticated algorithms that can monitor the road in an increasingly wide variety of roadway, weather, and traffic scenarios with greater awareness and 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 developing test procedures to evaluate the technologies and methods to assess their 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) V2V communications that activate various crash avoidance applications; 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 effective. 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.[2] 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.

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 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

[2] 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.

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.

Driver Distraction. In 2011, 3,331 people were killed in crashes involving a distracted driver, compared to 3,267 in 2010. An additional 387,000 people were injured in motor vehicle crashes involving a distracted driver, compared to 416,000 injured in 2010. Driver distraction is a very real problem on our roadways given the growing use of cell phones and other such handheld devices in the vehicle. We are also concerned whether new safety systems, with a variety of audio, visual, or haptic warnings, are appropriately designed and sufficiently effective. Additionally, we are concerned about non-safety applications causing further distractions.

Connectivity and Portable Devices. Drivers perform secondary tasks (communications, entertainment, informational, and navigation tasks not required to drive) using in-vehicle electronic devices by interacting with them through their user interfaces. The user interfaces of these devices can be designed to accommodate interactions that are visual-manual, auditory-vocal, or a combination of the two. Some devices may allow a driver to perform a task through manual manipulation with visual feedback, through voice command with auditory feedback, or a combination of the two. Given the potential for distraction, NHTSA focused new research in these two broad areas.

Last month, we issued voluntary guidelines for electronic devices installed in vehicles (at the time they are manufactured) whose use requires drivers to take their hands off the wheel or eyes of the road to use them.[3] Our goal in doing so is to encourage the design of in-vehicle device interfaces that minimize driver distraction associated with performing a non-driving task. The guidelines specify criteria and a test method for assessing whether a secondary task performed using an in-vehicle device may be acceptable for performance while driving. The guidelines also seek to identify secondary tasks that interfere too much with a driver's ability to safely control the vehicle and to categorize those tasks as ones that are not acceptable for performance by the driver while driving.

NHTSA will begin discussions very soon with the various stakeholder groups and organizations affiliated with portable and aftermarket devices. NHTSA values the input from the full range of stakeholders for portable devices, including device makers, operating system providers, cellular service providers, application developers, and industry organizations that represent these different groups. We are eager to listen to their input on how best to apply the visual-manual guidelines to this important device category.

In-vehicle and portable devices that use auditory-vocal interactions are on the rise and therefore must also be studied. These involve the driver controlling the device functions through voice commands and receiving auditory feedback from the device. NHTSA is conducting work in this new and complicated area to determine if guidelines are warranted. Because a single

[3] www.nhtsa.gov/About+NHTSA/Press+Releases/U.S.+DOT+Releases+Guidelines+to+Minimize+In-Vehicle+Distractions

device's driver interface could accommodate both visual-manual and auditory vocal interactions, NHTSA is evaluating appropriate auditory-vocal test procedures and acceptance thresholds that could be added to the visual-manual and portable distraction guidelines.

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.