Testimony of Glen W. De Vos
Vice President, Global Engineering & Services - Delphi Automotive

Senate Commerce, Science and Transportation Committee Hearing
"Hands Off: The Future of Self-Driving Cars"
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Thank you, Chairman Thune, Ranking Member Nelson, and Members of the Committee on Commerce, Science and Transportation, for giving me the opportunity to testify today on behalf of Delphi.

My name is Glen De Vos, and I am Vice President of Engineering and Services for Delphi Automotive. Delphi is a high-technology company that integrates safer, greener and more connected solutions for the automotive sector. We invest more than $1.7 billion annually into engineering development initiatives. In the U.S., Delphi operates major manufacturing facilities, technical centers, and/or administrative facilities in California, Michigan, Ohio, Indiana, New York, Mississippi and Texas that employ approximately 5,000 people. Delphi's technology portfolio places it at the center of vehicle evolution and innovation, making products smarter and safer as well as more powerful and efficient.

Given our proven expertise with market-leading original equipment manufacturers (OEMs) around the world and our broad automotive systems capabilities, we welcome the invitation to testify.

I would like to take this opportunity to thank the Committee for incorporating the Safety Through Informed Consumers (STICRS) Act into the Fixing America's Surface Transportation (FAST) Act which was signed into law last year. In particular, I would like to thank the bill's sponsors, Senators Heller and Markey, as well as Chairman Thune and Ranking Member Nelson for their successful efforts to get STICRS signed into law.

With the addition of STICRS, the FAST Act will speed the adoption of active safety technology, also known as Advanced Driver Assistance Systems (ADAS), by increasing consumer demand. The adoption of ADAS systems is a critical step on the road to automated vehicles since the same systems that will enable automated driving are part of today's active safety systems. I will talk more about the importance of these technologies later in my testimony.

Delphi is particularly pleased to testify today about the future of automated driving because the elements of the automated future all fit within Delphi's core strategy of producing products that make cars *Safe, Green and Connected*. To this end, in April of 2015, Delphi completed the first automated vehicle cross-country drive.

I believe many of the lessons learned from that drive will be instructive as Congress and the administration move aggressively forward to make the needed infrastructure and legal changes necessary to make autonomous vehicles a commercial success in the future. Accordingly, I will provide an overview of the cross-country drive, the existing technology that made it possible, and discuss some of the lessons learned from the trip.

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Description of cross-country drive

Delphi made history by completing a 15-state, 3,400-mile journey from San Francisco to New York City with a car that, 99 percent of the time, was driving without human input. The drive took place during daylight hours and included an engineer behind the wheel with the ability to assume control of the vehicle if the car encountered a situation the vehicle could not clearly navigate on its own.

Description of onboard technologies associated with drive

Delphi installed a broad suite of our active safety technologies on a 2014 Audi SQ5. The vehicle was equipped with the following technologies:

- **Radar systems**: Our vehicle uses a combination of short- and long-range radars--Electronically Scanning Radars (ESR) and Short Range Radars (SRR) in a 360^{o} configuration. The ESRs specialize in long-range sensing functions, such as adaptive cruise control and cross traffic detection.

- **Vision systems:** The vehicle is equipped with three cameras for vision-based perception: an ADAS camera, a high-resolution color camera, and an infrared camera. The ADAS camera is used for pedestrian, lane, and vehicle detection. The high-definition color camera is used for traffic light detection and the infrared camera provides redundancy for pedestrian and vehicle detection.

- **Lidar:** As opposed to the externally high-mounted, spinning lidars used in many other autonomous platforms, our vehicles use a fused system of lidars which are integrated around the periphery of the vehicle. This approach enables 360 degree coverage, while preserving the aesthetics of the vehicle. The lidars generate a high-resolution point cloud that is helpful for general object detection; particularly in densely packed urban environments. Each lidar is paired with one of our ESRs, which allows us to effectively fuse radar and lidar data.

- **Sensor fusion:** The perception system on Delphi's automated vehicles leverages our experience with multiple sensors through highly complex fusion. Radar, vision and lidar-based sensors each have unique strengths and weaknesses; fusing these sensors allows them to compensate for one another and provide an accurate picture of the driving environment with robust detection of vehicles, pedestrians, and general objects.

- **V2X:** Delphi's automated platforms make use of dedicated short-range communication (DSRC) for collaborative communication with infrastructure, such as traffic lights (V2I), other vehicles (V2V) and pedestrians (V2P). V2X communications provide redundancy that is especially useful in urban environments with numerous traffic signals, vehicles, and pedestrians.

- **Localization System:** Delphi uses precision GPS information for safely traveling through the driving environment; even when the infrastructure is marginal (e.g. poor lane markings). In situations with poor GPS reception, such as tunnels and urban canyons, our vehicles make use of a highly accurate IMU (inertial measurement system) for dead reckoning. Additionally, the environmental sensors on the vehicle can pick out key features of the environment for map-matching.

- **Drive-by-wire system:** The drive-by-wire system featured in Delphi's automated driving platforms is implemented in a manner that preserves the function of the production vehicle's steering and drivetrain. When manually operated, the vehicle drives exactly as a production vehicle would. When auto mode is engaged, the automated system uses the same vehicle input interfaces as a human driver, which allows passengers to directly see and feel how the vehicle is behaving. The automated driving system is completely separable from the stock system, which allows the driver to instantaneously assume full control of the vehicle at any time.

- **Driver State Monitoring:** Understanding the state of the driver is a vital aspect of automated driving. Delphi's automated driving platforms are equipped with state-of-the-art driver state sensing systems, which allow the vehicle to monitor the availability of the driver in situations where a takeover may be necessary. If the driver is found to be unavailable, the vehicle is capable of coming to a stop until it is safe to proceed.

- **Multi-domain controller:** As these active safety systems become more complex and computing technologies consume greater levels of processing power, Delphi's multi-domain controller brings together multiple electronic sub-systems, or domains, within a vehicle into a single, powerful control center. This technology makes it possible for vehicles to quickly and efficiently manage the massive flow of complex data through the vehicle, which is required for automated features to work well.

Some of these same technologies are available on cars today in consumer options such as Forward Collision Warning with Collision Imminent Braking, Lane Departure Warning, and Blind Spot Detection.

A key component of ensuring the vehicle could function was the integration of software and hardware. Vehicle technology is increasingly software based and dependent. If you don't get the software right, the car will not function.

Our vehicle performed flawlessly. It was able to make complex decisions necessary to drive safely across the country while, unlike human drivers, remaining alert the entire time.

Delphi engineers gathered more than two terabytes of data during the trip, including computer data and video footage of everything "seen" by the car. A few observations from our trip:

- Our vehicle was particularly cautious when approaching semi-trucks in adjacent lanes. In situations where our vehicle passed such large trucks, it remained in the center of its lane

rather than veering slightly to the far side of the lane. Engineers were able to adjust the programming to address this scenario.

- Artificial intelligence gaps remain that require our attention – such as "which vehicle has the right of way" upon approaching a four-way stop when one vehicle nudges forward to alert the other driver of its intention.
- We noted that HOV lanes are perfect for automated driving since lane markers are very clear. The idea of a dedicated lane may prove useful as automated cars become more mainstream.

Even with the use of radar, cameras, and other sensors, aggressive or speeding drivers can quickly appear during a lane-change, compromising the effectiveness of these technologies.

Lessons learned from the drive provide a foundation for understanding where we need to go from here.

Active safety ready and needed

One of the primary take-a-ways from the success of the cross-country drive is that we have available today in the consumer marketplace technology that, if more broadly adopted, will dramatically reduce deaths and injuries on our roads. Specifically, today's active safety technologies, or ADAS, operate well enough to drive a car on its own - 99 percent of the time. These technologies, when paired with a driver, can address one of the greatest causes of premature deaths – traffic crashes.

Every 30 seconds, there is a vehicular fatality somewhere in the world. That equates to 1.2 million people who die worldwide each year. It's a tragedy, and can be prevented. According to the World Health Organization, less than 20 years from now traffic injuries are projected to be the fifth leading cause of death worldwide – surpassing HIV/AIDS, cancer, violence, and diabetes. The impact is not just on lives lost, but on our global economy. Here in the United States, vehicle fatalities have declined with the use and widespread adoption of passive safety technologies such as seatbelts and airbags. However, progress toward further fatality and injury reduction has stalled, allowing over 33,000 fatalities annually in the US, and more than 200,000 serious injuries each year on our roadways. Additionally, vehicular crashes continue to be the number one cause of fatalities for people ages 4 to 34, with over 90 percent of crashes caused by driver error. The financial impact is also staggering, with one study estimating the total annual cost of road crashes in the United States alone to be over $231 billion.

Active safety technologies are the key to reducing crashes, injuries, and fatalities on our roadways. Government and industry groups have studied the benefit potential for these technologies for well over a decade. In particular, a recent study by the Insurance Institute for Highway Safety (IIHS) states a 31% reduction in fatalities is possible with full deployment of active safety systems across the vehicle fleet, namely, Forward Collision Warning with Collision Imminent Braking, Lane Departure Warning, and Blind Spot Detection. This reduction amounts to a potential savings of over 11,000 U.S. lives per year.

These technologies are not just life savers, but, as demonstrated by our cross-country drive, the building blocks for the automated cars of the future. A key element of broader penetration of active safety technologies in the US fleet is consumer awareness and demand.

How the government can help -- Modernize NCAP

This Committee's inclusion of STICRS in the FAST Act was a major step forward in driving consumer adoption of ADAS. National Highway Traffic Safety Administration (NHTSA) has responded and has announced its intentions to modernize the New Car Assessment Program, or NCAP – which includes the 5-star rating system that appears on all new vehicle window stickers – to require passenger vehicles to have ADAS systems in order to achieve a 5-star rating.

This is great progress and should dramatically increase the availability of active safety systems on vehicles at every price-point. It is critical that we capture these safety improvements quickly. STICRS requires NHTSA to promulgate its new NCAP rule within a year of enactment of the FAST Act. NHTSA has indicated its intention to meet this deadline, but it is important that the timeline does not slip.

Vehicle-to-Vehicle and Infrastructure (V2X) -- a critical element

In an automated future, cars will need to be able to communicate not just with their owner but also the surrounding environment, other vehicles and infrastructure. Knowing when traffic signals are going to change and where traffic is heaviest not only adds to the safety of the vehicle but allows cars to be driven, or drive themselves, more efficiently.

The roll-out of vehicle-to-vehicle and vehicle-to-infrastructure (together V2X) including in-vehicle Dedicated Short Range Communications (DSRC) systems that allow for V2X communication will be critical.

How can the government help? By protecting the needed spectrum and requiring V2X receivers be built into cars in the future

The Commerce Committee has already been active and helpful in negotiating an agreement that will allow the spectrum necessary for V2X to be protected from harmful interference without barring compatible uses. Obviously with any life-saving technology, any disruption in the communication signal from interference cannot be allowed. Keeping the necessary spectrum both available and free from harmful interference is critical as V2X communication systems are rolled-out in vehicles and infrastructure.

The STICRS rulemaking is not the only important policy issue requiring the release of a NHTSA rule. In August of 2014, the Department of Transportation announced it would issue a Notice of Proposed Rulemaking (NPRM) creating a requirement for adding V2V communications capacity to the US light vehicle fleet and minimum performance requirements for V2V devices and messages.

V2X can deliver important safety benefits in the mid-term and is a necessity for wide-spread autonomous vehicles adoption in the long-term. The release of the NPRM will be an important step forward.

In addition, it is important to not only consider DSRC in new vehicles, but also the manner in which existing vehicles can be retrofitted to accommodate DSRC requirements. There are approximately 262 million registered passenger vehicles on US roadways with the average vehicle age being 11.5 years. Unless retrofitting is built into the planning process, the roll-out of DSRC will take decades.

Rules of the road – need to permit driverless cars

In addition to supporting the technologies that are needed to enable automated vehicles, Congress, the Administration, and state governments will need to provide the flexibility necessary to enable driverless cars.

Uniform rules that allow for the safe operation of driverless vehicles in all 50 states will be critical. As production vehicles move from drive assist technology to full automation, varying requirements ranging from state mandates that licensed drivers must be in vehicles at all times, to federal requirements dictating the positioning of dashboard controls that presume a driver, will need to be assessed and addressed.

Another example would be the need to address the variation in lane markings across states and communities. During Delphi's cross-country drive, the automated vehicle encountered some roadways with wide white stripes, while others had narrow yellow markings. Some lane markings were new, others were faded, and some were marked with raised bumps. Delphi will have to further train its cameras to detect all kinds of lane markings, since that's one way autonomous cars keep themselves centered in a lane.

Consumer adoption – public's trust can be earned

A March 1, 2016 AAA survey of American drivers found that only one in five would trust a self-driving car. The same survey, however, found that over sixty percent of drivers would like active safety -- or ADAS – technologies on their vehicles. Active safety is clearly going to be critical to the transition to automated driving, not just because the underlying technologies are building blocks for autonomous vehicle but also because consumer acceptance of self-driving cars will develop as driver-assist technologies proliferate.

The bottom line is that the road to driverless vehicles is paved with life-saving drive-assist technologies that will make cars safer now, and into the immediate future, while setting the stage for fully autonomous vehicles.

Cyber security – a key element moving forward

Delphi is keenly aware of the cyber threats associated with today's connected vehicles, and is taking measures that will enable a safe and secure driving experience. Accordingly, Delphi has

committed to participate in the Automotive Information Sharing and Analysis Center (*Auto-ISAC*) to further improve cyber security threat awareness and coordination across the industry. The Auto-ISAC provides a forum for information exchange among entities in the automotive industry for the purpose of sharing trusted and timely cyber threat information about existing or potential cyber-related threats and vulnerabilities in light duty on-road passenger vehicle electronics and associated networks.

Delphi considers all aspects of a connected vehicle and associated embedded technology -- to include software, hardware, and architectural elements that connect the vehicle. While building products and systems according to OE customer specifications, our technical experts work to better understand vulnerabilities such that we can alert OEs and consumers to potential cyber threats – followed by working towards providing a solution.

Delphi has dedicated engineering and information technology resources focused on cybersecurity matters. To provide further leadership in this area, Delphi is working with several experienced organizations to ensure a coordinated approach to the safety and security of connected vehicles. These efforts are realized through various channels, including (1) active leadership and participation in the National Institute of Standards and Technology (NIST), Society of Automotive Engineers (SAE) and others; as well as working with Original Equipment Manufacturers (OEMs) to ensure that the products we engineer meet OEM specifications, and leverage open source and industry accepted information security protocols.

In addition, Delphi strategically engineers safety into technology. For example:

- Engine Control Units or ECUs – These devices are developed with a secure boot and programming functionality, so only valid and trusted programs and software are executed.
- Encryption – The wireless connectivity is protected using industry standards to protect the vehicle network and user's privacy. This includes security to authenticate and gain access (WiFi Protected Access 2 or WPA2), as well as transmission security across the wireless connection (using TLS or Transport Layer Security) across the broader network and internet.
- Device Connection – Leveraging Bluetooth to connect a user's personal devices, but ensuring that connection is via Secure Simple Pairing (or SSP) which allows for encryption of data between linked devices, thus providing additional security.

Delphi is also working with a number of organizations to ensure a coordinated approach to the safety and security of interconnected vehicles. These include:

- International Organizations: Adoption of ISO guidelines (including ISO 26262) to ensure a standardized approach to enabling a safe driving experience. Active leadership and participation in the Society of Automotive Engineers (SAE), National Institute of Standards and Technology (NIST), and others.

- Original Equipment Manufacturers (OEMs): Delphi ensures that products engineered by the Company meet the OEM specifications, and leverage open source and industry accepted information security protocols.
- Internal Structure and Governance: Delphi has a dedicated team of engineers, technology professionals, and legal professionals to provide the necessary oversight in the space of cybersecurity and interconnected vehicles. A steering committee meets regularly and provides appropriate guidance with respect to policies, procedures, and standards. Delphi considers this a very real threat that must be managed.

Pilots – can make a difference

The FAST Act set a great foundation to build towards the roll-out of widely-available automated vehicles. The Obama Administration's announcement of a ten-year, $4 billion effort to "accelerate the development and adoption of safe vehicle automation through real-world pilot projects" through the programs authorized by the FAST Act demonstrates the broad support for moving the US to an automated future. Clearly a coordinated multi-year effort is warranted and we look forward to working with this Committee, Congress and the Administration to make the effort a success.

Federal R&D – is important

Finally, Delphi supports Federal R&D efforts in this area. The ITS program plays an important role in enhancing the government's ability to assess new technologies and lay the foundation for their roll-out. ITS has focused its efforts recently on V2V and V2I roll-out -- both important objectives. ITS should place equal importance on needed analysis and research into active safety such as collision avoidance and mitigation technologies that are key building blocks for autonomous vehicles. Both V2V enabled and non-V2V enabled collision avoidance and mitigation technologies will be critical to the success of the driverless car. On-board active safety also has the added benefit of saving lives even before V2V communications technologies reach critical mass in the US fleet. Furthermore, non-V2V systems continue to operate in situations where the vehicle encounters communications interference. On-board active safety should be a priority for the ITS program.

Thank you again for this opportunity to testify before your Committee today. Delphi looks forward to playing an important role on the road to automated vehicles. As we look to a driverless future, we should work to democratize the availability of today's proven technology. Broad scale adoption of active safety will not only lay the foundation for the driverless cars of the future, but will save lives now. Delphi stands ready to assist this Committee as you forge the road ahead in advanced transportation technology, and I'll be happy to answer your questions.

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