THE FUTURE OF SURFACE TRANSPORTATION

HEARING

BEFORE THE

SUBCOMMITTEE ON RESEARCH AND TECHNOLOGY

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED THIRTEENTH CONGRESS

SECOND SESSION

JUNE 18, 2014

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Appendix I: Answers to Post-Hearing Questions

THE FUTURE OF SURFACE TRANSPORTATION

WEDNESDAY, JUNE 18, 2014

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON RESEARCH AND TECHNOLOGY
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to call, at 10:05 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Larry Bucshon [Chairman of the Subcommittee] presiding.

LAMAR S. SMITH, Texas
CHAIRMAN

EDDIE BERNICE JOHNSON, Texas
RANKING MEMBER

Congress of the United States
House of Representatives

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
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Subcommittee on Research and Technology

The Future of Surface Transportation

Wednesday, June 18, 2014
10:00 a.m. to 12:00 p.m.
2318 Rayburn House Office Building

Witnesses

The Honorable Gregory D. Winfree*, Assistant Secretary, United States Department of Transportation*

Mr. Scott Belcher*, President and CEO, Intelligent Transportation Society of America*

Mr. John Maddox*, Director of Collaborative Program Strategy, Texas A&M Transportation Institute and University of Michigan Transportation Institute*

Ms. Kristen Tabar*, Vice President, Technical Administration Planning Office, Toyota Technical Center*

Dr. Christopher P.L. Barkan*, Professor and George Krambles Faculty Fellow, Executive Director, Rail Transportation and Engineering Center, University of Illinois at Urbana-Champaign*

Mr. Troy Woodruff*, Chief of Staff, Indiana Department of Transportation*

U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON RESEARCH AND TECHNOLOGY

HEARING CHARTER

The Future of Surface Transportation

Wednesday, June 18, 2014
10:00 a.m. – 12:00 p.m.
2318 Rayburn House Office Building

PURPOSE

On Wednesday, June 18, 2014, the Research & Transportation Subcommittee will convene a hearing to review the research, development, and technology (RD&T) in surface transportation, including oversight on federally-sponsored research activities at the Department of Transportation (DoT). The hearing will give the Subcommittee an opportunity to understand current transportation RD&T activities ahead of a possible surface transportation reauthorization bill that Congress may consider later this session. Witnesses will represent a wide variety of stakeholders, including academia, industry, and government.

WITNESS LIST

- **Honorable Gregory D. Winfree**, Assistant Secretary for Research and Technology, United States Department of Transportation
- **Scott Belcher**, President and CEO, Intelligent Transportation Society of America
- **John Maddox**, Research Scientist, Texas A&M Transportation Institute
- **Kristen Tabar**, Vice President, Technical Administration Planning Office, Toyota Technical Center
- **Dr. Christopher Barkan**, Professor and George Krambles Faculty Fellow, Executive Director, Rail Transportation and Engineering Center, University of Illinois at Urbana-Champaign
- **Troy Woodruff,** Chief of Staff, Indiana Department of Transportation

BACKGROUND

Introduction

The U.S. Department of Transportation (USDOT) annually supports more than $1.1 billion in research, development, and technology deployment (RD&T) activities focused on surface modes of transportation (rail, transit, motor carrier and highway). USDOT classifies research funding into three main categories: applied, development, and technology. The first two categories are pre-implementation stage work, while the technology, or "T" classification, denotes that funds are being used for technology deployment or field demonstration.

The USDOT surface RD&T endeavor is conducted by a host of multi-modal Administrations: Those Administrations include the Federal Highway Administration (FHWA), the Federal Transit Administration (FTA), the National Highway Traffic Safety Administration (NHTSA), the Federal Railroad Administration (FRA), and the Federal Motor Carrier Safety Administration (FMCSA).

Department of Transportation R&D activities have traditionally been coordinated through the Research and Innovative Technology Administration (RITA). As part of the FY 2014 Omnibus bill, however, RITA was elevated into the Office of the Assistant Secretary for Research and Technology. The agency now refers to this office as the Transportation Planning, Research and Development (TPRD) within the Office of Science and Technology. This office coordinates USDOT's research and development activities and investments, awards and administers grants to universities, including 60 University Transportation Centers (UTCs), and sponsors advanced research.

Department of Transportation Research, Development and Technology (RD&T) Activities

Office of the Assistant Secretary for Research and Technology (ORT) [1]

The Office of the Assistant Secretary for Research and Technology is responsible for facilitating and reviewing the Department's research, development, and technology portfolio. The request includes $14.6 million for research and studies concerned with planning, analysis, and information development that is needed to coordinate research programs across the agency. ORT oversees the following programs, which are funded out of other Administration accounts: [2]

ORT RD&T Funding	FY 2014 Enacted		FY 2015 Request	
Intelligent Transportation Systems (FHWA)	$	100.0	$	113.0
Univ. Transportation Center (UTC) Program (FHWA)	$	72.5	$	82.0
Bureau of Transportation Statistics (FHWA)	$	26.0	$	29.0
Positioning, Navigation and Timing	$	1.6	$	1.6
Research, Development and Technology (Coordination)	$	0.5	$	0.5
Transportation Safety Institute*		-		-
Volpe National Transpiration System Center**		-		-

Budget in Millions of Dollars

[1] Formerly the Research and Innovative Technology Administration (RITA).
[2] http://www.dot.gov/sites/dot.gov/files/docs/OST-FY2015-Budget-Estimates.pdf
* Fee For Service
** Fee For Service

Federal Highway administration (FHWA)

The FHWA Research Development and Technology request for FY 2015 is $451 million[3]. Major research areas Under the Highway Research and Development Program include:

Program Activity	FY 2014 Enacted		FY 2015 Request	
Highway Research and Development	$	115.0	$	130.0
Technology Innovation Development	$	62.5	$	70.0
Intelligent Transportation System	$	100.0	$	113.0
University Transportation Centers	$	72.5	$	82.0

Budget in Millions of Dollars

Complementary to the above program areas, the FHWA R&D efforts are directed at advancing highway safety, improving mobility for people and commerce, maintaining infrastructure integrity, studying new information systems to provide actionable highway feedback to decision makers, promoting environmental sustainability, and long-term, high-risk research on disruptive technologies. [4]

Federal Transit Administration (FTA)

For FY 2015, FTA requests $60 million for the *Transit Research and Training* account.[5] These activities support the overarching goal of strengthening public transportation in the United States: $26 million for Research, Development, Demonstration and Deployment Projects such as advanced vehicle design. Other projects include control technologies for track, light rail and freight trains, low-cost track inspection technology, hybrid bus capabilities, and zero-Sulfur diesel fuel from non-petroleum sources.[6]

National Highway Traffic Safety Administration (NHTSA)

The NHTSA FY 2015 request for Vehicle Safety Research and Analysis is $38.3 million.[7] This request includes: Safety Systems ($8.2M), Biomechanics ($11.0M), Crash Avoidance ($8.0M), Alternative Fuels Vehicle Safety ($3.0M), Vehicle Electronic and Emerging Technology ($2.5M).[8]

Federal Railroad Administration (FRA)

The FRA research request for FY 2015 is $35.1 million.[9] These funds support the following R&D programs: Track Research Program ($11.3M), Rolling Stock Program ($8.3M), Signals,

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[3] http://www.dot.gov/sites/dot.gov/files/docs/FHWA-FY2015-Budget-Estimates.pdf
[4] http://www.dot.gov/sites/dot.gov/files/docs/FHWA-FY2015-Budget-Estimates.pdf
[5] http://www.dot.gov/sites/dot.gov/files/docs/FTA%20FY%202015%20CJ%20Final%20-%203.26.14.pdf
[6] http://www.dot.gov/sites/dot.gov/files/docs/FTA%20FY%202015%20CJ%20Final%20-%203.26.14.pdf
[7] [7] http://www.dot.gov/sites/dot.gov/files/docs/NHTSA-FY2015-Budget-Estimates.pdf
[8] http://www.dot.gov/sites/dot.gov/files/docs/NHTSA-FY2015-Budget-Estimates.pdf
[9] http://www.dot.gov/sites/dot.gov/files/docs/FRA-FY2015-Budget-Estimates.pdf

Train Control and Communications ($8.0M), Human Factors Program ($3.M), Railroad System Issues ($3.9M).[10]

Federal Motor Carrier Safety Administration (FMCSA)

The FMCSA RD&T program request for FY 2015 is $9.7 million. The request includes the following research and development activities: Produce Safer Drivers ($2.5M), Improve Safety of Commercial Vehicles ($2.7M), Produce Safer Carriers ($1.2M) and Advanced Safety through Info-Based Initiatives ($2.8M).[11]

Issues for Consideration

2014 RITA elevation into ORT

As part of the 2014 Appropriations Omnibus Bill, RITA was elevated into the Office of the Assistant Secretary for Research and Technology (ORT). According to USDOT[12], the mission of ORT will remain the same as RITA and the elevation will give ORT more opportunities to collaborate with all modes of transportation on research, innovation, and technology.

University Transportation Centers (UTCs)

As authorized by the Moving Ahead for Progress in the 21st Century Act (P.L. 112-141, the Research and Innovative Technology Administration of USDOT conducts a competition for the selection of UTCs. UTCs primarily serve to advance U.S. technology and expertise in the many modes and disciplines comprising transportation through the mechanisms of research, education, and technology transfer. They also provide critical transportation knowledge based outside USDOT and address vital workforce needs for the next generation of transportation leaders. For Fiscal Years 2013 and 2014, the breakdown is as follows:

- Five National UTCs: up to $3.0 million per Center per fiscal year
- Ten Regional UTCs, one of which must be dedicated to comprehensive transportation safety: up to $2.75 million per Center per fiscal year
- Up to twenty Tier 1 UTCs: up to $1.5 million per Center per fiscal year

Intelligent Transportation Systems

Connected vehicle safety technology is currently a major focus of surface transportation R&D. Applications are being developed and designed to increase situational awareness and reduce or eliminate crashes through vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) data transmission. These applications aid in driver advisories, driver warnings, and vehicle and/or infrastructure controls. V2I communications are significant in improving mobility and environment by reducing delays and congestion caused by crashes, enabling wireless roadside inspections, or helping commercial vehicle drivers identify safe areas for parking. Furthermore,

[10] http://www.dot.gov/sites/dot.gov/files/docs/FRA-FY2015-Budget-Estimates.pdf
[11] http://www.dot.gov/sites/dot.gov/files/docs/FMCSA-FY2015-Budget-Estimates.pdf
[12] https://www.transportation.gov/fastlane/rita-becomes-office-research-and-technology

these technologies may potentially address up to 82 percent of crash scenarios with unimpaired drivers, preventing tens of thousands of automobile crashes every year.[13] The goals of connected vehicle research are to make surface transportation safer, smarter, and greener by leveraging the potentially transformative capabilities of wireless technology. However, at the same time, issues surrounding the potential tradeoff between privacy and system security must also be explored.

In 1999, the Federal Communications Commission (FCC) dedicated the 5.9 GHz band to be used for vehicle-related safety applications. In recent years, the proliferation of wireless products and services has spurred policymakers to consider opening bandwidth that has been underutilized in spectrum. As specified in the Middle Class Tax Relief and Job Creation Act of 2012 (PL 112-96), the National Telecommunications and Information Administration (NTIA) was directed to examine the potential for opening up additional portions of the spectrum, including the 5.9 GHz band. The resulting report, released on January 25, 2013, expressed concern about the possible inclusion of additional unlicensed devices in the 5.9GHz band.[14] In March of 2014, the FCC has announced the authorization of an additional 100 MHz of unlicensed spectrum within the 5GHz band.[15]

Intelligent transportation systems are also being implemented in the railroad industry. Positive train control (PTC) is an advanced technology designed to automatically stop or slow a train before certain accidents occur. In particular, PTC is designed to prevent train-to-train collisions, derailments caused by excessive speed and unauthorized movement of trains onto sections of track where repairs are being made or as a result of a misaligned track switch.

[13] http://www.its.dot.gov/connected_vehicle/connected_vehicle.htm
[14] http://www.ntia.doc.gov/federal-register-notice/2013/spectrum-relocation-final-rule-html
[15] http://www.fcc.gov/document/fcc-increases-5ghz-spectrum-wi-fi-other-unlicensed-uses

Chairman BUCSHON. The Subcommittee on Research and Technology will come to order.

Good morning, everyone. Welcome to today's hearing titled, "The Future of Surface Transportation." In front of you are packets containing the written testimony, biographies, and truth-in-testimony disclosures for today's witnesses.

I now recognize myself for five minutes for an opening statement.

The research and development activities at the Department of Transportation are vital to our nation's prosperity. These efforts support the critical infrastructure and enhance both our economic competitiveness and way of life. The pathway forward for these programs continues to present significant challenges for Congress. We need to ask difficult questions to determine how best to address the issues facing our aging infrastructure within the limitations of our current budget environment.

In addition to my role as Chairman of the Subcommittee, I also serve on the House Committee on Transportation and Infrastructure. In that Committee, we have had several hearings on new car technology, for example, and what the role Congress and DOT have in research and testing this technology.

In 2014, the DOT annually supported more than $1 billion in research, development, and technology deployment activities focused on surface modes of transportation. These programs were last authorized in 2012 in the Moving Ahead for Progress in the 21st Century, or MAP–21, on which I served as a conferee. These programs are primarily supported through the Highway Trust Fund and Mass Transit Fund. Trust Fund revenue, at its current spend rate, will be insufficient to carry out authorized programs. The Transportation and Infrastructure Committee is currently considering how to resolve this problem before Trust Fund depletion.

Advancements in materials and technology, such as connected vehicles, autonomous cars, and positive train control, can help achieve long-term cost savings by reducing congestion, increasing economic output, reducing environmental effects, and improving the durability and lifespan of our transportation projects. It is therefore critical that we find a way to maintain a healthy, substantive research base behind our state and local transportation initiatives.

Today's hearing will allow us to examine research, development, and technology priorities at the United States Department of Transportation and to understand the important policy issues regarding the future of surface transportation. In addition, this hearing will provide an opportunity to understand RD&T activities in surface transportation both at federally sponsored research institutions, as well as RD&T conducted by the private sector, and understanding how these advances are being utilized by state and local governments.

I look forward to hearing today's testimony and to a productive and fruitful discussion on U.S. surface transportation research, development, technology, investments, priorities, and policies. I hope you will continue to work with us to maximize the effectiveness of surface transportation RD&T programs as we attempt to reauthorize our federal surface transportation programs.

Again, thank you all for joining us today. It is very much appreciated.

[The prepared statement of Mr. Bucshon follows:]

PREPARED STATEMENT OF SUBCOMMITTEE ON CHAIRMAN LARRY BUCSHON

The research and development activities at the Department of Transportation (DOT) are vital to the nation's prosperity. These efforts support critical infrastructure, and enhance both our economic competitiveness and way of life. The pathway forward for these programs continues to present significant challenges for Congress. We need to ask difficult questions to determine how best to address the issues facing our aging infrastructure within the limitations of our current budget environment.

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I hope you will continue to work with us to maximize the effectiveness of surface transportation RD&T programs as we attempt to reauthorize our federal surface transportation programs. Again, thank you all for joining us today.

Chairman BUCSHON. I now recognize the Ranking Member of the Committee, the gentleman from Illinois, Mr. Lipinski, for his opening statement.

Mr. LIPINSKI. Thank you, Chairman Bucshon. Thank you for calling this hearing. I also want to thank our witnesses for appearing before us today and for their assistance in helping us identify the research, development, and technology needs to ensure safer and more efficient transportation in our daily lives.

We all have multiple places we need to get ourselves and our families to and from in a day. We all wish that we could do it quicker and cheaper. The average household spends 17 percent of its budget on transportation. In all, transportation-related goods and services consume about $1.2 trillion to the U.S. economy.

As a Member of the House Committee on Transportation and Infrastructure along with Chairman Bucshon, I have been able to work on several bills to authorize funds and set policies for road, rail, mass transit, aviation, and other critical transportation projects across the country. I can't overemphasize the need for long-term investments in transportation to keep people and commerce moving.

As we focus today in this hearing on the future of surface transportation, I look forward to learning more from our witnesses about what this Committee should be thinking about, including in the Research Title of the upcoming surface transportation reauthorization.

If we are committed to making our transportation system more reliable and more efficient while at the same time ensuring that transportation planners are wisely investing taxpayer dollars, we need to have a robust and effective transportation R&D policy. This Subcommittee last examined transportation R&D in 2011. Since then, Congress has passed MAP–21, the two-year surface transportation reauthorization law that expires this year. In the past, we have examined a number of research and development challenges faced by the Department of Transportation. Some of these challenges have included improving planning and coordination at DOT, strengthening technology transfer, and environmental mitigation. These remain important topics for discussion today.

Safety is a top priority across all of DOT's research programs. I look forward to an update on the progress DOT and the private sector have made in developing vehicle-to-vehicle communication and other technology for safety and what barriers these face for full-scale deployment. Many of these technologies are precursors to technologies we will need when we eventually deploy self-driving cars.

I visited a Google campus in Mountain View, California, last December and saw the rapid progress they are making towards autonomous vehicles. V2V and V2I technologies have the capacity to greatly increase safety and efficiency in transportation, and I believe autonomous vehicles are the logical way to maximize these gains.

At the pace technology is currently progressing, I often ask people do you think a child born today will ever have to learn to drive a car? At this point I think it is an open question.

But we shouldn't focus solely on roads and highways. Rail transportation is hugely important for my district as well as the Nation. Nearly a quarter of all freight rail traffic in the United States passes through Chicago and it is a major hub for passenger rail as well. Moving forward, we must invest more in R&D to ensure the safety of our rail passengers and operators. Preventing another tragedy like the Metro North train derailment in New York and the Washington Metro train collision must be a priority. I look forward to hearing from Dr. Barkan about the latest in rail and rail safety research being conducted at the University of Illinois.

Through the University Transportation Center program, universities such as the University of Illinois play key roles in transportation R&D. Most DOT-funded research is applied research and development to address short-term needs and opportunities. Only a small fraction of the transportation research budget is dedicated to longer-term research, but it is through the longer-term research that will yield the big breakthroughs for a safer, faster, and less expensive transportation future. We need to ensure that universities are given the flexibility to pursue long-term research and that DOT continues to invest in mid- to long-term research through other programs such as the Exploratory Advanced Research Program.

The Committee on Science, Space, and Technology should play an important role in defining our transportation research priorities in the future. I am confident that today's witnesses will give us some solid ideas for moving transportation research forward. I want this Committee to be actively involved in writing the Research Title in the next surface transportation reauthorization bill.

Again I want to thank Chairman Bucshon for calling this hearing and the witnesses as well for being here. I look forward to your testimony and a productive discussion.

With that, I will yield back.

[The prepared statement of Mr. Lipinski follows:]

PREPARED STATEMENT OF SUBCOMMITTEE RANKING MINORITY MEMBER DAN LIPINSKI

Thank you, Chairman Bucshon, for calling this hearing. I also want to thank our witnesses for appearing before the Subcommittee and for their assistance today in helping us identify the research, development, and technology needs to ensure safer and more efficient transportation in our daily lives.

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As a Member of the House Committee on Transportation and Infrastructure—along with Chairman Bucshon—I have been able to work on several bills to authorize funds and set policies for road, rail, mass transit, aviation, and other critical transportation projects across the country. I cannot overemphasize the need for long-term investments in transportation to keep people and commerce moving. As we focus today in this hearing on the future of surface transportation, I look forward to learning more from our witnesses about what this committee should be thinking about including in the research title of the upcoming surface transportation reauthorization. If we are committed to making our transportation system more reliable and more efficient, while at the same time ensuring that transportation planners are wisely investing taxpayer dollars, we need to have a robust and effective transportation R&D program.

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And with that I yield back.

Chairman BUCSHON. Thank you, Mr. Lipinski.

I now recognize the Chairman of the full committee, Chairman Smith, for five minutes for his opening statement.

Chairman SMITH. Thank you, Mr. Chairman, and thank you for holding today's hearing.

The future of America's transportation systems is rooted in the effective development and use of new technologies. Technology allows us to enhance both the capacity and safety of our roadways, to better control traffic congestion and to extend the life of our transportation infrastructure.

The Moving Ahead for Progress in the 21st Century Act of 2012 outlines the Department of Transportation's research, development, and technology priorities. These priorities include promoting safety, reducing congestion, improving mobility, preserving the environment and existing transportation systems, enhancing the durability of our infrastructure, and improving movement along our transportation systems.

Taxpayer investments in these areas should be targeted to achieve desired outcomes. The investments we make today will transform the future of transportation. One example is the development of intelligent transportation systems. Such cutting-edge concepts encompass a broad range of information and communications technologies that have the potential to improve the safety, efficiency, and performance of our nation's transportation system.

In my home State of Texas, the Texas A&M Transportation Institute (TTI) works to develop interdisciplinary solutions to the challenges that face all modes of transportation. And I appreciate having a witness today, Mr. Maddox, from TTI. I look forward to his testimony later on. TTI has saved the State of Texas and the United States billions of dollars and thousands of lives through innovative strategies and products developed through its research and implementation programs. For example, TTI conducts groundbreaking research to explore the interaction between driver, cell phone, and roadway, and assesses the dangers and causes of distracted driving.

The problems studied at TTI are good examples of how science can yield solutions to societal problems. It shows that efficient, targeted R&D can help develop new innovative ideas and technologies that will make our transportation systems safer.

Mr. Chairman, I regret I may have to leave momentarily because of a markup in the Judiciary Committee that started at 10 o'clock, but I also want to thank another witness, Ms. Tabar, for the increasing presence of Toyota in Texas. Please keep it up.

Thank you, Mr. Chairman. I yield back.

[The prepared statement of Mr. Smith follows:]

PREPARED STATEMENT OF FULL COMMITTEEE
CHAIRMAN LAMAR S. SMITH

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The Moving Ahead for Progress in the 21st Century Act of 2012 outlines the Department of Transportation's research, development and technology priorities. These priorities include promoting safety, reducing congestion, improving mobility, preserving the environment and existing transportation systems, enhancing the durability of our infrastructure, and improving movement along our transportation systems.

Taxpayer investments in these areas should be targeted to achieve desired outcomes. The investments we make today will transform the future of transportation. One example is the development of intelligent transportation systems. Such cutting edge concepts encompass a broad range of information and communications technologies that have the potential to improve the safety, efficiency, and performance of our nation's transportation system.

In my home State of Texas, the Texas A&M Transportation Institute (TTI) works to develop interdisciplinary solutions to the challenges that face all modes of transportation. TTI has saved the state of Texas and the United States billions of dollars and thousands of lives through innovative strategies and products developed through its research and implementation programs. For example, TTI conducts groundbreaking research to explore the interaction between driver, cell phone and roadway, and assesses the dangers and causes of distracted driving.

The problems studied at TTI are good examples of how science can yield solutions to societal problems. It shows that efficient, targeted R&D can help develop new innovative ideas and technologies that will make our transportation systems safer.

I look forward to the witnesses' testimony and thank them for their participation this morning. And I yield back.

Chairman BUCSHON. That was a good plug for Texas, Mr. Chairman.

Thank you. If there are other Members who wish to submit additional opening statements, your statements will be added to the record at this point.

[The prepared statement of Ms. Johnson follows:]

PREPARED STATEMENT OF FULL COMMITTEEE
RANKING MEMBER EDDIE BERNICE JOHNSON

Good morning, I would like to thank the Chairman for holding today's hearing to examine the impact of research and technology on the future of transportation.

Our economy depends on our ability to move people and goods efficiently from one point to another. I have been representing the Dallas area in Congress for over 20 years. Our central location helps attract multinational corporations. Dallas is home to major sports and entertainment venues and has a world class hospital system.

This year we had the third largest population increase in the nation and the third busiest airport in the world. We have five interstate highways, a growing transit system, and a major rail corridor. In fact, Dallas was the capstone city for Secretary Foxx's national bus tour earlier this year highlighting the importance of transportation investment across the country.

Alongside the bricks and mortar infrastructure investments, continuing investments in transportation research and development will be critical to the future viability of this thriving city and the cities across the nation.

The nation's Interstate Highway System, a significant achievement of the Eisenhower Administration, is now nearly 60 years old. Our state DOTs are constantly repairing the decades-long wear and tear we have put on our roads, bridges, and tunnels. While growth across the country increases jobs and revenue, it also increases traffic congestion, accidents, and air pollution.

Fortunately, we are approaching a turning point in transportation technology and innovation. The ideas that our witnesses will share today, including vehicle-to-vehicle communications systems, have the potential to help reduce American's commute times, reduce accidents on our highways and railroads, and reduce emissions.

As a longtime supporter of public transportation, including Dallas Area Rapid Transit, I am also interested in hearing about the Department's innovative transit research, including how ridesharing may be changing our thoughts on public transportation. As transportation continues to become more high tech, it is important that we incorporate transportation applications in the teaching of STEM fields so that our students are prepared to join the workforce in this important area.

As more students look to transportation as a field of study, we should make sure policies are in place to support long-term research that will lead to revolutionary improvements in the safety and efficiency of our transportation systems. To reap the benefits of this paradigm-shifting research, my colleagues and I must come together from both sides of the aisle to support a multi-year, bipartisan transportation reauthorization bill that includes strong research provisions.

We can and should act now with sensible public policies to secure jobs, create growth, and provide for safe, clean, and efficient transportation. Again, I thank the witnesses for being here today and look forward to their testimony.

Chairman BUCSHON. At this time I would like to introduce our witnesses. Our first witness is Hon. Gregory D. Winfree, the Assistant Secretary for Research and Technology at the U.S. Department of Transportation. Mr. Winfree previously served as the Research and Innovative Technology Administration's Chief Counsel, Deputy Administrator, and Acting Administrator, and as Chairman of the Department of Transportation's Innovative—Innovation Council. Mr. Winfree also served as Chief Litigation Counsel for Freeport-McMoRan Corporation and as Director of Litigation for Wyeth Pharmaceuticals. Mr. Winfree earned a BS degree in communications, public relations from St. John's and a J.D. from Georgetown University. Thanks for being here.

Our second witness is Mr. Scott Belcher, the President and CEO of the Intelligent Transportation Society of America. Prior to joining ITS America, Mr. Belcher served as Executive Vice President and General Counsel at the National Academy of Public Administration. Mr. Belcher holds a juris doctor from the University of Virginia, a master of public policy degree from Georgetown, and a bachelor of arts degree from the University of Redlands. Thanks for being here.

Our third witness is Mr. John Maddox, the Director of Collaborative Program Strategy at Texas A&M Transportation Institute and the University of Michigan Transportation Institute. Mr. Maddox previously served as the Associate Administrator for Vehicle Safety Research at the National Highway Traffic Safety Administration, or NHTSA. Before working at NHTSA, Mr. Maddox spent over five years with Volkswagen Group as a Compliance Officer and 14 years with Ford Motor Company as a Senior Research Engineer. Thank you for being here.

Our fourth witness is Ms. Kristin Tabar. Did I pronounce that correctly? Ms. Tabar is the Vice President for the Technical Administration Planning Office at Toyota Technical Center. Prior to her current assignment, Ms. Tabar was the Vice President of Electrical Systems Engineering. She previously served as General Manager for Electrical Systems-1 department. Prior to joining Toyota Technical Center, Ms. Tabar worked as a Contract Engineer with a Ford supplier. Ms. Tabar holds a bachelor of science degree in electrical engineering from the University of Michigan. Thanks.

Our—we are getting there. Our fifth witness is Dr. Christopher Barkan. Dr. Barkan is Professor and George Krambles Faculty Fellow at the University of Illinois at Urbana-Champaign, my alma mater by the way. Thanks for being here. He also serves as Executive Director for the Rail Transportation and Engineering Center. Prior to moving to the University of Illinois, he was the Director of Risk Engineering at the Association of American Railroads. Dr. Barkan received his bachelor's degree from Goddard College and his M.S. and Ph.D. from State University of New York at Albany. Thank you.

And our final witness is Troy Woodruff from my home State of Indiana. Mr. Woodruff currently serves as the Chief of Staff for the Indiana Department of Transportation. Previously, Mr. Woodruff served as the INDOT Deputy Commissioner of Operations. Before joining the Indiana Department of Transportation, Mr. Woodruff held consecutive Regional Director positions with the Indiana Department of Environmental Management and WellPoint. Mr. Woodruff is a graduate of Indiana State University with a degree in communications. Thanks for being here.

And thanks to all our witnesses for being here. I know you have to take a lot of time to prepare and to travel to be here. It is very much appreciated.

As our witnesses should know, spoken testimony is limited to five minutes each after which the Members of the committee will have five minutes each to ask questions.

I now recognize Mr. Winfree for five minutes to present his testimony.

TESTIMONY OF THE HONORABLE GREGORY D. WINFREE, ASSISTANT SECRETARY, UNITED STATES DEPARTMENT OF TRANSPORTATION

Mr. WINFREE. Thank you so much, Chairman Bucshon, Ranking Member Lipinski, Chairman Smith, and Members of the Subcommittee, thank you for the opportunity to appear before you here today to discuss the challenges and future opportunities of the Department of Transportation's Surface Transportation Research Programs. I have submitted my full testimony for the record, so in the interest of time I will highlight a couple of major themes from my testimony and then I am happy to respond to your questions.

Transportation research, technology, and data are critical tools for improving the safety, efficiency, mobility, capacity, and state of good repair of America's transportation system and for reducing transportation's environmental and societal impacts. The Office of the Assistant Secretary for Research and Technology is pleased to continue to lead the Department's research coordination efforts driving cross-modal collaboration to meet 21st century challenges.

While my written statement touches on a broad cross-section of the Department's surface research programs, I am going to discuss two programs managed out of my office that will help us meet these challenges. First, the University Transportation Centers Program: Covering over 120 universities which bring expertise in multiple disciplines both traditional—as in civil engineering—and not traditional, such as public health, psychology, sociology, studying safety culture, human factors, et cetera—UTCs enable the systemic interdisciplinary cross-modal research we need to address increasingly complex challenges that cross traditional boundaries. UTCs do this while educating undergraduate and graduate students in the technical and problem-solving skills we need going forward, which is a win-win if ever I have heard one.

I always enjoy the opportunity to meet with the bright young students at our UTCs to hear about what exciting things—what exciting new things they are developing in the laboratories and in the classrooms and how their own lives are changing even as they add to our transportation knowledge. I certainly encourage the Members of this committee to take those opportunities to meet those students as well.

The second significant research program I would like to highlight is the Intelligent Transportation Systems Research program. The department has completed the Connected Vehicle Safety Pilot Program in Ann Arbor at the University of Michigan Transportation Research Institute. That research informed the resulting National Highway Traffic Safety Administration's (NHTSA) February decision to move forward with vehicle-to-vehicle communication technology to enable significant accident avoidance and other safety applications in light-duty vehicles.

This technology will improve safety and has the potential to reduce non-impaired crashes by up to 80 percent. It would do so by allowing vehicles to talk to each other and ultimately avoid many crashes altogether by exchanging basic, anonymous safety data such as speed and position 10 times per second.

This major decision was based largely on the research, technology developments, test deployments, and data collection and analyses conducted under the ITS Research program. The Department continues to work collaboratively across the operating administrations toward connected vehicle applications for heavy-duty vehicles and our colleagues at the Federal Highway Administration are preparing to issue guidance in 2015 for installing vehicle-to-infrastructure applications for roadway safety and improved traffic operations and maintenance.

Additionally, ITS is using connected vehicle technology research to reduce congestion, improve road weather information and real-time data capture, and reduce emissions. I note that all the success and the standards that support it are based upon the availability of the 5.9 gigahertz dedicated short-range communication spectrum. Allocated in the United States and internationally for transportation safety, the 5.9 gigahertz band was specifically selected to enable the 10 times per second exchange of information needed to bring to reality the safety improvements that remain the primary goal of ITS research.

We are actively involved in ongoing discussions related to the FCC's proposal in its notice of proposed rulemaking to permit unlicensed devices, e.g., wideband—broadband Wi-Fi and UNI devices to operate in the 5.9 gigahertz spectrum currently licensed for DSRC.

The Department also intends to participate in the National Telecommunications and Information Administration's upcoming technical analysis related to understanding interference and sharing of the 5.9 gigahertz spectrum. Sorry. Watching the clock go down gets you a little antsy.

We believe that the FCC and the NTIA must ensure that unlicensed devices do not compromise safety through harmful interference to the ITS architecture, operations, or safety critical applications if permitted to operate in the 5.9 gigahertz band. We have very serious concerns about any spectrum sharing that prevents or delays access to the desired channel or otherwise preempts the safety applications.

At this time the Department is unaware of any existing or proposed technical solution that guarantees interference-free operation of the DSRC safety critical applications while allowing Wi-Fi devices to share the 5.9 spectrum.

So in closing, I am excited about the research being conducted at the U.S. Department of Transportation. We are addressing serious issues serious in serious ways for the benefit of the traveling public. I look forward to answering your questions.

[The prepared statement of Mr. Winfree follows:]

WRITTEN STATEMENT OF
GREGORY D. WINFREE
ASSISTANT SECRETARY FOR RESEARCH AND TECHNOLOGY
U.S. DEPARTMENT OF TRANSPORTATION

BEFORE THE

SUBCOMMITTEE ON RESEARCH AND TECHNOLOGY
COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

HEARING ON

Challenges and Future of Federal Surface Transportation Research

June 18, 2014

Chairman Bucshon, Ranking Member Lipinski, and Members of the Committee, thank you for the opportunity to appear before you today to discuss the challenges and future opportunities of the Department of Transportation's surface transportation research programs. We all recognize that transportation research, technology and data are critical tools for improving the safety, efficiency, mobility, capacity and state of good repair of America's transportation systems; and for reducing transportation's environmental and societal impacts. The Office of the Assistant Secretary for Research and Technology is pleased to continue to lead the Department of Transportation's research coordination efforts, driving cross-modal collaboration to meet 21st Century challenges.

Continual development and adoption of new processes and advanced technologies are improving safety, reducing project delivery times, improving system operations and capacity, extending the life of transportation infrastructure, and providing actionable information to travelers and transportation planners. As Secretary Anthony Foxx noted at January's Transportation Research Board's Annual Meeting, research and data have a significant role to play in addressing America's infrastructure deficit by improving planning and adopting innovative best practices; stretching scarce resources with well-researched, data-driven innovation resulting in smarter capital projects which are built better and cost less. A good example of this is accelerated bridge construction, reducing the time for small bridge replacement – saving funds which can then be used for other work.

The future of the U.S. surface transportation system has the potential to be a safer, cleaner, more efficient, durable and resilient system if the necessary research is performed and results implemented to transform the current system into a system suitable to meet the nation's needs for personal mobility and goods movement for the 21st century. I see a system with highly automated vehicles of all types -- autos, trucks, trains and buses -- using alternative, non-fossil-fuel energy; and running on infrastructure that is constantly monitored, both for operational efficiency and infrastructure status, that is made of new, high technology materials that will last a century rather than decades.

We cannot create a transformational system by applying 21st century research to 20th century infrastructure. In other words, we cannot just keep finding better ways to fill pot holes. The National Academies, through the National Research Council, issued a report entitled "*Framing Surface Transportation Research for the Nation's Future.*" Funded by the state departments of transportation, one of the report's conclusions is that the USDOT needs to increase the amount of advanced research that it conducts or sponsors, to meet emerging challenges.[1] At the same time, we need to continue existing long-term research, and core

[1] "Framing Surface Transportation Research for the Nation's Future." Washington, DC: Committee on National Research Frameworks, Application to Transportation (Transportation Research Board Special Report 313), 2014.

research into human factors for safety. The Administration's surface authorization proposal, the GROW AMERICA Act, will improve vehicle and passenger safety by advancing intelligent systems in vehicles and in smarter infrastructure across all modes, and by exploring new ways to utilize real-time information to aid the flow of goods along America's freight corridors. The GROW AMERICA Act will accelerate deployment of surface transportation technologies and innovations in safety, infrastructure renewal, reliability, and capacity.

One example of successful advanced research is the Connected Vehicle program. Funded by the Intelligent Transportation Systems (ITS) Research program, the Department has completed the Connected Vehicle Safety Pilot program in Ann Arbor, Michigan. That research informed the resulting National Highway Traffic Safety Administration's (NHTSA) February decision to move forward with vehicle-to-vehicle (V2V) communication technology to enable significant accident avoidance and other safety applications in light duty vehicles.

Another opportunity for USDOT to execute advanced research is in reducing the greenhouse gases produced by the surface transportation sector. All modes of surface transportation produce greenhouse gases and other pollutants, with resulting public health and environmental impacts. The transportation sector was responsible for 28% of U.S. greenhouse gas emissions in 2012. Light vehicle use alone in the U.S. is responsible for 45% of the global production of vehicular CO_2 emissions.[2] An advanced program focused on reducing greenhouse

[2] Kahn Ribeiro, S., S. Kobayashi, M. Beuthe, J. Gasca, D. Greene, D. S. Lee, Y. Muromachi, P. J. Newton, S. Plotkin, D. Sperling, R. Wit, P. J. Zhou, 2007: Transport and its infrastructure. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. [Chapter 5 of the IPCC Fifth Assessment Report: Climate Change 2012, "Transport and its Infrastructure."

gas production in transportation would be a cross-modal effort involving all vehicular modes of travel in surface transportation, and is included in the proposals of the GROW AMERICA Act.

The Department of Transportation currently invests $804,726,000 (Fiscal Year 2014 enacted) in federal surface transportation research, development, and technology. Within the USDOT, and its various Operating Administrations, the allocation of this funding is based on DOT goals and defined missions or priorities within the Operating Administrations.

Safety continues to be the number one priority of the USDOT. Operating Administrations like the Federal Railroad Administration, the National Highway Traffic Safety Administration, and the Federal Motor Carrier Safety Administration have congressionally-mandated regulatory responsibility for safety within their individual modes. As a result, the majority of the research conducted by these modes always will be safety oriented. The same is increasingly true of the Federal Transit Administration. With the new responsibilities placed on that Operating Administration by MAP-21 for transit system safety oversight, more of the research funded by FTA will be focused on safety.

The Federal Highway Administration (FHWA) has by far the largest and widest-ranging research program of any of the surface modes. Research sponsored or conducted by the FHWA ranges from operations to safety to structures and many areas in between. The FHWA also has one of the few USDOT advanced research programs, the Exploratory Advanced Research program, which is relatively small (approximately $10 million per year in funding) but looks at means of applying new technologies, developed in other fields, to the transportation system.

The FHWA seeks and uses considerable stakeholder input when determining how research funds will be allocated. These stakeholders include the state Departments of Transportation, Metropolitan Planning Organizations, local and tribal governments, construction and consulting engineering firms, and the Transportation Research Board.

One key research program managed by the Office of the Assistant Secretary for Research and Technology is the University Transportation Centers (UTC) program. The UTC program is another way the DOT supports advanced research, by enabling universities to use their cross-disciplinary capabilities to conduct the advanced work for which they are well-suited.

Covering over 120 universities which bring expertise in multiple disciplines, both traditional (civil engineering) and not (public health, psychology and sociology, studying safety culture), UTCs enable the systemic, interdisciplinary, cross-modal research we need to address increasingly complex challenges that cross traditional boundaries.

UTCs do this while educating undergraduate and graduate students in the technical and problem-solving skills we need moving forward – a "win–win" if I've ever heard one. I always enjoy the opportunity to meet with the bright young students at our UTCs, to hear about what exciting new things they are developing in the laboratories and classrooms, and how their own lives are changing, even as they add to our transportation knowledge. I encourage the members of this Committee to take those opportunities as well.

At this point, I would like to provide a brief overview of DOT research investments, the subjects of which are linked to one or more of the Departmental strategic goals: Safety, State of Good Repair, Economic Competitiveness, Livable Communities and Environmental Sustainability.

In safety, the highest priority across the DOT is the reduction of transportation-related fatalities and injuries. This goal is being pursued by conducting research in many areas, including:

- Human behavior, operator distraction and fatigue.
- Connected Vehicles.
- Remote and wireless inspection of vehicles (trucks and trains).
- All types of vehicle crashworthiness (cars, trains, trucks, buses).

For state of good repair, some areas of emphasis are:

- Using of sensors for monitoring and non-destructive evaluation of infrastructure (bridges, roads, rails).
- Utilizing Asset Management tools to reduce maintenance costs.
- Reducing the frequency of infrastructure repair, rehabilitation, and re-construction.
- Building new structures that are more durable.

In the area of economic competitiveness, research is being conducted to:

- Improve traffic management to increase capacity and throughput.
- Create efficiencies in multi-modal freight movement.

- Use data to increase efficiency in freight logistics.
- Investigate the impact of financial policy on the efficiency of the overall transportation system.

For Livable Communities and Environmental Sustainability, research is being conducted to:

- Improve and increase access to transportation and human services for underserved populations.
- Help the traveling public make informed, multi-modal travel decisions.
- More safely integrate pedestrians and bicyclists into the system.
- Reduce energy consumption in operations, construction and maintenance.
- Increase the use of alternative fuel vehicles of all types.
- Adapt transportation infrastructure for resiliency to the effects of climate change and extreme weather events.

To summarize, research can reduce the gap that exists between the needs of the system and the funds available to operate and maintain the system, while improving the quality of life for the American public.

However, it takes time to implement new technologies, due to necessary approvals of the technology, environmental review, or other reasons. Review and approval of new technologies is often a federal responsibility, requiring a waiver from existing regulations or guidance, or the adoption of updated technical standards. Each Operating Administration endeavors to take actions within available resources to streamline these reviews, including involvement in standards developing organizations, assessing technology readiness, and listening to Advisory Boards and stakeholder groups, all to allow the implementation of new technologies as rapidly as possible. The GROW AMERICA Act includes proposals to reduce environmental review time.

I would like to provide more detail to the Committee about the Intelligent Transportation Systems (ITS) Research Program – both because it is managed directly by my office, and because it touches on all of the strategic themes of the Department's surface transportation research.

In ITS research, some of our team's progress has been attracting public attention – most notably through the ITS-funded Connected Vehicle Safety Pilot, the largest such test program in the world, conducted through the University of Michigan Transportation Research Institute (UMTRI) in Ann Arbor, Michigan. The Department tested safety applications with everyday drivers under both real-world and controlled test conditions. These test results led to the National Highway Traffic Safety Administration's (NHTSA) February decision to move forward with vehicle-to-vehicle (V2V) communication technology for light duty vehicles. This technology will improve safety and has the potential to reduce non-impaired crashes by 80%. It would do so by allowing vehicles to "talk" to each other and ultimately avoid many crashes altogether by exchanging basic, anonymous safety data, such as speed and position, ten times per second. This major decision was based largely on the research, technology developments, test deployments, and data collections and analyses conducted under the ITS Research Program. Research indicates that safety applications using V2V technology can address a large majority of crashes involving two or more motor vehicles. With safety data such as speed and location flowing from nearby vehicles, vehicles can identify risks and provide drivers with warnings to avoid other vehicles in common crash types such as rear-end, lane change, and intersection crashes.

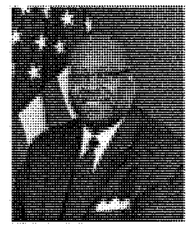
But that's certainly not all. The Department continues to work collaboratively across the Operating Administrations towards connected vehicle applications for heavy duty vehicles, and our colleagues at the Federal Highway Administration are preparing to issue guidance in 2015 for installing vehicle-to-infrastructure applications for roadway safety and improved traffic operations and maintenance, drawing on the connected vehicle data that will be made available. ITS research has enabled multimodal Integrated Corridor Management (in part through demonstration projects in Dallas and San Diego), and Next Generation-911. Additionally ITS is using connected vehicle technology research to reduce congestion, improve road weather information and real-time data capture, and reduce emissions.

To enable the deployment of this technology, additional research is needed to address the technical and policy challenges. The ITS program continues to assess the legal and policy structures needed to make these safety, operational and environmental improvements a daily reality, with an emphasis on ensuring data privacy and on the technologies enabling security of cyber-physical systems. And, we continue to work actively with our partners in the standards developing organizations to ensure that the many private sector actors involved in ITS deployment – from Original Equipment Manufacturers to suppliers to technology firms to infrastructure and construction firms – all produce interoperable equipment and systems that can seamlessly share the data that enables safety and other applications. We are conducting specific research on cyber-physical systems in collaboration with National Institute of Standards and Technology to ensure that these Connected Vehicle systems have sufficient security protections against any malicious cyber-attacks.

Finally, I note that all of this success, and the standards that support it, are based upon the availability of the 5.9 GHz Dedicated Short Range Communications (DSRC) spectrum. Allocated in the U.S. and internationally for transportation safety, the 5.9 GHz band was specifically selected to enable the ten-times-per-second exchange of information needed to bring to reality the safety improvements that remain the primary goal of ITS research. We recognize that spectrum is a scarce national resource and that it is important to find ways to expand wireless broadband capacity. We are actively involved in the ongoing discussions related to the FCC's proposal in its Notice of Proposed Rulemaking (NPRM) to permit Unlicensed National Information Infrastructure devices (e.g., broadband WiFi) to operate in the 5.9 GHz spectrum currently licensed for DSRC. The Department also intends to participate in the National Telecommunications and Information Administration's (NTIA) upcoming technical analysis related to understanding interference and sharing of the 5.9 GHz spectrum. We believe that the FCC and the NTIA must ensure that unlicensed devices do not compromise safety through harmful interference to the ITS architecture, operations, or safety critical applications if permitted to operate in the 5.9 GHz band. We have very serious concerns about any spectrum sharing that prevents or delays access to the desired channel, or otherwise preempts the safety applications. At this time, the Department is unaware of any existing or proposed technical solution which guarantees interference free operation of the DSRC safety critical applications while allowing WiFi enabled devices to share the 5.9 GHz spectrum.

With regard to full implementation of this technology in the U.S., the success of the Ann Arbor Safety Pilot has provided clear momentum toward Connected Vehicle deployment. The Department is planning to participate in additional Connected Vehicle pilot deployments in 2016. USDOT expects that state DOTs and local governments will have multiple operational pilot deployments of Connected Vehicle infrastructure operating in local environments by the end of this decade. A significant implementation of Connected Vehicle technology in vehicles, fleets, infrastructure, and aftermarket devices would follow soon thereafter. Please keep in mind that vehicles are just one exciting application for connected technologies. Indeed, applications can be found across the range of modes of transportation.

In closing, I am excited about the research being conducted at the U.S. Department of Transportation. We are addressing serious issues in serious ways for the benefit of the travelling public. I look forward to answering your questions.



Gregory D. Winfree, Assistant Secretary
Office of the Assistant Secretary for Research and Technology
U.S. Department of Transportation

January 23, 2014 – Present

Greg Winfree originally came to the U.S. Department of Transportation's Research and Innovative Technology Administration (RITA) in March, 2010 and was sworn in as its fourth Administrator on October 23, 2013. As directed in the Omnibus Bill of 2014, RITA was elevated to the newly-created Office of the Assistant Secretary for Research and Technology, and on January 23, 2014, Mr. Winfree was sworn in as the Assistant Secretary. During his tenure, Mr. Winfree has also served as the agency's Chief Counsel, Deputy Administrator, and Acting Administrator, and as chairman of the Department of Transportation's Innovation Council.

Prior to his USDOT appointments, Mr. Winfree served as Chief Litigation Counsel for Freeport-McMoRan Corporation, a leading international mining and natural resource producer; as Senior Litigation Counsel at Union Carbide Corporation; and as Director of Litigation for Wyeth Pharmaceuticals. Prior to his in-house corporate legal work, Winfree was a Trial Attorney in the Housing and Civil Enforcement Section of the U.S. Department of Justice, Civil Rights Division. He started his legal career as an Associate at the Venable law firm in Washington, D.C.

As both an innovator with design and utility patents to his credit and an experienced Intellectual Property litigator, Mr. Winfree has a special affinity for USDOT's diverse transportation research, innovation and knowledge management mission. Much of his career aligns with organizations with a strong focus in the STEM (Science, Education, Technology and Mathematics) disciplines, and in his official capacity at USDOT, Mr. Winfree has spoken extensively on the importance of STEM education to the future DOT and transportation workforce.

Assistant Secretary Winfree earned a B.S. degree in Communications/Public Relations from St. John's University and a J.D. from Georgetown University, where he served as Lead Articles Editor for The Tax Lawyer, the official publication of the American Bar Association Section of Taxation. He carries a valid motorcycle endorsement and is an advocate for advancing safety for motorcyclists and other vulnerable road users. An avid rider, he is a founding member of the USDOT Triskelions Motorcycle Club and has ridden cross country on a number of occasions.

Chairman BUCSHON. Thank you very much for your testimony. I appreciate it.

I now recognize Mr. Belcher for five minutes to present his testimony.

TESTIMONY OF MR. SCOTT BELCHER, PRESIDENT AND CEO, INTELLIGENT TRANSPORTATION SOCIETY OF AMERICA

Mr. BELCHER. Thank you. Good morning.

Chairman Bucshon, Ranking Member Lipinski, and Members of the Subcommittee, thank you for inviting me to testify on the future of surface transportation and the research and development efforts underway that will drive this nation to developing a fully modernized, 21st century transportation system.

The Intelligent Transportation Society of America is the Nation's largest transportation association that brings together transportation, technology, and research communities to promote technological solutions for our nation's safety, infrastructure, and mobility challenges. About half of our nearly 500 members are public agencies, University Transportation Centers, and research labs. The other half are private sector companies that range from the automobile manufacturers to high-tech, telecommuting—or telecom, tolling, infrastructure firms, actually all the way to small businesses, startups, and entrepreneurs.

Intelligent Transportation Systems represent the future of surface transportation, especially in a resource-constrained environment, and they encompass a broad range of information and communication technologies that are and that will continue to improve system performance. Examples of intelligent transportation systems include synchronized and adaptive traffic signals, electronic tolling and payment systems, real-time traffic, transit, routing, parking, and freight systems, collision avoidance and response technologies, vehicle-to-vehicle technologies, autonomous vehicles, high occupancy toll lanes, among many other high tech solutions. So it is really a very broad platform in which we are looking to try to bring solutions to our system.

As you know and as Assistant Secretary Winfree just mentioned, in February the Department of Transportation announced that it was moving forward with the deployment of vehicle-to-vehicle communications technology. Also as Assistant Secretary Winfree said, U.S. DOT estimates that this will reduce crash scenarios—unimpaired crash scenarios by more than 80 percent. That is huge. It is bigger than seatbelts, bigger than electronic stability control, it is bigger than airbags.

This is a major milestone for the future of vehicle safety and traffic congestion and it has been the result of many years of research in vehicle-to-vehicle technology by the Department of Transportation and by the private sector, by the automobile manufacturers. Without this collaboration, we wouldn't be where we are today at the—poised to move towards deployment.

Connected vehicle technology truly represents the next giant leap for vehicle and highway safety. Historically, the automobile industry has focused on protecting people in a crash. This new technology will allow the auto industry to focus on preventing crashes.

Imagine a transportation system where cars don't crash and how different that could be. Imagine the vehicles that can be built when you are not trying to protect people in those crashes.

Vehicle-to-vehicle communications technology operates on dedicated short-range communications within the 5.9 gigahertz bands of spectrum. This spectrum was set aside by the Federal Communications Commission to ensure high-speed, accurate, secure, and reliable communications, which are critical for connected vehicles. It is essential that the availability and performance of the spectrum is protected for safety purposes while also freeing up additional spectrum for Wi-Fi where it makes sense and where it can be done without jeopardizing safety. So we are not opposed to sharing; we just need to make sure that that sharing doesn't put the critical safety applications at risk.

Today's market is enchanted by driverless vehicles. They are creating tremendous excitement around the industry and around the world. The future of autonomous vehicles would benefit greatly from federally funded research conducted in partnership with the academic institution, United States Department of Transportation, and the private sector to model the safety benefits of commercially available autonomous motor vehicle technology.

Furthermore, both autonomous and connected vehicles produce incredible amounts of data which will need to be collected, analyzed, and secured, and in some cases, made available. While this provides a tremendous opportunity for innovation, new businesses, new opportunities, our future transportation network faces real threats from cybersecurity attacks and real concerns about driver anonymity in this system.

Sustained research and development will be critical for ensuring uncompromised security and—whereas autonomous—anonymity is already possible through the dedicated short-range communication protocols which allow for beaconing between vehicles, as well as between vehicles on the roadside. Such communications create immediate awareness for the driver and the vehicles surrounding it but cannot enable recognition of other vehicles.

In summary, vehicle-to-vehicle technologies represent the future of surface transportation, safety, mobility, and traffic congestion mitigation. With more than 33,000 fatalities annually on our Nation's roadways, continued full funding of the ITS Research Program will be critical in reducing these preventable tragedies and keeping the United States ahead when it comes to transportation and our transportation system.

The innovations that we will talk about today will be showcased next Wednesday at the Cannon Caucus Room at the ITS America Technology Fair, and I invite you all to come and see these technologies. They will also be showcased in Detroit in September at the 21st ITS World Congress. We will be demonstrating autonomous vehicles, connected vehicles, and the whole suite of ITS technologies.

I thank you for the opportunity to testify and look forward to answering your questions.

[The prepared statement of Mr. Belcher follows:]

ITS AMERICA

Testimony of

Scott Belcher
President and CEO
Intelligent Transportation Society of America (ITS America)

Committee on Science, Space and Technology
Subcommittee on Research and Technology
U.S. House of Representatives

Hearing on

The Future of Surface Transportation

Wednesday, June 16, 2014

Chairman Bucshon, Ranking Member Lipinski, and members of this Subcommittee, thank you for inviting me to testify about the future of surface transportation and the R&D efforts underway that will drive this nation to developing a fully modernized, 21st century transportation system.

The Intelligent Transportation Society of America (ITS America) is the nation's largest association bringing together the transportation, technology and research communities to advance solutions to our nation's infrastructure, safety and mobility challenges. About half of our nearly 500 members are public agencies, universities and research labs. The other half are private sector companies, from the major automakers, high-tech, telecom, tolling and infrastructure firms to small businesses, start-ups and entrepreneurs.

Intelligent Transportation Systems (ITS) represent the future of surface transportation, encompassing a broad range of information and communications technologies that are and will continue improving transportation safety, efficiency, convenience and system performance. When integrated into the nation's roadways, vehicles, and public transit networks, ITS reduces congestion, improves mobility, saves lives and optimizes existing infrastructure. Examples of ITS include advanced traffic, freight, and incident management systems; synchronized and adaptive traffic signals; electronic tolling and payment systems; real-time traffic, transit, routing and parking information; collision avoidance and response technologies; vehicle-to-vehicle communications, automated vehicle systems, high-occupancy toll (HOT) lanes; dynamic carsharing and ridesharing; infrastructure condition assessment technologies; and many other high-tech solutions.

It is widely accepted that a transportation system which enables the efficient movement of goods and people is necessary for economic growth. Inventory deliveries, shipments to customers and a ready workforce all benefit from a predictable and free-flowing transportation system. In the future, ITS will build upon these efficiencies using real-time traffic data to reduce congestion via integrated corridor management, real-time incident and emergency response systems, traveler information systems, traffic signal optimization, electronic truck inspections, and even simple things like ramp meters. In addition, this same real-time data is being used by private sector innovators to give today's commuters better information about current traffic conditions, more efficient routing alternatives, public transportation options and even available car and truck parking spaces.

Moreover, researchers from the Information Technology and Innovation Foundation (ITIF) and the London School of Economics have found that investing in ITS creates a network effect throughout the economy and stimulates job creation across multiple sectors, including the high-tech, automotive, information technology, consumer electronics, and related industries. The use of ITS technologies is estimated to provide a 9-to-1 benefit-cost ratio on average as compared to an estimated 2.7-to-1 benefit-cost ratio for the addition of conventional highway capacity.

Connected Vehicle Technology and the Importance of R&D

You may have seen the U.S. Department of Transportation's announcement in February about moving ahead toward deployment of vehicle-to-vehicle (V2V) communications technology which is expected to prevent or reduce the impact of up to 80 percent of unimpaired crash scenarios. This was a major milestone in the future of vehicular safety and traffic congestion relief that was a direct result from the years of research and testing of V2V technology by the ITS Joint Program Office (ITS JPO) within the U.S. Department of Transportation. The data resulting from field operational testing of connected vehicle technology in Ann Arbor, Michigan, which was performed through a joint collaboration by the ITS JPO, the University of Michigan Transportation Research Institute (UMTRI) and major automakers, underpinned the National Highway Transportation Safety Administration's (NHTSA) decision to move ahead towardV2V technology deployment.

Connected vehicle technology truly represents the next giant leap for vehicle and highway safety. Historically, the auto industry has focused its safety efforts on mitigating the impacts of a crash after it happens. V2V technologies will sharply reduce the number of fatalities and injuries on our nation's roads by preventing crashes before they happen. A recent NHTSA study found the estimated impact from vehicle crashes to be $871 billion, reflecting $277 billion in economic costs and $594 billion from the fatalities and injuries caused by crashes.

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V2V communications will also have a direct impact on reducing congestion on our roadways. According to the Texas A&M Transportation Institute's latest Urban Mobility Report, the financial cost of congestion is more than $120 billion each year, wasting nearly 5.5 billion hours and $3 billion gallons of gasoline, causing the average commuter to spend almost a full work week stuck in traffic, and putting more than 56 billion additional pounds of emissions into our communities.

V2V communications technology operates via Dedicated Short Range Communications (DSRC) within the 5.9 GHz band of spectrum, which was set aside by the Federal Communications Commission (FCC) to ensure high-speed, accurate, secure and reliable communications which are critical for connected vehicle safety systems. It is essential that the availability and performance of this spectrum is protected for safety purposes, while also freeing up additional spectrum where it makes sense and where it can be done without jeopardizing safety for expanded WiFi applications.

Other companies are working to integrate DSCR into smart phones, aftermarket devices and traffic infrastructure so these groundbreaking safety benefits can be extended to all transportation users including pedestrians, motorcyclists and bicyclists. This promises to further reduce the number of deaths and injuries on our nation's roads while unleashing a new wave of innovation, from advanced traffic management systems to real-time traffic, transit, road weather and parking information.

Even before we achieve a fully-deployed connected vehicle network, the explosion of real-time transportation information, location data, wireless billing and smart phone platforms made possible by the continued advancement of V2V technologies, will have dramatically transformed mobility,

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providing commuters with a plethora of new options from car-sharing, ride-sharing and on-demand services to smart parking and navigation apps. Already, small businesses like Uber, Lyft, WAZE, RideScout, Car2Go, Streetline, ParkMobile, Parkopedia, Getaround, and many other companies, which didn't exist five years ago, are fast becoming household names using wireless technology and transportation data to provide more efficient and convenient services to the public.

Connected Vehicle Technology: Ensuring Security and Anonymity

Today's market is enchanted by driverless vehicles, which is creating even greater excitement around the ITS industry. However, autonomous and connected transportation produces incredible amounts of data which needs to be collected, analyzed, secured and in some cases made available. While this provides tremendous opportunity for innovation, our future transportation network faces the potential for cyber-attacks and concerns regarding driver anonymity. Sustained R&D will be critical toward ensuring uncompromised security for the V2V system. Though a final security system design has been developed, it still requires testing and verification and will continually need to be monitored and tested as we advance the deployment of connected vehicle technologies. Ensuring anonymity on the other hand, is already possible through the DSRC protocols which only allows for beaconing between vehicles as well as between vehicles and infrastructure on the 5.9 GHz band of spectrum. Such communications create an immediate awareness for the driver about the vehicles surroundings but cannot enable the recognition of other vehicles and/or drivers.

In summation, V2V technologies represent the future of surface transportation safety, mobility and traffic congestion mitigation. This nation is poised to leap into this new world of vehicle communications with vastly improved throughput, expanded mobility and, most importantly, a reduction in car crashes by as much as 80 percent. With more than 33,000 fatalities annually on our nation's roadways, continued full funding of the ITS Research Program will be critical for reducing these preventable tragedies and for enabling the more efficient movement of goods and people to drive our nation's economy forward.

Finally, the innovations described here will be showcased from September 7 – 11, 2014 at the 21st World Congress on Intelligent Transportation Systems which will be held in the birthplace of America's auto industry in Detroit, Michigan. I invite each of you to visit Detroit and ride in a connected or automated vehicle or check out the latest transportation innovations on display.

I thank you for the opportunity to testify, and look forward to answering your questions.

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ITS AMERICA

SCOTT F. BELCHER
PRESIDENT AND CEO

Scott F. Belcher was appointed President and CEO of the Intelligent Transportation Society of America in September 2007 after a successful legal and nonprofit management career.

Scott brings to ITS America more than 20 years of private and public sector experience in Washington, DC. Prior to joining ITS America, Scott served as Executive Vice President and General Counsel at the National Academy of Public Administration (NAPA) in Washington, DC.

Scott's vision for moving ITS to the next level includes raising awareness of the value of ITS among consumers, legislators, and the media and seeking increased federal funding of ITS initiatives. This vision will help guide our nation's transportation network to a level of enhanced safety, reduced traffic congestion, decreased fuel consumption and emissions, and a lowered economic burden on our society.

Scott holds a Juris Doctor from the University of Virginia, a Master of Public Policy from Georgetown University, and a Bachelor of Arts from the University of Redlands.

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Chairman BUCSHON. Thank you very much.

I now recognize Mr. Maddox for five minutes to present his testimony.

TESTIMONY OF MR. JOHN MADDOX, DIRECTOR OF COLLABORATIVE PROGRAM STRATEGY, TEXAS A&M TRANSPORTATION INSTITUTE AND UNIVERSITY OF MICHIGAN TRANSPORTATION INSTITUTE

Mr. MADDOX. Good morning. Thank you, Chairman Bucshon, Ranking Member Lipinski, Chairman Smith, and all the Members of the Subcommittee, for the chance to speak with you today. I am honored to speak on behalf of Texas A&M Transportation Institute about the future of surface transportation technology and key research needed for creating a much safer and more efficient transport system.

Transportation is the lifeblood of our economy and society. Our current surface system has served us well for the last 100 years; however, it is showing signs of strain. Yet our society, economy, and international economic competitiveness depend directly on the ability to transport people and goods in an efficient manner. Largely, we have accepted undesirable outcomes of crashes, congestion, and wasted energy, as stated earlier, as the status quo. We have attempted to address these problems of course, primarily with separate siloed approaches for vehicles, roads, and human behavior, but those separate approaches are only producing incremental results instead of the significant breakthrough improvements that we need. It is clear we need a significant change.

The next wave of breakthrough innovation will be connected vehicles, first connected to each other through V2V, then to roadway and infrastructure devices through V2I, then finally to other vulnerable road users such as pedestrians, motorcyclists, and bicyclists. And collectively, these technologies represent a critical component of the transportation future. The first of these, V2V, has a foreseeable path to deployment through a NHTSA mandate or consumer information program, though focused and applied research remains needed to bring it to a point where it is ready to be deployed at scale. This includes research to support NHTSA's rigorous rulemaking process, research on spectrum congestion, and field testing of the Security Credential Management System which is critical to the operation of that V2V system, amongst others.

Policy is equally important and significant progress has been made over the last three to four years, but additional research is needed in a few key areas. Privacy has been one of the key policy aspects identified since the inception of the V2V program. The V2V system has been designed from the very beginning to be very protective of privacy of individual drivers or vehicle owners or operators, and the result is that the basic message that is broadcast from these vehicles is anonymous and contains no information that identifies the vehicle or driver. By design, the system does not track or record vehicle movement. Because of this, it is practically impossible to track the location or meaningful path history of a vehicle or person through the V2V system, as contrasted to the relative ease of doing so with cell phones.

Additionally, similar protections are designed into the Security Credential Management System that is being finalized by the automotive OEMs with help from experts in academia and the security industry. Of course no electronic data system is completely impervious to cyber attacks and hacking and vehicles are potential targets of such attacks. Therefore, it is prudent to continue conducting research on that topic for vehicles and infrastructure.

While liability concerns may slow U.S. deployment of fully cooperative systems, other countries may very well benefit first from the technologies developed here. Because of this, it is advised to consider policy research and to share liability regimes, including limiting but not eliminating the liability of automakers and other device makers, as well as the operators of connected infrastructure so that we can realize the greater societal benefit of these technologies sooner.

While V2V has a clear path for deployment, much research remains to be done on V2I. The United States needs a V2I deployment strategy that clearly supports and funds the voluntary installation of connected vehicle technology by state and local governments and is directly supported by research and field operational tests that demonstrate and quantify the cost and benefit of these systems. These results will allow state officials to make informed decisions on whether to invest on these deployments that are beneficial to their individual transportation needs.

U.S. DOT has signaled that it intends to sponsor such V2I field operational tests in the 2015 through 2018 time frame. This is a critical step towards deployment of V2I and this research effort should be fully funded.

Importantly, vulnerable road users make up 30 percent of our traffic fatalities and this is a growing number. Research must be funded and started on establishing connected applications for their safety and mobility, including V2P, V2—V2Pedestrian, V2Bicycle, and V2Motorcycle.

Alongside the development of connected vehicle technologies, research on automation will occur simultaneously. These technologies are not competing against each other but are actually very complementary. Automated vehicle research is proceeding at a rapid pace but it is clear that operation of these vehicles will rely on having a human in the driver's seat for some time to come. This is partially due to technical limitations but also to yet-unanswered policy questions.

The U.S. DOT can help the industry developed these AV technologies with studies on how connection complements automation, how improved or enabled infrastructure can aid automated vehicles, and policy research would be very helpful as U.S. DOT is in the unique position, along with the state DOTs, to begin to address some of these key questions.

In closing, U.S. DOT, along with industry, academia, and other governmental bodies, should continue its very successful public-private research program on connected transportation and be funded to finish the work we started on this technology as it holds great promise for improving our transportation system and our economic competitiveness.

I appreciate this opportunity very much. Thank you for your attention. I look forward to your questions.

[The prepared statement of Mr. Maddox follows:]

U.S House of Representatives Committee on Science, Space and Technology - Subcommittee on Research and Technology

Future of Transportation Technology

Expert Testimony by

John M. Maddox
Texas A&M Transportation Institute &
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Wednesday June 18, 2014

Good morning. Thank you Chairman Buchon, Ranking Member Lipinski, and all of the members of this subcommittee for the chance to speak with you today. I am John Maddox, Director of Collaborative Program Strategy at the Texas A&M Transportation Institute (TTI), and the University of Michigan Transportation Institute (UMTRI). I am honored to speak with you on behalf of TTI about the future of surface transportation technology, and key steps for creating a much safer and more efficient transport system.

My perspective includes research, development and deployment, with a focus on how to maximize the benefits of new transportation technologies for the people and economy of the United States. I will cover near-term and long-term future vehicle and infrastructure technologies, including the role of government and industry research and development, as well as related policy issues.

The Texas A&M Transportation Institute, established in 1950, has a long, successful history of performing groundbreaking research on a wide range of significant transportation issues. Recognized as one of the premier higher education-affiliated transportation research agencies in the nation, TTI's research and development program has made significant breakthroughs across all facets of the transportation system—from safety, mobility and planning, to intelligent transportation systems, infrastructure, and the environment—and other critical areas vital to an efficient transportation system and quality of life.

TTI's headquarters is located on the campus of Texas A&M University in College Station. The Institute maintains a full-service safety proving grounds facility; environmental and emissions facility; and a sediment and erosion control laboratory, as well as numerous other facilities and laboratories. TTI has 10 locations in Texas and an office in Mexico City, and is home to 10 state and national research centers, including one focusing on railway safety research and another focusing on connected transportation.

TTI is well-positioned to offer objective and credible guidance on a wide range of transportation topics and emerging issues, such as connected vehicles and connected infrastructure. The Institute annually works on more than 600 transportation research projects totaling more than $54 million dollars with over 200 sponsors at all levels of government and the private sector. At any one time, TTI has research sponsors in about 30 states and has conducted research for sponsors in all 50 states and more than 20 foreign countries. TTI has about 400 professional researchers with significant expertise in all disciplines impacting transportation, such as technology, engineering, planning, economics, policy, landscape architecture, environmental sciences and the social sciences.

Transportation is the lifeblood of our economy and society. The ability to efficiently and effectively move people and goods is critical to the social and economic well-being of the United States, and will help us remain competitive with other international economies. It is clear we need a significant change.

Our current transportation system has served us well for the last one hundred years, however our current roadway transportation is showing signs of strain. We experience significant congestion, especially in our largest cities. The cost of this congestion exceeds $121B in direct operating costs, wasted fuel, and lost opportunity costs, including $27B worth of wasted time and fuel for trucks moving goods (1). And this is a growing number. Many people experience the frustration of a congested commute to work or home, including byproduct effects of unpredictable arrival times. Yet our society and economy depend directly on the ability to transport people and goods in an efficient manner. While this is also true of other international economic regions, it may be particularly important for the competitiveness of the US and the NAFTA Region given the vast size of the geographic trading area. Additionally, the basic funding mechanism whereby we maintain our roadway infrastructure is uncertain.

Even more tragic is the fact that approximately 33,000 Americans lose their lives on US roads every year, and another 3.9M are injured. The National Highway Traffic Safety Administration (NHTSA) estimates the societal cost of these crashes at $871B, or the equivalent of 1.9% of the national GDP. (2). And while the numbers of fatal crashes have decreased steadily over the last 10 years, largely due to NHTSA's efforts, , the Automotive Industry, and State DOTs, the numbers of fatalities of vulnerable road users (VRUs: motorcyclists, pedestrians, bicyclists) have not declined, but have even slightly increased. These VRUs are an increasingly important part of road safety, perhaps as urbanism, congestion, and energy costs entice more people to find alternative means of transport. All of these fatalities should be viewed as unacceptable.

Largely we have accepted these undesirable outcomes, including crashes and congestion and wasted energy, as the status quo. We have of course attempted to address these problems, primarily with separate "siloed" approaches for vehicles, roads, and human behavior. But those separate approaches are only producing incremental results, instead of the significant breakthrough improvements that we need.

New technologies such as Connected Vehicles and Infrastructure are creating a significant opportunity to vastly improve our transportation system, especially the way

we move people and goods. This will have great social and economic benefit to the United States, and will help us remain competitive with other international economies.

Vehicles, and the way they are operated, are undergoing a fundamental change. Currently, vehicles are increasingly being equipped with two significant technologies, namely advanced telecommunications systems, and Advanced Driver Assistance Systems (ADAS). These technologies provide convenience and safety, respectively, for today's drivers. Both are the result of significant and successful research and development programs that have been transferred to deployment. Both will be building blocks for future transportation systems.

The telecommunications systems are largely the result of collaborations between the automobile and telecommunications industries, primarily to satisfy the customer's desire to be connected and entertained at all times. These systems have been somewhat helpful for mobility in deployment of navigation and real-time traffic information to drivers. But, while people enjoy ubiquitous connection, operation of handheld devices, such as smart phones, has led to significant additional driver workload, and in some cases, distraction. Integration of these devices or functions with the vehicle itself allows for maintaining that connection but with possibly lessened workload and distraction. So far, issues of privacy and security have not come to the forefront, probably largely due to the fact that they are primarily linked to personal cellular-based accounts which consumers "opt-in" to use.

At the same time, on-board ADAS systems have been developed as a result of collaboration between the automobile industry and governmental agencies in the US, Europe and Asia. These were initially deployed to provide added warning and aid to drivers, while the driver kept complete control of the vehicle, including systems such as Forward Collision Warning (FCW), Lane Departure Warning (LDW), and Blind Spot Warning (BSW). But now increasingly more complex systems are being deployed that actually intervene and take partial control to help the driver avoid or mitigate specific crash-imminent situations. These include Electronic Stability Control (ESC), Forward Collision Avoidance (FCA) or Crash Imminent Braking (CIB), Lane Keeping Systems (LKS), Pedestrian Crash Avoidance, and combinations of these. Even though these are already being deployed, research on these systems continues in efforts to improve their capability, reduce costs, and to identify methods to test and evaluate their effectiveness in a wider range of roadway scenarios. However, these systems are relatively costly, may not operate effectively under all weather and roadway conditions, and even with full deployment, can only directly affect individual equipped vehicles.

The next wave of vehicle innovation will be Connected Vehicles, first connected to each other (Vehicle-to-Vehicle; V2V), then to roadway and infrastructure devices, (Vehicle-to-Infrastructure; V2I), then finally to other road users such as pedestrians (V2P), motorcyclists (V2M) and bicyclists (V2B). Connection will likely prove to be an invaluable asset, as it allows for a "systems approach" instead of "siloed" solutions, creates the possibility for "big-data" solutions for transportation, and is an enabler of automated vehicle technology. Collectively, these technologies represent the future of transportation, and have the possibility to provide significant improvements in safety, mobility, and energy use in transportation.

The USDOT, in collaboration with the Auto Industry primarily through the Crash Avoidance Metrics Partnership (CAMP), and Academic partners, has spearheaded the successful effort to research and develop Connected Vehicle technology. Federal involvement has been critical from the beginning, and continues to be, because the Federal government is in a unique position to bring together companies who would otherwise be unable or unwilling to develop the technology in a very competitive environment with otherwise unclear deployment strategies. NHTSA's regulatory authority provides a pathway to create a deployment strategy for V2V that can ensure a level playing field amongst competitors as well as a known trajectory towards a critical mass of vehicles. Auto Industry involvement, with its in-depth expertise, ensures an outcome that is deployable in a real-world environment. And Academic involvement brings critical expertise and bandwidth to conduct research at many levels, and serves as a neutral third party between the government and industry. And of course Academia can also educate and train the engineers of the future who will take this technology to even further levels. This collaboration is a very successful example of how public private research partnerships can achieve significant results that could not be achieved otherwise, or that would take a much longer timeframe to achieve.

The first of these technologies, V2V, has a foreseeable path to deployment, though focused applied research remains needed to bring key remaining aspects of related technology to a point where it is ready to be deployed at scale.

USDOT and NHTSA announced in February 2014 that they will move forward with V2V technology, stating that *"V2V crash avoidance technology has game-changing potential to significantly reduce the number of crashes, injuries and deaths on our nation's roads."* (3) Indeed, that statement generally represents the collective opinion of the research community who have been involved in this program for the last 5-6 years. At this time we are still awaiting NHTSA's report to understand specific outcomes, but the previous estimates from USDOT have been that V2V is potentially capable of addressing 79% of vehicle crash scenarios. (4) Currently, V2V using 5.9GHz Dedicated Short Range Communication (DSRC) is the only proven technology that can reliably communicate between vehicles within the millisecond timescale that is required in a broad range of critical crash-imminent scenarios.

It is that broadcast communication that allows vehicle-based algorithms to generate information and warnings to drivers, as well as provides a building block to enable further levels of automated control in greater numbers of roadway scenarios. Additionally, the broadcast communication from vehicles will also enable the deployment of V2I, V2P, V2M, and V2B, which will themselves allow significant improvements in our roadway transportation system.

The USDOT and the auto industry have invested significant resources to research and develop these V2V technologies, culminating in NHTSA's February 2014 decision to move forward. This extensive collaborative research and testing effort, including the Safety Pilot Model Deployment in Ann Arbor, MI being conducted by UMTRI, has successfully demonstrated the functionality and efficacy of the V2V system. At this time, we are still awaiting NHTSA's full report to understand the specific outcomes.

However, it is clear that there still remains detailed technical follow-on work to be completed to allow full V2V deployment through a potential NHTSA mandate or consumer information program.

Firstly, as NHTSA transitions from a research program into a rulemaking program, the primary technical challenge will be to identify appropriately rigorous performance requirements, test procedures, and potentially new test equipment that can be used in the development of practicable FMVSS standards or NCAP requirements. This is a necessary step for any and every rule or requirement that NHTSA codifies, and in this case it is more complex because it is the first time NHTSA, or any automotive regulatory body, would require equipment for over-the-air safety-related communications between vehicles. The collaboration with the Auto Industry and Academia will continue to be critical to identify new methods that are practicable in the real world, and it is very likely that these requirements can and will be developed.

Additionally, there are concerns about the potential effects of congestion on the 5.9GHz spectrum. Since V2V relies on this spectrum, any other broadcasts or messages other than safety related messages have the potential to degrade the efficacy of V2V safety benefits for connected vehicles. There are discussions regarding the potential sharing of this spectrum for non-safety and even non-transportation use. We must fully investigate and understand the feasibility of any potential sharing regime, and ensure that this does not degrade or inhibit V2V's ability to provide the safety benefit for road users. If there is potential for degradation, then we must investigate effective countermeasures to ensure that broadcast communications get through to the vehicles that need to receive them. And we must ensure that any spectrum-sharing regime does not preclude other critical safety or mobility applications, such as V2I, V2P, V2M, and V2B.

The operation of a Security Credential Management System (SCMS) is critical to the performance of a V2V system to ensure that messages transmitted and received can be trusted and therefore acted upon. While the Safety Pilot Model Deployment successfully included an early version of a security system, continued USDOT, Auto Industry, and Academic research has already eclipsed this level and design of a full-scale capable system is now being finalized. Further research and testing will be required to demonstrate that system's practicability in the real world at significant scale. This must be a continuation of the collaborative effort between government, industry, and academia, as it will be the first of its kind and must be capable of growing to a very large scale. Again, it is anticipated that practicability of this system will successfully be demonstrated.

Lastly, while not absolutely critical to the operation of V2V, the introduction of aftermarket or retrofit devices can help accelerate the trajectory towards a "critical mass" of connected vehicles and devices. Because V2V is a communicative system, it is reasonable to expect that effectiveness of the system will increase with the distribution of equipped vehicles. Since it is expected that aftermarket devices can be introduced faster than the vehicle fleet turns over, it is also reasonable to expect that they will help achieve greater benefit in an earlier timeframe. Research is needed on the design, reliability, and Human-Machine Interface (HMI) of these aftermarket and retrofit devices to ensure they perform at an acceptable level of precision and reliability and don't generate unwarranted workload or additional distraction for drivers. These devices must be field-tested at a level of scrutiny similar to the OEM-developed in-vehicle systems. These devices are also important from a consumer-adoption point of view, in that they can potentially bring additional mobility and energy-saving applications which can help ensure there is recognizable consumer value from "day-one" of deployment. And lastly, but importantly, these devices may pave the way for development of smart-phone based applications that can also act to protect pedestrians from vehicle collisions.

In addition to the technical research work over the last 5-6 years, USDOT and the Auto Industry have engaged in research and discussion on policy aspects of Connected Vehicle technology. Significant progress has been made, and some research questions remain.

USDOT formed an internal multi-modal Policy Task Force that identified, examined, and made decisions and recommendations on those key policy aspects, such as authority, privacy, deployment models, etc. Similarly, the Auto Industry formed a collaborative group, the Vehicle Infrastructure Integration Consortium (VIIC) that identified and addressed policy issues from an industry perspective. While USDOT and NHTSA have not published their research report yet, it is expected that it will address many of these policy issues.

Privacy has been one of the key policy aspects identified since the inception of the program. The V2V system has been designed from the beginning to be very protective of privacy of individual drivers or vehicle owners or operators. And the result is that the Basic Safety Message (BSM) that is broadcast from the vehicles is anonymous and contains no information that identifies the vehicle or driver. As standardized by the Society of Automotive Engineers (SAE) it only contains information about a generic vehicle's instantaneous location, heading, acceleration, speed, and vehicle status such as brake application and steering wheel angle. By design, the V2V system does not track or record vehicle movements, and security credentials are updated on a very short-term basis. Because of this specific design it is practically impossible to track the location or meaningful path history of a vehicle or person through the V2V system, as contrasted to the relative ease of doing so with cell phones.

Additionally, similar protections are designed into the Security Credential Management System that is being finalized by the Automotive OEMs with help from Academia and the Security industry. This system is based on the principle of maximizing individual privacy while maintaining highest levels of security. While the full details of this system have not been released, it is understood that it will incorporate multiple layers of security credentialing and a separation of organizations and databases that will not allow any one organization, or individuals inside or outside of those organizations, to ascertain both the vehicle identification and location at the same time.

Of course no electronic data system is completely impervious to cyber attacks and hacking attempts, and vehicles and vehicle systems are potential targets of such attacks. While no known attacks have been mounted in the real world environment, there have been a small number of demonstrations of hacking into embedded (built into the individual vehicle) systems by academic and research organizations. And V2V/V2I systems, along with infotainment and communications systems, may offer an additional "attack surface" into the vehicle due to their nature of enabling data exchange. Therefore it is prudent to conduct continued research on cybersecurity for vehicles, including these V2V/V2I messaging and security systems, to understand any vulnerabilities and potential countermeasures. This also should be organized as a collaborative research effort between government, industry and academia to leverage the best outcomes for transportation safety and security of mobility.

Liability concerns, though not a strict impediment to V2V deployment, may slow deployment of fully cooperative systems and the resultant benefits therefrom. By definition, the effectiveness of V2V relies on the shared use of data between vehicles, infrastructure, and devices. But inherently there is risk for any one manufacturer when the safety of their product's passengers is partially dependent on another manufacturer's product. There will be a wariness to introduce the full functionality of these technologies in the United States due to our litigious climate. Other countries may very well benefit first from the technologies developed here, resulting in delayed benefits for US consumers and a potential loss of economic competitiveness. Because of this, it is advised to consider research into shared-liability regimes, including limiting (but not eliminating) the liability of automakers and other device makers, as well as the operators of connected infrastructure including the security system and traffic operations, so that we can realize the greater societal benefit of these technologies.

Perhaps the key non-technical issue that remains, and that must be addressed, is that of identifying an entity to operate the Security Credential Management System, along with a viable business model that allows for self-sustaining indefinite operation of the system. The current assumption is that the operator of this system should be a non-government agency to minimize any public concerns regarding invasion of privacy, but that does not preclude the possibility of federal funding that would contribute or fully fund this operation. As the design of this system is finalized, and then communicated and tested, it is expected that a number of potential business models and operating entities will emerge. This could be aided by focused research by government, academic institutions, non-profit organizations (such as the Intelligent Transportation Society of America; ITSA) and stakeholders from various industries including automotive, telecommunications, transportation operators, data companies, and others.

While V2V has a clear path for deployment, much research work remains to be done on a deployment strategy for V2I and I2V to ensure we meet our mobility and energy goals for transportation.

V2V will form the backbone upon which other Connected Vehicle technologies will be built. Data from vehicles will enable many V2I applications that can address key transportation performance needs, especially mobility and energy improvements. For example, V2I connection holds unique promise for addressing congestion. Key applications include adaptive traffic signal control, which uses the real-time data coming from vehicles to alter signal phase and timing (SPAT) to maximize vehicular throughput in a given intersection or corridor. And "probe" vehicle data enables real time traveler information that can guide drivers of passenger vehicles and freight vehicles to take alternate routes to minimize their delay in congested areas. Additionally, vehicle data will enable the operators of the transportation system to understand dynamic traffic conditions, as well as the physical condition of the roadway including the presence and severity of potholes, or the need to deploy snowplows and salt trucks. The list of these potential applications is quite extensive, limited only by the imagination and lack of direct experience of understanding the data availability.

Additionally, I2V (Infrastructure-to-Vehicle) communications will enable yet another group of beneficial applications. For example, if the vehicle knows the intersection's signal phase and timing it can advise the driver to adjust its coast-down approach to minimize fuel usage, and can advise the vehicle of exactly when to restart its engine after sitting at a red light that is about to turn green. Additionally, the infrastructure can alert the vehicle to the presence of a pedestrian in a crosswalk, or the presence of road workers in a construction zone. Again the list is extensive and currently limited by experience with the data.

The USDOT, especially FHWA and OSTR, has undertaken a great deal of research in identifying and defining these and many other V2I applications, and has started on the work of writing initial specifications for communications and application performance. FHWA has announced their intention to publish guidance in the FY2015 timeframe to states and local governments on deployment (5). But they have stopped short of *requiring* any deployment, as their authority may not allow a mandate. They have signaled a willingness to allow V2I/I2V technology deployment as part of their grant and state funding programs, and that is an encouraging step. Additionally, AASHTO has published their "Footprint Analysis" which elucidates potential key-application deployment installations and operations possibilities, and estimates total build-out costs for the US, but does not describe a clear deployment or financing strategy to accomplish that in the near timeframe.

As of yet, a clear deployment strategy for V2I has not emerged in the US. Contrarily, the Europe Commission and some Asian countries have established and begun to implement an infrastructure deployment strategy. These strategies are based on results of research and Field Operational Tests (FOTs) that have quantified the cost and benefit of critical V2I applications, similar to what Safety Pilot Model Deployment has done for V2V safety applications.

The US needs a V2I deployment strategy that clearly supports and funds the voluntary installation of key applications by the State and Local governments, and is directly supported by research and FOTs that quantitatively demonstrate the installation, operation, and maintenance costs, and the resulting benefit to mobility, energy, and safety. These results will allow state and local governments to make informed decisions to invest resources into deploying applications that are beneficial to their individual transportation needs.

USDOT has signaled that it intends to sponsor such V2I FOTs in the FY2015 – 2018 timeframe, focused on mobility, energy, and safety. (6) This is a critical step towards deployment of V2I, and this research effort should be fully funded. It is anticipated that these FOTs can also form the backbone of regional initial deployments. Additionally, research should continue on developing and defining V2I applications for transportation operations, including passenger and freight mobility, smart parking, data acquisition and manipulation, and other areas.

Building on the success of the V2V collaboration between government, industry, and academia, the V2I research and demonstration efforts need to call upon significant engagement from the manufacturers and users of infrastructure-based equipment, such as traffic signal controllers, data systems, roadside sensing hardware, etc. A consortium of those manufactures and users could be formed to help provide that engagement in a manageable way.

There have been incidents of cybersecurity attacks on our transportation infrastructure such as traffic signals, networks, and variable message road signs. Some portion of our existing roadway infrastructure is already connected through wireless and cellular networks. As with vehicles, additional and more ubiquitous connection of our infrastructure can create additional attack surfaces. Research is needed on cybersecurity of our infrastructure to ensure the integrity of our transportation system.

Importantly, early research must be started on establishing connected applications for safety and mobility of vulnerable road users (VRUs), including V2P, V2B, and V2M.

Pedestrians, Motorcyclists, and Bicyclists collectively make up 30% of all of the traffic fatalities in the US. These road users are very hard to protect in the event of a collision, and the key to improving their safety is to avoid the collision in the first place. While onboard vehicle technologies are beginning to help address this, the effectiveness of collision avoidance technologies can likely be enhanced greatly by providing a channel of communication between the VRU and nearby vehicles. Such V2P technologies have been developed at the concept and demonstration level using smart phones. But significant research questions still exist around positioning accuracy and connected device options and tradeoffs. The smart phone approach can also theoretically be applied to bicyclists, and again additional research is needed to address unique questions around localized travel patterns of bicyclists, and positioning requirements.

Additionally, while motorcycles are technically another vehicle, the current V2V research has not directly focused on their unique requirements for communication systems. They have significantly different usage patterns, such as variable lane position, higher speeds and increased maneuverability, and reduced conspicuity when compared to passenger vehicles, light trucks, and large vehicles. Again, the key to improving safety for motorcyclists is to avoid the collision in the first place by making the driver of the other vehicle completely aware of the presence of the motorcycle, especially under critical crash scenarios. M2V /V2M has great potential to communicate that presence and create that awareness. Additionally, I2M may be helpful in certain crash scenarios by transmitting slippery or otherwise hazardous conditions that can be tailored to motorcycle riders. Both of these technologies require careful thought on the best way to communicate these messages to the rider, and will require unique HMI considerations. This research must also be started and fully funded.

Alongside the development of Connected Vehicle technologies, research on Automated Vehicles will occur simultaneously. These technologies are not competing against each other, but are very complementary.

Currently, there are a great deal of media stories and reports on the development of Automated Vehicles (AVs), or Self-Driving Vehicles. AV research is indeed proceeding at a rapid pace, primarily by certain auto companies, suppliers, academic institutions, and Google. These efforts are primarily aimed at consumer convenience. AVs will result from a convergence of current ADAS driver assistance technology, the connected vehicle and infrastructure platform that can act as an additional and very powerful "sensor", and self-driving vehicle technology, including further advanced vehicle-based sensors and decision making algorithms.

Development will occur along a continuum of increased levels of automated control. But it is clear that operation of these vehicles will still rely on having a human in the driver's seat for some time to come. This is due partially to technical reasons, including limitations of current-level sensing systems and algorithms, but it is also due to yet-unanswered policy questions. Driver responsibility forms the basic assumption of our transportation systems, including responsibility for maintaining safe control of a vehicle, and also for ensuing licensing, insurance, enforcement, liability, and even criminal penalty systems. Therefore policy research is needed to begin to answer questions about these basics when control responsibility is directed away from the driver and towards the vehicle itself.

However, AV technology may also hold great promise for improving the safety, mobility and energy use of our transportation system. Since approximately 93% of fatal crashes involve human error, (7) aiding the driver and providing direct control in normal driving situations to avoid crash-imminent situations altogether through automation should help reduce crashes. Automation has the potential to help smoothing of traffic to reduce congestion in certain limited scenarios, and to aid fuel economy in others. However, it is important to recognize that none of this has been proven as of yet.

The USDOT, especially OSTR, can help the industry develop these AV technologies with studies of how connection complements automation, and how improved or enabled infrastructure can aid automation. Policy research would be very helpful, as USDOT is in a unique position along with State DOTs to begin to address some of the key questions. As stated before, cybersecurity is a growing concern for embedded and connected systems, but is absolutely critical for automated systems that have the ability to autonomously control a vehicle or infrastructure element. NHTSA must continue its basic research on cybersecurity and safe-reliability of these vehicle control systems, and FHWA could begin significant work on cybersecurity of infrastructure systems. Additionally, since higher-level automation can spur new usage patterns and new business models, even potential changes in roadway and urban design and payment systems should be researched, as well as how these vehicles integrate to a full multi-modal system including transit and shared-use models.

In closing, I wish to reiterate that we are entering a new era for a greatly-improved transportation system built on key technologies. True collaborative research partnerships, such as the public-private partnership between USDOT and the Auto Industry and Academia, will be required to develop and realize the best results from these technologies. Other industries should be brought into this effort. USDOT should continue its very successful public/private research program on Connected Transportation as a whole, and be funded to finish the work we have started by:

- **Completing the deployment strategy for V2V.**
- **Establishing a deployment strategy for V2I / I2V and conducting field tests.**
- **Establishing a comprehensive research plan on Connected Vulnerable Road Users (V2P, V2B, V2M).**
- **Conducting public/private research on transportation cybersecurity.**
- **Spurring innovation and deployment of AVs.**

I appreciate this opportunity very much and welcome your questions. Thank you for your attention.

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References

1) Shrank, Eisele, Lomax; (2012, December), TTI's 2012 Urban Mobility Report Texas A&M Transportation Institute, The Texas A&M University System

2) Blincoe, L. J., Miller, T. R., Zaloshnja, E., & Lawrence, B. A. (2014, May). The economic and societal impact of motor vehicle crashes, 2010. (Report No. DOT HS 812 013). Washington, DC: National Highway Traffic Safety Administration

3) David Fiedman, Acting Administrator, National Highway Traffic Safety Administration (2014, Feb 3). Press release: U.S. Department of Transportation Announces Decision to Move Forward with Vehicle-to-Vehicle Communication Technology for Light Vehicles

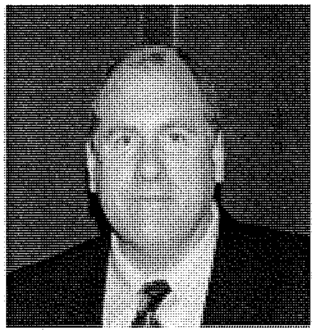
4) Wassim G. Najm, Jonathan Koopmann, John D. Smith, and John Brewer (2010, October) Report No DOT HS 811 381. Research and Innovative Technology Administration; John A. Volpe National Transportation Systems Center

5) Federal Highway Administration (2014, February). USDOT Connected Vehicle Activities Vehicle to Infrastructure Workshop: FHWA 2015 V2I Deployment Guidance

6) Federal Highway Administration (2014, March). Federal Register Notice 79 FR 14105; Connected Vehicle Pilot Deployment Program; Request for Information

7) National Highway Traffic Safety Administration (2008, July). DOT HS 811 059

National Motor Vehicle Crash Causation Survey; Report to Congress



Maddox bio

John Maddox serves as the Director of Collaborative Program Strategies at both UMTRI and TTI. In this position, he develops collaborative research strategies, initiatives and opportunities for both organizations with federal/state agencies and industry stakeholders and other partners to tackle significant problems in transportation safety, the environment, and mobility that can be addressed only through collaborative research.

Broadly his work focuses on public-private research programs, and he plays a key role in helping to create and direct strategies that build, support, and promote connected-automated vehicle test environments and initial deployments in Michigan and Texas. This includes the development of a strategy geared toward maximizing the value of the test environment for innovation in vehicle-to-vehicle, vehicle-to-infrastructure communications technologies, and automated vehicle technologies as well as policy and legal issues and new business opportunities.

Mr. Maddox has an extensive background at the U.S. Department of Transportation and in the auto industry. From December 2008 to August 2012, Mr. Maddox served as the associate administrator for Vehicle Safety Research at the National Highway Traffic Safety Administration (NHTSA).

Before working at NHTSA, Mr. Maddox spent over five years with Volkswagen Group as a compliance officer, with the responsibility of ensuring compliance with all federal and Canadian motor-vehicle safety standards. And he spent fourteen years with Ford Motor Company as a senior research engineer and had multiple international assignments in product development, engineering design, and automotive safety.

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Chairman BUCSHON. Thank you very much for your testimony. I now recognize Ms. Tabar for her five minutes.

TESTIMONY OF MS. KRISTEN TABAR, VICE PRESIDENT, TECHNICAL ADMINISTRATION PLANNING OFFICE, TOYOTA TECHNICAL CENTER

Ms. TABAR. Thank you, Chairman Bucshon, Ranking Member Lipinski, and Members of the committee, for giving me this opportunity to testify before you this morning.

Toyota has a long-standing and unwavering commitment to research and development. As the world's top-selling automaker, Toyota spends over $1 million per hour globally on R&D activities that range from basic research to the development of new technologies and products. This commitment is evident in the United States where we have world-class R&D facilities. For example, the Toyota Technical Center where I work is Toyota's leading technical center outside of Japan. Today we have over 1,100 engineers, scientists, and technologists that work in our facilities in California, Michigan, and Arizona to develop the smartest and most advanced vehicles.

The automobile is currently undergoing a technological transformation that is reducing crashes, improving fuel efficiency, and bringing greater convenience and improved quality of life to the drivers and passengers. Much of what is to come will be made possible by the increasing level of connectivity, including the ability for the vehicles to communicate with each other and infrastructure around them.

Vehicle-to-vehicle, or V2V, and vehicle-to-infrastructure, or V2I, communications are such technologies. The revolutionary advances in sensor-based technologies that we are bringing to the automotive safety can be enhanced even further through these V2V and V2I communication technologies. They have greater range, better field of view, and better line of sight than the sensor-based technologies and therefore can identify collision threats much—at a much longer distance or with a vehicle that is out of sight. It is complementary to combine these technologies with the communication technologies and on-board sensors that allow us to make progress towards our ultimate goal of zero casualties and zero vehicle crashes.

Although our initial focus is on safety applications, the technology will be used for many other applications beyond the collision avoidance. For example, it can be used to assist with navigation, making electronic payments, for example, tolls or parking, improving fuel efficiency through speed pacing at traffic lights, or gathering and disseminating real-time traffic information. This type of technology also unleashes the creativity and innovative spirit and connected car applications that are just now starting to be imagined or envisioned.

Toyota is committed to this critical safety technology. In Japan we have already commercialized the first generation of V2I communication technologies and providing detailed traffic information, lane merges, and other road condition information. In addition, several months ago we announced the commercialization in Japan of an automated highway driving system. This revolutionary technology will combine next-generation lane trace control and cutting-edge cooperative adaptive cruise control that will use V2V communications to help maintain a safe distance from the vehicles in front of you. We intend to bring these technologies to the U.S. market in the very near future.

A few key challenges do remain but there are a number of steps that Congress and the federal government could take to help us overcome these. First, the federal government should preserve and protect the spectrum that is necessary to support these communication technologies in the United States. The use of the spectrum allocated for V2V and V2I communication is unlicensed—by unlicensed devices raises significant concern about harmful interference. This could result in undermining the integrity of the system. We cannot deploy this type of technology unless the possibility of this interference is ruled out.

We are working closely with our partners to make sure that sharing of the spectrum is possible. However, this is a big technological challenge and needs time and effort and testing to prove out. We strongly discourage Congress or the FCC from taking any further action to force the sharing before a viable solution is found.

Second, the V2I communication technology offers important supplemental benefits that should not be ignored. These V2I also provide a means by which the transportation planners can gain important information about how the roads are used and being used in the future. Congress and the DOT should be looking at ways to incentivize or facilitate the build-out of the intelligent transportation infrastructure and V2I communications.

Thirdly, we encourage NHTSA to proceed expeditiously at the formation of the communication rules that it announced in February. The sooner we have clarity on this subject, the better we will be able to incorporate their requirements into our commercialization plans in the United States.

Finally, the DOT can play an important role in continuing the development and research for roadside infrastructure and testbeds. At the same time, we are very eager to move to these commercial deployment phases of our technology and we encourage the DOT to focus additional resources on helping ensure a smooth and rapid deployment of the technology, including education and outreach activities.

As with any new technology, there are legitimate concerns about security and privacy. However, these are of utmost importance to Toyota and we have been considering those from the very outset. We have taken important measures to make sure that only legitimate messages and authorized devices are on the system.

Thank you again for the opportunity to testify before you today. It is a very important and exciting time in the automobile industry and I look forward to working with the Committee on the benefits of this technology. Thank you very much.

[The prepared statement of Ms. Tabar follows:]

TOYOTA

Statement of

Kristen Tabar

Vice President – Technical Administration Planning Office

Toyota Technical Center

on

"The Future of Surface Transportation"

before the

U.S. House of Representatives

Committee on Science, Space, and Technology

Subcommittee on Research and Technology

June 18, 2014

Chairman Bucshon, Ranking Member Lipinski, and other Members of the Subcommittee, thank you for the opportunity to testify before you this morning. And thank you for holding this hearing on the future of surface transportation.

My name is Kristen Tabar. I am Vice President of the Technical Administration Planning Office at the Toyota Technical Center in Michigan. Prior to assuming this role several months ago, I was Vice President of Electronics at the Toyota Technical Center and oversaw Toyota's U.S.-based activities related to intelligent transportation technology, including vehicle-to-vehicle and vehicle-to-infrastructure communication. I started my career at Toyota in 1992 as an Associate Engineer responsible for vehicle application audio development.

Toyota has a long and proud history in the United States. Toyota produces over 1.2 million vehicles each year at our 10 U.S. manufacturing plants, including plants in Indiana, Texas, Mississippi, and Kentucky. We directly employ more than 32,000 people, and are responsible for the creation of 365,000 jobs, in the U.S. - including those that have been created by our 1,500 U.S. dealers and our network of U.S.-based suppliers. Over our more than 50 year history in the United States, we have directly invested more than $20 billion.

Toyota also has a long-standing and unwavering commitment to research and development. As the world's top-selling automaker, Toyota spends $1 million per hour globally on research and development activities that range from basic research to the development of new technologies and products. Toyota has consistently been ranked in the top 10 in terms of research and development spending by publicly traded companies, including being ranked #1 in spending in four of the last seven years.

Our commitment to research and development is evident in the United States, where we have formed and maintained world-class research and development facilities. The Toyota Technical Center is Toyota's leading technical center outside of Japan and has been the driving force behind our North American research and development activities for the past 25 years. Today, more than 1,100 engineers, scientists and technologists work at our Technical Center facilities in California and Michigan, and at our proving grounds in Arizona, to develop some of the smartest and most advanced cars and trucks on the road.

The Toyota Technical Center is also home to the Collaborative Safety Research Center (CSRC), which was launched in 2011 to serve as a catalyst for the advancement of auto safety in North America. CSRC works with leading North American universities, hospitals, research institutions and federal agencies on research projects aimed at developing and bringing to market new safety technologies to help reduce the number of traffic fatalities and injuries. Toyota has committed approximately $50 million to fund the Center and its research, with the vast majority of funding going to our research partners. Toyota has also adopted a unique open approach to CSRC's activities, making the results of our collaborative research available to federal agencies, our competitors, and academia.

In addition, our design research facilities in Michigan and California are serving as laboratories for new design ideas, providing an open field for form, shape, and materials exploration, and leading the way on future design and production engineering. Our Toyota InfoTechnology Center in Silicon Valley is working at the forefront of the rapidly-changing information technology sector and conducting research that will lead to greater innovation in the automobile industry. Our InfoTechnology Center is Toyota's technical lead on spectrum and other wireless-related research, including research related to vehicle-to-vehicle and vehicle-to-infrastructure communication.

A Vision of the Future

The automobile is currently undergoing a technological transformation that is helping to reduce crashes, improve fuel efficiency, and bring greater convenience and improved quality of life to drivers and passengers. However, despite the remarkable technological advances we've seen over the last decade, the truth is that we are only in the very early stages of this transformation. The innovation we will see in the future will be staggering.

Much of the transformation that is to come will be made possible by an increasing level of connectivity in vehicles. Cars will be connected to each other and to the world around them. They will be outfitted with next-generation telematics systems that will offer sophisticated information services, including real-time accurate traffic information and route optimization assistance to help people get to their destinations more efficiently. This type of information will certainly offer day-to-day convenience to drivers and passengers, but can also play a critical role in post-disaster situations when information on safe evacuation routes may be necessary.

In the future, there will be even more integration of vehicles and other mobile devices, offering seamless connectivity and unleashing new and innovative services, such as those that help people link diverse forms of mobility and public transportation to reach their destinations in the smartest way possible. Cars will also be communicating with homes and businesses as part of a smart energy management system and will have the ability to power your home with stored energy when electricity prices are high or during a power outage.

Most importantly, cars will be able to communicate with each other and with roadside infrastructure about potential hazards, slow or stopped vehicles ahead, or signals, signs, and road conditions that may be difficult to see. This communication capability can be coupled with advanced active safety technologies - including increasing levels of automation - that are capable of responding to the information and safely taking action to avoid the hazard altogether, potentially saving tens of thousands of lives in the United States each year.

An Introduction to Vehicle-to-Vehicle and Vehicle-to-Infrastructure Communication

There have been remarkable advances in the crashworthiness of vehicles in recent years, resulting in an impressive reduction in traffic casualties and fatalities. Despite this, however, more than 30,000 people are still dying in traffic accidents each year in the United States. Toyota and the automobile industry firmly believe that the next great opportunity to reduce injuries and fatalities from traffic accidents rests with the deployment of innovative new technologies that will prevent crashes in the first place.

Companies like Toyota are leading the way by outfitting vehicles with top-of-the-line sensors, like radars and cameras, that can identify and notify drivers of potential hazards. The revolutionary advances that sensor-based safety technologies are bringing to auto safety can be enhanced even further with vehicle-to-vehicle and vehicle-to-infrastructure communication. Communication-based technologies have greater range, field-of-view, and line-of-sight than sensor-based technologies, and can therefore identify collision threats at a greater distance or with a vehicle that is around a corner or behind a truck. It is the complementary combination and redundancy of communication capability and on-board sensor technology that will allow Toyota to make additional progress towards our ultimate goal of zero casualties from vehicle crashcs. It is also the combination of these technologies that will open the door to automated vehicle systems in the future that are safe and reliable.

Vehicle-to-vehicle safety communication is enabled by two-way, short-to-medium range wireless communication capability. Vehicles broadcast precise information – such as their location, speed, and acceleration – several times per second over a range of a few hundred meters. Other vehicles outfitted with the technology receive these "messages" and use them to compute the trajectory of each neighboring vehicle, compare these with their own predicted path, and determine if any of the neighboring vehicles pose a collision threat.

Vehicles can also communicate with equipped roadside infrastructure, enabling additional information to be provided to drivers. This includes information about the potentially unique layout of an approaching intersection or road, the current and future state of upcoming traffic signals, and the existence of a potential hazard such as ice, fog, a disabled vehicle, a bicyclist, or a pedestrian.

If a vehicle determines that a potential collision or other hazard exists, the on-board system can warn the driver or, in the future, take action to avoid a collision. Feedback to the driver can be conveyed audibly, visually through a heads up display, dashboard screen, or other signal, or through a haptic mechanism (such as a shaking steering wheel or vibrating seat) and can be formulated to range in intensity based on the risk.

The potential of this technology to save lives is tremendous. In a 2010 report entitled *Frequency of Target Crashes for IntelliDrive Safety Systems*, the National Highway Traffic Safety Administration (NHTSA) concluded that connected vehicle technology – including both vehicle-to-vehicle and vehicle-to-infrastructure communication – has the potential to prevent a majority of the types of crashes that typically occur in the real world, such as crashes at intersections or while changing lanes. The longer-range capability that this technology offers over traditional sensors also allows these dangerous situations to be predicted long before they are imminent, providing for more time to avoid them safely.

It is important to note that, although our initial focus is on safety applications, this technology can - and almost certainly will – be used for many other applications beyond collision avoidance and related safety purposes. For example, it can be used to assist with navigation, to make electronic payments (tolls, parking, fuels, etc.), to improve fuel efficiency through speed pacing at traffic lights, or to gather and disseminate real-time traffic information. In addition, just as the Internet has moved far beyond its original limited email and file transfer applications, the technology is also likely to unleash creative and innovative connected car applications that are only just now starting to be imagined and envisioned. We have no doubt that the technology will save lives, improve the environment, create jobs, and help the United States to maintain technical leadership in a field that will be an important contributor to economic growth in the future

A Commitment to Vehicle-to-Vehicle and Vehicle-to-Infrastructure Communication

Toyota is committed to this critical safety technology. In Japan, we have already commercialized first-generation vehicle-to-infrastructure communication technology that provides specific and detailed information on stopped or slowed traffic, lane merges, and other road conditions. In addition, several months ago, we announced commercialization in Japan of an automated highway driving system. This revolutionary advanced driving support technology combines next-generation Lane Trace Control with cutting-edge cooperative-adaptive cruise control that uses vehicle-to-vehicle communication technology to help maintain a safe distance from the vehicle ahead. This is an important milestone in our journey to automated vehicles and one that would not be possible without the use of vehicle-to-vehicle communication technology.

We intend to bring these technologies to the United States in the near future. That is why we've been working closely with other automakers and the U.S. Department of Transportation (U.S. DOT) over the last decade on the development of this communication technology, and why we are pleased to be here with you today discussing the technology, its potential, and some of the challenges that exist.

Collaboration with the U.S. Department of Transportation

The research and development of vehicle-to-vehicle and vehicle-to-infrastructure communication technology in the United States is an example of a successful collaboration between industry, academia, and the Federal government. The truth is that we would not be as far along today if it hadn't been for the collaborative research that has taken place to date jointly by Toyota and other automakers in the U.S. and U.S. DOT.

For more than 10 years, U.S. DOT has been working closely with automakers in the United States through the Crash Avoidance Metrics Partnership (CAMP) on a range of research activities relating to vehicle-to-vehicle and vehicle-to-infrastructure communication - including proof of concept, feasibility demonstrations, and field testing - to prepare for widespread deployment of crash avoidance systems that use vehicle-to-vehicle and vehicle-to-infrastructure communication. At this point, pre-production prototypes have been developed by a number of automobile companies, including Toyota, and are currently supporting demonstrations and large-scale evaluations of the applications that address the most critical crash scenarios.

Toyota and seven other automakers supported a year-long connected vehicle pilot program with U.S. DOT in Ann Arbor, Michigan that was completed in August of last year. The Model Deployment, which included nearly 3,000 vehicles outfitted with the communication technology from different manufacturers, demonstrated vehicle-to-vehicle applications in real-world driving scenarios and verified the maturity and stability of the technology.

Efforts are currently underway to expand the Ann Arbor pilot program from 3,000 vehicles to 9,000 vehicles and then eventually to 20,000 vehicles. There are also corresponding efforts to expand equipped roadside infrastructure over large areas of the Ann Arbor area to further test and validate vehicle-to-infrastructure communication technology. In addition to the Michigan-based programs, pilot programs are popping up around the country to further demonstrate and evaluate the efficacy of the technology. These pilot programs are important next steps in the technology's maturation and essential components of ongoing efforts to garner public understanding and acceptance of these transformational technologies.

Technical and Policy Challenges

Certainly, we should celebrate that great strides have been made in the area of vehicle-to-vehicle and vehicle-to-infrastructure communication and that we are on the cusp of realizing the potential of this technology here in the United States. However, we should also acknowledge that a few key challenges remain. We believe that there are a number of steps that Congress and the Federal government could take to help overcome these challenges and spur the deployment of the technology.

1. **Wireless Spectrum.** The Federal government should preserve and protect the short- to medium-range wireless spectrum that is necessary to support vehicle-to-vehicle and vehicle-to-infrastructure communication in the U.S. This communication capability, which is known as dedicated short-range communication (DSRC), is based on the IEEE 802.11 wireless protocol, but has been adapted for this specific vehicle-to-vehicle and vehicle-to-infrastructure communication use.

   In 1999, the Federal Communications Commission (FCC) allocated 75 MHz of spectrum in the 5.9 GHz band to be used for DSRC and, in 2003, the Commission adopted the licensing and service rules for DSRC systems operating in the band. Unfortunately, as part of a legitimate desire to find additional spectrum that can be opened up to unlicensed use in order to support the proliferation of wireless devices, the FCC issued a Notice of

Proposed Rulemaking last year soliciting comments on the possibility of opening the 5.9 GHz band up to use by unlicensed devices.

For the auto industry and those who have been involved in the development of this technology, the use of the spectrum allocated for vehicle-to-vehicle and vehicle-to-infrastructure communication by unlicensed devices raises significant, and possibly insurmountable, concerns about the potential for harmful interference. Interference that results in delayed or missed driver warnings will undermine the connected vehicle system's entire foundation, rendering it essentially useless and putting the entire future of vehicle-to-vehicle and vehicle-to-infrastructure technology in the United States at risk. Although Toyota is strongly committed to it and its potential, we cannot responsibly deploy this "safety-of-life" technology unless the possibility of harmful interference from unlicensed devices is ruled out.

We are working closely with our colleagues in both the wireless and automobile industry on the possibility of sharing the spectrum with unlicensed users in a way that will eliminate the potential for harmful interference. This is a very difficult technical challenge, and will require a significant amount of time and effort. We strongly discourage the FCC or Congress from taking any further action to force spectrum sharing until this work is completed, a viable spectrum sharing solution is identified, and testing verifies that there is no harmful interference from unlicensed devices.

2. **Infrastructure Investment.** Vehicle-to-infrastructure communication offers important supplemental benefits to vehicle-to-vehicle communication that should not be ignored. This includes information about stopped vehicles ahead, complicated or sudden lane merges, and upcoming roadway construction, as well as the ability to detect pedestrians or bicyclists. Vehicle-to-infrastructure communication also enables communication from the vehicle to the infrastructure, providing a means through which transportation planners and policymakers can gain important information about when and how roads are being used.

   Intelligent transportation infrastructure also helps ensure greater value to drivers during the earliest stages of deployment. With intelligent transportation infrastructure in place, even the earliest adopters of the technology receive an immediate benefit the moment they drive a vehicle outfitted with the technology off the lot in the form of infrastructure-enabled warnings and information.

   The immediate benefit to drivers is in part why Toyota started with the commercialization of vehicle-to-infrastructure communication technology in Japan, where there is - and has been over time - a strong commitment by the government to intelligent transportation infrastructure investment. Unfortunately, since a similar commitment to intelligent transportation infrastructure does not exist in the U.S., Toyota and other automakers have been forced to flip that commercialization model on its head and start with the commercialization of vehicle-to-vehicle communication technology.

It would be unfortunate to shut the door on vehicle-to-infrastructure communication technology in the United States. For that reason, Congress and U.S. DOT should be looking at ways to incentivize or facilitate the build out of intelligent transportation infrastructure to support vehicle-to-infrastructure communication in the United States.

3. **NHTSA Rulemaking**

The results from the year-long connected vehicle pilot program in Ann Arbor served as the basis of a decision by NHTSA in February of this year to proceed with rulemaking to require vehicle-to-vehicle communication capability in future vehicles. We encourage NHTSA to proceed expeditiously with the formulation of these rules and to move towards finalization of those rules as quickly as possible. The sooner we have a full understanding of and clarity around the rules of the road under which we will be required to operate and what minimum functionalities, if any, will be required of us, the sooner we can incorporate those requirements and functionalities into our commercial deployment plans in the United States.

We believe that, if done correctly, the rulemaking has the potential to accomplish two important goals: (1) accelerating the penetration of the technology in vehicles from multiple manufacturers; and (2) setting a common communication protocol so that we can be assured not only that Toyota vehicles will be able to communicate effectively with vehicles from other manufacturers, but also that Toyota vehicles today will be able to communicate with Toyota vehicles tomorrow. These are important, and helpful, goals and we look forward to working with Congress and NHTSA to achieve them.

4. **Research and Development at the U.S. Department of Transportation**

There is more research that can, and should, be conducted by U.S. DOT and the automakers related to vehicle-to-vehicle and vehicle-to-infrastructure communication. For example, we believe that U.S. DOT can play an important role in supporting ongoing and expanded pilot programs to further demonstrate vehicle-to-vehicle communication technology and can help develop roadside infrastructure testbeds that will support further testing and evaluation of vehicle-to-infrastructure communication technology. We also believe that U.S. DOT should consider additional research with respect to autonomous driving technologies, including how vehicle-to-vehicle and vehicle-to-infrastructure communication technology can be leveraged effectively to support automated driving.

At the same time, we are excited and eager to move to the commercial deployment phase of the technology. To that end, we encourage U.S. DOT to focus additional resources on helping to ensure a smooth and rapid deployment of the technology. These activities could include education and outreach activities, including activities around privacy and security, to introduce state and local transportation agencies and the public to the technology. These activities could also include programs to facilitate access to and availability of after-market devices for vehicles already on the road that are not outfitted with the communication capability.

Privacy and Security

As with any new connected technology, there are legitimate concerns about security and privacy. The truth is that the success of the technology is in large part dependent on public acceptance, and public acceptance requires that the network be adequately secure and that the privacy of drivers and passengers be preserved. These issues are of the utmost importance to Toyota and the other automakers who have been involved in the development of the technology in the United States, and have both been top priorities from the outset.

In the very early stages of commercial deployment, Toyota envisions that our vehicles will use the vehicle-to-vehicle communication system to offer our drivers information or warnings about potential hazards. Only when we are sufficiently confident in the technology's ability to perform even in the most challenging situations, and only when our consumers have a full understanding and appreciation of the value of the technology, will we enable our vehicles to take action (braking, veering out of the way, etc.) in response to the hazard warnings that they receive. In other words, in the early days, we do not anticipate a full integration of the vehicle-to-vehicle communication system and the electronic control elements of a vehicle. To a significant extent, this will limit the ramifications of a potential cyber incident.

Over time, as the systems become more integrated, security will become an undeniably critical element. The good news is that the connected vehicle system is being developed to support the security that is required and to minimize the potential for hacking. The system has been designed so that a vehicle will only accept messages from another vehicle with a secure digital signature. Digital signatures are only provided to those devices that have been authorized, or credentialed, to be on the system.

This security system will require infrastructure, or a security backend, to issue certificates and perhaps even revoke certificates in the unusual case that someone is using legitimate credentials to send false or misleading messages. Discussions are currently underway between the various automakers and U.S. DOT on the best way to structure and fund this security infrastructure, including whether it should be a public-private partnership or whether it should be run exclusively by the private sector. We are confident that these issues will be worked out, and the infrastructure in place, to support the system by the time it is needed.

Similar steps have been taken to ensure the privacy of drivers and passengers. The system has been developed through privacy-by-design so that no personally identifiable information is transmitted with the messages. However, the industry has also gone a step further to ensure that even information that has the potential to serve as an identifier of the vehicle is not transmitted. For example, we realized that if the same security certificate remained with a vehicle over time, it could enable someone to potentially track a specific vehicle. As a result, we've designed the system so that multiple security certificates would be used by a single vehicle over the course of single trip. We've also made a conscious decision to break the envisioned certificate issuing organization into several components (one that validates certificate requests, one that generates new certificates, etc.) to help ensure that even an internal bad actor is unable to track a specific vehicle over time.

In addition, we are concerned that a vehicle's exact length and width information – which must be transmitted with the message so that neighboring vehicles can determine if the vehicle poses a collision threat – could potentially be used to identify a specific vehicle. As a result, we are working to randomize the length and width of vehicles within certain parameters so that the length and width transmitted at Point A will differ slightly from the length and width transmitted down the road at Point B. The result of this structured randomization is that the integrity and effectiveness of the messages are not compromised, but the ability to track a vehicle is also minimized.

We welcome discussions about security and privacy, and appreciate the opportunity to share the steps that we've tried to take as an industry to address these potential issues. At the same time, it would be tragic if uninformed or exaggerated concerns about security and privacy ended up chilling the further development of this transformational technology that will save lives. We need to fully understand the risks, communicate those risks clearly, and manage those risks by taking the steps necessary to make the system as secure as it can be while also protecting consumer privacy. We also need to be cautious about taking actions, including opening up the spectrum allocated to vehicle-to-vehicle and vehicle-to-infrastructure communication to other unrelated uses, that may introduce new security and privacy challenges.

Conclusion

Thank you, again, for the opportunity to testify before you today. This is truly an exciting time in the automobile industry, and we look forward to working with the Committee to realize the benefits of vehicle-to-vehicle and vehicle-to-infrastructure technology in the United States. I look forward to your questions.

Kristen Tabar

Kristen Tabar is the Vice President of the Technical Administration Planning Office at Toyota Technical Center (TTC) located in Saline, Michigan. TTC is a division of Toyota Motor Engineering & Manufacturing, North America, Inc. (TEMA). In this position, Tabar is responsible for overseeing the Resource Planning & Management and Technical Administration responsibilities at Toyota Technical Center.

Prior to her current assignment, Tabar was the Vice President of Electrical Systems Engineering where she was responsible for overseeing the departments of the Electrical Systems Product Development. Before being promoted to Vice President, Tabar was the General Manager for Electrical Systems-1 department where she was responsible for the design and development of multimedia and telematics, including component, systems, and vehicle applications for all Lexus and Toyota models.

Tabar joined TTC in 1992 as an Associate Engineer, responsible for vehicle application audio development. Later that same year, she was promoted to the position of Engineer for audio systems and component development. In 1999, she was promoted to Manager, responsible for multimedia systems and component development for TTC-developed vehicles.

Prior to joining TTC, Tabar worked as a contract engineer with a Ford supplier in the quality group.

In 1991, Tabar earned a Bachelor of Science degree in Electrical Engineering from the University of Michigan. She is a member of the Society of Automotive Engineers (SAE), as well as the Audio Engineering Society (AES).

Chairman BUCSHON. Thank you for your testimony.
I now recognize Dr. Barkan for his testimony.

TESTIMONY OF DR. CHRISTOPHER P.L. BARKAN, PROFESSOR AND GEORGE KRAMBLES FACULTY FELLOW, EXECUTIVE DIRECTOR, RAIL TRANSPORTATION AND ENGINEERING CENTER, UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Dr. BARKAN. Thank you, Chairman Bucshon, Ranking Member Lipinski——

Chairman BUCSHON. Mike. Is your mic on?

Dr. BARKAN. Sorry. Thank you, Chairman Bucshon, Ranking Member Lipinski, and Members of the Subcommittee. I appreciate you inviting me to participate in this important discussion today.

In addition to my role as a Professor at the University of Illinois, I also wanted to mention that I serve as the Executive Director of the Rail Transportation and Engineering Center and as Director of the National University Rail Center. The NURail Center is funded by the U.S. DOT and it is one of the UTCs that Secretary Winfree already referred to. In addition to our university, it includes the University of Illinois at Chicago, University of Kentucky, University of Tennessee Knoxville, Massachusetts Institute of Technology, the Michigan Technological University, and Rose-Hulman Institute of Technology in Indiana.

Prior to my position with the university, I worked with the Association of American Railroads here in Washington where I managed and conducted research to improve the environmental and safety performance of railroads. The point is that rail research has been the principal focus of my entire professional career of 26 years with the AAR and the university.

Now let me state at the outset that the opinions I express here are my own and do not necessarily represent those of the University of Illinois.

As has already been stated, the economic competitiveness of the United States depends on safe, reliable, and efficient movement of goods and people over an integrated, multimodal transportation network. Rail plays an essential role in this system. Each transport mode has a particular niche and use of an inappropriate mode for the incorrect task reduces U.S. efficiency, competitiveness, and environmental sustainability. Changing demands of the transportation system will require new approaches to meet 21st century needs and effectively responding to these changes requires research to develop solutions.

Railroads uniquely combine high speed and energy efficiency with the ability to safely move large quantities of heavy freight or large numbers of passengers at low cost. The demand for greater efficiency and capacity in the U.S. transportation system means that rail's already important role will increase and research is needed to help fulfill this potential.

Overseas, passenger rail transport has become highly advanced. Meanwhile, a similar transformation has occurred on North American freight railroads, which have developed sophisticated technologies that allow them to efficiently move enormous volumes of freight. This benefits the U.S. economy and society, so a significant issue facing the U.S. rail community is how to improve passenger rail service while at the same time helping our freight rail system continue to prosper. The Federal Railroad Administration, the AAR, the NURail Center, and other organizations are conducting strategic research aimed at improving rail safety, efficiency, capacity, environmental impact, and performance, which all benefit U.S. economic competitiveness. Addressing these is a principal theme of the NURail Center, especially as they relate to shared rail quarters. Among the challenges to implementing research is adapting regulations to take full advantage of advanced technologies that can improve rail safety.

Another challenge is that rail research receives much less funding than other modes. The development of beneficial NURail technologies and solutions could be accelerated if more funding were available.

The NURail Center is a consortium of seven colleges and universities that I already mentioned. It was formed in 2012 and it is the first rail-focused U.S. DOT UTC. Its role is particularly important because, by the late 20th century, rail research and education had nearly disappeared from U.S. college campuses with the resultant decline in graduates educated in the principles of rail engineering and transport. Ironically, this coincided with the increasing demand for such students due to the renaissance of the U.S. railroads. The NURail Center's mission includes rail education, research, and technology transfer, all of which include significant railroad workforce development activities aimed at undergraduates, graduate students, and other students of all ages.

Now, as the Chairman has already mentioned, Congress understands the need for funding transportation infrastructure and it should be equally mindful of the corresponding need for a new generation of well-educated transportation professionals to plan, design, build, and operate the most efficient transportation system in the world.

The UTC Research Program is critical to development of the transportation solutions needed for the 21st century and educating the next generation of transportation professionals. The UTC program should be reauthorized in full with a clear multi-modal focus that allows centers to take full advantage of all their strengths addressing interrelated U.S. DOT strategic goals. It should also allow other government agencies to fund additional centers beyond the core program. Finally, competitive selection of centers helps ensure that U.S. UTC awards are based on merit and that the program will provide maximum value to U.S. taxpayers and to the transportation community.

Thank you very much and I would be happy to take any questions.

[The prepared statement of Dr. Barkan follows:]

BEFORE THE
UNITED STATES HOUSE OF REPRESENTATIVES

COMMITTEE ON
SCIENCE, SPACE AND TECHNOLOGY

SUBCOMMITTEE ON RESEARCH AND TECHNOLOGY

Christopher P.L. Barkan
Professor of Civil and Environmental Engineering
George Krambles Faculty Fellow
Executive Director – Rail Transportation and Engineering Center
Director – National University Rail Center
University of Illinois at Urbana Champaign

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18 June 2014
Washington, DC

Chairman Bucshon, Ranking Member Lipinski, and members of the Subcommittee, thank you for the opportunity to participate in this important discussion today. My name is Chris Barkan and I am a Professor in the Department of Civil and Environmental Engineering at the University of Illinois at Urbana-Champaign (UIUC) where I also serve as Executive Director of the Rail Transportation and Engineering Center at the University and Director of the National University Rail (NURail) Center, which UIUC leads, and includes the University of Illinois at Chicago, University of Kentucky, University of Tennessee – Knoxville, Massachusetts Institute of Technology, Michigan Technological University and Rose-Hulman Institute of Technology and is managed by the U.S. DOT Office of the Assistant Secretary for Research and Technology. Prior to my position with the university, I worked at the Association of American Railroads (AAR) in Washington, DC, where I managed and conducted research on behalf of the rail industry to improve the environmental and safety performance of railroads. Rail research has been the principal focus of my entire professional career of 26 years with the AAR and UIUC.

Let me state at the outset, that the opinions I express are my own and do not necessarily represent those of the University of Illinois.

I was invited to participate today to address the following three topics:

1) What is the future of U.S. rail transportation? What will be the role of R&D in achieving this vision for the future?
2) What are some technical and policy challenges in railroad R&D? How will this research and technology improve passenger safety, increase economic output, and lower environmental effects? How soon will this research be widely implemented in the U.S.?
3) Please describe some workforce development initiatives at your Center.

Although I will primarily be discussing rail, it is critical to understand that rail is part of an integrated, multi-modal transportation system and the overarching theme of my remarks should be viewed in this context.

The economic competitiveness of the United States in the global marketplace is highly dependent on safe, reliable and efficient movement of people and goods over an integrated, balanced, multi-modal transportation network. The U.S. achieved its position of international economic leadership in the 20^{th} Century in no small part because it had developed the best transportation system in the world; first its railways, and later its highways and airways, supplemented where appropriate and feasible by inland and coastal waterways and pipelines.

Each of these modes has unique attributes that make it best suited for a particular niche within the system. Although transportation discussions sometimes devolve to pitting one mode against another, that is really not the appropriate way to consider the matter. If we use one mode where another is better suited, then we are sub-optimizing because we are using more energy, land, labor or some other resource less efficiently than would otherwise be the case. In the competitive, global marketplace that has emerged over the past several decades, sub-optimizing our use of transportation puts us at a serious disadvantage from the outset.

Despite significant inefficiencies, our 20^{th} Century transportation system succeeded because of abundant U.S. resources and limited international competition. However, neither of those conditions exists today, and certainly will not in the future. Resources are becoming scarcer, the demand for them is increasing, and there are a number of vigorous, foreign economies competing with our own. Furthermore, we now understand that wasteful use of resources, particularly, energy, is not sustainable and has long-term impacts that we must be mindful of. This is particularly true of petroleum. Transportation is the largest consumer of petroleum-derived energy in the U.S. and even with the influx of newly tapped, domestic sources, the amount is finite and its consumption has implications for air quality.

In short, business as usual – including how we transport goods and people – will not suffice in the 21st Century. We need new solutions to align our transportation system to this new era and research is all about finding those solutions, while at the same time developing a new generation of transportation professionals who will plan, design, build, maintain and operate the transportation systems of the future.

1a) What is the future of U.S. rail transportation?

The resurgence of the U.S. freight railroad system over the past three decades is one of the stunning transportation success stories of the latter 20th and early 21st centuries. As a result, the North American freight rail system is considered among the best in the world. U.S. railroads transport 43% of the intercity freight ton-miles, the largest share by a considerable margin (trucks are second with 31%). While the nation struggles with the problem of funding the necessary renewal of its highway system, the private sector freight railroads are investing billions renewing, improving and expanding their physical plant, almost entirely without taxpayer support. As already mentioned, railroads' efficiency provides the U.S. with substantial economic, energy, environmental and safety benefits that are crucial to our future as a successful, globally competitive nation.

With regard to passengers, increasingly congested highway and air transport systems, concerns about energy scarcity and cost, and the need for safe, environmentally sustainable public mobility and urban livability favor investment in modern and efficient urban, regional and intercity passenger rail systems. Numerous cities are developing or expanding their rail transport systems and intercity passenger travel continues to increase, despite only limited improvements. Nevertheless, our passenger rail system is on a much less secure financial footing than the freight railroads because of the need for public sector support.

Railroads' niche in the transportation system is that they uniquely combine high speed and energy efficiency with the ability to move large quantities of heavy freight or large numbers of passengers at relatively low cost. However, they can only achieve this with substantial investment in a capital-intensive physical plant. Railroads excel when there are large economies of scale, i.e. when there are large quantities of freight that need to be moved long distances, or large numbers of people moving along the same route. Under these conditions, investment in the physical plant needed can be justified because the cost of the investment is shared by large numbers of users, thereby making the cost to each individual quite low. It is generally inefficient to use other modes when the criteria for rail are met, and conversely, it is generally inefficient to use rail if they are not.

The physical characteristics inherent to rail transport are the fundamental reason for its tremendous efficiency and they also drive the need for sophisticated infrastructure. These lead directly to a suite of characteristics unique to rail transport that contribute to its ability to provide safe, economical, energy efficient, environmentally sustainable transportation. The underlying physics of rail transport mean that no other mode can offer its unique combination of characteristics, hence its significant role as part of a multi-modal system.

The factors driving these trends favoring the efficiencies offered by freight and passenger rail will only increase, so its integral importance as part of a balanced, multi-modal freight and passenger transportation system is destined to further increase as well. Simply put, the U.S. must take optimal advantage of all of its transport modes in a balanced manner, and rail has an increasingly vital role to play.

1b) What will be the role of R&D in achieving this vision for the future?

Those unfamiliar with rail transport might be inclined to suggest that because of its maturity, there is little need for research. In fact, nothing could be further from the truth. Although the basic elements of modern rail transport have been around for nearly two centuries, both the technologies and the demands being placed on them are dramatically different than they were even a few decades ago. Railroads are under continuous pressure to advance by improving safety, efficiency, speed, capacity and performance, as well as adapting to new market demands and the availability of new technologies. The rapid growth in rail transport is placing intensive new demands on railroads, which requires R&D on a broad range of topics including all branches of engineering, information technology, computer science, analytics, operations research, planning and policy. Put another way, there is a virtuous circle by which railroad's ongoing quest for improved performance demands R&D solutions, which in turn creates new opportunities for rail.

2a) What are some technical and policy challenges in railroad R&D?

Perhaps the most important technical and policy challenge facing US railroads is how to continue to improve our economically healthy, self-sustaining freight rail system, while at the same time increasing its potential to provide high-quality, sustainable passenger rail transport.

Development of both incremental (passenger trains on track shared with freight trains) and very High-Speed Rail (HSR) lines (with right-of-way dedicated to high-speed passenger trains) in the U.S. poses a number of new challenges related to shared trackage, shared right of way, and shared corridor engineering, operation and policy. Despite more than 50 years of international experience planning, designing, building and operating high-speed passenger rail infrastructure and rolling stock elsewhere in the world, there are numerous questions unique to North America that need to be answered if advanced passenger rail technologies are to be successfully implemented.

Passenger rail transport has advanced to a complex set of integrated, advanced systems overseas. Meanwhile, a similar transformation has occurred on North American freight railroads.

U.S. railroads have developed sophisticated technologies that allow them to move enormous volumes of freight at very low cost, with the resultant benefit to manufacturers, consumers, and our economy in general. Most people outside the rail community do not realize that just as we look with envy at the high-speed passenger rail systems elsewhere in the world, they look at our highly efficient freight rail system with similar envy. That these two different types of rail system are not congruent is not a coincidence. It is because each system has been optimized for its respective mission: very high-speed passenger rail, or high efficiency freight rail. A major R&D challenge is developing new knowledge to continue advancing the state of the art of freight rail, while at the same time, understanding when, where and how we can safely and efficiently expand passenger train frequency and speed in a manner that does no harm to the freight rail franchise that we all benefit from. The research topics to address this range from pure engineering to pure policy, and we need to address the entire spectrum of challenges and opportunities. An important role of government should be to pursue policies that will encourage partnerships between potential passenger rail operators and the freight railroads so that both parties benefit.

Aside from the shared rail corridor challenges, another important policy concern affecting implementation of R&D is regulatory constraints that may inhibit adoption of new technologies. Many current safety regulations were written decades ago and some as long as a century ago. Although some of the safety concerns they are intended to address remain similar, the technology options to measure and monitor the condition of railroad infrastructure and rolling stock have advanced enormously. Advanced sensing, analysis and inspection technologies are being developed that can measure and monitor component condition in a reliable, repeatable manner. This information, integrated with proper use of the resultant data and management systems will enable further improvements in safety, efficiency and quality of rail service. Our regulations should be designed to encourage the development and implementation of such advances, rather than be a barrier to deployment.

Current regulations often do not account for, or even permit these technologies to be used to their full advantage, even though their use could improve safety. The regulatory structure should embrace and encourage development and implementation of such technologies, coupled with a modern, risk-based approach.

2b) How will this research and technology improve passenger safety, increase economic output, and lower environmental effects?

The Federal Railroad Administration (FRA) Office of Research, Development and Technology (RD&T) conducts research on a variety of topics related to infrastructure, rolling stock, signals and communication, and human factors with a unifying theme focused on safety, consistent with their mandate from Congress. The FRA also funds the Transportation Research Board Safety IDEA (Innovations Deserving Exploratory Analysis) Program, which sponsors research on rail safety and innovative technology topics. The TRB National Cooperative Rail

Research Program sponsors research on rail policy, planning, practice and efficiency. The Federal Transit Administration also has a research program that includes projects addressing certain aspects of rail safety, infrastructure condition and operating efficiency.

In the private sector, major railroads and suppliers conduct research on various topics addressing safety, infrastructure, rolling stock performance, efficiency, environmental impact, network planning and efficiency, and in addition, collaborate on an array of research topics through the Association of American Railroads research program, which is managed and conducted by the Transportation Technology Center, Inc. on behalf of AAR. In addition to its own research activities, the AAR program includes support for rail research at three U.S. universities known as AAR Affiliated Labs. UIUC has been one of these Affiliated Labs for over 30 years and this AAR support has been invaluable to development of our successful rail program, and continues to be a fundamental cornerstone. The Railway Supply Institute also cooperates with the AAR on an ongoing program of research specifically focused on improving the safety design of railway tank cars, intended to reduce the risk of transporting hazardous materials.

These organizations are engaged in, or sponsoring, research on a number of topics that will improve passenger and freight rail safety. There is less research directly addressing economic output, but a number of topics focused on safety, infrastructure condition, rolling stock reliability and improved energy efficiency indirectly address this. The principal research addressing reduction of environmental impacts is related to energy efficiency and locomotive emissions reduction.

The NURail Center is also addressing many of these questions through its research projects. In addition, we are taking a longer-term view by developing Strategic Development Plans (SDP), to address a broader suite of related topics in an coordinated manner and help us prioritize and focus our research and educational activities. These SDPs involve a several sub-themes ranging from technology and operations, to planning and policy as follows:

Integrated Railroad Track/Vehicle Interaction and Dynamics Modeling
Railroad Safety and Risk
Rail Network Capacity Analysis and Planning
Urban, Regional and High-Speed Passenger Rail Implementation
Multimodal Freight Transportation
Funding, Finance, Community and Economic Development

2c) How soon will this research be widely implemented in the U.S.?

The implementation of research results can range from weeks or months, to years or even decades, depending on the topic and the nature of the results. The principal constraints on implementation of new technologies are related to the rate that they can be developed and deployed, which are two separate processes. Development is related to completion of the necessary R&D and deployment is related to whether the results are intended to change practices or will require new hardware. If the latter, the time and investment needed to develop manufacturing capacity, plus the time and financial resources required to install the technology will affect implementation rate.

Development is primarily constrained by the financial and human resources available to address problems. Quite simply, more funding and more people with knowledge and understanding of rail engineering and transport has a direct impact on the rate of development of new knowledge and solutions to problems. There is far less funding for rail research than other modes. There is little doubt that this constrains development of new solutions and it also undermines the ability to attract and educate faculty and their students in the principles of rail transport. I will return to this topic later.

The ability to implement these new technologies is affected by the regulatory environment described above and by the financial resources needed for deployment. I have already discussed the need for regulatory reform. With regard to funding, railroads are a highly capital intensive industry so every investment must be judged carefully on its ability to achieve its intended safety, operational or efficiency objective. The U.S. freight railroads are almost entirely owned and operated by the private sector. Since they were partially deregulated in 1980 these railroads have invested hundreds of billions of dollars upgrading their infrastructure and rolling stock with corresponding benefits in safety, efficiency, reduced environmental impact and reliability. As their financial health has continued to improve they are investing in even more new and advanced technologies that improve all aspects of their performance. I see no reason why this trend will not continue as long as railroads are permitted to operate in a manner that provides a reasonable rate of return that encourages capital investment.

The passenger side is more challenging, Amtrak suffers from perennial uncertainty in its funding and many commuter rail agencies struggle to find the capital resources needed for them to maintain their existing physical plant in a state of good repair, never mind implement new technologies. This is not to say that they are not advancing but the pace of this could be considerably accelerated if more funding were available.

3) Please describe some workforce development initiatives at your Center.

In the latter half of the 20^{th} Century, colleges and universities in the U.S. shifted their transportation education programs to focus on educating young engineers and transportation practitioners in highway and air transport. As a consequence, we developed an extensive, highly skilled workforce with world-class expertise in these fields. However, this was accomplished at the expense of education in other modes, including rail. A colleague and I estimated that by the early 2000s, there was approximately 100 times more funding for highway education and research programs in the U.S. than for rail. The results of such an imbalance are predictable, we have far fewer professors and students with sufficient education and understanding of the fundamental principles of railway engineering and transport than we need, especially given the renaissance in rail that is now underway.

Academic rail programs might have disappeared entirely, were it not for the AAR Affiliated Lab program, which for more than two decades was the only program in the U.S. whose mission specifically included support for academic rail research and encouraged rail education at the three affiliated universities. This led to engagement and development of faculty expertise in rail at these universities. Faculty serve as magnets to attract, inspire and educate students in rail topics, thereby encouraging and preparing them for rail careers. Despite the limited number of universities involved, a number of graduates went on to positions in the rail industry. The situation began to improve in the late 2000s when FRA began to understand that they could support rail workforce development by funding rail research at colleges and universities thereby building upon the initial AAR success.

A major breakthrough occurred in 2011 when the US DOT Research and Innovative Technology Administration (RITA) reorganized its University Transportation Center (UTC) Program and issued a request for proposals encouraging a multi-modal perspective. This was a significant change for the UTC program, which had focused primarily on highway transport throughout its nearly 25-year history. In the resultant competition the University of Illinois at Urbana-Champaign led a consortium of seven colleges and universities that proposed formation of the National University Rail (NURail) Center. The NURail proposal was selected and for the first time in the program's history, there was a UTC whose principal focus was on rail transportation and engineering. The NURail Center selected Shared Rail Corridors as its principal theme because we recognized the topic's critical importance to freight and passenger railroads, and to both private and public sector rail organizations.

From its inception, railroad work force development has been a principal objective of the NURail Center and is an important element of the UTC program's mission in general. Work force development is important throughout the transportation sector, but it is a particularly important problem for railroads due to their aging work force. Some railroads have estimated that 50% of their employees will reach retirement age in the next five years, making the need to replace them acute.

Work force development activities in the NURail Center include education of students at all levels ranging from elementary school to doctoral students, and all levels in between. Our mission also includes educating professionals already in the work force through continuing education activities such as workshops, conferences, short courses and on-line education and NURail partners are engaged in all of these.

Attracting students and educating them in rail transportation includes a range of activities. An important traditional approach is to offer courses and a curriculum in rail transport topics for students. NURail has been quite active in this role addressing it in diverse and complimentary ways. For example, one of our parters, Rose Hulman Institute of Technology, is developing an introductory course in railroad engineering suitable for use by smaller engineering colleges. It will include elements of civil, mechanical and electrical engineering, thereby providing a general course introducing students to the topic. At the other end of the spectrum, at my school, the University of Illinois at Urbana-Champaign, we are expanding our existing four-course curriculum on freight rail transportation and engineering, and are also developing a new, three-course, specialized curriculum in high-speed rail planning, engineering and construction management. NURail partners are also developing specialized technical topics to be integrated into other areas of their academic curriculum. For example, the University of Kentucky is developing specialized modules on railway material science topics that will be incorporated into their materials engineering courses. At MIT their graduate curriculum presents rail transport as part of a complex socio-technical system, helping students understand how railroads interact with other elements of society and the economy, and their consequent impact on private and public sector policy.

In addition to activities on our campuses with traditional college-age students, NURail partners are also educating other age groups in various ways. For example at our sister campus, the University of Illinois at Chicago, they are developing a management training program for METRA, which is Chicago's regional commuter railroad. The University of Tennessee at Knoxville, offers short courses to short line and regional railroads to assist them developing more effective railroad track safety inspection practices. At Michigan Technological University, they host a Rail and Intermodal Transportation Summer Youth Program that attracts high-school age students from cities throughout the midwest, with a specific focus on inner city youth.

In addition there are a number of other ways that NURail is encouraging and supporting work force development. In addition to course work, graduate students conduct research on a broad range of rail-related topics. In addition to the advanced domain knowledge this provides them, their experience developing and managing an independent research project substantially enhances their organizational and problem-solving skills preparing them well for entry-level management positions in the rail industry. Those graduate students who are completing Ph.D.s may enter industry or rail research positions, or they may pursue academic careers where they will leverage their rail knowledge by teaching a new generation of rail students at other universities.

Another NURail workforce development activity is also about leveraging. NURail faculty members collaborate with the American Railway Engineering and Maintenance of Way Association (AREMA) and the American Society of Civil Engineers (ASCE) to conduct a "teach the teacher" event called the Railway Engineering Education Seminar (REES). Dozens of professors from all over the nation gather for three days of intense classes, presentations and discussions by NURail faculty. NURail faculty provide these professors with teaching materials that they can incorporate into courses and curricula at their respective colleges and universities.

As already discussed, there are extensive opportunities for new, state-of-the-art freight and passenger rail technologies. 21st Century rail transportation requires increasingly sophisticated skills and expertise, but the U.S. lacks sufficient educational infrastructure to replenish the generation of rail professionals that are retiring every day. The NURail Center's educational and work force development activities are a beginning, but more is needed. Furthermore, it will take time to rebuild an academic "infrastructure" comparable to that of other modes, especially highway transport, yet this is essential to achieving the vision.

Congress and the transportation community understand the need for funding to renew, rebuild and expand our nation's transportation infrastructure. However, we need to be equally cognizant of the need to attract and educate the next generation of transportation professionals who will plan, design, build and operate this infrastructure. We must find the funds to rebuild our transportation system, and we must ensure that they are used as effectively as possible by taking advantage of the latest research and employing the best and brightest young minds. This is one reason why the UTC program is so important, not just to rail, but to the entire transportation enterprise.

UTCs are a critical element in our nation's ability to achieve this goal and should be reauthorized in full. The legislative language should clearly support a multi-modal focus and allow centers latitude to take full advantage of their strengths addressing the often inter-related U.S. DOT strategic goals. It should also allow for additional centers beyond the core program to be funded by other government agencies. Finally, competitive selection of centers helps ensure that UTC awards are based on merit. This takes best advantage of the human and institutional resources available to advance the quality of the U.S. transportation system. It encourages and supports development of a world class, modally balanced, transportation infrastructure and work force.

Transportation professionals agree that the U.S. (indeed any nation) needs a balanced transportation system that properly accounts for its particular combination of demands and takes advantage of the strengths that each mode has to offer. Achieving a balanced transportation system requires a balanced transportation <u>education</u> system. Federal and state DOTs invest heavily in education and research that supports highway transport, we need to expand investment in education in other modes, including rail so that we can rebuild the technical expertise needed for the rail workforce of the 21st century.

Christopher P.L. Barkan

Professor
Exective Director RailTEC
George Krambles Faculty Fellow
Department of Civil & Environmental Engineering
University of Illinois at Urbana-Champaign

Christopher Barkan is Professor, Executive Director of the Rail Transportation & Engineering Center and George Krambles Faculty Fellow, at the University of Illinois at Urbana-Champaign. Chris received his Bachelors' degree from Goddard College, and his MS and PhD from the State University of New York at Albany. Prior to moving to the U of I, he was Director of Risk Engineering at the Association of American Railroads in Washington, DC where he was employed for 10 years with principal responsibility for the rail industry's cooperative research program in environment, hazardous materials transportation safety and risk analysis. Chris moved to the University of Illinois in 1998 to direct and rejuvenate the railroad engineering academic and research programs there.

Chairman BUCSHON. Thank you very much.

I now recognize Mr. Woodruff for five minutes for his testimony.

TESTIMONY OF MR. TROY WOODRUFF, CHIEF OF STAFF, INDIANA DEPARTMENT OF TRANSPORTATION

Mr. WOODRUFF. Thank you, Mr. Chairman, Ranking Member Lipinski, and Members of the Subcommittee. I appreciate this opportunity to appear here today and take part in this important discussion about research and development.

[Slide]

The first slide I have today shows—we had a 75-year collaborative effort—in all due respect to our friend from University of Illinois here—but with Purdue University where we have done a lot of research and innovative projects in cooperation for the last 75 years. Annually, the state DOT we are mandated—required to spend 25 percent of our SBR funds, so our planning dollars, towards research. We choose to spend 40 percent in actual spending. That has—should be an indicator about how important the State of Indiana and the DOT view this research within our transportation system.

Next slide.

[Slide]

How do we look at projects and how do we make decisions on which projects to fund? One, it has to be deliverable, it has to be in the near-term and mid-term. We have to be able to have it and we have to be able to have it quickly. Any project that comes before us that were looking to fund, it has to either make us better, faster, or be able to do something cheaper, or be able to make—provide some sort of a safety improvement to our infrastructure. We are looking for solutions today to the problems of today on our infrastructure.

We believe in a measure-versus-model formula in which case what we are saying is if we are going to do a research project, it has to be measurable. We believe that you have to be able to keep score. If you are not keeping score, it is just practice. It is not really applied, it is not helping our infrastructure, it is not helping our travelers.

The recent focus areas we are looking at today, we are looking at data from probe vehicles, so that is information provided by a third party, which we get in real time. We are also looking at data from infrastructure, which has to do with traffic signal controllers and the technology that is available there at the actual signal itself.

Next slide.

[Slide]

Okay. So data from probes, you will see a couple different things that we are looking at. The first left half of this slide you will see recurring congestion. That is I–65 in the State of Indiana from one end of the State to the other where you see those high concentrations of color. That is where we have congestion problems. What this slide does for us, it gives us another basis for making good decisions when it comes to investment of our transportation dollars. We want to solve problems when we are making these investments in what projects we pick and how we pick them. That is one way the probe data helps us.

The other is when we have accidents, crashes, you will have your initial crash. In real time we see the queue build up and in real time we can dispatch our people or the State Police so that we can stop the often fatal secondary crashes because people are coming up on the crash, they don't see the traffic stopped, and that is where you have the additional secondary crashes. So what we are able to do with this real-time data is we see where it is queuing, we can send our resources, get people off the road, get them slowed down so that we were making it safe today, immediately.

Winter weather operations, we look at—we can look at a snow event and we can look at the data that comes from that snow event on that day to see how traffic is moving and that will tell us the next day from our measurement perspective how well did we handle getting the snow off the road, how safe did we make our roads? So in real time we are able to get this data, we are able to make decisions in real time that allows us to, one, protect our motorists; and two, make good smart decisions with the precious dollars we are given to make investments.

Next slide, please.

[Slide]

The other data comes from infrastructure. You know, whenever we talk about signals, it is how are we moving people through from green to red? So when you see those little black dots on there, those are all cars, and what we want to see is those large groups make it through our signals on green so that we have free flow of traffic the best we can provide. Prior to this technology, you had to wait and you would get calls from people complaining, which I am sure none of you all get those calls, but—so as you get those calls, that is when you would saddle up a signal tick, you would send him out there, and we would retime it based on a model that says cars should be going 35 or 40 miles an hour through here. Well, now in real time we can make those decisions to say, hey, hold on a second; let's make sure our signal timings match up so we can get the maximum amount of cars free flowing through our roads.

The other way we look at it is a volume versus capacity, so if we are not getting enough cars through on a left turn lane, we only have so much volume, so much capacity that tells us we have to readjust some other signal to add volume or to be able to handle capacity.

So those are just a few examples of how we are using our R&D dollars today to problem—solve problems today. From a policy perspective, it is just two things that I would encourage the Committee to think about. One is continue to give us flexibility on funding. The more flexibility we have and how many dollars we spend towards this effort, the better for us to make those smart decisions. And two, allow us the ability to choose the projects that meet our needs so that we are funding the projects that help our infrastructure.

Again, I appreciate the opportunity to appear before the Committee and I look forward to answering any questions you might have.

[The prepared statement of Mr. Woodruff follows:]

Testimony of Troy Woodruff
Chief of Staff, Indiana Department of Transportation
to the
U.S. House of Representatives
Committee on Science, Space, and Technology
Subcommittee on Research and Technology

"The Future of Surface Transportation"
June 18, 2014

Mr. Chairman, Ranking Member Lipinski, and Members of the Committee, my name is Troy Woodruff, and I am the Chief of Staff for the Indiana Department of Transportation (INDOT). I appreciate the opportunity to share with you what INDOT is doing related to the future of surface transportation and how research and development (R&D) funding assists in those efforts. Enhancing Indiana's transportation infrastructure is a priority at INDOT, and we are proud to be led by Governor Mike Pence, who is a true advocate for our state's transportation system. In fact, Governor Pence has directed us toward three guiding principles as we manage Indiana's roadways – taking care of what we have, finishing what we started, and planning for the future – and this was not more apparent than his fight to secure additional funding for Indiana's highway projects. Over two years, Governor Pence's legislative initiatives have increased state funding for roads and bridges by $800 million, about $600 million of which is going to INDOT. Because of his leadership, Indiana's transportation system will continue to flourish and our innovations will continue to be implemented throughout the nation.

As the "Crossroads of America," Indiana's highways are vital to our national transportation network and the state's economy. More than $500 billion of freight moves from, to, or within Indiana on our highway system each year. According to the Bureau of Transportation Statistics, Indiana has the fourth highest number of vehicle miles traveled (VMT) per capita, and the twelfth highest total VMT among all U.S. states.

INDOT is committed to efficient management of our capital program and operations activities at the highest satisfaction level and the lowest cost. For more than 75 years, INDOT has collaborated with Purdue University through the Joint Transportation Research Program (JTRP) to research and implement transportation innovations. This program is primarily funded by federal surface transportation R&D funding and is supplemented by state funds to further develop initiatives. This collaboration focuses on solving current and near-term transportation challenges while improving efficiency and quality, decreasing risk, enhancing innovation, reducing operating costs and saving taxpayer money. The JTRP program has resulted in nationally recognized practices relating to Intelligent Transportation Systems (ITS), and I'm pleased to share some of those in my following testimony.

How federal government surface transportation R&D funding helps initiatives within Indiana

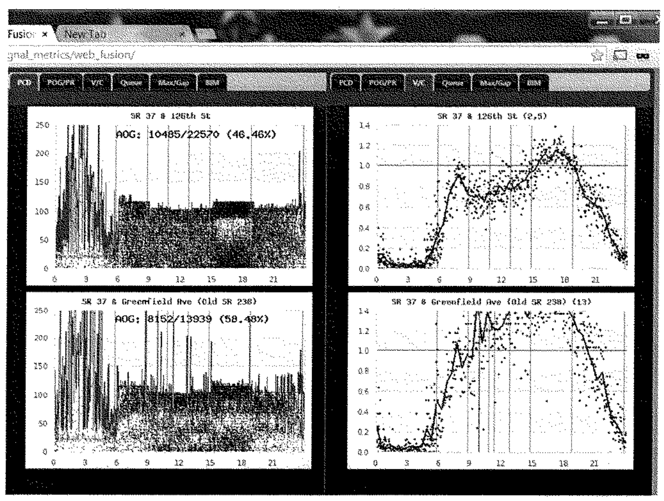
INDOT is solidly committed to R&D and delivers on that commitment through its longstanding partnership with Purdue University and JTRP. JTRP's facilitation of the collaboration between INDOT, higher education institutions and industry leads to implementing innovations that result in continuous improvement in the planning, design, construction, operation, management and economic efficiency of Indiana transportation infrastructure. INDOT's ITS projects in the areas of Mobility, Operations, and Traffic Safety have been particularly successful. This success can be attributed to choosing research that has both a high probability of solving specific challenges that Indiana faces, and those that have a realistic and well-defined near-term path to implementation. Through the JTRP partnership, we are integrating commercial probe vehicle data into INDOT's processes to quantitatively manage our operations activities, shape our infrastructure investment priorities, and measure the impact of those investments.

INDOT's commitment to R&D is also shown in the annual investment for research. While the annual minimal State Planning and Research (SPR) required investment for research is 25 percent; INDOT routinely averages 40 percent each year.

Specific ways INDOT uses and develops this research to benefit citizens of Indiana

INDOT is aggressively advancing "big data research" on two fronts.

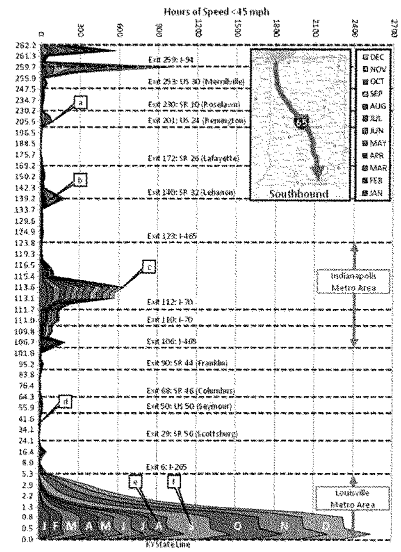
First, at the local level of the signalized intersection, we are leading a multi-state pooled fund study that uses traffic signal event data to develop operational performance measures that allow us to tactically identify emerging problems with allocation of green time and synchronization of traffic along a corridor. To provide some perspective on the magnitude of this data, 100 signals generate over 30 million events per day. For years the traffic signal field was data rich, information poor (DRIP). Our research and partnerships resulted in aggressive national implementation by other transportation agencies as well as the private sector software vendors. In fact, several other states and consultants are using techniques developed in Indiana to evaluate the impact of adaptive control systems deployed as part of FHWA's Every Day Counts initiative.



What % of vehicles arrive on green? Engineers can now optimize for this.

What is our volume vs. our capacity? Engineers can reallocate green time.

Second, at a regional level, we are partnering with private sector probe data providers to develop performance measures and visualization graphics that enable us to prioritize capital projects and identify emerging interstate congestion that requires our attention. Over the past three years, we have been using a data set which now contains over 7 billion speed and location records to develop reports and graphics. From these records, decisions are made to assess the amount of delay our customers experience during events such as weather, crashes, lane restrictions, and work zone queuing. With this data we can also make longer term decisions such as capital program investment.



In addition, we have used this data for both enhanced traveler information, as well as communicating to the media. When we took the bold step of closing I-65/I-70 in downtown Indianapolis to get in and get out quickly for a bridge and pavement rehabilitation project, this data was used both to justify the closure and to monitor the reliability of established alternate routes.

Programs and policies most helpful to Indiana

Policies that are most helpful to Indiana are those that allow the greatest flexibility to focus resources directly on the specific challenges of the state at that point in time. Indiana's focus is to look for solutions that can be scaled appropriately to size and scope, and integrate into, grow and evolve with the larger system. INDOT avoids piecemeal solutions that function in silos. I offer an example of how this approach has worked. A recent research project was borne from examining how we collect reimbursements for damage to traffic signals and ITS infrastructure, to a more widespread program that examines damage to all state property. We began implementing this program in 2011, and by June 2014, our financial estimates indicate we are on track to collect more than $6 million this fiscal year, ending June 30, an increase of 86% since 2011.

What Indiana is doing to implement Intelligent Transportation Systems

INDOT's ITS system monitors traffic and delivers traveler information that improves transportation reliability across the state. INDOT has both urban and rural statewide ITS traffic monitoring capabilities that are managed from two traffic management centers – one in Indianapolis and one in northwest Indiana serving the greater Chicago traffic.

Two examples of our implementation efforts include replacing current models of infrastructure-based sensors with emerging crowd-sourced technologies such as Bluetooth MAC Address re-identification and data derived from GPS/cellular probe vehicles. In addition, we are partnering with manufacturers in the traffic signal industry to upgrade their equipment capabilities making available the results of our research to all users, nationwide.

Importance of an improved strategy for addressing the impacts of weather on surface transportation

INDOT's research and implementation strategy is focused on better integration with existing national weather data sources to proactively manage and measure our response to weather events. We are currently researching whether private sector probe data can serve this purpose for us.

Effect this research will have to help mitigate roadway congestion and safety

Research data allows for more informed and better decision making. When INDOT's staff can plan and execute well (e.g., design better snow routes), road conditions recover more quickly, therefore improving mobility and safety.

What will be the role of connected vehicles?

Connected vehicles will affect the realm of possibilities that improve safety and mobility for all vehicles. INDOT is finding the private sector probe data we are purchasing, which fuses vehicle telematics and mobile phone data, to be our most cost-effective near-term opportunity. This is allowing us to develop new techniques and business processes for using this data, without extensive investment in roadside equipment. Longer term, we anticipate more growth in this area and are looking forward to working with the various industries that are currently developing solutions on this front. We hope many of the new devices and tools are manufactured in one of our thriving Indiana auto parts factories.

Conclusion

INDOT has a proven record of success and leads the nation in Traffic Signal Optimization and System Performance Measures. INDOT's applied research activities focus on investment in those short- to medium-term well-defined implementable solutions that have an immediate use by our end-users. We do not pursue high risk, long-term conceptual projects. With increased flexibility in the use of our funds, we look forward to continuing to work with academia and industry to further Indiana's, and our nation's, transportation system.

In closing I would like to again express my appreciation to this Committee for the opportunity to share INDOT's strategy and successes in the field of transportation R&D, and I am happy to respond to any questions you may have on these topics.

Summary of Testimony

- INDOT seeks flexibility in funding opportunities. INDOT places priority on investment in those short- to medium-term, well-defined implementable solutions that have an immediate use by our end-users. We do not pursue high risk, long-term conceptual projects.
- INDOT is committed to transportation R&D and the depth of that commitment is demonstrated in its annual investment for research. While the annual minimal SPR required investment for research is 25 percent; INDOT routinely averages 40 percent each year.
- The longstanding partnership with Purdue University through the Joint Transportation Research Program results in collaboration between INDOT, higher education institutions and industry to implement innovations that result in continuous improvement of Indiana's transportation system.
- INDOT ITS has recently focused on benefits obtained through data analysis, including data from probe vehicles as well as data from infrastructure embedded technology. This allows for better capital investment decision making and real-time decision making by measuring how well we responded to an event.
- INDOT is a leader in the nation in Traffic Signal Optimization and System Performance Measures. Techniques have been implemented by other transportation agencies as well as private sector software vendors, and several other states and consultants are using Indiana-developed techniques as part of FHWA's Every Day Counts initiative.

"The Future of Surface Transportation"

U.S. House of Representatives

Subcommittee on Research and Technology

Committee on Science, Space and Technology

Indiana Department of Transportation

June 18, 2014

Indiana
A State that Works

INDOT Research Program

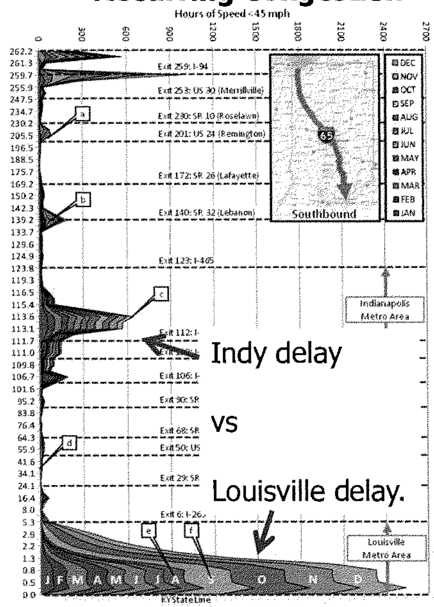
- **Joint Transportation Research Program (JTRP)**
  - 75-year collaboration with Purdue University
    - Research and implement transportation infrastructure innovations
  - Annual funding for research
    - SPR funds
      - 25% required
      - 40% actual spending

INDOT ITS Research

- **Deliverable in near- to mid-term**
- **Better, faster, cheaper, safer**
- **Solutions for today's problems**
- **Measure vs. model**
- **Recent focus areas**
  - Data from Probe Vehicles
    - "Crowd sourced" data supplied by a 3rd party
  - Data from Infrastructure
    - High resolution data from traffic signal controllers
    - Partnered with manufacturers to change industry

Data from Probes

Recurring Congestion



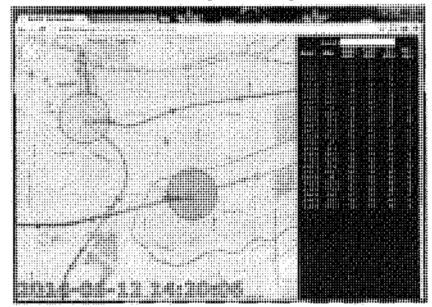
Real time decisions.

Dispatch Resources.

Measure response.

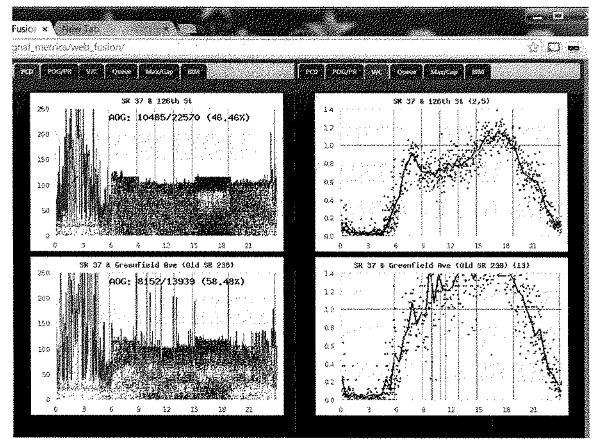
How well did we do?

Non-recurring Congestion



Data from Infrastructure

- **Traffic signal equipment telling us how good our timings are – when they need maintained**
- **INDOT and Purdue leaders in this area**
- **Brought manufacturers into one room and agreed on metrics and capabilities without dictating HOW – i.e. partnering**
- **Now measuring instead of modeling**



What % of vehicles arrive on green? Engineers can now optimize for this.

What is our volume vs. our capacity? Engineers can reallocate green time.

Policy- Practical Innovation

- Flexibility in funding opportunities
  - Focus is short-to medium-term, well-defined implementable solutions
    - Have an immediate use
- Identify projects independently
  - Avoid higher risk, long-term conceptual projects
  - Successful partnership through JTRP
    - Proven success

Indiana
A State that Works

Thank you.

Biography
Troy A. Woodruff
Chief of Staff
Indiana Department of Transportation

As Chief of Staff for the Indiana Department of Transportation (INDOT), Troy Woodruff is responsible for leading the agency's Communications, Public Information, LPA/MPO and Grants Administration, Contracts, Economic Development, Multi Modal and Legislative Affairs divisions.

Woodruff previously served as INDOT Deputy Commissioner of Operations, where he was responsible for all construction, maintenance and traffic operations statewide, including 3,200 employees and a $290 million annual operating budget. He previously led field operations for one of INDOT's six regional districts located in Vincennes, which covers 16 counties in southwest Indiana.

Prior to joining INDOT, Woodruff held consecutive regional director positions with the Indiana Department of Environmental Management and Wellpoint. He has represented southwest Indiana as a member of the Indiana House of Representatives and as a field representative for Congressman John Hostettler. For two years he also served as president and chief executive officer of the Knox County Chamber of Commerce. Woodruff is a graduate of Indiana State University with a degree in communications.

Chairman BUCSHON. Thank you very much. And thank all of you for your testimony.

This is actually I think a very fascinating hearing. And I am going to open the line of questioning. I recognize myself for five minutes.

There are a couple things that we were talking about. First of all, I would like to say that, as a Member of Congress, one of my roles is to make sure that the things that we do protects people's constitutional rights and that is in the forefront of everything that we do.

That said, there are a couple things that I am interested in as it relates to information gathering and also the potential for impaired driver analysis to try to—you know, beforehand so that they are not able to drive a vehicle. I mean, anyone want to comment on the breathalyzer technology and where that might be and where the concerns are? You know, if you come to a vehicle and you are impaired, the vehicle won't let you—you essentially can't drive the vehicle. Anyone want to comment on that?

Mr. Maddox, you have any—anybody have any comments on that at all or anybody have any information on that?

Mr. MADDOX. Yes, I can comment a little bit. I know that the National Highway Traffic Safety Administration, partnering with the Alliance of Automobile Manufacturers, is conducting a research program now that would look at detectors in the vehicle that could reliably detect a blood alcohol level greater than the legal limit.

Whether—I don't think that there has been any decisions made on that, how to move forward. I believe it is still very much in the research stage. It is an early research program. I think it is quite clear that some significant portion—I don't have the numbers off the top of my head—of our fatalities in the United States are related to alcohol consumption.

Chairman BUCSHON. Well, I can tell you I was a cardiovascular and thoracic surgeon prior to coming to Congress and as part of my training I spent a lot of time on the trauma service in Milwaukee, Wisconsin, and I would say 90 percent of the big accidents there was some level—I mean that I saw coming in—related to some impairment of some sort.

Mr. MADDOX. Yeah. I would think that if that technology—to be successful, it would have to be proven to be extremely reliable.

Chairman BUCSHON. And there are privacy issues and I get that.

Mr. MADDOX. Yeah. Yeah.

Chairman BUCSHON. Anyone else? Ms. Tabar?

Ms. TABAR. I can add to that that there are vehicle technologies today that we have available to measure things such as your eyes, where you are looking, if your head is drooping, if your eyes are drooping, if your head is turned away from the primary task of driving. And so I think in combination with that and related to Mr. Maddox's comments, the issue here is just reliability and repeatability and making sure that it is really accurate. And so the technologies just need to be combined and researched to make sure that we are getting the best possible results.

Chairman BUCSHON. The other question I have that is similar to that is related to so-called black box type analysis of crash data and we do that for airplanes. And again, there are privacy issues;

I understand that. But if you don't understand why something happened, then you can never figure out how to fix the problem, right? So where are we on that type of analysis?

Someone—if a car crashes, we might find out there was a vehicle failure, for example, or we might find out there was some other issue and that might help us in our R&D. Anyone want to comment on the? Ms. Tabar, you want—Toyota——

Ms. TABAR. Yes. So data recorder devices do exist and they are available. There are privacy issues additionally surrounding those technologies. There is also—you know, we have to be careful what is actually connected to that, what are the appropriate items to monitor how long does the data get stored, where does it get stored, how is that accessed, who can access it, those type of things. But certainly in the mobility industry, as you said, understanding the things leading up to, during, and post-crash are important to improve the overall safety of the vehicles and prevent those types of incidents in the future.

Chairman BUCSHON. Anyone else want to comment? Mr. Winfree.

Mr. WINFREE. I would add there were also other means other than vehicular; smartphones nowadays carry accelerometers and have other data so the privacy issue is larger than transportation. Certainly the—our FMC—Federal Motor Carrier Safety Administration is in the midst of a debate about electronic on-board recorders and the privacy interests have a strong say in how that develops going forward. But it is certainly more difficult in a light vehicle setting than perhaps in a controlled fleet. But they are important issues and important consideration and the Department is in the middle of the discussion.

Chairman BUCSHON. Thank you very much. Yeah, my son uses that technology on his iPhone when he is going down on a snowboard and he says look how fast I was going. It is crazy. Totally true story. He was going 45 miles an hour at one point.

With that, my time is expired. I will recognize the Breaking Member, Mr. Lipinski, for five minutes.

Mr. LIPINSKI. Thank you. I wanted to start out with Dr. Barkan and Mr. Maddox. MAP–21 made numerous changes to the UTC selection process, including instituting a peer review-based selection of UTC as opposed to the earlier earmarked system. There was some feedback that I had received afterwards from some applicants for UTCs who were not successful about the way that the review was done and especially about the transparency. Now, you have been successful in that process but I just wanted to ask both of you, starting with Dr. Barkan, is there any way you can see this process improved?

Dr. BARKAN. Well, thank you for the question and obviously thank you for your support of transportation research in general.

We did win twice and so we are obviously happy with the process. I would say that it was very transparent. The RITA staff offered to provide us with detailed feedback on what the strengths and weaknesses of our proposal were, and I think that was made available to all competitors. As part of our meeting with RITA staff, we went through that and that was useful to us in terms of modifying how we were—because there were—even know we won, we—there were some weaknesses identified and we responded to those and improved, I think, our ability to fulfill those aspects and—as well as emphasize obviously the strengths that they saw. So I am quite satisfied with the situation as it stands now.

Mr. LIPINSKI. Mr. Maddox, do you have any——

Mr. MADDOX. Yes.

Mr. LIPINSKI. —comments?

Mr. MADDOX. I could add to that. We think that the UTC program is critical. I think you mentioned in your opening statement that we need a continuity of research and the UTC program helps provide that. It allows universities to contribute on the basic and early research and we think it is critical.

Any, I guess, slight improvement could go towards perhaps making the system a bit more flexible so that a given academic organization could throw its hat in the ring for multiple UTC awards because the—our organizations are very diverse and the needs—the transportation research needs are very diverse so putting them into one bucket or one award for a UTC program where we could be doing multiples would be a large improvement.

I think also just keeping with the need of this longer-term focus for the UTC program. It is difficult of course for any academic organization to ramp up quickly and then stop when an award stops and the problems don't stop. So anything that could be done to broaden the time span of the awards would be a big help. But we think overall the UTC program is very successful, is very much appreciated and should be clearly continued.

Mr. LIPINSKI. Dr. Barkan, do you have another comment there?

Dr. BARKAN. And I want to say I agree with my colleagues' statements. I would add one thing. I think one thing that would be helpful in the future, as I said in my remarks, I think very clearly stating, assuming it is Congress' intent, that the UTC program should be multi-modal. It encourages all modes—participation of all service modes as part of the research and education program.

Mr. LIPINSKI. Thank you. I don't have much time left here and this is a question that we could spend an hour having everyone comment on, but I am going to throw it to Ms. Tabar because you said Japan—from what you said, it sounds like Japan is further ahead than the United States on this. We have—across here we have state, federal, universities, private industry. What would—ideally, how do we move forward most quickly in getting all of—everything in place to have an intelligent system here? What would you like to see from the private industry side if you could ideally put it—set it out there?

Ms. TABAR. So I guess to start with we are putting it out there, so I think——

Mr. LIPINSKI. Well, I am looking at getting to the end where we have an entirely intelligent system. How do we most quickly get there?

Ms. TABAR. So I think, as you mentioned, and from my remarks, Japan's side has focused a little more on the V2I as opposed to the V2V as their first step wherein the U.S. market we are focusing a little more on the V2V. But to get both benefits and the full benefit of the system I think both aspects are necessary. So I think although the automotive industry is maybe making a lot of steps towards the V2V, the V2I still does need some reinforcement and additional research is necessary to understand and test those scenarios.

So I guess from our perspective we would like to see more collaboration and more funding towards that testing as well as making, as I mentioned, outreach to the actual end consumer to help them understand the technology, help them experience the technology, and maybe dispel any myths that they may have about the benefits and the overall robustness of the systems.

Mr. LIPINSKI. Well, if I could just briefly follow-up. Is the government—federal government—doing enough or doing it quickly enough to set a—set standards or does that need to move more quickly?

Ms. TABAR. So, again, we—from my comments, we are encouraged that the rulemaking and for the communications protocol has been moving forward. We would like to encourage that to happen as quickly as possible. The automotive cycle is a little slow and so we want to make sure that we have time to incorporate any requirements like that. So the sooner those requirements can be solidified I think the sooner we can merge those into the market.

Mr. LIPINSKI. Thank you very much.

Chairman BUCSHON. That was very diplomatic of you the way you said a little slow.

Ms. TABAR. Well, it does take time——

Chairman BUCSHON. I understand.

I now recognize Mr. Collins for his questions.

Mr. COLLINS. Thank you, Mr. Chairman.

I would like to start by saying all of us on this Subcommittee certainly understand the importance of research and development and the appropriate use of it. We may not know even where that research takes us and that is quite okay. But what I am curious—maybe I will start with Mr. Belcher. The public is fascinated with the whole concept of autonomous driving and getting in their car and so forth and I will later ask the question of where you think we might be 20 years from now, but does autonomous driving—could that work if you are intermixing cars that are not participating in that? You know, you have got your 1965 Mustang out there that is not going to talk to another car. Can that work where you have intermixed intelligent cars and then others that either are and that is turned off or not?

Mr. BELCHER. Sure. I think there are a couple of parts to that answer. I think in some respects the connected vehicle program that I talked about before and that a system that we have all talked about a bit is a really great transition to autonomous vehicles and will work really well collaboratively with autonomous vehicles and so that you can have vehicles that are outfitted either with connected vehicle technology or with aftermarket technology that provides much of the same safety applications. So that can help you with cars that don't—that aren't autonomous.

The second part of the answer is that I also think it can, based on the way that they autonomous vehicles are deployed, if you look at what many of the manufacturers are doing, it is based on a system that maps the existing space. And so for that individual autonomous vehicle, it doesn't really matter whether the other vehicles are autonomous or not; you can still maintain the safety that you are trying to do. So it is really dependent upon the deployment.

I think one thing that we—that Congress can do is to continue to fund the research on the basic deployment of safety applications associated with autonomous vehicles so that we can move to a common platform in a common data platform comparable to what Congress did in funding the connected vehicle program. Without that investment, we never would have gotten to where we are today and I think we are kind of in the same space on autonomous vehicles because we want to make sure that we don't have multiple systems that are operating inconsistently.

Mr. COLLINS. Thank you. I think the next question, Mr. Maddox, you mentioned how liability—there are liability concerns and you just let it drop on that. I wonder when I think about the litigious part of this society and everything else we are seeing with the current GM situation and is it billions of dollars because of a switch issue liability, whether at the end of the day liability concerns are a showstopper in the United States?

And then I would ask Ms. Tabar to—as—from—a representative of Toyota to answer that as well, that we can have all the technology we need but we throw those unlimited liability concerns in, could that in fact be a showstopper?

Mr. MADDOX. Yeah, thanks for that question. I don't think they—liability will be a showstopper. I think it will be a slowing down result. And what—why is that? If you think about these connected technologies, inherently what that means is one car company has to decide to trust data from another car company and trust data from an infrastructure device and a city that operates that device and maybe even in the future a device—data from a cell phone device that might be a pedestrian beacon. And so that question of if you are making that product decision that says, okay, here is what I am going to do to act on that little piece of data, I have to trust it. So that—car companies generally are somewhat risk-averse, not always but some, and they want to make the best decision for their customer to protect their safety.

And so things in the United States, our tort system I believe will slow down the deployment of the key—of the full functionality of this system. I think we will see early deployers. Toyota may be a very good example. But I think in general we won't see the full benefit.

And it is interesting also because if you think about the benefits, they go certainly to the driver of that one vehicle but also that benefit goes very much to society as a whole because we have reduced congestion, reduced traffic accidents, fatalities, et cetera, et cetera. So for both reasons I think we ought to be looking at a shared liability regime to minimize the risk of—to encourage early deployment and full deployment but also because we all get the benefit of it; therefore, we should all share in the risk.

Mr. COLLINS. Okay. Thank you. My time is expired, so unfortunately, Ms. Tabar, we will have to wait for your answer. But thank you.

Chairman BUCSHON. You can have some latitude if you want to have her answer.

Mr. COLLINS. Yeah. I just—as a car manufacturer, where do you think the liability issue lies, and again, would it be a showstopper for Toyota?

Ms. TABAR. So, definitely we do consider the liability. It is different in each market. However, I think Mr. Maddox's comments, I echo those. It is not a showstopper. It certainly—as he eloquently explained, it is a complex system and so there is a lot of data sources, which just reinforces the need to do extensive testing and research before deployment. And so that is really our philosophy to ensure that the system is as robust as possible, but given the complexity, that does take time, this may be back to my comment about a little bit slow to introduce. So I completely agree with that sentiment.

Mr. COLLINS. Okay. Good. Thank you.

Thanks, Mr. Chairman.

Chairman BUCSHON. Thank you.

I now recognize Ms. Kelly for her line of questioning.

Ms. KELLY. Thank you, Mr. Chair.

Mr. Winfree, historically the Department has put a lot of priority on highway programs but it seems that young people are choosing dense urban areas instead of moving back to the suburbs or to the suburbs. Can you expand on the Department's efforts to prioritize multimodal research? In other words, they don't necessarily need cars——

Mr. WINFREE. Right. Right. Exactly.

Ms. KELLY. —as much.

Mr. WINFREE. Well, one of the areas that we are focused on has to do with pedestrian and bike safety. We realized and are monitoring the uptick in roadway fatalities, and unfortunately, that number of pedestrian fatalities is 4,400 of that 5,000 or so, so it is an important issue because at some point we are all pedestrians.

So we have made pedestrian and bike safety a core issue of focus. We have at the U.S. DOT a Safety Council that brings together the Modal—Chief Modal Safety Officers for each of our operating administrations and we have set up a technical team to address these issues. The Federal Highway Administration has done significant work in this area, as well as the National Highway Traffic Safety Administration. So there is a lot of effort that has been put into it. It is just a matter of increasing the focus and finding a permanent home.

You know, the DOT is set up largely by a mechanized means of transportation and pedestrian and bike is important but it tends to fall into the cracks. So since it is an issue of great importance and certainly we hear from city mayors, we hear from MPOs and other entities that are focused on this important area, we are bringing our resources to bear to address it.

But from a multimodal perspective at the Office of the Secretary—Assistant Secretary for Research and Technology, that is our principal mission, to focus across the enterprise and help each of the OAs get out of silo thinking or stovepipe thinking so that we are better custodians of taxpayer dollars.

So we also have a Research and Development Planning Council and Planning Team and that is comprised of the Chief Research Officers for each of the OAs focusing on a monthly basis on important topics across the enterprise. So it is a means for us to bring together and foster that collaboration multimodally.

Ms. KELLY. That is very good to hear.

Dr. Barkan, given that you are the only non-vehicle-focused witness here, do you have any thoughts on how the Department can continue to expand its investments beyond highway?

Dr. BARKAN. Sure. As I said in my comments, one of the things that I think should be considered in the upcoming legislation is to allow other modal administrations—the Federal Railroad Administration I would have in mind—to—if they want to add funds to the University Transportation Center Program to—that that would be a very good thing.

I—as I mentioned in my comments as well, we spend far less on rail-related research in this country than the other modes by a pretty considerable margin and yet I think many people would agree that the importance of railroads is already extremely important and growing daily both on the passenger and the freight side. There is lots of technologies that I think—or other solutions that could be developed if there was more funding devoted to rail research, whether it is through the UTC program or the FRA's R&D budget. However, if that can be made to happen I think would be very good for rail and for the transportation system as a whole.

Ms. KELLY. I don't know if anybody else wanted to comment.

Mr. BELCHER. I think we are in a transformational stage in transportation and it really excites me and it is not just around the cars. We have talked a lot about cars, but, Congresswoman, I mean I think you really tapped into it and it is really the shared-use mobility environment that we are moving into. And you are seeing all kinds of really interesting opportunities to provide those people who live in urban environments to utilize different modes of transportation, and that is one of the areas that ITS America focuses on and it is trying to highlight those new opportunities.

So there are now applications like there is a company that actually has an application here called RideScout. RideScout is one of the most interesting companies around. What they do is they are a consolidator and so you can go on to the RideScout application and it will tell you whether you—whether there is a car share, a rideshare, what the transit options are, whether it is a bus, the train, where—how long it will take in each opportunity, how much it will cost, and it will allow you to make an informed decision about what the best way to get from point A to point B is. And that is what people who live in urban centers need now. It gives you the opportunity to compare that to driving and you can do that in a cost-effective way. Then you can actually drill down on Google maps and figure out where you need to walk to get to that next Metro stop or to that next bike share program.

The thing that I think is the next wonderful stage for that is going to be a common pricing platform over the top so you can—once you put your data in, you can actually pay for all of those applications in one—for all of those transportation options in one application. We are not there yet but I think that is the next phase for a company like RideScout.

There are a lot of other really cool innovative companies that are providing us the kind of information that we need to be—to really—to be a multimodal and really take advantage of the transportation options that we have got in this country. And they are expanding on a daily basis and it is really being driven largely by communications opportunities.

Ms. KELLY. Thank you.

Mr. MADDOX. If we have time, I would add to that. I completely agree that ITS has to be applied to all of our transportation modes, and pedestrians, motorcyclists, and bicyclists I think are critically important. Clearly, there are great mobility applications potentially, also safety applications, where that phone that you are carrying could become a beacon for you so a car doesn't hit you. And we all are in the same day pedestrians, we get on the train, we drive in our car, some of us take a bus.

The other beautiful thing about that is that that phone, if you then clunk it into your 1965 Mustang with a good antenna on the roof, it could become a connected vehicle. And if you think about how quickly we turn over phones, we get a new phone every two years or those of us—most of us do, we get a new car every 5 or 10. And so we could—and—through that phone as a "deployment device," we could make all those other vehicles connected in a much quicker fashion and I think there is a lot of research that needs to happen to protect pedestrians and bicyclists and motorcyclists for safety but also to use that as what I call a nomadic seeding device to get us to that critical mass much faster.

Ms. KELLY. Thank you.

Chairman BUCSHON. Thank you very much. One thing—I am just going to make a brief comment on bicycle and pedestrian safety. I think one of the things that we should probably loop law enforcement into that because anyone that has driven through D.C. knows that violation of the existing laws on the books by both bicyclists and pedestrians I think is a serious issue. I just went around a curve—made a right turn 2 days ago, bicyclist came inside of me and I almost hit them, couldn't see them. They violated the law; nothing happened. So that is just an editorial comment, but I do think that you should loop in law enforcement about what types of existing compliance issues that we have related to that.

With that, I will recognize Mr. Massie for five minutes.

Mr. MASSIE. Thank you, Mr. Chairman.

As an engineer by training, I subscribe to the axiom that without data, all you have is an opinion, and so I was very encouraged by Mr. Woodruff's data that he showed and the way that it is collected. I would like to think that regardless of which party you belong to that your road is going to get taken care of in order of priorities that make sense.

And I serve on a Transportation Committee and now we don't have the ability anymore to direct with earmarks where these projects are going, but I feel more confident about that when I know that data is being used to drive those decisions.

So really my question on this is to Mr. Winfree. To what extent is the Federal DOT using data like they are using an Indiana, anonymous aggregate cell phone data, crowdsourced data, or are we still dragging out the little rollover sensors to find out which roads are being used the most?

Mr. WINFREE. Again, I think we are at an interesting point in transportation history. You are going to certainly see both technologies still deployed depending on largely state resources. What we do at the DOT through our Bureau of Transportation Statistics, our data-gathering efforts range from surveys to onsite data-gathering so it is a wide range of tools that we rely upon.

But there are apps that we are aware of. Certainly the City of Boston has a great app for potholes and the accelerometer in the phone and the GPS signal capability pinpoints where a disruption occurs and sends a signal to a database that gets it to the—to MassDOT about how to repair that pothole. You are probably familiar with that.

But that is the kind of technology that we certainly see a lot of future and a lot of promise in, but that is a commercial model that needs to be built out. That is not something we have control over.

Mr. MASSIE. Well, I would encourage you to use at the DOT—I know you are in research but—to use as much of that data and those new methods as you can because it is very encouraging to see it being used at the state level. I would hope that my State of Kentucky would be using it but a lot of times politics do enter into who gets the bridge first unfortunately.

My next question has to do with mapping aids in vehicles. There was a recent article in the New York Times June 15, actually, 2014, said "Agency aims to regulate map aids in vehicles." And this causes me a little bit of concern. I am concerned that regulations are going to make it cumbersome for these technologies to be implemented.

Now, I drive through 30 miles of traffic every morning in D.C. but I have got a Tesla with a 17-inch screen that shows me where all the traffic is, and I would just ask when we think about regulating this and implicating mapping aids in accidents, let's think back to ten years ago we didn't have these, how many U-turns, or 30 years ago when I was in my parents' car and my mom and dad were arguing with each other, how many accidents were caused by not knowing where you are and stopping on an on-ramp or an off-ramp or doing a U-turn where you shouldn't be? Let's make sure we consider that as the base case when we look at mapping aides.

Do you think that regulations could hinder adoption of mapping aids? Or—Mr. Belcher, I ask you that question.

Mr. BELCHER. Well, I think what you are referring to as we move into the new generation of mapping and travel information system, we are doing—we are starting to overlay crowdsourcing and gamification, so if you look at WAZE or INRIX or any one of those systems—and so the—what those systems due to make them effective is you engage with the traveler information system itself.

And so I think the question is really a safety question and it is not any different from any other distracted driving safety question that we are all very focused on. We want to make sure that people are—when they are using these systems are not diverting their attention from the very important aspect of driving.

But believe me, my children don't use any other system unless they are part of it. You know, this is a whole new generation that we are living with and we want to be part of that transportation system.

Mr. MASSIE. They are probably looking at the map and steering the wheel. They are probably——

Mr. BELCHER. Well, I hope they are looking at the road but——

Mr. MASSIE. Well, but all I am saying is that let's consider that the reason for the distraction actually may be improving safety as well by having an awareness of where you are and where the worst traffic is and preventing some of these extraordinary measures like taking U-turns or whatnot.

Mr. BELCHER. Well, we just don't want to throw the—I mean I agree with you we don't want to throw that technology out what we are trying to address important safety issues like distracted driving. We have got to figure out the right balance and I think that is an important question.

Mr. MASSIE. Great. Thanks. I just don't want to lose my 17-inch screen that gets me through traffic every morning.

Chairman BUCSHON. I was going to propose a limit up to a 15-inch screen.

So thank you very much.

We are going to have a brief second round of questioning. Ranking Member Lipinski and I have a couple other questions we are going to ask so—and then any other Members that do that so we will do that briefly.

I want to do the first, Mr. Woodruff, since you are from Indiana and we haven't asked you a question yet, I figure you don't want to be left out.

So we are talking about deploying connected vehicle technology. What—do you see challenges that state and local governments might face in deploying connected vehicle technologies, vehicle-to-infrastructure, for example? And what specifically, if you can, do you think that U.S. DOT could assist the States in coordinating that?

Mr. WOODRUFF. Well, you have to remember with the state systems we will always adapt to the technology. So as connected cars come online into our system, our system will adapt to that. It naturally does. So from a state DOT perspective our focus is always going to be at probably the micro level, the today problem with our transportation. You know, it will vary but the reality is for us the system is always going to adapt. So if cars get smarter and as they communicate with each other that only makes our system safer. So our system will—we will always adapt to the technology.

Now, what I have found on the state level is normally a lot of the issues—I know that the Congresswoman—and I noticed she had left, but when you think about pedestrians or—our system will always adapt to that. If we start to have an issue with people crossing the roads, we will have to come up with a solution at a state level. Very rarely can we wait for that solution to come from, say, this state—the DOT so we have to move that way.

But to answer your question it would adapt. It just naturally would over time. But we have to deal more with the reality that like my son, he drives a 2000 Mustang, which is probably a bad decision on Dad's part, but his car is not going to communicate and so we have to look out for those passengers today.

Chairman BUCSHON. I am also interested in long-term research and development mainly on traffic patterns like I would just comment on Evansville, for example. I moved to the east side of Evansville of Newburgh, which is right outside Evansville, and when I moved there in 1999, the major really highway going through Evansville, what is called the Lloyd Expressway really hadn't extended out that far and there was nothing there but it was very clear to me and to many others that this was going to be a—potentially an area of growth and in the long-term to prevent traffic snarls and backups. So what is kind of the long-term vision of how the state DOT looks at those type of things and is there ongoing pattern research in that regard?

Mr. WOODRUFF. Absolutely. And when I showed the one chart that had the multicolors where we maybe look at an entire corridor, we would do the exact same thing with the Lloyd Expressway where we know today where are the backups occurring. You know, when we planned for our infrastructure improvements if we need to do an interchange at Burkhardt and Lloyd, for instance, that would be a——

Chairman BUCSHON. You do.

Mr. WOODRUFF. Yeah, I am sure we do. That would be one that would have that high visibility of colors so we would know that. So a lot of times what we see those as it stretches back, we would make those investments because it would actually have a positive impact where we are currently having a traffic problem. So when we plan out, we do look to the future on this project to say, all right, what is this project, how will it impact our current problem here, and maybe that is a cheaper alternative so that we can stretch those dollars further by doing something futuristic to say, well, maybe we just—if we put an interchange 5 miles back, the traffic will start using that area as opposed to coming up here and we may not have to build an interchange here.

Chairman BUCSHON. Yeah, I think that is a very important issue because in the larger context of what we are talking about in Congress as it relates to the mission control not only with other environmentally related issues, I mean if you look at—and I don't have the numbers in front of the—the amount of fuel, for example, that we burn sitting in traffic, wasted, just might as well throw it away, the amount of emissions that are a result of traffic snarls around the country, I see that type of research in traffic patterns being really critically important to the larger discussion we are having in America about how we utilize fuel, how we improve our environment, and make those things meld together.

So thanks for that information because I do think that that vision—and sometimes I think Congress needs a little assistance in having a longer-term vision versus a today. You have to have both, of course, as you have commented on, but I think had we looked ahead many, many years ago in certain areas of our country on population growth and that, we probably could have mitigated and directed resources to improving the infrastructure in those areas ahead of time that may have a very well prevented a lot of the wasted fuel and environmental impact that we see today.

It is tough because of the funding, and I get that, but I really am very interested in how moving forward we really need to know this. That is why data, as Mr. Massie said, data is critically important.

So I am going to recognize Mr. Lipinski.

Mr. LIPINSKI. Thank you.

Yes. Data are critically important but I hope no one latches onto the first part of what Mr. Massie said and thinks that because we don't do earmarks here in Washington that we are—the money is being spent according to data because I assure you, the governors and state legislators are not spending the money by data. So I always like to make that point because I always think earmarks are a—something Congress should be doing.

But—and I almost—Mr. Massie got to that point about politics still being very much involved and——

Mr. MASSIE. I assure you there is not enough data in Kentucky either.

Mr. LIPINSKI. I am going to give this to Mr. Belcher and—just because of your position. I am sort of looking for an idea about where we are going and how quickly we are going to get there. Where are we going to be five years from now, ten years, 15, 20? I am not sure how long all of this is going to take, but I am just sort of looking at—looking for an idea, a vision of what is the future going to be like and how quickly are we going to get there? Five years from now, how much intelligent transportation—how much is going to be in place ten years from now, 15, and where do you see this—how quickly do you see this coming about? Because we have talked about all these different ideas, V2V, V2I, and then bringing in pedestrians, cyclists. How quickly do we get there? Can you give some idea? I know it is a very tough question but you, being President and CEO of ITS America, you must have some ideas about this and how quickly we are getting there.

Mr. BELCHER. You decided to give me the easy one, right?

Mr. LIPINSKI. Yeah. Well, I am sure someone else would love to take it if you——

Mr. BELCHER. Yeah. I will take a cut at it. I think we are at a position unlike any other time in our history with respect to where—with respect to transportation and what is possible. Congressman Massie talked about data. I mean we are just barely scratching the surface of using data in meaningful ways and using data analytics. And so if I look at the data that we have got in the transportation system and the data that Mr. Woodruff talked about at the state level, right now we have got isolated segments of data, so the state transportation system has got one color of data, the transit system has got another, the emergency response system has got another, and in any given city you might have 20, 25 different data systems.

And so we are at the point—we are getting close where you can start to scrape those data systems and to utilize them in an intelligent way. Once you start to do that, then you can start to manage transportation not just in a block-by-block and not just in a city and not just in a single mode but start to manage transportation on a regional basis and a multi-modal basis.

That really opens up opportunities that we currently can't do and we are going to have to use things like data, things like technology because, quite frankly, I don't see a big investment in our infrastructure coming anytime soon even though it desperately needs it. And so the States and cities are going to have to look, one, to technology, two to the private sector. I think we are going to see greater partnerships between the public and the private sector, and you are going to see opportunistic deployment.

So a perfect example is in southeast Michigan both Toyota, the University of Michigan, the state, other private sector agencies, the federal government are invested in the first full—the first real deployment of connected vehicles, and that is going to happen over the next three to five years, going to move from 3,000 vehicles in a safety pilot to 30,000 vehicles in southeast Michigan. This is going to be before the rules come out.

So what can Congress do? Congress can make sure that, as we do this, we protect those bold people that are willing to take the risk, willing to get equipment, willing to make investments so that they are grandfathered when we finally get the rules. Because if we don't take advantage of the spectrum we have got, we don't take advantage of the opportunities that we have over the next three to ten years, we are going to lose everything. And so it is going to take bold people like Michigan, like Florida, like Texas, like Indiana that are going to be early adopters that are going to partner with the private sector, going to partner with universities, and start to see deployment.

So I think what you are going to see over the next five to ten years is I do think you are going to see adoption of connected vehicle technology. I think it is going to happen before the rules come out. I think you are going to see it in cities where you have got courageous leaders that we can protect. I think you are going to see it at university centers where you have got universities that are willing to put their money where their mouth is, and you are going to see the private sector pushing this along in very difficult—in very, very aggressive ways.

And we are going to do it in partnership with the federal government but I do think it is going to happen—we are going to have to move more quickly than the federal government is capable of moving. We are going to have to move more quickly than vehicle fleets turnover. And so I do see that.

The final thing that I will say, because I can talk about this forever, when I talked about the shared use mobility, I really think that is part of the future. I think you are—I think we are going to start to see people, especially younger generation that don't have the same interest in owning cars that we had. I mean I had a car when I was 16, the day I turned 16. That is changing. You know, what is way more—what is far more important is being connected and the cars are just becoming a node on the network at this point, especially in the urban environment.

And so we are seeing different ownership models. I mean every automobile manufacturer now has a car share—now has a car share company or is thinking about one. Think about that. So that is the future we have. It is really exciting. It is hard to predict but it is going to be exciting and I think it is going to be a lot of fun.

Mr. LIPINSKI. Thank you.

Chairman BUCSHON. Or in D.C. or other cities, you have a car when you need it. You get a Zipcar if you need a car that day. If you don't, you don't own a car.

I recognize Mr. Massie for five minutes.

Mr. MASSIE. Well, to use a transportation analogy here, I am going to flirt with the third rail and talk about funding, and not funding for your projects but funding of transportation in general because I am on the Transportation Committee and we have got a shortfall that we have to deal with. This is partly a result of not indexing the gas tax. It has been the same it is right now for 20 years while at the same time the CAFE standards go up and alternate fuel vehicles are on the road. And nobody wants to be a freeloader and people value surface transportation and roads and whatnot.

But talk to me a little bit about how technology could help us with an alternative. And whether it helps the federal government, whether we decide to come up with that shortfall in transportation and infrastructure at the federal level or whether some of these obligations get devolved to the States and cities like you were talking about. Somebody is going to have to pay for it and it seems like the gasoline tax is, if not outdated now, it is going to be outdated in 10 or 20 years. How do we solve these problems with technology? Mr. Belcher, I will put you on the spot again here.

Mr. BELCHER. Well, I think where you are heading is probably curious about mileage-based user fees and I think that is really where we are——

Mr. MASSIE. I think—yeah, user fees I think are the best. You know, put the cost——

Mr. BELCHER. Right.

Mr. MASSIE. —right there where it is being used, so——

Mr. BELCHER. Yeah, I think—I mean, Congressman Blumenauer has a bill that he has introduced about opening up the use of mileage-based user fees and some new—some additional pilots. The State of Oregon—there have been a number of States that have done pilots. I think the legislation that has been adopted in Oregon is actually pretty interesting and it deals actually with electric vehicles right now. And what their experience has been is that people need choice and that the technology solution that we may all be enamored of may not be the best solution. When they tried to implement a pure technology solution, they got a lot of pushback from the public.

And so what they found is they needed to give the public options. And so now within their legislation you can pay a flat fee on an annual basis. You can pay a fee that is based on your odometer on a regular basis. Or you can actually utilize the technology that is available so that you can actually pay for what you use. The technology is there to do that and you can do it with GPS technology pretty easily.

The biggest challenge I think that we have to overcome is the administrative cost of administering the system because right now the gas tax is amazing efficient. We spend very little money administering it and it is very efficient across state lines. When you start to get into a mileage-based user fee system, the back office costs are much higher and so we have got to really focus on bringing those costs down and reducing the cost of managing it across state lines. But the technology is there. It is more policy issues in my mind.

Mr. MASSIE. So one of the policy issues that is going to be inevitable though is privacy as well. And, Mr. Maddox, I think you talked about how you can anonymize—make anonymous some of the peer-to-peer stuff, but how would people retain their privacy in a vehicle-miles-traveled sort of situation or a toll—maybe micro tolling? How would they maintain privacy in that situation?

Mr. MADDOX. Yeah. And I was actually going to ask the—interject the same comment that we need to be very careful about that. The V2V system as designed is intended—is designed to be completely anonymous. When we ask to—for someone to pay using that system or a related system, by definition it is no longer anonymous. In fact, it has to be very personal and your location has to go along with it. So I like Scott's comment about the fact that in Oregon they realized they need a bevy of solutions and maybe the best solution is not the one that is the most precise, i.e., not the one that relies on knowing exactly where you are and who you are at the same time. Maybe there is a better solution that is a little less complicated and perhaps even a little less administratively costly that still protects privacy but provides a generally accurate cost, you know, basis.

I don't have an answer what that system is but I do know that we need to be very careful when we want to use a system designed to be private to be no longer private.

Mr. MASSIE. Right. Well, just to throw something out there, one idea that I have thought of is instead of sending my dot, my GPS location to the cloud and telling everybody where I am every second and then let them—computing the cost of my trip, send my car or my phone the cost of the roads per mile that I am going to travel on and my phone or my car could calculate that. And so all that I transmit to the government is what I owe in tolls that day or that month. You wouldn't even know—need to know how many miles I drove. So I think there is a way to do that and I think if we are going to use an alternative payment method for the roads, we have to solve that problem. Otherwise, the public won't support it and I wouldn't support it either myself so——

Mr. MADDOX. Yeah, and I do agree with you. I think there are probably many creative solutions if we put our heads together. There is a large policy question that goes along with it, and once we get past that policy question, I am sure the technology would be capable—I am sure we could come up with creative solutions that still protect privacy.

Mr. MASSIE. Thank you very much.

Chairman BUCSHON. Thank you very much. I would like to thank all the witnesses for your valuable testimony. This has been very important. Like I said, it is important for a bigger context to where we are in our country as it relates to a multitude of issues, as we have heard today.

The record will remain open for two weeks for additional comments and written questions from Members. In fact, I probably will submit some questions regarding spectrum because one of the takeaways from here today I heard from multiple witnesses is concerned about—concerns about spectrum. That is not under the purview of our Subcommittee but I think having that—the answers to those questions on the record—Congressional record is going to be extremely important. So it may be open for two weeks for additional comments and written questions from Members. Please answer back as quickly as you can so that we can get that to be part of the record and get that information.

At this point the witnesses are excused and the hearing is adjourned.

[Whereupon, at 11:47 a.m., the Subcommittee was adjourned.]

Appendix I

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

Responses by The Honorable Gregory D. Winfree
HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON RESEARCH AND TECHNOLOGY

"The Future of Surface Transportation"

The Honorable Gregory D. Winfree, Assistant Secretary for Research and Technology, United States Department of Transportation

Questions submitted by Rep. Larry Bucshon, Chairman, Subcommittee on Research and Technology

1. **Several Agencies conduct transportation-related research that falls under the Science Committee's jurisdiction. Could you discuss how DOT works with the Department of Energy's Office of Science and the National Science Foundation to coordinate research priorities?**

   A: USDOT has active targeted relationships with both the Department of Energy (DOE) and the National Science Foundation. A few examples:

   USDOT signed an interagency agreement with the Department of Energy's National Renewable Energy Laboratory in 2013, establishing the Clean Transportation Sector Initiative (CTSI). The initiative aims to stimulate a dialogue with stakeholders and subject matter experts on strategies to advance transportation technologies and systems to achieve zero or near-zero emissions by mid-century. The CTSI team held a workshop on February 5-6, 2014 to develop interagency consensus on next steps and to explore the role of disruptive technologies in moving transportation into the 21st Century.

   USDOT is also a member of the interdepartmental Biomass Research and Development Board. Our membership allows us to articulate transportation impacts both as a user of various transportation fuels and as a transporter of biobased products. The Department hosted the interagency biofuel infrastructure workshop in June 2011. This workshop led to next steps needed for infrastructure investment to support a diverse fuel portfolio and other renewable energy resources. This information is noted in the 2014 National Biofuel Action Plan Update.

   USDOT provides subject matter experts to support National Science Foundation proposal development and review, as requested, to ensure research coordination.

2. **Who owns the data recorded by these V2V devices? How could the data be used in civil litigation or criminal proceedings? How could it be accessed for law enforcement purposes? Could private parties such as insurers access the data?**

   A: The Department takes privacy very seriously. We are committed to supporting deployment of Vehicle-to-Vehicle (V2V) technology in a manner that both protects personal privacy, and improves safety. We have worked closely with our industry partners to develop a technical approach to V2V communications that helps protect individual privacy. For this reason, V2V equipment is not designed to store data. Rather, the equipment transmits generic safety information in a very limited geographical range. Except in the rare case of malfunction, the system will not collect, and motor vehicles will not store, the messages sent or received.

Because V2V messages travel over an unrestricted, dedicated short range communications channel, the individual or entity whose vehicle is transmitting a V2V message does not, in a traditional sense, "own" this generic data once transmitted. Rather, other vehicles, individuals and entities, public or private, with equipment capable of accessing the generic safety messages broadcast by V2V devices may do so. However, because these messages do not identify specific drivers or vehicles, standing alone, we do not believe these messages would have significant utility for insurance, law enforcement or litigation purposes.

3. **I am concerned that a nefarious entity could remotely hijack a connected vehicle; is this scenario a serious concern? How easily can vehicle data be hacked or manipulated for malicious purposes? What specific cybersecurity safeguards need to be in place to prevent this type of intrusion?**

A: With regard to Vehicle-to-Vehicle (V2V) communications based on 5.9 GHz Dedicated Short Range Communications (DSRC), a security management approach has been developed through cooperative research with vehicle manufacturers that is integral to its design. This approach uses a Public Key Infrastructure (PKI) and other cryptographic methodologies to ensure communications are secure and trustworthy.

While V2V is not yet deployed in production vehicles, the Department's Intelligent Transportation Systems-Joint Program Office (ITS-JPO) and National Highway Traffic Safety Administration (NHTSA) have been researching cybersecurity in existing vehicle systems. We are unaware of any real world instances where the safety of a vehicle has been compromised due to remote hacking of existing systems deployed on today's vehicles. However, we recognize that the lack of an event does not imply impossibility. In fact, academics and security experts have demonstrated vulnerabilities that potentially exist within modern vehicles in the non-V2V context. These vulnerabilities could potentially be exploited via physical or wireless entry portals existing in today's vehicles.

The ITS-JPO and NHTSA are actively pursuing research in this area, and NHTSA is working with vehicle manufacturers to ensure that cybersecurity issues are addressed. Our research plan specifically includes identification of vulnerabilities and evaluation of potential solutions so that safety concerns with regard to the ability of these systems to remain free of unauthorized access or malicious attacks can be addressed. In addition, through discussions with vehicle manufacturers it is clear that they are becoming more cognizant of cybersecurity threats and are taking actions to secure remote access points into their vehicles. As NHTSA works to develop regulations for V2V technology, the Department will continue to work closely with vehicle manufacturers and cybersecurity experts to minimize (and eliminate, if possible) potential new risks that might arise with V2V, including "hardening" the vehicle against cyber-attack and working to ensure that the Security Credentials Management System that manages the security and trustworthiness of V2V communications is as resistant as possible to attack.

4. **Who will develop the technical standards for connected vehicle technologies such as vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and autonomous vehicles? How will these standards be decided and enforced?**

A: Development of technical standards to meet Intelligent Transportation Systems (ITS) requirements, including V2V, V2I and autonomous vehicles is primarily conducted in a cooperative manner between industry and governmental stakeholders in accordance with both legislative direction and good engineering practice. In order to guide interoperable deployments as well as identify interfaces which are candidates for standardization, USDOT makes available and maintains an ITS National Architecture and has finalized an initial version of a more detailed Connected Vehicle Reference implementation Architecture (CVRIA) which will evolve to become part of the National Architecture. For those interfaces where there is public interest (e.g. safety and/or nationwide interoperability) in assuring that technical standards are available and/or mandated, USDOT cooperates with and provides funding support to Standards Development Organizations (SDO, e.g. SAE International, Institute for Electrical and Electronics Engineers [IEEE]) to expedite development and publication with broad stakeholder input via the SDO's well-established open consensus processes.

USDOT encourages and facilitates participation of funded research partners in the SDO's technical standards development processes and will when needed provide additional specific technical input via contractual and other means. Should SDO processes be insufficient to provide required technical standards when needed, USDOT also has authority to establish provisional standards. When practical, USDOT seeks to harmonize technical standards content internationally, recognizing that, in a global vehicle market, avoiding different technical standards will both speed adoption and reduce cost of ITS technologies. To the extent appropriate, USDOT modal agencies choose to reference appropriate technical standards in rulemaking actions. In cases where there is not a significant public interest in standardizing a particular interface within an ITS architecture, USDOT's role is limited to identifying the interface in a reference architecture.

5. **Regarding the issue of ensuring that unlicensed devices not compromise safety through harmful interference to the ITS architecture, operations, or safety critical applications if permitted to operate in the 5.9 GHz band, what has been your office's interaction with NTIA and the FCC (Federal Communications Commission) on this issue? What are outstanding issues that need to get resolved, and what is the current status? What have you all been able to agree on?**

A: On April 10, 2013, the FCC published in the Federal Register, a Notice of Proposed Rulemaking (NPRM) to revise Part 15 of its Rules to permit U-NII devices in the 5.580-5.925 GHz band. USDOT submitted comments to the FCC NPRM to the National Telecommunications and Information Administration (NTIA) and NTIA filed those comments with the FCC on June 10, 2013. In order to discuss the situation and provide input, USDOT has met several times with NTIA and FCC.

The Institute for Electrical and Electronics Engineers (IEEE) 802 standards committee has established a working group, known as the IEEE 802.11 DSRC Coexistence Tiger Team, that provides an international multi-stakeholder technical forum that includes industry experts previously involved in developing standards for both wireless local area networks and vehicular wireless communications. USDOT has membership in the Tiger Team. While NTIA's January 2013 5 GHz Report indicated that NTIA would follow up with quantitative studies in connection with domestic and international regulatory proceedings involving the 5350-5470 MHz, 5850-5925 MHz, and other bands, NTIA believes that industry participants should first be afforded adequate time to identify acceptable technology approaches for coexistence in the 5850-5925 MHz band. The Tiger Team's meetings have provided a venue for evaluating coexistence ideas. On January 24, 2014, the Tiger Team sent a letter to the FCC to summarize activities coordinated by IEEE 802.11.

As discussed in the letter, the current work items for the group include:

- Review of ITS/DSRC field trials conducted to date
- Review of work to date on coexistence
- Presentations on use cases
- Presentation of possible coexistence approaches
- Modeling/simulation of possible coexistence approaches
- Prototype testing of proposed approaches

As the work of the Tiger Team progresses USDOT has established testing capabilities so that we can analyze possible interference and sharing possibilities. We are ready to work with the NTIA to review and analyze any sharing proposals, recognizing that any sharing proposal will have to protect critical ITS safety applications to be considered acceptable by USDOT. To date, no sharing proposals have been offered by industry for USDOT testing and analysis. Once any spectrum sharing technology proposal analysis is complete, USDOT, along with the NTIA and the FCC, will be better positioned to assess how the proposed changes to existing rules and regulations for harmonization across such a large swath of spectrum will impact DSRC and its lifesaving potential.

6. **The recent appropriations bill reorganized RITA (Research and Innovative Technology Administration) to a new office titled "Office of the Assistant Secretary for Research and Technology (OST)." Does the creation of this new office transfer/assign new responsibilities and additional activities that were not otherwise under the purview of RITA?**

A: In January, via the Consolidated Appropriations Act, 2014 (P.L. 113-76; at Division L, Title I), the Research and Innovative Technology Administration (RITA) was elevated into the Office of the Secretary as the Office of the Assistant Secretary for Research and Technology. Importantly, there was no change in mission or programmatic structure. No new authorities or responsibilities were conveyed as part of the elevation.

Questions for the Record from Rep. Dan Lipinski
June 18, 2014 Hearing "The Future of Surface Transportation"

Questions for the Record for Assistant Secretary Winfree, U.S. Department of Transportation

1. **Research and deployment efforts have been carried out at the state and local level funded by state and local tax dollars. An example of this is Oregon's effort to deploy a vehicle miles travelled tax. What efforts has DOT made to support local deployment efforts and what could be done to support this innovation at the local level?**

   A: USDOT has a long history of partnering with local agencies to deliver innovations, especially in infrastructure and safety solutions. The best-known of these programs is the Local Technical Assistance Program (LTAP) and Tribal Technical Assistance Program (TTAP), composed of a network of 58 Centers – one in every state, Puerto Rico and regional Centers serving tribal governments, often linked with University Transportation Centers. The LTAP/TTAP Centers enable local counties, parishes, townships, cities and towns to improve their roads, bridges, safety and operations by supplying them with a variety of training programs, an information clearinghouse, new and existing technology updates, and personalized technical assistance. Thousands of local transportation agencies benefited from the information and training provided to them through the LTAP/TTAP Centers, which annually:

   - Conduct approximately 6,200 training sessions
   - Provide nearly 40,000 training hours
   - Train over 174,000 participants at LTAP/TTAP events.

   Another example of specific local support is the Federal Highway Administration's (FHWA) Local & Rural Road Safety Peer-to-Peer Assistance, a form of technical assistance for local and rural highway agencies to adequately address safety problems on the roads they maintain. Most recently, FHWA has responded to the needs of local and county governments to better access and make use of Federal Aid funding through the "Federal-aid Essentials for Local Public Agencies" website, which provides tailored information on environment, finance, right-of-way, project development and construction, and contract administration, with more topics added as requests are made.

   USDOT also supports local Intelligent Transportation System (ITS) deployment efforts. The ITS research program includes a robust professional capacity building element that provides training to state and local agencies on ITS solutions and standards. Additionally, USDOT maintains a database of benefit and cost information to help local agencies make investment and deployment decisions. USDOT routinely funds demonstration programs, such as Integrated Corridor Management, Mobility Services for All Americans, and the Connected Vehicle Safety Pilot to help state and local organizations understand the value of ITS solutions for infrastructure management and vehicle safety. For example, USDOT is in the process of funding deployment planning grants for Integrated Corridor Management (ICM). These small, $200,000 grants will provide seed money to accelerate planning and stimulate local investment in actual deployment of ICM solutions.

The Department is now planning to conduct Connected Vehicle Pilot Deployments to build off the success of the Safety Pilot and to provide a forum to support the deployment and testing of mobility, environment and safety applications at the regional, state and local level.

2. **This Committee has long been concerned with the balance of long-term versus short-term transportation research. As I stated in my opening statement, while short-term R&D is essential for addressing current needs and opportunities, the big breakthroughs in safety and efficiency won't happen without a dedicated source of funding for longer-term, exploratory research.**

   Can you expand on what steps the Department has taken to ensure an appropriate balance between short-term and long-term R&D needs? What programs do you have in addition to the UTC program that focus on longer-term research?

   A: The Federal Highway Administration (FHWA) Highway Research and Development Program (HRD), a comprehensive and nationally-coordinated program, supports long-term and short-term research activities associated with safety, infrastructure preservation and improvements, environmental mitigation and streamlining, livability considerations, operations, and policy. "Next Generation Research & Technology (R&T)" is an HRD program that provides policymakers and the research community with information needed to address critical knowledge gaps, develop collaboration opportunities, and accelerate innovation and technology deployment to meet future highway transportation needs.

   Next Generation R&T encompasses the Exploratory Advanced Research (EAR) Program, which conducts longer-term, higher-risk research with the potential for dramatic breakthroughs in surface transportation. The Program is closely coordinated with, but does not duplicate, R&D conducted through the University Transportation Center Program, the Intelligent Transportation Systems Program, the pooled fund National Cooperative Highway Research Program, and State-based research and technology initiatives. Finally, FHWA coordinates extensively with other USDOT modal agencies in the selection and review of topics and proposals, and shares relevant results and future activities with other modes.

During SAFETEA-LU and the first full year of MAP-21, the EAR Program funded 74 projects involving over 50 universities, 35 businesses, 10 federal laboratories, and 12 state and local agencies totaling an investment of over $70 million in Program funds and $25 million in matching funds. Examples of EAR Program funded research include:

- The "Connected Highway and Vehicle Systems Concepts" focus area, which is expected to provide the government with an improved understanding and confidence about the system-level impacts – positive and potentially negative – from increasing automation in the highway system.
- The "Breakthrough Concepts in Material Science" focus area, which is expected to provide new approaches for increasing the durability of highway materials while accommodating more marginal and recycled materials into construction.
- The cross-cutting "Information Sciences" focus area is expected to provide new tools for automating the extraction of information from large and complex data while also providing new techniques that will make analysis practical for a range of academic and industry researchers.

DOT also collaborates with other Departments that have established basic and advanced research programs to leverage knowledge and outcomes that are applicable to the transportation enterprise. One example of a recent deliverable from these collaborations is Precision Departure Release Capability (PDRC), a new NextGen software tool that was developed by NASA and transferred to the Federal Aviation Administration (FAA), which will improve the flow of aircraft from runways to cruising altitudes.

3. **DOT consists of multiple Operating Administrations with defined missions and priorities, but also with similar overarching goals in many instances. The lack of intradepartmental coordination of research activities at the Department has long been a concern for this Committee and many others. The most recent appropriations bills and budgets have announced a reorganization of the Research and Innovative Technology Administration, or RITA, and moved the functions of RITA to a newly named Office of the Assistant Secretary for Research and Technology (OST).**

   I am interested in learning more about how DOT and its Operating Administrations coordinate internally to ensure that research is conducted synergistically, cross-modally, but without duplication? What are the Department's expectations in reorganizing? What metrics will you use to evaluate any improvements under OST?

   A: OST-R's role as research coordinator is to provide the informational and organizational framework necessary for the Department as a whole to make informed decisions regarding the allocation of research resources, conduct of research activities, and the implementation of research results. For example, OST-R led the development of the *USDOT Research, Development and Technology (RD&T) Strategic Plan*, which sets out the Department's research goals, activities and performance measures (both mode-specific and cross-modal research) for the period of 2013 to 2018.

Other specific coordination activities include:

- *RD&T Planning Team*: An established forum composed of the Department's Research Program Directors. Monthly meetings are chaired by OST-R's Associate Administrator for RD&T.
- *USDOT Research Hub*: A web-based searchable database of the Department's research portfolio and its "real world" impacts www.rita.dot.gov/researchhub. Used to identify opportunities for cross-modal collaboration and to mitigate the risk of duplicative work.
- *Technology Transfer Program*: Assists the Operating Administrations in achieving effective technology transfer, coordinating the adoption of technology transfer best practices across the Department, and tracking the results of research implementation.

OST-R's elevation to the Office of the Secretary of Transportation is expected to raise the profile of research and technology within the Department and to allow RD&T to be more closely aligned with the Department's other Secretarial Office functions. Specifically, the elevation will allow OST-R to work more closely with OST-Budget on research budget development and with OST-Policy on aligning the research portfolio with the Department's Strategic Goals and other Administration initiatives.

Defining measurable, quantitative performance metrics for research coordination is challenging due to the subjective nature of the research coordination task. Performance metrics defined by the Department in 2011 for measuring research coordination include:

- Total visits to USDOT Research Hub website
- Number of projects listed in *USDOT Research Hub*
- Number of USDOT-funded Research Technologies identified for potential transfer.

4. Many technologies such as materials, information security, and sensors have cross-cutting applications. How are you collaborating with other agencies in shared R&D needs? What efforts are you making look at other agencies for nascent technologies that may have transportation applications?

USDOT is well aware that cross-cutting applications are being developed in other Federal agencies for various mission uses. Constrained transportation research funding, as well as limited advanced research funding, makes cost-bearing collaborations difficult; however, USDOT seeks to maintain awareness of science and technology developments through both formal and informal relationships.

For example, USDOT has consistent involvement in several national-level interagency research initiatives under the auspices of the National Science and Technology Council (NSTC). Chief among these are involvement in the Networking and Information Technology Research and Development (NITRD) Program (for cyber physical systems, cyber security and information assurance, wireless spectrum R&D, and big data); the

National Nanotechnology Initiative (for infrastructure materials); the Smart Grid Initiative (for electric vehicle deployment); the Interagency Working Group on Language and Communication (for human factors symbology and distraction issues); the Subcommittee on Disaster Reduction (for disaster preparedness, evacuation and infrastructure resilience and recovery); and the Committee on Science, Technology, Engineering, and Math Education.

There are also multiple routine interagency venues for information sharing and joint work that advance the Department's mission goals. For example, USDOT's responsibilities as the lead civilian agency within the U.S. government on Global Positioning System (GPS)-related issues leads to USDOT awareness of new positioning, navigation and timing (PNT) developments across the Department of Defense and all civilian departments and independent agencies. Likewise, active involvement in the National Telecommunications and Information Administration's (NTIA) Interdepartment Radio Advisory Committee (IRAC) enables USDOT to be involved in new spectrum and communications technology developments. USDOT has developed a close working relationship with the National Institute of Standards and Technology (NIST) through the Interagency Committee on Standards Policy and the NSTC Subcommittee on Standards, which has led directly to standards-related work not only with NIST, but with other Federal agencies. The Federal Aviation Administration's longstanding RD&T work with NASA is well-documented.

In addition, USDOT develops *ad hoc* relationships to meet the RD&T needs of USDOT missions – NIST for metrology and specific materials needs; DOE on energy technologies; DOE and EPA on emissions sensors and technologies; and the natural resources agencies on environmental sensing issues, among others.

5. **DOT research develops vital technologies and provides valuable education opportunities for future transportation planners and innovators. However, an important part of research is deployment and tech transfer. How does DOT measure the effectiveness of technology transfer efforts in the research it funds?**

A: By necessity, the methods for measuring the effectiveness of our technology transfer activities are as numerous as the methodologies used to transfer technologies to end users. In support of our primary mission of enhancing the safety of the traveling public, our research is most often applied research that is transferred through written technical reports, as well as through the issuance of guidelines, standards, best practices and regulations. Often, our research results and developed technologies are the inputs of still further research. Through our Technology Transfer Plan we train our researchers to incorporate technology transfer best practices into their research processes.

Some examples of how we measure the effectiveness of our technology transfer efforts include measuring the following:

- The number of technologies, processes, or methods adopted in an operational setting to reduce fatalities and injuries;

- The number of research results used in the issuance of guidelines, standards, and best practices;
- The number of technologies, processes, or methods adopted in an operational setting to improve the state of good repair of highways and bridges; and
- The standardized metrics of performance used in the development of the annual Department of Commerce Technology Transfer Report to Congress, including: the number of patent applications filed; patents received; patent licenses entered into; the number of Cooperative Research and Development Agreements entered into; and others.

6. **The Administration's GROW AMERICA plan permits the Secretary to cooperate with "international entities" to carry out international highway transportation outreach. How much emphasis and effort does DOT make to scan the international community for transportation research and technology developments for highways as well as other modalities? Are there ways to improve our current efforts at DOT to look at the international community's efforts? Could it be useful, for example, to have either the DOT or the TRB conduct a study of international technologies and their potential application here?**

A: Experience in cooperating with international entities has confirmed that the U.S. can benefit from the knowledge of other countries that are addressing transportation challenges similar to our own. Obtaining information on innovations successfully employed in other countries allows us to learn directly from the development and deployment experience of foreign counterparts and, where appropriate, move efficiently toward the adaptation of technology and practices to conditions in the U.S. The provision in Sec. 8112 of the GROW AMERICA Act would help to ensure our ability to interact with a broad range of actors working internationally.

International cooperation activities are a small, but valuable, component of USDOT's research program. However, we integrate these interactions into our pursuit of USDOT's research and program priorities. For example, in the highway area, such exchanges have led to the use of cost- and time-saving innovations such as warm mix asphalt and accelerated bridge construction technology. Information on high speed rail technologies and bus rapid transit has also been obtained through international outreach. Additionally, international visits have provided valuable information on creating safe and convenient bicycle and pedestrian networks.

Generally, maintaining awareness of developments in the international community and positioning ourselves to share information is valuable. Rather than a broad study approach, we think we can accomplish this through efforts that focus on specific challenges and involve the organizations responsible for the adaptation and application of the potential solutions identified abroad.

7. **Interoperability of V2V safety communications systems is critical. One manufacturer's system must be able to communicate with another's for these systems to have the full intended benefits. What is the status of standards development for V2V? What kinds of activities are DOT and the private sector undertaking to help vendors test their connected vehicle devices to other vendors to ensure their devices work with each other and meet the base standard requirements of the Connected Vehicle Test Bed?**

   A: Nationwide interoperability of V2V communications systems is unquestionably critical to enable successful deployment of V2V technologies. The recently concluded Safety Pilot model deployment has confirmed that current versions of the key standards available today (IEEE 802.11p, IEEE 1609 and SAE J2735) combined with additional published guidance is sufficient to assure interoperability between equipment from many manufacturers installed in a broad variety of vehicles. Work is currently underway in cooperation with industry and Standards Development Organizations (SDOs) to refine these standards to assure that they are suitable to support large-scale deployment. To support ongoing development and testing, USDOT operates and maintains a connected vehicle test environment in southeast Michigan as well as continuing to keep the Safety Pilot model deployment infrastructure available to support testing and development work by any interested parties. USDOT is cooperating with industry stakeholders to develop a robust certification environment, and recently issued a request for applications to result in the award of new Cooperative Agreements to establish a future certification environment for connected vehicle devices and applications.

   To better assure V2V interoperability throughout the worldwide auto manufacturing and supply market, the Intelligent Transportation Systems-Joint Program Office (ITS-JPO) supports ITS international standards harmonization efforts through a series of Memoranda of Agreement with the governments of Canada, the European Commission, Japan and Korea; and through international standards harmonization working group meetings that are fully open to all interested parties.

Questions for the Record
Zoe Lofgren
June 18, 2014 Hearing:
The Future of Surface Transportation

Unfortunately, I was unable to attend this important hearing. As we approach a Surface Transportation reauthorization, a sustained effort on Transportation research and development will help inform and improve our transportation policy.

The Mineta Transportation Institute, at San Jose State University in my district, has been providing high quality research and training in focusing on multimodal surface transportation policy and management since 1991.

<u>Assistant Secretary Winfree</u>: **a) My understanding is that the latest competition for University Transportation Centers (UTCs) a focus on conforming to the Department of Transportation's five strategic goals: Economic Competitiveness, Environmental Sustainability, Livable Communities, Safety and State of Good Repair, resulted in elimination of funding for UTCs exclusively devoted to research and training in public transit. Would you endorse an additional round of UTC funding to support critical research focused on transit?**

A: The 2013 competition was indeed structured around USDOT's strategic goals; MAP-21 required that the five National UTCs focus on national transportation issues, as determined by the Secretary, which USDOT determined to be the USDOT strategic goals, and MAP-21 further required that one of the ten Regional UTCs focus on comprehensive transportation safety, which also aligned with the USDOT strategic goals. In planning for the 2013 competition, USDOT identified the use of these strategic goals as an effective tool for focusing grant applications program-wide on what USDOT considered to be the most important issues facing the U.S. transportation enterprise, and so applied them to all types of centers being competed. One of the 20 Tier 1 UTCs that were selected in 2013, the National Center for Transit Research headed by the University of South Florida, applied for its grant under the USDOT strategic goal of Livable Communities and focuses its work on transit as well as the related area of bicycle/pedestrian transportation. In general under the UTC Program, centers tend to do work in more than one mode of transportation. Examples of UTCs that do work in the transit area along with other modes are: the National UTC led by Portland State University, the Regional UTCs led by the City University of New York and the University of California at Berkeley, and such Tier 1 UTCs as Montana State University, the University of Central Florida, and Western Michigan University.

With MAP-21, funding from the Federal Transit Administration (FTA) to support the UTC Program ceased, so all UTC funding now comes through the Federal Highway Administration. UTC Program grants require non-Federal matching funds to be provided by the grantee, and USDOT has received feedback from UTC grantees over the years that match funding in the transit area has been difficult to obtain.

b) Given the critical role transit and coordinated multimodal transportation will play in developing cleaner, less-congested and more livable transportation networks in the future, do you have other suggestions as to how to maintain a focus on transit, in what often remains heavily highway-centric transportation spending and research?

Public transit research continues to be strongly represented in Department's research portfolio. For example:

- FTA maintains a robust multi-million dollar research program designed to address the short- and long-term needs of the transit industry. This includes support for extramural programs like the Transit Cooperative Research Program (TCRP) which is managed by the Transportation Research Board.
- The FTA Administrator participated in the formal executive review of the UTC funding competition awards, providing recommendations on behalf of FTA to the Secretary on the

final selection of awardees. This is consistent with MAP-21 and ensured that transit research interests were taken into account in the process of awarding of UTC funds.

- Transit-focused research continues to be well-represented within the UTC program. For example, the University of South Florida's National Center for Transit Research was successful in receiving funding in the 2013 competition under the Strategic Goal of "Livable Communities," and transit-related research projects are being undertaken at many UTCs, whether or not the primary theme of those UTCs is transit. As the UTC Program emphasizes multi-modal and multi-disciplinary research, transit concerns are often folded into larger research projects.

Responses by Mr. Scott Belcher

ITS AMERICA

Responses for the Record
Hearing on "The Future of Surface Transportation"
Committee on Science, Space and Technology
Subcommittee on Research and Technology

Who owns the data recorded on V2V devices? How could the data be used in civil litigation or criminal proceedings? How could it be accessed for law enforcement purposes? Could private parties such as insurers use this data?

The U.S. Department of Transportation (DOT) announced it would chart a regulatory path that would require all new automobiles to be equipped with vehicle-to-vehicle (V2V) communication systems sometime in the next several years. This follows a National Transportation Safety Board (NTSB) recommendation that connected vehicle technology be mandated on all new vehicles. There are a number of challenges that have been addressed in the Connected Vehicle program related to data privacy.

The U.S. DOT, auto industry and legal experts in the field of privacy developed a set of Privacy Principles in 2007 that has driven development of the V2V technology since that time. V2V has been developed with privacy and security as integral and paramount, not an afterthought, understanding that consumer acceptance is critical for the adoption of this lifesaving technology.

Crash avoidance applications in V2V devices calculate the likelihood of a neighboring vehicle colliding at any moment. If data suggests there is a high likelihood of a collision, the V2V device sends an alert to the driver if there is imminent risk. Data is then discarded after the driver has received the crash alert.

If the data were to be recorded by someone for a purpose unrelated to driver safety, the location data is protected and completely anonymized. Vehicles sending the data do not identify themselves in any way (e.g., no driver name, vehicle make/model, license plate number or other ID). Because the V2V beacon is only short-range, it is accessible to immediately adjacent vehicles only, making it completely impractical for anyone to easily track drivers' origins and destinations. Data is made completely useless for law enforcement, litigation, insurance or any other use that is unrelated to crash avoidance features.

V2V devices are designed to be far more secure and private than mobile phones or personal GPS navigation systems currently available to consumers. In essence, the V2V system works like radar. The blip on the screen tells you there is a car in your immediate path; but to you and other drivers, you will always be just an anonymous blip.

I am concerned that a nefarious entity could remotely hijack a connected vehicle; is this scenario a serious concern? How easily can a vehicle data be hacked or manipulated for malicious purposes? What specific cyber security safeguards need to be in place to prevent this type of intrusion?

Safety, security and privacy are the major design principles behind the vehicle-to-vehicle (V2V) safety communications system. The U.S. DOT and automakers have focused on security-by-design to ensure robustness to a number of cyber threats. A security management system has been constructed to ensure that false alerts cannot be transmitted. In the rare event that a false alert is transmitted, the security system will inform all other drivers to ignore the message. The National Highway Traffic Safety Administration (NHTSA) has examined the performance of V2V technology for risks related to security and will review the performance of V2V technology for safety.

In information technology, personal computing and consumer electronics, "first-to-market" competitive advantage and "fix-it later mentality" with respect to software reliability and security have been the unfortunate norm for industry. ITS America recently completed a report on Cybersecurity in Transportation which recognized that security will need to be comprehensively addressed in nearly all future transportation technologies – from smart traffic signals to self-driving cars. The designers of V2V communication technology, however, understand that consumer confidence and trust in a safety critical system cannot be "fixed later" if security is compromised. For that reason, a vigorous effort has been underway to design security into V2V that will be robust and last the lifetime of any given vehicle.

What standards are being developed for security and privacy of connected-vehicle data? How will this be addressed in the future and how will you know that they will be adequate?

The main security standard for Dedicated Short-Range Communication (DSRC) is referred to as IEEE 1609.2 Security Services, which was published in 2013 and will likely be revised by the industry in the next couple of years. This standard defines the cryptography and data formats that enable safety messages to be authenticated while providing for "pseudonymous" communication that allows a sender to avoid identifying itself. Frequent changes in the pseudonymous identifiers not only protect the privacy of a single message, but also prevent easy tracking of a sender across a set of messages sent minutes, hours, or days apart. In other words, one cannot easily determine that a given message came from a given car, or that a given pair of messages came from the same car.

In addition to the IEEE 1609.2 standard, the industry is developing the J2945.1 Minimum Performance Requirements for sending Basic Safety Messages through the Society of Automotive Engineers (SAE), which will include security components such as specifying how to change identifiers to protect privacy.

Who will develop the technical standards for connected vehicle technologies such as vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and autonomous vehicles? How will these standards be decided and enforced?

Most technical standards for V2V and V2I safety technologies are processed through private standard development organizations (e.g., the Institute of Electrical and Electronics Engineers (IEEE), the International Standards Organization Technical Committee – 204 (ISO TC-204) and the Society of Automotive Engineers (SAE)) and could potentially be incorporated or modified through rulemakings by the National Highway Traffic Safety Administration and/or the Federal Highway Administration. Regarding autonomous vehicle technology, SAE is developing word definition standards while the Crash

Avoidanee Metrics Partnership (CAMP) – which represents the major automakers – is working with NHTSA to develop automation level definitions.

What are your thoughts on opening the 5.9 GHz band for unlicensed use? What would be the effect on V2V technology if this band is opened? Would this result in innovation and widespread permeation of this intelligent transportation system technology, as was seen with radio innovation when the 2.4 GHz band was opened in the 1940's? Or would the use of unlicensed devices introduce potentials risks and harmful interferences, as noted in the National Telecommunications and Information Administration's (NTIA) January 2013 study?

ITS America is extremely concerned that allowing unlicensed use of the 5.9 GHz band could potentially introduce interference from Wi-Fi devices that would jeopardize the high-speed, secure and reliable transmission of V2V and V2I safety signals between vehicles and with infrastructure and aftermarket devices in which over a billion dollars have been invested by the private sector and U.S. taxpayers. ITS America filed comments and reply comments to the FCC (ET Docket No. 13-49) detailing these concerns.

Motor vehicle crashes are the leading cause of death for children and young adults in the United States, with more than 33,000 annual fatalities, 2.3 million injuries, and an economic cost of $871 billion according to the U.S. Department of Transportation (DOT). While we support efforts to make better use of the nation's airwaves, we cannot think of a more appropriate, innovative and important use of spectrum than saving tens of thousands of lives each year and reducing the nearly $1 trillion cost of crashes and traffic congestion to American families and our nation's economy.

V2V and V2I communications require secure, wireless interface dependability utilizing dedicated short range communications (DSRC) in the 5.9 GHz band. DSRC's two-way short- to medium-range wireless communications capability permits very high-speed data transmissions in the 5.9 GHz band critical for V2V and V2I safety applications. DSRC is the only viable medium for communications-based active safety systems because it operates in a licensed frequency band, provides a secure wireless interface required by active safety applications, supports high-speed, low-latency, short-range communication between vehicles operating at highway speeds, is immune to extreme weather conditions (rain, fog, snow, etc.), and is designed to be tolerant to multi-path transmissions typical with roadway environments.

We and the U.S. Department of Transportation are currently unaware of any existing or proposed technical solution which guarantees interference-free operation of the DSRC safety critical applications while allowing Wi-Fi enabled devices to share the 5.9 GHz spectrum. U.S. DOT Assistant Secretary for Research and Technology Gregory Winfree testified during the Subcommittee's hearing that, "We have very serious concerns about any spectrum sharing that prevents or delays access to the desired channel, or otherwise preempts the safety applications. At this time, the Department is unaware of any existing or proposed technical solution which guarantees interference free operation of the DSRC safety critical applications while allowing Wi-Fi enabled devices to share the 5.9 GHz spectrum."

ITS America supports the collaborative effort, which is already underway, to explore whether a technical solution exists that would allow Wi-Fi devices to operate in the 5.9 GHz band without interfering with these critical safety applications. But this process should be allowed to proceed without arbitrary deadlines, restrictive parameters or political pressure that could influence the outcome, especially since a technical solution has not even been proposed yet that can be tested for interference in the 5.9 GHz band. As such, the FCC's NPRM, and the Wi-Fi Innovation Act which has been introduced in the House and Senate, are premature and potentially put the future of V2V and V2I communication at risk.

ITS America shares concerns expressed by the U.S. DOT, NHTSA, the National Telecommunications and Information Administration (NTIA) and NTSB about the potential risks associated with introducing a substantial number of unlicensed devices into the 5.9 GHz band, and supports NTIA's conclusion that further analysis is needed to determine whether and how the multiple risk factors could be mitigated. We furthermore agree that the FCC must protect licensed users from interference and that the primary mission of federal spectrum users should not be compromised.

ITS America stands ready to work with NTIA, the wireless industry, and other federal and non-federal stakeholders to evaluate the feasibility of existing, modified, proposed and new spectrum sharing technologies and approaches. However, this process should be allowed to proceed without a predetermination that spectrum sharing in the 5.9 GHz should be the ultimate outcome. We also support efforts to identify spectrum that may be utilized to expand Wi-Fi applications, but the FCC and NTIA must ensure that unlicensed devices, if permitted to operate in the 5.9 GHz band, do not cause harmful interference to the ITS architecture, operations or safety-critical applications.

Attached for your review are letters from U.S. Deputy Transportation Secretary John Porcari and National Transportation Safety Board Chairman Deborah Hersman to the FCC voicing similar concerns.

National Transportation Safety Board

Washington, DC 20594

Office of the Chairman

May 28, 2013

Mr. Aole Wilkins
Electronics Engineer
Office of Engineering and Technology
Room 7-A431
Federal Communications Commission
445 12th Street SW
Washington, DC 20554

Attention: ET Docket No. 13-49

Dear Mr. Wilkins:

The National Transportation Safety Board (NTSB) has reviewed the Federal Communications Commission (FCC) Notice of Proposed Rulemaking (NPRM), which was published at 78 *Federal Register* 21320 (April 10, 2013). The proposed rule would revise Part 15 of the Commission's rules to permit operation of Unlicensed National Information Infrastructure (U-NII) devices within the 5 gigahertz (GHz) band. The 5 GHz band, specifically the frequency band between 5.850 and 5.925 GHz, serves as the platform for connected vehicle technologies essential to the advancement of transportation safety.

Connected vehicle technologies that rely on Dedicated Short Range Communications Service (DSRCS) systems are operating in the Intelligent Transportation Service (ITS) allocation on the 5 GHz band. Careful attention to interference risk is essential when considering permitting spectrum sharing, as proposed in this NPRM.

Since the mid-1990s, the NTSB has advocated intelligent vehicle technologies that rely on radar, vehicle-to-vehicle, or vehicle-to-infrastructure communications. Such technologies include collision warning and collision avoidance systems. The NTSB first addressed collision avoidance during its investigation of a 1995 multivehicle collision in Menifee, Arkansas,[1] in which a commercial vehicle entered dense fog, slowed from 65 mph to between 35 and 40 mph, and was then struck from behind. Subsequent collisions occurred as vehicles drove into the wreckage. This accident, which involved eight loaded truck-tractor semitrailer combination units, resulted in five fatalities.

[1] National Transportation Safety Board, *Multiple Vehicle Collision with Fire During Fog, Near Milepost 118 on Interstate 40, Menifee, Arkansas, January 9, 1995, and Special Investigation of Collision Warning Technology*, HAR-95/03 (Washington, DC: National Transportation Safety Board, 1995).

Even then, before today's wirelessly connected world existed, the need to establish dedicated communication airwaves for technologies that could prevent such collisions was recognized. As a result of the Menifee accident, the NTSB issued Safety Recommendation H-95-46 to the FCC, which states as follows:

> H-95-46
>
> Expedite rulemaking action on the allocation of frequencies that would enhance the development possibilities of collision warning systems.

The FCC successfully allocated spectrum for collision avoidance systems, and Safety Recommendation H-95-46 was classified "Closed—Acceptable Action" in 1999. The NTSB is concerned that the proposed rulemaking for spectrum sharing may compromise this necessary spectrum allocation for collision avoidance systems, by increasing the potential for dangerous interference.

Since the closure of Safety Recommendation H-95-46, the NTSB has issued several additional safety recommendations concerning technologies that rely on wireless communication in the frequency band established by the FCC in response to Safety Recommendation H-95-46. These include recommendations to the National Highway Traffic Safety Administration (NHTSA) to research, establish performance standards for, and then require, advanced collision avoidance safety technologies on passenger and commercial vehicles. The NTSB issued the following recommendations as a result of investigations into accidents that killed or injured dozens of people.[2]

> **To the National Highway Traffic Safety Administration:**
>
> H-01-6
>
> Complete rulemaking on adaptive cruise control and collision warning system performance standards for new commercial vehicles. At a minimum, these standards should address obstacle detection distance, timing of alerts, and human factors guidelines, such as the mode and type of warning.
>
> H-01-7
>
> After promulgating performance standards for collision warning systems for commercial vehicles, require that all new commercial vehicles be equipped with a collision warning system.

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[2] (a) National Transportation Safety Board, *Vehicle- and Infrastructure-based Technology for the Prevention of Rear-End Collisions*, SIR-01/01 (Washington, DC: National Transportation Safety Board, 2001). (b) National Transportation Safety Board, *Truck-Tractor Semitrailer Rear-End Collision into Passenger Vehicles on Interstate 44, Near Miami, Oklahoma, June 26, 2009*, HAR-10/02 (Washington, DC: National Transportation Safety Board, 2010).

H-01-8

Complete rulemaking on adaptive cruise control and collision warning system performance standards for new passenger cars. At a minimum, these standards should address obstacle detection distance, timing of alerts, and human factors guidelines, such as the mode and type of warning.

H-08-15

Determine whether equipping commercial vehicles with collision warning systems with active braking and electronic stability control systems will reduce commercial vehicle accidents. If these technologies are determined to be effective in reducing accidents, require their use on commercial vehicles.

These recommendations to NHTSA have been repeatedly reiterated as a result of more recent investigations in which we have seen fatalities and injuries as a consequence of the absence of such accident-prevention technology.[3]

These systems have advanced over the years since the NTSB began advocating their development, standardization, and inclusion in modern vehicles. The US Department of Transportation has sponsored voluntary standards, conducted cost-benefit analyses, and begun fleet operational testing. NHTSA analyses show that DSRCS-based connected vehicle technology could address approximately 80 percent of the crash scenarios involving non-impaired drivers.[4] Given the progress that has been made by government and industry leaders in this area, such an outcome is a realistic possibility. The NTSB believes that all newly manufactured automobiles and commercial motor vehicles should be equipped with these crucial lifesaving technologies and has made "Mandate Motor Vehicle Collision Avoidance Technologies" a priority on our current Most Wanted List.

The implementation of this technological opportunity to improve transportation safety so significantly must not be compromised by issues associated with interference on the 5 GHz band. The NTSB is not opposed to spectrum sharing in principle, but the security of preestablished communication frequencies related to transportation safety must first be ensured. Spectrum sharing could put the frequencies at risk of dangerous interference, and much is still unknown about frequency interference when it comes to vast numbers of connected vehicles in motion. A

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[3] (a) National Transportation Safety Board, *Multivehicle Collision on Interstate 90, Hampshire-Marengo Toll Plaza, Near Hampshire, Illinois, October 1, 2003,* HAR-06/03 (Washington, DC: National Transportation Safety Board, 2006). (b) National Transportation Safety Board, *Truck-Tractor Semitrailer Rollover and Motorcoach Collision with Overturned Truck, Interstate Highway 94, Near Osseo, Wisconsin, October 16, 2005,* HAR-08/02 (Washington, DC: National Transportation Safety Board, 2008). (c) National Transportation Safety Board, *Multivehicle Collision, Interstate 44 Eastbound, Gray Summit, Missouri, August 5, 2010,* HAR-11/03 (Washington, DC: National Transportation Safety Board, 2011).

[4] US Department of Transportation Safety Pilot Connected Vehicle Technology: *NHTSA Fact Sheet: Improving Safety and Mobility Through Connected Vehicle Technology.*

single incident like the case of interference encountered by the Federal Aviation Administration (FAA) with its Doppler radar could stall progress and cause concern within the industry—or even result in accidents, once these systems are deployed.[5]

The National Telecommunications and Information Administration (NTIA) is beginning its evaluation process to test the use of UNII devices on the 5 GHz band. The NTIA 5 GHz report, cited in the subject NPRM, identifies a number of risk elements associated with the likelihood of harmful interference from large numbers of U-NII devices and concludes that further analysis will be required to determine how the identified risk factors can be mitigated. Such analysis should be conducted before safety-sensitive frequencies are opened up to UNII devices. Yet, the need for such analysis will likely delay the widespread deployment of these much-needed safety systems.

The NTSB appreciates the opportunity to provide these comments. Given our long history of advocating for collision avoidance technologies, the NTSB is very concerned that the development of these technologies—potentially saving thousands of lives each year—would be put at risk. Consequently, we urge the FCC to ensure that potential delays to the development of the collision avoidance development are considered before UNII devices are allowed to operate in the 5 GHz band and that the key elements of the transportation safety systems that communicate on the same frequency are adequately and reliably protected.

Sincerely,

Deborah A.P. Hersman
Chairman

[5] The FAA issue is recounted in "Background," paragraph 8, of the subject NPRM. (See 78 *Federal Register* 21322 [April 10, 2013]).

UNITED STATES DEPARTMENT OF COMMERCE
National Telecommunications and
Information Administration
Washington, D.C. 20230

JUN 10 2013

Mr. Julius Knapp
Chief, Office of Engineering and Technology
Federal Communications Commission
445 12th Street, SW
Washington, DC 20554

RE: Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band, *Notice of Proposed Rulemaking* in ET Docket No. 13-49 – Department of Transportation Comments

Dear Mr. Knapp:

The National Telecommunications and Information Administration (NTIA) has discussed with the Department of Transportation (DOT) questions and issues raised regarding the 5850-5925 MHz band in the above-referenced *Notice of Proposed Rulemaking*. Accordingly, NTIA forwards for inclusion in the record the enclosed DOT comments relating to the deployment of Intelligent Transportation Systems (ITS) in this band.[1]

NTIA understands the vital role that Unlicensed National Information Infrastructure (U-NII) devices play in the telecommunications economy. In our January 2013 report to Congress and the FCC, NTIA presented the results of its initial study evaluating known and proposed spectrum-sharing technologies and the risk to federal users if the FCC allows U-NII devices to operate in the 5350-5470 MHz and 5850-5925 MHz bands.[2] Our report identified a number of risks to FCC-authorized ITS stations operating Dedicated Short Range Communication Service (DSRCS) systems in the 5850-5925 MHz band and suggested mitigation strategies. Some of the key ITS applications will perform important public safety functions by acting to prevent the majority of types of roadway crashes.[3] Therefore, direct interaction and cooperation between wireless and transportation industry representatives is essential for the development of constructive proposals to accommodate evolving U-NII and ITS technologies.

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[1] *See* Letter from John D. Porcari, Deputy Secretary of Transportation, to Lawrence E. Strickling, Assistant Secretary for Communications and Information (May 16, 2013) (enclosed). NTIA authorizes the use of the radio spectrum by the U.S. Government, establishes the policies concerning spectrum assignments and the use of radio stations owned and operated by the U.S. Government, and represents the views of the Executive Branch before the Federal Communications Commission (FCC). *See* 47 U.S.C. § 902 (b)(2)(A), (J), (K).

[2] *See* United States Department of Commerce, *Evaluation of the 5350-5470 MHz and 5850-5925 MHz Bands Pursuant to Section 6406(b) of the Middle Class Tax Relief and Job Creation Act of 2012* (Jan. 2013), *available at* http://www.ntia.doc.gov/files/ntia/publications/ntia_5_ghz_report_01-25-2013.pdf. For the purpose of this study, NTIA treated DSRCS systems like a federal system in assessing the feasibility of allowing U-NII devices to operate in the 5850-5925 MHz band.

[3] *Id.* at 5-1.

NTIA looks forward to working with the FCC, DOT, and other interested parties to review approaches to the introduction of wireless broadband devices in this band while protecting ITS applications. If you have any questions regarding these comments, please contact Mr. Edward M. Davison (edavison@ntia.doc.gov; 202-482-5526) of my staff.

Sincerely,

Karl B. Nebbia
Associate Administrator
Office of Spectrum Management

Enclosure

THE DEPUTY SECRETARY OF TRANSPORTATION
WASHINGTON DC 20590

May 16, 2013

Mr. Lawrence E. Strickling
Assistant Secretary for Communications and Information
U.S. Department of Commerce
1401 Constitution Avenue, NW
Washington, DC 20230

Re: FCC ET Docket No. 13-49
Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band

Dear Mr. Strickling:

On April 10, 2013, the Federal Communications Commission (FCC or Commission) published in the *Federal Register* its Notice of Proposed Rulemaking (the NPRM or the Proposed Rule) in the above-referenced matter. Among other things, the FCC proposes to make available additional spectrum in the 5.850-5.925 GHz band for use by National Information Infrastructure (U-NII) devices, so as to "increase wireless broadband access and investment." 78 Fed. Reg. 21320, 21321 (April 10, 2013).

The United States Department of Transportation (DOT or the Department) appreciates the attention that the FCC and the National Telecommunications and Information Administration (NTIA) have devoted to this matter, and recognizes that spectrum is a scarce national resource and that it is important to find ways to expand wireless broadband capacity. However, the Department has concerns about the FCC's proposal, particularly as it relates to the deployment of Intelligent Transportation Systems (ITS)—a DOT priority for improving safety across all surface transportation modes. DOT has invested significant resources in ITS research and development activities, given the technologies' potential to save thousands of lives annually and to achieve other important national transportation goals (such as reducing roadway congestion). Indeed, the Department has worked extensively for well over a decade, in partnership with a variety of stakeholders in the public and private sectors, domestically and internationally, to make broad deployment of these technologies in vehicles and infrastructure a reality in the near future.

Thus, DOT respectfully asks that the NTIA share the concerns outlined here, in their entirety, with the Commission. Further, the Department requests that it be given a full and continuous opportunity to be engaged in the technical analyses necessary to achieving a thoughtful resolution of the issues raised by the proposed rule.

Background

ITS broadly refers to the integration of advanced communications technologies into the transportation infrastructure and into vehicles to improve transportation safety and mobility. Among other applications, ITS includes Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) architecture. V2V involves the dynamic wireless exchange of data between nearby vehicles regarding position, speed, and location. This enables a vehicle to maintain a 360-degree awareness of the position of other vehicles to identify potential hazards, calculate risk, issue driver advisories or warnings, and potentially take preemptive action to avoid or mitigate imminent crashes. Similarly V2I, through the wireless exchange of safety and operational data between vehicles and highway infrastructure, is intended to avoid and reduce the severity of crashes, and to enable a broad range of additional safety, mobility, and environmental benefits. Thus, the aim of these systems is to foster a "smart infrastructure" that recognizes high-risk situations in advance, provides appropriate driver alerts and warnings to reduce accidents, and promotes other vital transportation interests.

In recognition of these benefits, and as described more fully below, DOT has taken a lead role for over a decade in fostering the development of ITS. Further, the Department has been closely involved in working with the FCC and the NTIA over time to ensure that there is adequate spectrum to support ITS as it has evolved from theory to reality.

With DOT's input, in 1999, the FCC allocated 75 megahertz of spectrum in the 5.850-5.925 GHz band to support ITS and the Dedicated Short Range Communications (DSRC) upon which V2V and V2I depend.[1] The Commission recognized that the 5.9 GHz band is especially appropriate for ITS, given the need for system reliability, the short distances over which the communications would occur, and the growing international consensus over the deployment of ITS in this area of the spectrum. 1999 Order at ¶ 1.7. The Commission explained that its decision to set aside this spectrum for ITS would "further the goals of the United States...Congress and the Department of Transportation to improve the efficiency of the Nation's transportation infrastructure." *Id.* ¶ 1.1. Furthermore, the FCC expressly stated that its allocation was intended to meet the needs of ITS *as it developed*. For example, the Commission said in its 1999 Report and Order that the 5.850-5.925 GHz band allocation would "ensure that adequate spectrum will be available for advanced DSRC applications *that are anticipated in the future*," including highway systems requiring "dedicated wideband channels to ensure service reliability." *Id.* ¶ 1.9 (emphasis added).

Since that time, the Department has taken substantial interest in the Commission's and the NTIA's efforts to help develop the technical standards and policy principles that would govern the 5.9 GHz band. As you know, the 5.9 GHz band is also used for certain fixed satellite service operations (FSS) and military radar systems. The FCC and the NTIA, with assistance from the Department, have worked to establish service rules and other guidelines to help ensure that these

[1] *See* Report and Order, ET Docket No. 98-95, *Amendment of Parts 2 and 90 of the Commission's Rules to Allocate the 5.850-5.925 GHz Band to the Mobile Service for Dedicated Short Range Communications of Intelligent Transportation Services* (Oct. 21, 2009) (1999 Order).

various users can coexist harmoniously within the same portion of the spectrum.[2] The Department looks forward to continued efforts among interested federal agencies and other parties to update those service rules to accommodate evolving technologies.

The FCC and the NTIA are keenly aware of Congress's interest in these issues and in considering the ways in which the radio spectrum may be made more accessible to additional users, particularly for wireless broadband applications. DOT recognizes the challenging requirements for both the FCC and the NTIA set by section 6406 of the Middle Class Tax Relief and Job Creation Act of 2012 (Act), "Unlicensed Use in the 5 GHz Band," which led directly to the NPRM. While section 6406(b) includes the 5.850-5.925 GHz band as a candidate for the NTIA studies, section 6406(a) does not require FCC action in the 5.850-5.925 GHz band; however, the NPRM includes the 5.850-5.925 GHz band as part of the proposed amendment of FCC's Part 15 rules. NPRM ¶ 2, 15, 62.

The Department's Interests and Investments in ITS

More than 30,000 people die and more than 2 million people are injured in traffic crashes on our nation's highways every year, resulting in hundreds of billions of dollars in economic costs. More than 90 percent of these crashes are due to human error. National Highway Traffic Safety Administration (NHTSA) analyses show that connected vehicle technology could potentially address approximately 80 percent of human-factor crashes involving unimpaired drivers, thereby preventing many thousands of deaths each year.[3] DOT respectfully asks that the FCC and the NTIA also take into consideration the DSRC-based innovations in which DOT, the U.S. and international auto industry, auto suppliers, and foreign governments have invested hundreds of millions of dollars over the past decade in anticipation of an international deployment of safety and other critical transportation applications.

As you know, DSRC was allocated for ITS services due to its key characteristics for mobile, active safety transportation applications. More specifically, these characteristics provide:

- Reliable, secure communications among quickly-moving vehicles;
- Fast communication speed for low latency;
- Invulnerability to extreme weather; and
- Tolerance of multi-path transmissions.

Over the past decade, the DOT ITS program has invested approximately $450 million in researching and developing the technology and applications that will fully leverage the DSRC spectrum. From 1999 – 2003, with the DSRC allocation set, DOT partnered with industry to develop the initial round of standards, while furthering our understanding of the functionality of collision warning systems and their impact on safety. From 2004 – 2009, DOT conducted the proof of concept testing on DSRC-dependent technology. Since 2010, DOT has updated the

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[2] *See* Report and Order, WT Docket No. 01-90, *Amendment of the Commission's Rules Regarding Dedicated Short-Range Communication Services in the 5.850-5.925 GHz Band*, & ET Docket No. 98-95, Memorandum Opinion and Order (July 20, 2006); Report and Order, WT Docket No. 01-90, ET Docket No. 98-95 (Dec. 17, 2003).
[3] *See* NHTSA Technical Report, *Frequency of Target Crashes for IntelliDrive Safety Systems*, DOT HS 811 381 (October 2010).

standards, enhanced the safety applications, moved to the second generation of technology, operated a DSRC-enabled testbed, and is now in the midst of the world's most comprehensive on-the-road test of the safety applications enabled by the DSRC technology, the Connected Vehicle Safety Pilot in Ann Arbor, Michigan. Data derived from this deployment of nearly 3,000 vehicles will provide critical support for NHTSA's decisions on the agency's next steps concerning V2V technology. NHTSA will decide in 2013 whether to begin rulemaking action to require the technology in all new light vehicles, conduct additional research, or to combine regulatory action and further research. In 2014, NHTSA will make such a decision concerning heavy vehicles. In making these decisions, NHTSA will assume that the 5.9 GHz spectrum will remain fully available, without any disruptive interference, to permit implementation of the technology's safety potential.

In addition to the eight global automotive manufacturers supporting this work, DOT has certified for operational use in the Safety Pilot five roadside equipment manufacturers and six onboard equipment manufacturers. Retrofit systems for truck and transit fleets have also been developed. DSRC investment by U.S.-based industries continues to grow significantly. The Department and the American Association of State Highway and Transportation Officials (AASHTO) are actively planning initial deployment of infrastructure to support V2I messaging. Initial implementation pilot programs could be underway as early as 2015.

In addition to the Connected Vehicle Safety Pilot, our European and Japanese colleagues and their auto industries are conducting similar demonstrations, expecting to move swiftly to broader deployment. Other nations and the European Commission (EC) have allocated the same or similar spectrum for DSRC, and have generally harmonized allocations to enable international ITS interoperability and to enable manufacturing across the interconnected worldwide auto market supply chain. DOT has worked closely with its EC and Japanese counterparts to develop internationally harmonized, interoperable Connected Vehicle standards, based on DSRC availability and its unique technical characteristics. This international harmonization around the 5.9 GHz band is a unique opportunity for the global community to coalesce around a standard prior to widespread development and deployment—a prospect that would significantly reduce overall costs for all participants through global economies of scale. DOT is significantly concerned by the prospect of failing to maintain this harmonization, as it would likely significantly delay, or even cancel, planned implementations at a moment when the global transportation community is poised to deploy Connected Vehicle safety, mobility and environmental solutions, and related infrastructure applications.

The FCC's Proposal

The Department remains critically interested in the deployment of ITS and views this technology as an important means of promoting safety, mobility, and other goals. The 5.9 GHz band at issue in this proceeding is crucial to ITS, and the Department asks that the FCC and the NTIA take steps to ensure that this portion of the spectrum remains adequately protected for ITS purposes. In particular, the Department respectfully asks that the FCC and the NTIA fully take into account the following concerns in the course of this proceeding.

First, in considering the extent to which new technologies or users will be permitted in the 5.9 GHz band, the FCC should ensure that this portion of the spectrum remains available on a co-primary basis for the purpose for which it was allocated in the Commission's 1999 decision, the Intelligent Transportation Systems radio service. In the Department's view, the FCC is correct in recognizing that it "must protect incumbent authorized services, both Federal and non-Federal." NPRM ¶ 38. In particular, the FCC and the NTIA should ensure that unlicensed devices, if permitted to operate in the 5.9 GHz band, "do not cause harmful interference" to the ITS architecture, operations or safety-critical applications. *Id.* ¶ 1. To do otherwise would be to undermine the Commission's stewardship in allocating this spectrum and to frustrate the ongoing regulatory and engineering development processes by which ITS technical standards, and other operating parameters, are established.

Recognizing that the detailed technical definition of "harmful interference" is a subject of the planned NTIA-led testing and assessment effort, DOT notes that, in order to provide a reliable and trusted public safety service, DSRC-enabled safety applications 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 safety information 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 safety applications for which the spectrum is allocated.

Second, the Department wishes to remain actively involved in the ongoing discussions and technical analyses relating to this proceeding. We appreciate being fully included in the NTIA's study efforts in the 5.850-5.925 GHz band required by the Act, efforts that include fully considering DOT comments to the NTIA's January 25, 2013 report, "Evaluation of the 5350-5470 MHz and 5850-5925 MHz Bands Pursuant to Section 6406(b) of the Middle Class Tax Relief and Job Creation Act of 2012." DOT appreciates the NTIA's collaborative efforts thus far, and looks forward to working closely with the NTIA on developing and implementing a work plan to assess all of the technical risks documented in the initial report. In support of addressing the technical questions surrounding the NPRM's impact on DSRC, DOT is submitting a Technical Appendix to provide the NTIA and the FCC with additional information about the technical issues raised in the NPRM, as well as the Department's approach on how these technical issues may be considered or resolved. DOT requests that the NTIA ensure there is sufficient time to complete the necessary technical assessments in the 5.9 GHz band while supporting the FCC's goals for the NPRM.

Finally, DOT has specific technical concerns about the NPRM's request to consider spectrum sharing with U-NII devices in the 5.9 GHz band. The NTIA has not completed its statutorily mandated study to evaluate spectrum sharing in the 5.9 GHz band. Consequently, it would appear untimely for the FCC to move forward prior to the conclusions of such an evaluation. DOT has not, to this point, encountered any proposed technical solution to maintaining the channel (or medium) access needed to guarantee interference-free operation of the critical safety applications if U-NII devices were granted access; nor have we seen an assessment of the technical risk to Connected Vehicle safety operations of potential interference from U-NII devices. We have set forth the suite of technical assumptions and interference characteristics that DOT believes need to be tested and verified (Technical Appendix). We ask that the NTIA continue to consider fully the information that DOT brings to this proceeding, just as we know that the FCC will consider data and test results provided by the private sector entities and others with a direct interest in safety, mobility, Connected Vehicle and the DSRC spectrum.

The Department looks forward to participating in the technical analyses relevant to this proceeding and stands ready to offer any assistance that it can to the NTIA or the FCC throughout the process. If I can provide further information or assistance, please feel free to call me.

Sincerely,

John D. Porcari

Enclosure

Technical Appendix:
DOT Comments to NTIA on FCC NPRM on U-NII Devices in the 5 GHz Band

1.0 Introduction

DOT respectfully submits this Technical Appendix to its letter to the NTIA regarding the FCC's NPRM on U-NII Devices in the 5 GHz Band. The purpose of this Technical Appendix is to provide the NTIA and the FCC with additional information about the technical issues raised in the NPRM, as well as the Department's views on how those technical issues should be considered.

2.0 General Discussion

2.1 Description of DSRC Applications With Emphasis on Safety

DSRC has been developing over the past decade and has reached the point where the large investment of both the Federal Government and private industry is achieving its goal – deployment of safety services for the traveling public. This is no small feat as the transportation community must assure a high degree of availability and reliability when deploying any sort of technology that the traveling public will use. Where public safety is concerned, we must be certain that changes "do no harm."

Safety is the Department's highest priority. DSRC should continue to be protected for the uses and goals for which it was allocated: reducing crashes, injuries, and fatalities. The FCC's proposals should not be implemented until and unless rigorous testing has shown that these critical safety goals will still be satisfied.

Safety is the primary objective of the Intelligent Transportation System's (ITS) use of DSRC, and there are other additional benefits that can be gained. Applications are generally divided between Safety, Mobility, and Environment. These application areas are further described in the following paragraphs.

2.1.1. *Safety*

Safety applications include intersection collision avoidance, collision warning, emergency signal preemption, and highway-rail intersection warning.

DSRC supports communications-based active safety applications, implemented as Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications. Safety applications save lives by warning drivers of an impending dangerous condition or event in time to take corrective or evasive actions. Examples of DSRC-supported safety applications include:

V2I Safety Applications	*Cooperative V2V Safety Applications*
Intersection Red Light Running	Intersection Movement Assist
Emergency Vehicle Prioritization	Forward Collision Warning
Approaching Emergency Responder Vehicle	Emergency Electronic Brake Lights
In-Vehicle Signage[1]	Blind Spot/Lane Change Warning
Pedestrian Signal Assist	Do Not Pass Warning
Rail Crossing Warning	Highway Merge Assist

DSRC channels support safety application transmissions at a specific periodicity and need highly reliable reception. This requires an instantly available communication link with very low latency. In 2011, there were 32,367 fatalities and approximately 2,200,000 injuries from an estimated 5,338,000 crashes resulting in billions of dollars in cost to society in the U.S.[2] Many of the applications that use DSRC could significantly reduce these numbers.

One compelling safety application is the Red Light Warning Violation application, which is designed to improve safety at signalized intersections by integrating vehicle-based and infrastructure-based DSRC equipment. By integrating Signal Phase and Timing (SPaT) information, the system can inform drivers of an impending red light in time to bring the vehicle safely to a stop. Furthermore, this application can warn drivers about other vehicles that are likely to violate traffic signals, thereby preventing a crash.

Another compelling safety application is the Intersection Movement Assist (IMA) collision warning application, which is designed to improve safety at both signalized and non-signalized intersections solely through the broadcast and receipt of a vehicle-based DSRC safety message. Through analysis of the data contained within Basic Safety Messages broadcast by nearby vehicles, the IMA application warns the driver when it is unsafe to enter an intersection due to a high likelihood of collision with other vehicles approaching the same intersection. This application has the potential to prevent crashes which are not currently addressable with non-cooperative vehicle-based safety technologies (e.g., radar, camera or laser-based).

2.1.2. *Mobility and Environmental Applications*

While safety is the driving factor behind the development of DSRC and applications that use it, both mobility and environmental improvement applications will use DSRC as an enabling technology to improve traffic flow and reduce environmental impact. DSRC has been specifically engineered to work well in situations where rapidly-moving devices need to communicate over short distances. Mobility and environment improvement applications often depend on communication from moving vehicles to devices close by the side of the roadways.

Mobility applications include electronic toll collection, fleet management, weather information, in-vehicle signage, and traffic information. Additional environmental applications can reduce fuel consumption and emissions, such as managing public transportation, optimizing intersection traffic, and collecting additional probe data.

[1] In-vehicle signage displays signs, such as speed limits, no passing, and exit signs, on the driver-vehicle-interface.
[2] NHTSA Traffic Safety Facts, Research Note, December 2012. http://www-nrd.nhtsa.dot.gov/Pubs/811701.pdf

To illustrate a mobility application, consider electronic screening (E-Screening). By applying two-way DSRC Wireless Access in Vehicular Environments (WAVE) radiocommunication technology, E-Screening systems enable commercial vehicle (large truck and bus) operators to transfer vehicle inspection information automatically as the vehicle passes an inspection point, and ensuring smooth, continuous flow of traffic – without the need to stop at the gates, or even to have gates. E-Screening systems can improve traffic flow on Interstate highways, and reduce fuel consumption and pollution. In addition, allowing heavy vehicle traffic to pass through without stopping can increase road capacity and relieve traffic congestion at high traffic times. It is also expected that E-Screening systems will reduce the operating costs of roads by replacing some aspects of manual inspections. Due to the inherent security protocols being considered for DSRC-based communications, motor carriers will be able to securely send data in support of motor carrier e-screening processes.

To illustrate an environment application, consider a vehicle approaching a signalized intersection with DSRC WAVE available to provide SPaT and Geometric Intersection Description (GID) data to a vehicle properly equipped with onboard computer processor and a display device to provide the driver with speed advice. The onboard computer received SPaT and GID messages from the intersection, interprets the received information along with current vehicle speed and location with an algorithm designed to improve environmental performance, and suggests a vehicle speed trajectory for both the approach and departure legs of the intersection.

2.2. International Harmonization

The Department places significant value in developing DSRC in harmony with the international community. This can benefit domestic users by creating larger markets for individual products as well as increasing the size of the creativity pool of new applications. By working with global standards organizations to harmonize DSRC standards, devices designed and manufactured in the United States can also be used in other international markets. This will enable greater economies of scale to decrease costs and improve safety for both domestic and international users, while creating a larger overall market for U.S. device makers.

These efforts have been particularly fruitful in North America. Starting in the 1990s, the ITS program has worked with Industry Canada to ensure cross border compatibility. Like the United States, Canada has also allocated the 5850-5925 MHz band to support DSRC applications and gives priority to fixed and mobile services over the fixed-satellite service.[3] There have also been discussions with Mexico about greater use of DSRC devices as the applications are deployed. Most recently, the focus has been on U.S.-Mexico border aspects with the intent to support not only routine operations such as electronic toll collection, but transportation safety, policy and operations as well.[4]

The international agreements and coordination to harmonize DSRC across North America have been significant and ongoing for many years. In Canada and Mexico, the DSRC band is already

[3] Industry Canada, Canadian Table of Frequency Allocations 9 kHz to 275 GHz (2009 Edition), http://www.ic.gc.ca/eic/site/smt-gst.nsf/vwapj/cane2009edition-eng.pdf/$FILE/cane2009edition-eng.pdf

[4] Rajbhandari, Rajat, PhD, PE, Juan Carlos Villa, Roberto Macias, and William Tate, Texas Transportation Institute, Transportation Research Board, January 2013, http://docs.trb.org/prp/13-2064.pdf

coordinated, with limited or no flexibility, as the system crosses international borders, due to rules and regulations that were in place prior to DSRC development. Adding an additional layer of sharing with Part 15 devices in the U.S. would introduce significant more uncertainty and negatively impact deployment scenarios.

DOT is working collaboratively with the European Commission on connected vehicle research. In particular, we are focused on the international harmonization of standards. Over the past year, we worked with the global automotive industry, the Society of Automotive Engineers, and the European Telecommunications Standards Institute to harmonize the core safety message operating on DSRC. DOT has also initiated harmonization activities with Japan and, more recently, the Republic of Korea. This harmonization will lead to more effective applications at reduced cost worldwide.

3.0 <u>Specific Questions Raised By The Commission</u>

3.1. Current rules – Harmonization across U-NII 1 and U-NII 2 bands

In NPRM ¶ 39, 40, and 41, the Commission seeks comment on whether to harmonize rules across the U-NII-1 and U-NII-2 bands and whether the rules for the U-NII-1 band should be modified to harmonize with rules in the U-NII-3 band. In ¶ 97, the Commission further asks if the technical requirements specified in Section 15.407 should apply across the expanded U-NII-3 and the U-NII-4 bands. Thus, it seems reasonable to address the question of harmonization raised in ¶ 39, 40, and 41 across all bands, including the new proposed U-NII-4 band. Section 15.407 addresses the following topics, among others: power limits, undesirable emission limits, indoor/outdoor restrictions, frequency stability, transmit power control, dynamic frequency selection and related topics.

DOT is working with the NTIA to analyze the current proposals for sharing. Once this analysis is complete, DOT, along with the NTIA and the FCC, will be better poised to assess how the proposed changes to existing rules and regulations for harmonization across such a large swath of spectrum will impact DSRC. There is insufficient information about how U-NII devices would detect DSRC devices, and how U-NII devices would yield access to the channels within the 5850-5925 MHz band. Therefore, we cannot accurately and reliably assess the impacts on sharing in the 5850-5925 MHz band at this time. As a result, we are concerned that taking steps toward a sharing scheme would jeopardize safety.

3.2. Interference

3.2.1. *Implications of NPRM Proposed U-NII-4 Expansion into the DSRC Band*

Figure 1 depicts the current DSRC channel plan in the 5850-5925 MHz band showing a 5 MHz guard band, the control channel (Channel 178), and the six service channels, overlaid with the NPRM proposed U-NII-4 channels based on elaborated IEEE 802.11ac (or other implementation) into this band. The proposed channels in the NPRM include 20 MHz, 40 MHz, 80 MHz, and 160 MHz bandwidths. These proposed channels step on all DSRC channels with the exception of channel 184.

Safety-critical applications on the DSRC channels require that the channels be instantly accessible. The NTIA risk assessment on sensing of DSRC signals (see Chapter 5 of the NTIA report[5]) plus the non-alignment of the two channels schemes suggest that DSRC safety-critical applications will not be able to coexist in exactly the same spectrum as U-NII-4 without modifications to the U-NII devices. As the existing standards require sensing on the center frequency, they will not detect DSRC activity. Additionally, if U-NII devices are listening before a mobile DSRC device enters its listening area and begins to transmit, they will not detect the DSRC device. Clearly, there are concerns over shared use of the same spectrum in the same geographic area. In areas where there is no geographic overlap, there may not be any issues, but that will be difficult to define, because listening alone will not be 100% effective.

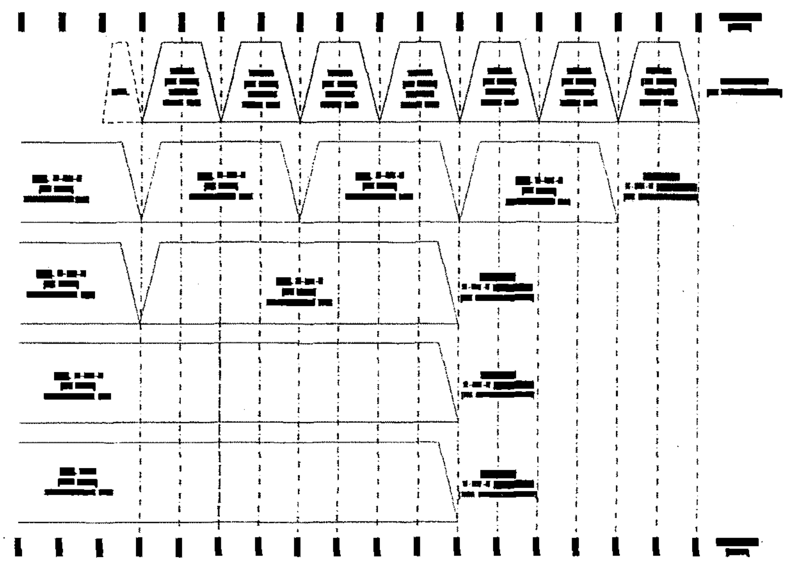

Figure 1 - Envisaged Overlay of Proposed U-NII channels on Current DSRC Channel Plan

3.2.2. ***Existing Interference and Potential Impact on a Safety Service***

As described previously, DSRC is a safety service and must have a very high level of assurance to ensure that the time and location information from both fixed and mobile devices reaches the intended destination. Failure to achieve these service levels will undermine the value of the safety service, and of drivers' confidence in warnings and other information received.

[5] Evaluation Of The 5350-5470 MHz and 5850-5925 MHz Bands Pursuant to Section 6406(b) Of The Middle Class Tax Relief and Job Creation Act of 2012

It is unclear at this point if the parameters and techniques used by U-NII devices identified thus far can ensure the level of communication reliability required to support DSRC as a safety service. As noted in various reports, even FCC-certified devices were found not to function properly – in one case failing to detect the Terminal Doppler Weather Radar (TDWR)[6] used by the Federal Aviation Administration. Furthermore, in some cases the U-NII device's firmware had been updated by the manufacturer and still could not detect the TDWR signal to avoid interfering with it.

In other cases, the U-NII device firmware may have been modified in the field. Clearly, devices that currently operate in other portions of the U-NII spectrum have been manufactured either without the appropriate safeguards or without sufficient firmware "guards." This makes it difficult to ensure that, once the device leaves the manufacturer, it cannot be modified to produce signals outside legal operating parameters.

3.2.2.1. Potential Impact from Easily Modified Equipment

As noted in Paragraph 49 of the NPRM, equipment is "designed so that end-users can modify them to operate in bands for which they are not certified and this does not meet the specific requirements intended to protect sensitive incumbent services." Given the safety critical aspect of DSRC, there must be clear assurance that harmful interference will not occur. The level of flexibility envisioned by the NPRM, as well as the sharing of the DSRC band, introduces significant risk to DSRC safety services. Rules must be developed to ensure this risk is mitigated.

3.2.2.2. Inadequacy of Indoor Only Restrictions

In paragraph 37, the FCC raises the issue of the use of indoor-only devices. The Commission is correct in its assessment that many devices are incorporating U-NII capabilities, and that these devices are increasingly portable or mobile in nature. Such devices include cellular phones and in-vehicle devices for sharing audio and video content. An examination of devices authorized for indoor-only use finds that any distinction between indoor and outdoor use has been lost on end users, given that consumers are not informed of this restriction until deep within the owner's manual. While this may meet the applicable rules and regulations, strengthening the warning to include a notice on the device itself may be appropriate.

It may be beneficial to integrate U-NII devices on vehicles to aid in applications as diverse as engine monitoring, warranty notices, and other non-time critical information to and from infrastructure. The beneficial aspects of U-NII devices must be balanced with the DSRC-based applications' requirement to provide time and location specific information to vehicles, their subsystems, and their operators to reduce crashes, save lives, and create a more robust transportation infrastructure.

3.2.3. *Similarities with Existing U-NII Operations*

The NPRM states that the "FCC believes that because the types of incumbent services across the 5 GHz spectrum share similar characteristics, the technical requirements for unlicensed devices could also share similar characteristics." NPRM ¶ 95. When addressing DSRC, DOT agrees that

[6] NTIA Technical Report TR-11-479, Executive Summary.

some characteristics may be similar to some unlicensed devices already in the lower portion of the 5 GHz spectrum, but there are also some fundamental differences. First and foremost, DSRC has been developed as a safety service to reduce fatalities and injuries in our nation's surface transportation network. For this to occur, implementers must be assured of a high level of availability. It is imperative that no interference will occur that disrupts this level of reliability in communication. Furthermore, a significant portion of this communication will take place between vehicles. Traveling late at night or on rural roads, there are few vehicles, and detecting DSRC transmissions becomes difficult.

Carrier Sense Multiple Access (CSMA), a recognized means of detecting an operating device, works by looking at the center of the sought-for channel. If the Wi-Fi device is looking there, it won't see DSRC because, by design, DSRC's channel centers are misaligned. In addition, a device searching for the center of an 80 MHz channel will miss most DSRC channels in the existing Channel Plan, whether or not the center is misaligned.

In NPRM ¶ 98, the Commission seeks comment on whether Dynamic Frequency Selection (DFS) might be effective. It may well work with radar systems. However, in order for DFS to work with DSRC, it must be able to sense a vehicle as the vehicle transits an area, starting out beyond the U-NII-4 unit's sensing range, transitioning into it, and then transitioning out of that range. If U-NII-4 units are arranged along a roadway, the DSRC unit may transition in and out of multiple U-NII pockets very quickly, making it exceedingly difficult for DFS to be effective. Technologies like DFS, unless they are implemented on an "always listen, never transmit if heard" basis will interfere with V2V operations as these vehicles constantly transition from outside the receivers' listening range to within it.

3.3. NTIA Report

The NTIA has begun the process of addressing the potential for sharing of the 5350-5470 and 5850-5925 MHz bands based on direction from Congress in the Middle Class Job Creation and Tax Relief Act of 2012. The first phase of this effort was to describe the risks associated with sharing with U-NII devices. As noted in the NTIA report,[7] current U-NII regulations were not developed to detect DSRC signals, and U-NII signal detection technologies may not be capable of detecting DSRC signals. Current U-NII regulations were not developed to protect non-co-located transmitters and receivers, and changes to U-NII detection parameters may not protect systems from serious degradation.

DOT is working with the NTIA to analyze the current proposals for sharing. Further analysis is needed to determine if there are appropriate mitigation techniques. Once this analysis is complete, DOT, along with the NTIA and the FCC, will be better poised to assess how the proposed changes to existing rules and regulations for harmonization across such a large swath of spectrum will impact DSRC. In all events, safety cannot be compromised.

[7] Evaluation Of The 5350-5470 and 5850-5925 MHZ Bands Pursuant To Section 6406(b) of the Middle Class Tax Relief and Job Creation Act of 2012, January, 2013.

3.4. Sensing Technologies

The FCC seeks comments on various technologies that could support spectrum sharing, including sensing based technologies, beaconing/pilot channel technologies, and geo-location based technologies. The first two technologies will be difficult to support with the mobile nature of the V2V applications for DSRC due to their transitive nature of entering and leaving U-NII zones. There may be some benefit for stationary V2I applications, but that may be limited by the mobile nature of the vehicle platform and its need to sense and respond to infrastructure-based services. For activities which are strictly infrastructure, a geo-location based service may work well, but there are concerns that identifying all stationary DSRC devices will be difficult, especially since some are likely to be used with work zones (they will be temporary in nature, perhaps for only a few hours in some cases) and the other aspect of providing a list of potential high value infrastructure services that are geo-coded.

4.0 Summary

DSRC should continue to be protected for the uses and goals for which it was allocated: reducing crashes, injuries, and fatalities. The FCC's proposals should not be implemented until and unless rigorous testing has shown that these critical safety goals will still be satisfied.

The Commission has raised some good points and asked questions that focus on the immediate issues of sharing and competing services being able to maintain an operational effectiveness. At this time, it is unclear if such sharing can take place. We are confident that the Commission will take the time to allow the NTIA and others to look cooperatively at this issue and present sound facts and technical analysis that will lead both to greater spectrum flexibility, and to saving lives.

Responses by Mr. John Maddox

Questions for the Record

Responses to questions submitted by Rep. Larry Bucshon, Chairman, Subcommittee on Research and Technology:

1. USDOT is in the best position to answer this question.

2. The UTC Program supports university-based transportation research, education and technology transfer programs that enhance the body of knowledge, provide new technologies and processes for transportation stakeholders, and enable universities to recruit, educate, and train leaders, engineers, planners and technicians who will comprise the transportation workforce of tomorrow. The program is extremely beneficial to USDOT, universities, and the transportation industry as a whole.

There are many positive things about the way the program is administered.

- OST-R staff who guide and support the program are well-informed, dedicated and passionate about the UTC Program. They can be relied upon to provide requested information and guidance to grantees and are exemplary professionals in every sense of the word.
- The transparency provision in MAP-21 was useful for universities participating in the competition. The information required by the transparency provision gave successful and unsuccessful competitors invaluable feedback on their proposals.
- The decision deadline imposed by MAP-21 was useful in that it ensured the competition would be completed within a given timeframe, which was very helpful for planning purposes. For example, many universities had personnel to support in anticipation of the award of the grant, and were able to determine the maximum amount of time they would have to "float" personnel due to the legislated deadline.
- The current tier structure provides a means for participation for both large and small programs, with both specialized and broad expertise. Also, geographical distribution is guaranteed by the presence of the regional tier.
- The current structure of the UTC program allows universities competing to choose to be a part of a consortium or not. While it is recognized that many times the strongest team in a particular theme might require more than one university, in some cases the required level of expertise exists in one institution.
- The competitive aspect of the UTC program aids in ensuring that the very best programs are participating in the program in every tier. TTI fully supports free and open competition.
- The UTC program should continue to be supported as a core transportation program by the Highway Trust Fund. The innovation required to manage and improve our transportation infrastructure happens through research, and only through research will better ways to design, construct and maintain infrastructure be developed.

However, there are several ways the UTC program could be improved. It should be noted that some of the bullet points noted below would not necessarily be detrimental on their own, but combined with others have the unintentional consequence of adversely impacting free and open competition.

- The requirement to choose one focus area should be eliminated. Under the current UTC structure, each center must specifically select one of USDOT's five strategic goals: Economic Competitiveness, Environmental Sustainability, Livable Communities, Safety, and State of Good Repair. As a result, universities -- and consortia of universities -- are required for all tiers to compete for a center specifically focused on one of these strategic goals – even in the regional centers tier, where meeting the needs of the region should encompass all focus areas. As a result, universities and consortia with multiple areas of expertise, education and training capabilities were required to pigeonhole their activities into one specific focus area. This unintentionally limits competition. For example, in the national center tier, only nine universities competed for the five designated centers. However, it would be reasonable to require all centers competing in all tiers to discuss in their proposals how their chosen theme supports the priorities of USDOT.

- Competitions should be conducted sequentially. In an effort to increase the quality of competition for each UTC tier, USDOT should stagger the solicitation of proposals for each tier, similar to how the competition was conducted in 2002 and 2006. The competition for the larger centers should be conducted first. This would increase the quality of the competition by ensuring that the most highly qualified universities and consortia will be competing for each tier (instead of choosing a higher tier where they may or may not be successful).

- Restrictions placed on universities' participation based on lead and/or consortium member status should be removed. The restriction that universities who are lead in the National or Regional Tier cannot participate as a consortium member in the National or Regional Tier and also can't lead a Tier 1 UTC adversely affected the quality of the competition. Because of the requirement to choose one focus area, and the lead restrictions, large programs with multiple areas of expertise were forced to choose just one consortium to lead or participate in the two largest tiers, limiting both their options and those of other institutions that may wish to partner with them. For example, TTI has expertise in all five of DOT's focus areas, but because of the requirement to choose one area, and due to its status as a lead regional UTC, TTI could not contribute in any way to any consortia seeking a National UTC. Neither could TTI contribute in another focus area as lead of a Tier 1 UTC. In order for the nation to benefit fully from the expertise of all universities in the competition, and to enhance free and open competition, the restrictions placed on lead institutions in the top two tiers should be eliminated.

3. The cybersecurity of modern vehicles is a serious concern, whether they are connected or not. While I am not aware of any real-world instances of hacking a vehicle to take remote or malicious control, there have been academic and research demonstrations that show it is technically possible. And even though it took a significant technical effort to demonstrate that ability, it is expected that the technical hurdle will decrease over time as more hackers develop and share methods, unless countermeasures are put into place to prevent such attacks.

In contrast, there have already been real-world cyber attacks on transportation infrastructure systems, including variable message signs and traffic signals and others. It is expected that hacks on many transportation infrastructure systems, including traffic signal control systems, information systems, remotely controlled managed lane systems including highways, bridges, and tunnels, etc, will represent an increasing concern. Cybersecurity of these systems and other infrastructure assets must also be addressed along with vehicles themselves.

It is expected that hacking of vehicles will include both malicious control attempts, as well as attempts at accessing or manipulating data resident in the vehicle. Adding additional connections to vehicles, including satellite, cellular, wi-fi, and DSRC, does increase the number of "attack surfaces" that hackers might exploit, and therefore must be considered. The same is true for infrastructure devices as well as operating and data systems that support transportation.

There is a strong and immediate need for adequately-funded basic research on cybersecurity for transportation, including a thorough examination and risk quantification of existing and potential threats, intrusion testing of systems in laboratories, establishment of appropriate reporting mechanisms, and exploration of potential countermeasures including firewalls and secure operating systems. This includes vehicles, infrastructure, and data systems.

4. The automobile industry and USDOT (including OSTR, NHTSA, and FHWA) are working together to define standards for interoperability of connected vehicles, followed by standards for infrastructure, security systems, and data. The Society of Automotive Engineers (SAE International) has published standards for the "Basic Safety Message" which will form the backbone of the V2V system, and may possibly be referenced in NHTSA FMVSS requirements. These standards were developed in close cooperation of the parties above, along with the Crash Avoidance Metrics Partnership (CAMP), which largely has been funded by the USDOT. These standards have been designed from the very beginning to be secure and anonymous.

Currently, CAMP is finalizing the design of a fully-functional Security Credential Management System (SCMS) through funding from USDOT and in collaboration with academia. It is anticipated that this system will fully support the technical standards and will maintain the core principles of anonymity and security. Further research and testing will be required to demonstrate that system's practicability in the real world at significant scale. This must be a continuation of the collaborative effort between government, industry, and academia.

However this is just the beginning. Similar standards need to be established and finalized for the Infrastructure, including V2I (vehicle-to-infrastructure), I2V (infrastructure-to-vehicle), and I2I (infrastructure-to-infrastructure). These are currently lagging the V2V standards, but must be put in place in the very near future. As with the V2V standards, this must be a collaborative effort between government, industry, and academia.

The establishment of these standards would be greatly aided by the formation of an industry consortium for manufacturers and users of infrastructure. This consortium could play an important role, similar to the role CAMP played for V2V.

Lastly, but very importantly, USDOT should focus future resources on development of communication standards for vulnerable road users, including P2V (pedestrian-to-vehicle), M2V (motorcycle-to-vehicle), and B2V (bicycle-to-vehicle) to make drivers aware of the presence of these other users.

5. Standards for connected vehicles and infrastructure are addressed above in Question 4.

It is too early to begin development of standards for automated vehicles (AVs), other than perhaps to establish minimalistic basic requirements for testing on public roads. The SAE Int'l has already begun work in this area, and working with NHTSA and state agencies, they should be allowed to continue work on basic testing requirements.

USDOT should fund significant research efforts, both basic and applied, in collaboration with industry and academia. Key questions include: concept of operations, communications for automated vehicles, approaches for verifying safety, cybersecurity, and the role of simulation in prove-out and certification.

Equally important to the technical research will be policy research, including liability, licensing, insurance, data ownership, privacy and others. Additionally, since infrastructure-planning horizons stretch into 25-year timeframes, basic research should also be conducted on planning the built environment, including supporting data systems.

6. There are significant concerns about the potential effects of congestion on the 5.9GHz spectrum. 5.9GHz Dedicated Short Range Communication (DSRC) is the only proven technology that can reliably communicate between vehicles within the millisecond timescale that is required in a broad range of critical crash-imminent scenarios. Since V2V relies on this spectrum, any other broadcasts or messages other than safety related messages have the clear potential to degrade the efficacy of V2V safety benefits for connected vehicles.

There are discussions regarding the potential sharing of this spectrum for non-safety and even non-transportation use. There has not been a clear indication as to other uses for the spectrum, and therefore it is unclear whether innovation would occur and to what end. Additionally, as of yet, a potential technical sharing approach has not been established.

We must fully investigate, research, and understand the feasibility of any potential sharing regime, and ensure that this does not degrade or inhibit V2V's ability to provide the safety benefit for road users, including testing at scale. If there is potential for degradation, then we must establish and prove effective countermeasures to ensure that broadcast communications get through to the vehicles that need to receive them. And we must ensure that any spectrum-sharing regime does not preclude other critical safety or mobility applications, such as V2I, V2P, V2M, and V2B.

Responses to questions submitted by Rep. Daniel Lipinski, Ranking Member, Subcommittee on Research and Technology:

1. Long-term vs. short-term research:

Support is needed for both basic and applied research, and both long-term and short-term research. One of the advantages of the UTC program is that a grant is typically of the duration of the current authorization legislation, which historically has been from 2-6 years. This provides a structure that supports all necessary basic and applied research, especially for authorization bills of longer duration. For example, for long-term and/or basic research, a multi-year UTC grant provides the ability to conduct research from concept to implementation, with funding for a project awarded from year to year as the research matures. However, transportation stakeholders also benefit from short-term, applied research to meet current, sometimes urgent needs. The UTC program provides a structure to support both.

Match:

TTI historically has benefited from strong match support. The state of Texas provides TTI with $1 million as a line item in the state budget, which is provided specifically to match national federally-funded centers that require a match. This funding provides TTI with the flexibility to conduct research in emerging or new transportation topics that might be difficult to match otherwise. Additional match has been provided by the Texas Department of Transportation (TxDOT). TTI also has several state-sponsored centers whose activities complement its national centers and whose funding can be leveraged as match. This diversity of match funding ensures that TTI can respond to the changing needs and priorities of transportation stakeholders in a timely and effective manner.

Balance:

There is great diversity within the UTC program in terms of size, capabilities and expertise. This diversity provides the means to address both long-term and short-term research within the program overall, although not necessarily within an individual UTC. A UTC's chosen theme (or more recently, focus area) will dictate a certain balance as well depending on the demands of their program. Building on that, Congress could provide a framework supportive of long term basic research within the UTC program by passing a long-term transportation bill and funding transportation research programs (including the UTCs) under the Highway Trust Fund. Using the HTF as a research funding mechanism provides a consistent, dependable source of funding free of the distractions and inherent risk of a yearly appropriations process.

2. As of yet, a clear deployment strategy for V2I has not emerged in the US. Contrarily, the European Commission and some Asian countries have established and begun to implement an infrastructure deployment strategy. These strategies are based on results of research and Field Operational Tests (FOTs) that have quantified the cost and benefit of critical V2I applications, similar to what Safety Pilot Model Deployment in Ann Arbor, MI has done for V2V safety applications.

The US needs a V2I deployment strategy that clearly supports and funds the voluntary installation of key applications by state and local governments, and is directly supported by research and FOTs that quantitatively demonstrate the installation, operation, and maintenance costs, and the resulting benefit to mobility, energy, and safety. These results will allow state and local governments to make informed decisions to invest resources into deploying applications that are beneficial to their individual transportation needs.

As we have learned in Ann Arbor and with other FOTs, there are significant challenges to conducting effective FOTs, especially at a meaningful scale. Firstly, since connected transportation systems rely on interactions, it is very important to have a "critical mass" of vehicles and infrastructure nodes to ensure a sufficient quantity of interactions to form a statistically valid sample. Secondly, FOTs must be designed to address real-world problems in the geographic area in which they are established, so that real-world cost and benefit can be meaningfully assessed. Additionally, the technology must be established at an adequate base level of maturity so that real systems, applications, and devices can be obtained. Lastly, since these systems rely on participation from many organizations from industry and government, an effective team approach must be established that includes participation from groups of industrial, governmental, and academic partners. But we have met these challenges and have implemented successful FOTs, and have every expectation that we can achieve success for V2I FOTs to support a national V2I deployment strategy.

USDOT has signaled that it intends to sponsor such V2I FOTs in the FY2015 – FY 2018 timeframe, focused on mobility, energy, and safety. This is a critical step towards deployment of V2I, and this research effort should be fully funded. It is anticipated that these FOTs can also form the backbone of regional initial deployments. Additionally, research should continue on developing and defining V2I applications for transportation operations, including passenger and freight mobility, smart parking, data acquisition and manipulation, and other areas.

Responses by Ms. Kristen Tabar

Kristen Tabar
Vice President, Technical Administration Planning Office
Toyota Technical Center
"The Future of Surface Transportation"
Questions for the Record

Rep. Larry Bucshon

1. I am concerned that a nefarious entity could remotely hijack a connected vehicle; is this scenario a serious concern? How easily can vehicle data be hacked or manipulated for malicious purposes? What specific cybersecurity safeguards need to be in place to prevent this type of intrusion?

Just as with any wireless communication technology, the possibility exists that a connected vehicle or the data that it generates and uses can be hacked or manipulated for malicious purposes. The auto industry recognizes this risk and, since the inception of the connected vehicle research program, has been working diligently to reduce that possibility and maximize the security of the technology. For example, automakers have engaged security experts - both from academia and industry - to scrutinize developing methodologies and provide confidence that the solutions being developed are secure.

At the most fundamental level, the system is being designed so that only those devices that are certified to conform to the security standards will be authorized to gain access to the network and only legitimate messages sent by authorized users will be processed by vehicles. As a result, one would need to have access to secure keys that are protected using various layers of secure storage and transmission to generate an over-the-air message that could be accepted for processing by a connected vehicle.

As noted in my testimony, this system will require a formal security infrastructure to issue certificates and perhaps revoke certificates if someone is using legitimate credentials to send false or misleading messages. Discussions are currently underway between the various automakers and the U.S. Department of Transportation on the best way to structure and fund this security infrastructure, including whether it should be a public-private partnership or whether it should be run exclusively by the private sector.

The auto industry recognizes that additional steps need to be taken to further minimize the risk that the connected vehicle network will be hacked. For example, in order to address the potential for someone to use a connected vehicle wireless communication access point to infiltrate the vehicle's electronic control units and "take over" the vehicle, individual automakers are implementing increasingly robust software and security design practices. In addition, in order to reduce the chance that falsified data transmitted to a vehicle may be mistakenly accepted, some level of sensor redundancy may be appropriate. For example, in some cases, a vehicle system may be designed to "distrust" vehicle-to-vehicle data if the data is not validated in some way by data available through other vehicle sensors.

Finally, the possibility that data transmitted from a vehicle will compromise the sender's privacy can be reduced by preserving and protecting the anonymity of the data. The connected vehicle system is being designed so that no personally identifiable, or even potentially identifiable, information is transmitted with the messages. For example, as noted in my testimony, in order to reduce the possibility that a security certificate could be used to track a specific vehicle over time, the industry has designed the system so that multiple security certificates will be used by a vehicle over the course of a single trip. The industry has also made a decision to break the envisioned security organization into several components (registration authority, linkage authority, certificate authority, etc.) to help reduce the chance that even an internal bad actor would be able to identify a specific vehicle over time.

2. What standards are being developed for security and privacy of connected-vehicle data? How will this be addressed in the future and how will you know that they will be adequate?

The main security standard for Dedicated Short-Range Communication (DSRC) is called IEEE 1609.2 Security Services. It was published in 2013, and the industry is working on a revision that will likely be published in the next couple of years. This standard defines the cryptography and data formats that enable safety messages to be authenticated. It also provides for "pseudonymous" communication that allows a sender to avoid identifying itself. Frequent changes in the pseudonymous identifiers not only protect the privacy of a single message, but also prevent easy tracking of a sender across a set of messages sent minutes, hours, or days apart. In other words, one cannot easily determine that a given message came from a given car, or that a given pair of messages came from the same car.

In addition to the IEEE 1609.2 standard, the industry is developing the J2945.1 Minimum Performance Requirements standard for sending Basic Safety Messages through SAE. This standard will include important security components, such as specifying how to change identifiers to protect privacy.

I've enclosed a paper drafted by John Kenney, one of my colleagues from the Toyota InfoTechnology Center in Mountain View, California, on the content and status of the DSRC standards being developed for deployment in the United States that further explains these and other relevant standards.

3. Who will develop the technical standards for connected vehicle technologies such as vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and autonomous vehicles? How will these standards be decided and enforced?

As it relates to vehicle-to-vehicle and vehicle-to-infrastructure communication, most of the technical standards are being developed through various private standards development organizations, including IEEE and SAE. Some of these technical standards may be incorporated or modified for vehicle-to-vehicle and vehicle-to-infrastructure communication in future rulemakings by the National Highway Traffic Safety Administration (NHTSA) and the Federal Highway Administration (FHWA), respectively.

Some activity is underway with respect to technical standards for autonomous vehicle technology, but these activities are less advanced than those for DSRC. The SAE is currently working on the development of word definition standards, and the industry collaborative Crash Avoidance Metrics Partnership (CAMP) is working with NHTSA on automation level definition and test procedures.

4. In your written testimony you write: "We also need to be cautious about taking actions, including opening up the spectrum allocated to vehicle-to-vehicle and vehicle-to-infrastructure communication to other unrelated uses, that may introduce new security and privacy challenges." What are these new and potential challenges, and why is caution warranted? Please explain.

Currently, 75 MHz of spectrum have been allocated by the Federal Communications Commission (FCC) specifically for vehicle-to-vehicle and vehicle-to-infrastructure communication. These 75 MHz have been divided into seven channels. While three of these channels have specific designations from the FCC, the industry intends to use the remaining channels to support other intelligent transportation applications and functions. One such identified function is communication in support of security and privacy control. Examples of such communication include: a request by a vehicle to the communication infrastructure for new security certificates, and the delivery of certificates in reply; a report by a vehicle to the communication infrastructure of the detection of a misbehaving node on the network; and dissemination of lists of revoked credentials to vehicles via infrastructure-to-vehicle and vehicle-to-vehicle communication. A sharing scenario that would reduce the number of channels available exclusively for DSRC may very well compromise the industry's ability to dedicate some of the spectrum specifically for DSRC security and privacy controls.

In addition, sharing the spectrum with unlicensed devices has the potential to cause harmful interference which results in delayed or dropped communication. If this occurs with respect to security and privacy control communication, it may impact the ability to implement and exercise necessary controls in real-time. For example, it may not be possible to meet the challenge of delivering a batch of new certificates during the short interval when a vehicle is in range of a given roadside infrastructure device if some of the channel capacity is used by unlicensed devices.

In addition, if a hacker gains access to secret keys, allowing it to send authenticated messages with false data, it is important that those keys be revoked in a timely manner. The communication needed to report the misbehaving node and to revoke the credentials might be significantly delayed if a vehicle is not able to successfully engage with a roadside infrastructure device due to interference from unlicensed traffic.

Finally, in order to manage congestion on DSRC channels, DSRC devices will be programmed to react to channel congestion by reducing transmissions. This approach will be ineffective in the face of uncontrolled transmissions from unlicensed devices. In fact, DSRC back-off might encourage even more unlicensed traffic, having the effect of a denial of service attack on the DSRC network

INVITED PAPER

Dedicated Short-Range Communications (DSRC) Standards in the United States

IEEE and SAE Standards for Wireless Access in Vehicular Environments (WAVE), most of which have been published in the past 12 months, are described in detail in this paper.

By JOHN B. KENNEY, *Member IEEE*

ABSTRACT | Wireless vehicular communication has the potential to enable a host of new applications, the most important of which are a class of safety applications that can prevent collisions and save thousands of lives. The automotive industry is working to develop the dedicated short-range communication (DSRC) technology, for use in vehicle-to-vehicle and vehicle-to-roadside communication. The effectiveness of this technology is highly dependent on cooperative standards for interoperability. This paper explains the content and status of the DSRC standards being developed for deployment in the United States. Included in the discussion are the IEEE 802.11p amendment for wireless access in vehicular environments (WAVE), the IEEE 1609.2, 1609.3, and 1609.4 standards for Security, Network Services and Multi-Channel Operation, the SAE J2735 Message Set Dictionary, and the emerging SAE J2945.1 Communication Minimum Performance Requirements standard. The paper shows how these standards fit together to provide a comprehensive solution for DSRC. Most of the key standards are either recently published or expected to be completed in the coming year. A reader will gain a thorough understanding of DSRC technology for vehicular communication, including insights into why specific technical solutions are being adopted, and key challenges remaining for successful DSRC deployment. The U.S. Department of Transportation is planning to decide in 2013 whether to require DSRC equipment in new vehicles.

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KEYWORDS | Dedicated short-range communication (DSRC); networks; safety; standards; vehicles; WAVE; 5.9 GHz

I. INTRODUCTION

Vehicles utilize a variety of wireless technologies to communicate with other devices. This paper focuses on one specific technology, dedicated short-range communication (DSRC) [1], which is designed to support a variety of applications based on vehicular communication. DSRC is under active development in the United States and in other countries. The goal of the paper is to explain the content and status of the major standards that support interoperable DSRC in the United States [2]–[7].

The primary motivation for deploying DSRC is to enable collision prevention applications. These applications depend on frequent data exchanges among vehicles, and between vehicles and roadside infrastructure. The U.S. Department of Transportation (DOT) has estimated that vehicle-to-vehicle (V2V) communication based on DSRC can address up to 82% of all crashes in the United States involving unimpaired drivers, potentially saving thousands of lives and billions of dollars. The National Highway Traffic Safety Administration (NHTSA) within the U.S. DOT plans to decide in 2013 whether to use regulations to require or encourage deployment of DSRC equipment in new vehicles in the U.S. [8].

The basic paradigm of DSRC-based collision avoidance is illustrated in Fig. 1. Each DSRC-equipped vehicle broadcasts its basic state information, including location, speed, and acceleration, several times per second over a range of a few hundred meters. Each vehicle also receives these "safety messages" from DSRC-equipped neighbors. A receiving vehicle uses these messages to compute the

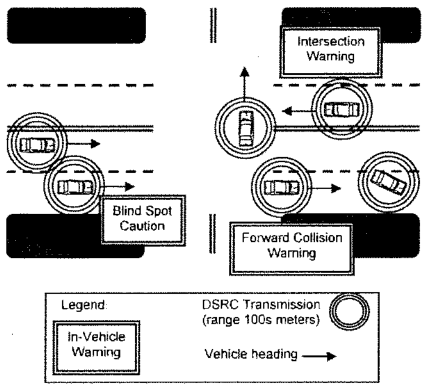


Fig. 1. *Vehicles sending safety messages, displaying in-vehicle warnings.*

trajectory of each neighbor, compares these with its own predicted path, and determines if any of the neighbors poses a collision threat. In addition to V2V communication, vehicles may also communicate to and from DSRC roadside units (RSUs) using safety messages and other types of message. Examples of information a vehicle may learn from an RSU include: the geometry of an approaching intersection, the state of the signals at an intersection, and the existence of a hazard (e.g., disabled vehicle, emergency vehicle, ice, fog).

If a vehicle determines that a potential collision or other hazard (e.g., violating a red light) exists, the onboard system can take action to warn the driver, or even to assist in controlling the vehicle. Feedback to a driver can be conveyed audibly, visually (e.g., heads-up-display, dashboard screen, mirror signal), and haptically (e.g., shaking seat or steering wheel), and can range in intensity from inform to caution to warning. While the communication between DSRC devices must follow carefully designed interoperability standards, the internal threat computation and warning system employed by a vehicle is determined by the automobile manufacturer.

The U.S. Department of Transportation and several automakers in the United States have teamed up to study DSRC-based collision avoidance. The Vehicle Safety Communications—Applications project, completed in 2009, demonstrated the feasibility of several V2V safety applications [9], including:

- forward collision warning (stopped vehicle ahead);
- emergency electronic brake lights (hard-braking vehicle ahead);
- blind spot warning;
- intersection movement assist;
- do not pass warning;
- control loss warning;

A few of these are illustrated in Fig. 1.

DSRC can be used for many other applications beyond collision avoidance. Most of these involve communication to and from RSUs. For example, DSRC can be used to assist navigation, make electronic payments (e.g., tolls, parking, fuel), improve fuel efficiency, gather traffic probes, and disseminate traffic updates. It can also be used for more general entertainment and commercial purposes.

The word "Dedicated" in DSRC refers to the fact that the U.S. Federal Communications Commission has allocated 75 MHz of licensed spectrum in the 5.9 GHz band for DSRC communication [10], [11]. This spectrum is divided into several channels. V2V safety messages are expected to be exchanged on Channel 172, a specific channel designated for safety [12]. The term "Short Range" in DSRC is meant to convey that the communication takes place over hundreds of meters, a shorter distance than cellular and WiMax services typically support.

II. OVERVIEW OF DSRC STANDARDS

DSRC communication relies fundamentally on standards-based interoperability among devices from different manufacturers. This paper provides a description of the core DSRC standards under development for use in the United States. Most of these standards are either recently published or in the final stages of specification. The U.S. DOT and a consortium of automotive manufacturers (Vehicle Safety Communications 3—VSC3) have begun a project to test the interoperability and scalability of DSRC technology [13]. The first phase of this V2V-Interoperability project focuses on whether the emerging standards are clear and comprehensive enough so that independent implementations will be able to communicate. Testing to date has shown that DSRC equipment from four suppliers can communicate effectively, with no significant gaps in the standards identified [14].

This overview provides a brief description of the DSRC protocol stack. The sections that follow examine the major standards for each of the layers in turn: Physical (PHY), Data Link (including medium access control—MAC), Network/Transport, and Application. A few of the abbreviations used frequently in this paper are defined in Table 1.

Fig. 2 illustrates the protocol stack for DSRC communication, including shorthand names of protocols and standards intended for use at the various layers. At the PHY and MAC layers DSRC utilizes IEEE 802.11p Wireless Access for Vehicular Environments (WAVE), a modified version of the familiar IEEE 802.11 (WiFi) standard. In the middle of the stack DSRC employs a suite of standards defined by the IEEE 1609 Working Group: 1609.4 for Channel Switching, 1609.3 for Network Services (including the WAVE Short Message Protocol—WSMP), and

Table 1 Frequently Used Abbreviations

Abbreviation	Definition
AP	Access Point
BSS	Basic Service Set
CCH	Control Channel
DSRC	Dedicated Short Range Communication
GPS	Global Positioning System
MAC	Medium Access Control
OCB	Outside the Context of a BSS
PLCP	Physical Layer Convergence Procedure
QoS	Quality of Service
RSU	Roadside Unit
STA	Station
V2V	Vehicle to Vehicle
WAVE	Wireless Access in Vehicular Environments
WSA	WAVE Service Advertisement
WSM	WAVE Short Message
WSMP	WSM Protocol

1609.2 for Security Services. DSRC also supports use of well-known Internet protocols for the Network and Transport layers, i.e., Internet Protocol version 6 (IPv6), User Datagram Protocol (UDP) and Transmission Control Protocol (TCP). These protocols, defined by the Internet Engineering Task Force (IETF), are stable and well documented in other places, so they are not further discussed in this paper. The choice between using WSMP or IPv6+UDP/TCP depends on the requirements of a given application. Single-hop messages, like those upon which collision prevention applications are based, typically use the bandwidth-efficient WSMP, while multi-hop packets use IPv6 for its routing capability.

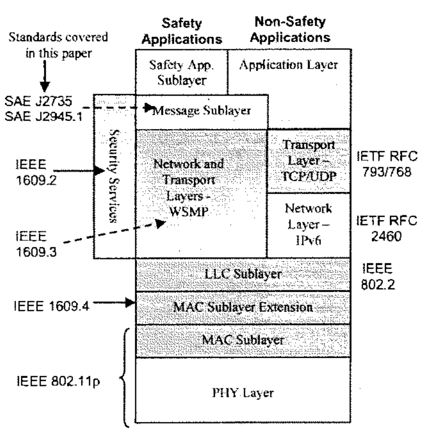


Fig. 2. ***Layered architecture for DSRC communication in the US.***

At the top of the stack, the SAE J2735 Message Set Dictionary standard specifies a set of message formats that support a variety of vehicle-based applications. The most important of these is the basic safety message (BSM), which conveys critical vehicle state information in support of V2V safety applications. Vehicles exchanging frequent BSMs can track each other's position and movement, and take action to prevent potential collisions. SAE J2735 defines message syntax, but leaves other norms for V2V safety to be specified in the emerging SAE J2945.1 communication minimum performance requirements standard. Among the topics to be addressed in SAE J2945.1 are BSM transmission rate and power, accuracy of BSM data elements, and channel congestion control.

Some of the material in this paper draws on the standards discussion in [15, ch. 10], with significant new content reflecting the evolving standards. A reader seeking additional details is encouraged to consult that reference.

Geographic Scope: The IEEE and SAE standards described in this paper have international scope, but have been developed in close coordination with U.S. automotive and governmental strategic plans. Efforts to develop standards for collision avoidance based on vehicular communication are also underway in regional standards organizations in other parts of the world, most notably the European Telecommunications Standards Institute (ETSI), the European Committee for Standardization (CEN), and the Japanese Association of Radio Industries and Businesses (ARIB). Harmonization efforts among government and standards organizations have also begun, particularly between the U.S. and Europe. It remains to be seen how the standards described here will be used outside of the United States. It appears that the protocols at the bottom of the stack, especially IEEE 802.11p, are most likely to be used elsewhere, with a decreasing probability for protocols higher in the stack. Note also that in some regions the term DSRC is either not used or carries a narrower, nonsafety connotation.

III. DSRC PHYSICAL LAYER STANDARD

The next several sections examine the various layers of the DSRC protocol stack (Fig. 2) in detail, working from bottom to top, and starting with the Physical layer. The DSRC PHY protocol is defined in IEEE 802.11 [16] (specifically clause 17), as amended by IEEE 802.11p [2]. It is divided into two sublayers: the *physical medium dependent (PMD)* sublayer and the *physical layer convergence procedure (PLCP)* sublayer. As the name suggests, the PMD interfaces directly with the wireless medium. It utilizes the familiar orthogonal frequency division multiplexing (OFDM) technique, originally added to 802.11 in the 802.11a amendment. The PLCP defines the mapping between the MAC frame and the basic PHY layer data unit, the OFDM symbol.

In 2003 an earlier version of the DSRC PHY was published under the auspices of ASTM International in the

ASTM E2213-03 [17] standard, which was also based on IEEE 802.11. In 2004 interested parties obtained approval to create the IEEE 802.11p WAVE amendment for DSRC within the IEEE 802.11 Working Group (WG). The amendment was publisbed in 2010. The deviations from the main 802.11 standard were minimized to encourage 802.11 silicon vendors to add support for 802.11p, which would help keep costs down by leveraging the large volume of 802.11 chips produced annually. There are orders of magnitude more WiFi equipped cell phones sold every year than new vehicles. The automotive industry considers the PHY and MAC portions of ASTM E2213-03 to be deprecated in favor of IEEE 802.11 and 802.11p. The United States Federal Communication Commission (FCC) regulations for DSRC [18], [19], however, still incorporate by reference rules contained in ASTM E2213-03. It is anticipated that the FCC regulations will eventually be updated to instead require conformance to IEEE 802.11 and 802.11p.

The IEEE 802.11 WG periodically integrates its amendments into a new baseline standard. As this paper is written, the WG is undertaking this integration for all amendments completed since the prior integration effort in 2007. The integrated standard will be referred to as 802.11-2012 if it is published as planned in 2012. At that point the 802.11p amendment will no longer exist as a separate document, but the features it added to the baseline standard will informally still be referred to as 802.11p (as we still refer to 802.11a, b, and g, for example). It is also possible that in the integration process minor modifications will be made to the WAVE capabilities described in this paper.

The concept and theoretical basis of OFDM are well documented in other sources [15], so the present discussion focuses on the specific OFDM protocol defined in 802.11, including the modifications in the WAVE 802.11p amendment.

A. OFDM Physical Medium Dependent (PMD) Function

The OFDM protocol used in 802.11 is defined for three channel widths: 20, 10, and 5 MHz. While most 802.11a implementations use the 20 MHz channel, DSRC will more commonly use the 10 MHz channel. The basic parameters of the 802.11 10 MHz OFDM channel are shown in Table 2.

Table 2 IEEE 802.11 10 MHz OFDM Channel Basic Parameters

Parameter	Value
Number of data subcarriers	48
Number of pilot subcarriers	4
Total number of subcarriers	52
Subcarrier frequency spacing	156.25 KHz
Guard interval (GI)	1.6 μsec
Symbol interval (including GI)	8 μsec

Table 3 Data Rate Options in a DSRC 10 MHz OFDM Channel

Modulation Technique	Coded Bit Rate (Mbps)	Coding Rate	Data Rate (Mbps)	Data Bits per OFDM Symbol
BPSK	6	1/2	3	24
BPSK	6	3/4	4.5	36
QPSK	12	1/2	6	48
QPSK	12	3/4	9	72
16-QAM	24	1/2	12	96
16-QAM	24	3/4	18	144
64-QAM	36	2/3	24	192
64-QAM	36	3/4	27	216

Four modulation techniques are available for use on a subcarrier, each of which corresponds to a different number of bits encoded per subcarrier symbol. *Forward error correction (FEC)* coding is applied to the user bits, which reduces the effective user bit rate but also improves the probability of successful decoding. Eight combinations of modulation rate and FEC coding rate are specified in IEEE 802.11, as shown in Table 3. For example, binary phase shift keying (BPSK) uses one bit per subcarrier symbol and thus 48 bits per OFDM symbol. With 1/2 rate coding, there are 24 data bits and 24 coding bits per OFDM symbol. With 24 data bits per OFDM symbol and an 8 μs symbol period, the resulting data rate is 3 Mb/s.

PMD Transmitter: When the PLCP requests the PMD to transmit a frame, it supplies the coded bits that make up each OFDM symbol (the contents of which include MAC data and PLCP overhead described below). It also provides the data rate and the transmit power. The PMD sublayer performs the OFDM modulation, including Inverse Fast Fourier Transform calculation, Guard Interval (cyclic prefix) insertion, wave shape filtering, RF modulation, and power amplification. An 802.11 device (a.k.a. "station" or STA) implementing the OFDM 10 MHz PHY must support transmission and reception of the 3. 6. and 12 Mb/s data rates. The other rates are optional in 802.11. Most DSRC testing in the U.S. has utilized the 6 Mb/s configuration (Quadrature PSK with rate 1/2 coding), since it seems to provide a good compromise between channel load and signal-to-noise requirement [20], but it remains an open question whether other rates will also be supported. For example, perhaps a higher rate will be useful to reduce channel load in high vehicle density environments. The rules concerning which bit rates to use for DSRC V2V safety will likely be standardized in SAE J2945.1.

The FCC defines four classes of device, labeled A–D. As shown in Table 4, each class is associated with a maximum allowed transmit power at the antenna and a desired range (CFR 47 §90.375 [18]).

Devices participating in V2V safety will normally be in Class C. Each device class is also associated with a transmit

Table 4 FCC Device Classification

Device Class	Max. Output Power (dBm)	Communication Zone (meters)
A	0	15
B	10	100
C	20	400
D	28.8	1000

spectral mask, defined in IEEE 802.11p, which limits the out-of-band energy of a transmitter. A given mask specifies a frequency dependent upper bound on the permitted power spectral density (PSD) of the transmitted signal (with 100 KHz resolution bandwidth). The PSD limits are specified at certain frequency offsets from the signal center frequency, and are relative to the peak PSD of the signal (i.e., in dBr). The mask is defined as the piecewise linear function passing through the specified points. Table 5 shows the spectral mask PSD limits at the breakpoints between the linear segments for each of the four FCC device classes. Progressing from Class A to Class D, each class allows a higher maximum transmit power and enforces a tighter spectral mask.

Mask C, is shown graphically in Fig. 3 for a 10 MHz channel.

PMD Receiver: The PMD receiver performs the demodulation steps, including automatic gain control (AGC), clock recovery, RF demodulation, guard interval removal, and Fast Fourier Transform. When the PMD sublayer passes a received frame up to the PLCP sublayer, it also makes available the received signal strength indication (RSSI).

Receiver performance is specified in IEEE 802.11 in terms of minimum sensitivity and channel rejection. Minimum sensitivity is defined as the minimum absolute signal energy for which a reference 1000 byte packet must be correctly received at least 90% of the time. IEEE 802.11 specifies minimum sensitivity levels as a function of the modulation technique and FEC coding rate, and thus of the data rate of the packet. For the 10 MHz OFDM signal these levels vary from −85 dBm at 3 Mb/s to −68 dBm at 27 Mb/s (802.11p does not modify the sensitivity requirements).

Table 5 Power Spectral Density Limits for 10 MHz DSRC Channels in the United States (Standardized in IEEE 802.11p [2])

Freq. Offset	±4.5 MHz	±5.0 MHz	±5.5 MHz	±10.0 MHz	±15.0 MHz
Class A	0 dBr	-10 dBr	-20 dBr	-28 dBr	-40 dBr
Class B	0 dBr	-16 dBr	-20 dBr	-28 dBr	-40 dBr
Class C	0 dBr	-26 dBr	-32 dBr	-40 dBr	-50 dBr
Class D	0 dBr	-35 dBr	-45 dBr	-55 dBr	-65 dBr

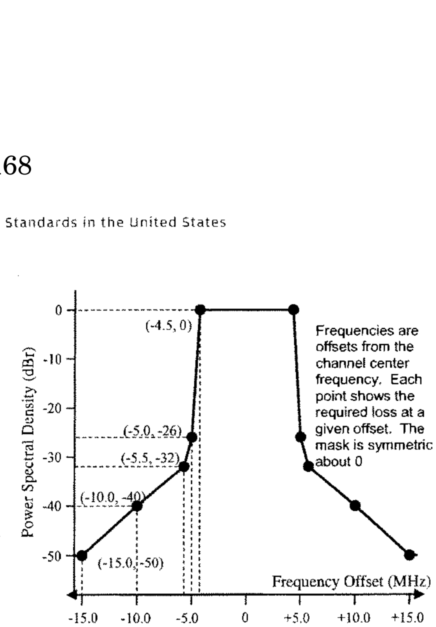


Fig. 3. ***Transmit Spectral Mask C. (Reproduced by permission of © 2010 John Wiley and Sons Ltd.)***

Channel rejection is an indication of a receiver's ability to filter out energy that is outside the 10 MHz channel of interest. There are different specifications depending on whether the interfering transmitter is in an adjacent channel or not. The IEEE 802.11 standard defines *adjacent channel rejection (ACR)* and *nonadjacent channel rejection (NACR)* requirements for each bit rate and channel bandwidth. The WAVE 802.11p amendment supplements the required ACR and NACR levels with more stringent optional enhanced channel rejection levels. These were introduced to compensate for the more challenging communication environment associated with rapidly moving vehicles, but they remain optional out of deference to the goal of encouraging WiFi silicon vendors to support the amendment.

DSRC Spectrum: The FCC has allocated the spectrum from 5.850 GHz to 5.925 GHz, i.e. the "5.9 GHz band," for DSRC operation in the United States [10], [11]. This spectrum is divided into seven 10 MHz channels with a 5-MHz guard band at the low end, as illustrated in Fig. 4. Pairs of 10 MHz channels can also be combined into a 20 MHz channel. Testing of DSRC in the U.S. has focused on 10 MHz channels, based on the desire to support many parallel types of applications, and on physical testing that suggests this width is well suited to the delay and Doppler spreads likely to be encountered in the vehicular environment [21]. However, it remains an open question whether concerns for channel congestion, particularly in the channel used for V2V safety communication (probably Channel 172), might be better addressed with the increased capacity of a 20 MHz channel. A frame with a given modulation and coding (Table 3) takes approximately half as long to transmit on a 20 MHz channel as on a 10 MHz channel, thus reducing the collision probability for a given number of

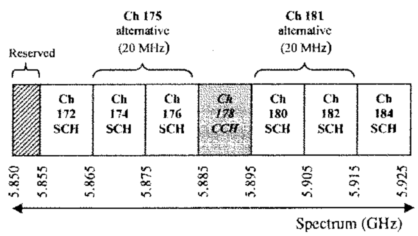


Fig. 4. ***United States DSRC Band Plan channel designations. (Reproduced by permission of © 2010 John Wiley and Sons Ltd.)***

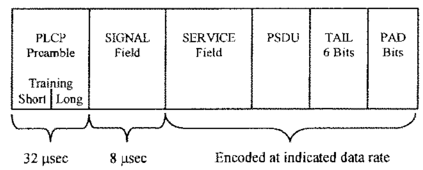


Fig. 5. ***Physical Protocol Data Unit format. (Reproduced by permission of © 2010 John Wiley and Sons Ltd.)***

frame transmissions per second. On the other hand, a 20 MHz channel has more noise for a given background spectral density and may pose a greater challenge for some environments, e.g., inter-symbol interference due to a delay spread that exceeds the shortened cyclic prefix length.

The FCC has also designated each channel as either a Service Channel (SCH) or as the Control Channel (CCH). These designations, as well as more specific rules for use of individual channels by application type, are discussed below in Section V-A, which addresses the IEEE 1609.4 standard.

Cross-Channel Interference (CCI): The multichannel nature of the United States band plan heightens the concern about cross-channel interference (CCI), which the transmit mask and channel rejection requirements are meant to control. CCI testing has demonstrated the potential problems caused by simultaneous operation, particularly on adjacent channels, in a given region [22]. Many stakeholders in the automotive and IEEE 802.11 communities believe that stricter transmit mask or channel rejection constraints would be cost-prohibitive. The channel switching mechanism described in Section V-A uses time division to largely insulate CCH traffic (e.g., service advertisements) from SCH interference. CCI between two SCHs may result in some performance degradation if a receiver and an adjacent cbannel transmitter are in close proximity (especially if they are on the same vehicle). For non-safety related information, the performance penalty of CCI is likely to be tolerable. This leaves CCI involving BSM receptions on the safety channel (likely Channel 172, see discussion in Section V-A) as the biggest concern. It may be necessary to adopt additional constraints, either in standards or regulations, for the adjacent Channel 174. For example, transmissions on Channel 174 could use reduced power, could be limited to RSUs, or could be prohibited altogether.

In addition to addressing the transmit mask and channel rejection requirements, the IEEE 802.11p amendment also explicitly specifies OFDM operation in the 5.9 GHz hand in the United States, as well as in a similar band defined for use in Europe.

B. OFDM Physical Layer Convergence Procedure (PLCP) Function

In a transmitter, the PLCP function is to process the bytes in a MAC frame so that they can be transformed into OFDM symbols for transmission over the air by the PMD. The PLCP adds PHY layer overhead to the MAC frame to create the PHY Protocol Data Unit (PPDU). The MAC sublayer passes three parameters to the PLCP along with the MAC frame: length of the MAC frame, transmit data rate (see Table 3), and transmit power. In a receiver the PLCP performs essentially the inverse function to extract a MAC frame from the PPDU. In addition to passing the received MAC frame up to the MAC sublayer, the PLCP also provides the RSSI. The PPDU format is shown Fig. 5.

The details of these fields have been stable in the IEEE 802.11 standard for a long time, and are not altered in the IEEE 802.11p amendment, nor are these fields used in any novel ways in DSRC. The *Preamble* is used to synchronize and equalize the signal at the receiver. A receiver operating on a 10 MHz channel must classify the channel as "busy" within 8 μsec after detecting the start of the *Preamble*. The *SIGNAL* field conveys the data rate and frame length. Since the data rate is unknown prior to reception of the *SIGNAL* field, the *Preamble* and *SIGNAL* are sent at a predetermined rate, more specifically at the lowest rate in Table 3, corresponding to BPSK and rate 1/2 coding. The lowest data rate is specified to maximize the probability that a receiver will successfully decode that portion of the frame. Even if the remainder of the frame cannot be decoded, reception of the *Preamble* and *SIGNAL* allows a receiver to estimate when the frame will end. The remainder of the PPDU uses the data rate indicated in the SIGNAL field. The *SERVICE* and *TAIL* fields facilitate bit scrambling. The *PAD* field ensures that the final OFDM symbol encodes the proper number of user bits from Table 3. The payload of the PPDU, the PHY Service Data Unit (PSDU), is the MAC frame.

IV. DSRC DATA LINK LAYER STANDARD (MAC AND LLC)

Like the PHY layer, the Data Link layer is commonly divided into sublayers. The lower of these is the *medium-*

access control (MAC) sublayer, which defines the rules by which STAs compete to share a wireless medium. The upper sublayer is the simpler *logical link control (LLC)*. The DSRC Data Link sublayers are described in the sections immediately following.

A. Medium-Access Control (MAC) Sublayer

The purpose of the MAC sublayer is to establish rules for accessing the common medium so that it can be shared efficiently and fairly among a set of STAs. The IEEE 802.11 rules fall into two categories: the session-based rules that define steps a STA must take before it is allowed to communicate information on behalf of Layer 3, and the frame-by-frame rules governing an individual transmission. The IEEE 802.11p amendment [2] makes significant changes to the session-based rules, while using the frame-by-frame rules as defined in the baseline IEEE 802.11 standard [16].

Session-Based Rules: The 802.11 standard defines a concept called the *Basic Service Set (BSS)*. A BSS is a set of STAs that agree to exchange data plane information. There are two types of BSS: *infrastructure* and *independent*. The infrastructure BSS is more common. It has a special *Access Point* (AP) STA that announces the BSS, and establishes some parameters and constraints for using the BSS. The AP serves as a gateway to a *distribution system* (DS) that provides access to additional networks beyond the wireless LAN, for example to the public Internet. Before a STA can transmit user plane data to the AP it first must hear the BSS announcement, in a beacon or probe response frame, and then go through a series of "setup" steps: Joining (which includes synchronizing with the AP STA's clock), Authenticating, and Associating.

The *independent* BSS has no AP or DS to provide backhaul connectivity; the STAs interact directly as peers. These STAs collectively shoulder the responsibility of announcing the existence of the BSS along with its parameters. Communicating within an independent BSS requires that the BSS first be announced, via a beacon frame, and that other STAs synchronize with the announcing STA.

For DSRC there are concerns about the delays attendant to following the setup steps outlined above, especially in the case of communicating through an AP. In a highly mobile vehicular environment, the opportunity to communicate may be fleeting, lasting only a few seconds, so there is a desire to define alternate, "lightweight" rules for accessing the medium.

That desire is in fact the primary motivation for the 802.11p WAVE amendment. The result of this effort is the definition of a new type of 802.11 communication "outside the context of a BSS" (abbreviated here "OCB"). In traditional 802.11, all data frames are sent between STAs that belong to the same BSS. By contrast, communication of data frames OCB is limited to STAs that do not belong to a BSS. There is no MAC sublayer setup required before STAs exchange data frames OCB.

The 802.11 frame header includes a 6-byte BSS identifier (BSSID) field. Each BSS is assigned an identifier by the STA that sends the beacon, for example in an infrastructure BSS the BSSID is the MAC address of the AP. Each frame sent within the context of a BSS includes the BSS's identifier in its header. The BSSID field of a frame sent OCB is set to all 1 s, i.e., 0xFFFFFF in hex notation, which is called the *wildcard* value. The purpose of the BSSID is to allow a receiver to easily distinguish frames that should be passed up the stack from frames that should be ignored. A receiver with the OCB capability enabled will configure the MAC to pass up any data frame with the wildcard value in the BSSID field, and to ignore any data frame sent by a STA in a coexistent BSS, i.e., with a non-wildcard BSSID. The OCB capability in IEEE 802.11p is designed to permit this type of coexistence with BSSs generally. However, the standard is more restrictive with respect to operation for DSRC. A STA operating in the 5.9 GHz DSRC band in the United States and in Europe is required by IEEE 802.11p to operate using the OCB capability, which means there will be no coexistent BSS in that band. This restriction might be relaxed in the future, e.g. , BSS operation might be permitted on a DSRC channel that does not support critical safety applications. The restriction in IEEE 802.11p might also be codified for United States operation in FCC regulations when they are updated to reflect the changing standards (see Section III).

A data frame sent OCB may carry an individual (unicast) or group (multicast or broadcast) destination address. The Basic Safety Message (see Section VI-A) will generally be encapsulated in a WAVE short message (WSM—see Section V-B) and then sent OCB to the broadcast destination address.

The IEEE 802.11p amendment introduces a new management frame, the *Timing Advertisement (TA)* frame, which can be used to announce information about the sender's time source. The 802.11p amendment also modifies the definition of the 802.11 *Vendor-Specific Action (VSA)* frame so that it can be used by organizations that have either a 24-bit or a 36-bit Organization Identifier (assigned by IEEE). The IEEE 1609 WG has a 36-bit identifier, and when the VSA is sent with this identifier, the payload of the frame may be used to convey a WAVE Service Advertisement (WSA—see Section V-B) on behalf of the management plane. The VSA frame could thus be used, for example, by an RSU that has a tolling service, traffic service, or commercial service to offer to passing vehicles.

There are few MAC-sublayer rules governing OCB communication. The most important is that a STA cannot engage in OCB communication while it belongs to a BSS. Management Frames must be of subtype TA or Action (including VSA). The definition of OCB communication is notable more for what it leaves out than for what it adds, and this proved somewhat controversial among long-time 802.11 WG members. In particular, OCB communication does not:

- use a beacon frame;
- require one STA to synchronize with another before they can communicate;
- use authentication at the MAC sublayer; or
- include any notion of the STAs "associating" before they communicate.

Here are some reasons why these omissions are acceptable in the vehicular environment.

Lack of beacon: The 802.11 beacon periodically announces the existence of a BSS, and conveys parameters important to its correct operation, including the BSSID. The OCB type of communication does not utilize a BSS, and so does not need most of the beacon contents (see [16, Tabs. 7 and 8]). Some beacon contents, however, e.g., supported data rates or Quality of Service (QoS) parameters, are relevant and so alternative means of specifying them are needed for OCB communication. This can be within the 802.11p amendment (e.g., it specifies a distinct default set of QoS parameters for OCB communication), in another standard (e.g., SAE J2945.1), or via higher layer or management plane communication (e.g., the VSA frame carrying a WSA defined in IEEE 1609.3 can convey information about allowed data rates).

Synchronization: MAC sublayer synchronization between STAs is used within a BSS primarily to facilitate "power management" whereby a STA may alternate between "awake" and "doze" states. DSRC devices frequently have access to adequate power, and furthermore may wish to monitor a channel continually, so power management is not used with OCB communication, and MAC sublayer synchronization is not required. Vehicles engaged in V2V safety communication are assumed to have GPS for positioning, so they are inherently synchronized at the application layer. A device without GPS can synchronize via reception of a TA frame, if desired.

Authentication: Like synchronization, the need for authentication in OCB communication is determined at higher layers. In the DSRC model, a means of authenticating messages is provided by the IEEE 1609.2 standard [3]. This method, which is further discussed in Section V-C, is preferable to that defined in 802.11 for efficiency and privacy reasons. OCB communication that uses IPv6 rather than the 1609 upper layers can utilize a variety of well-established techniques for authentication, if desired.

Association: The association of STAs in an infrastructure BSS has a specific purpose, to help the AP bridge frames between a non-AP STA within the BSS and a node on the other side of the DS. V2V safety messages have no need of bridging. Many other DSRC messages (V2V or between a vehicle and an RSU) also reach their destinations in a single hop. If multihop forwarding is desired using an RSU as an intermediate node between a vehicle and a server, it can be achieved by layer 3 routing (e.g., using IPv6) or by bridging if the forwarding address is provided through other means (e.g., management frame, configuration). The OCB type of communication would only be used on the wireless link between the vehicle and the RSU. Multi-hop forwarding is beyond the scope of IEEE 802.11 for OCB communication; in particular it does not use the "To DS" and "From DS" bridging indicators that are available for communication to and from an AP [16].

In summary, the traditional 802.11 functions of beaconing, synchronization, authentication, and association are not needed at the MAC sublayer for OCB communication. The TA frame offers an optional, lightweight alternative to the beacon for synchronization. The other functions are optionally implemented at higher layers, either as part of a separate standard or via proprietary means.

The IEEE 802.11 WG has recently established a new task group (TGai) to develop an amendment for "Fast Initial Link Setup," [23] for scenarios in which the BSS AP hierarchy is still desired. It remains to be seen if this can be utilized for DSRC communications that are more "session-based," e.g., a service provided by an RSU. The OCB capability, however, is clearly preferred for V2V safety exchanges in which there is no AP. When the FCC updates its rules for DSRC operation, it may require OCB communication for the entire band, or for individual channels (e.g., the safety channel 172) within the band.

Medium Access Rules: IEEE 802.11 defines a complex set of rules that allow STAs to efficiently share the wireless medium. The most important points are summarized here. IEEE 802.11p does not alter these rules; they apply identically to frames sent within and outside of the context of a BSS. The basic medium access paradigm of IEEE 802.11 is "carrier sense multiple access/collision avoidance," or CSMA/CA. The simplest communication scenario under CSMA/CA is as follows:

1) A STA that has a frame to send first senses the wireless medium.
2)
   a) If the medium is idle the STA begins transmission of its frame.
   b) If the medium is busy, the STA performs a random "backoff" by choosing a number of idle time slots to wait before transmission. The countdown begins when the medium becomes idle, is interrupted during any non-idle interval, and resumes when the medium returns to idle.
3) The sender of a unicast frame waits for an acknowledgment (ACK) from the recipient; if it does not receive the ACK within a timeout interval it retransmits the frame after another random backoff. A frame sent to a group address is not acknowledged and is sent only once.

The *Enhanced Distributed Channel Access (EDCA)* QoS mechanism [16] provides different priorities of wireless

Bytes: 2	4	6	6	6	2	2	0-2304+	4
FC	Dur	Addr 1	Addr 2	Addr 3	Seq Ctrl	QoS Ctrl	Frame Body	FCS

Fig. 6. *IEEE 802.11 MAC header, frame body, and FCS (most common form). (Reproduced by permission of © 2010 John Wiley and Sons Ltd.)*

access primarily through selection of the idle time and backoff range parameters. There are many excellent papers that describe IEEE 802.11 EDCA in detail [24], [25], so it is not further discussed in this paper.

802.11 MAC Frame Format: Every 802.11 MAC frame consists of a *header*, *frame body*, and a *Frame Check Sequence (FCS)*. The frame body is passed into the MAC sublayer from a higher layer or from the management plane. The frame header can have a variety of formats, depending on the frame type (control, data, management).

The most common frame format is shown in Fig. 6 and briefly summarized here. The *Frame Control* field (shown as *FC* in the figure) includes a protocol version, a frame type and subtype, and several other hit fields. The *Duration* field (shown as *Dur* in the figure) indicates frame's time duration, possibly including some overhead beyond the physical transmission time. For a frame sent OCB, *Addresses 1, 2, and 3* contain respectively the MAC address of the sending device, the MAC address of the destination device, and the wildcard BSSID. The *Frame Check Sequence* field (shown as *FCS* in the figure) carries a 4-byte Cyclic Redundancy Code (CRC) computed over the header and frame body, which is used for detecting bit errors. The other fields, *Sequence Control* and *QoS Control* are outside the scope of this paper.

B. Logical Link Control (LLC) Sublayer

The LLC sublayer of the DSRC protocol stack uses the standard IEEE 802.2 [26] protocol supplemented with the *subnetwork access protocol (SNAP)* [27]. IEEE 1609.3 requires support of the LLC *unacknowledged connectionless (Type 1) service* with *unnumbered information (UI)* frames. With LLC SNAP [28], the protocol associated with the LLC payload is indicated by the EtherType. In DSRC the two recognized EtherType values are 0x88DC (WAVE Short Message Protocol) and 0x86DD (IPv6). Fig. 7 shows the LLC PDU format for DSRC, including the LLC and SNAP headers. This becomes the frame body of the MAC frame.

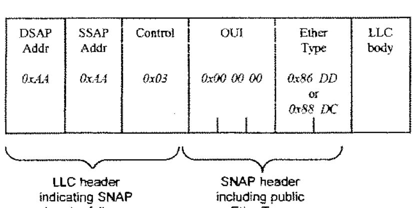


Fig. 7. *IEEE 802.2 LLC frame format used in DSRC. (Reproduced by permission of © 2010 John Wiley and Sons Ltd.)*

V. DSRC MIDDLE LAYERS

This section describes the architecture and standards that specify the middle portion of the DSRC protocol stack, as envisioned by the IEEE 1609 WG. Three principal functions are covered: *multichannel operation* (IEEE 1609.4 [5]), *networking services* (IEEE 1609.3 [4]), and *security services* (IEEE 1609.2 [3]).

The IEEE 1609 architecture (see IEEE 1609.0 [29]) generalizes the MAC sublayer of Fig. 2 into a set of one or more instances of the IEEE 802.11p MAC defined above, plus a channel switching protocol that defines how a given device can operate efficiently on multiple DSRC channels, one channel at a time. This multichannel operation concept [5] is described in more detail below.

As shown in Fig. 2, the DSRC protocol stack splits into two branches above the LLC sublayer. The first uses the WAVE Short Message Protocol (WSMP) defined in IEEE 1609.3 [4], which is optimized for the non-routed data exchanges that are common to vehicular networks, e.g., V2V safety messages. The second uses traditional internet protocols, principally IPv6, UDP, and TCP. In general, a service can choose to run over WSMP or IPv6, depending on its requirements. IEEE 1609.3 also defines the WAVE Service Advertisement (WSA).

The third major function defined within the IEEE 1609 suite is Security. Optional message authentication and encryption protocols are standardized in IEEE 1609.2 [3]. IEEE 1609.3 and 1609.4 were published in December 2010. IEEE 1609.2 is expected to be balloted and published in 2011.

In addition to the IEEE 1609.2, 1609.3, and 1609.4 standards, the IEEE 1609 WG is also developing the following standards (not discussed in detail in this paper):

- IEEE 1609.1—Remote management (e.g., for simple WAVE devices);
- IEEE 1609.11—Electronic Toll/Fee Collection;
- IEEE 1609.12—Defines Provider Service ID (PSID) allocations; [30]. The PSID is described later.

A. MAC Extension for Multichannel Operation: IEEE 1609.4

IEEE 1609.4 is applicable when DSRC is operating in a multi-channel environment, as it will in the U.S. 5.9 GHz band (see Fig. 4). IEEE 1609.4 defines a management extension to the MAC that allows a system with one or more radios to effectively switch among those channels.

Under this extension, a system maintains a separate logical instance of the IEEE 802.11p MAC, including queues and state variables, for each channel on which it operates. IEEE 1609.4 channel switching is optional; in particular a DSRC device is permitted to remain tuned to a single channel all the time.

The goal of IEEE 1609.4 is to define a mechanism by which devices that are switching among multiple channels will find each other, i.e., tune to the same channel at the same time. The problem is especially challenging for devices that have a single radio. The IEEE 1609.4 solution involves two concepts: the *control channel (CCH)* and *time division*. The CCH concept designates one channel (Ch. 178 in the US) as a special "rendezvous" channel that the devices will tune to on a regular basis. All other channels in the band plan are designated *service channels (SCH)*. The time division concept assumes that all devices have access to Universal Coordinated Time (UTC), e.g., from a GPS signal. IEEE 1609.4 defines a division of time into alternating CCH intervals and SCH intervals. During a CCH interval devices wishing to find each other rendezvous on the CCH. There they may hear WSAs announcing the availability of any services offered in the immediate area. The WSA provides information about one or more services, and indicates the SCH on which each is offered. During an SCH interval devices may switch to one of the SCHs.

Fig. 8 illustrates the basic time division concept defined in IEEE 1609.4. Time is segmented into "sync periods," which by default are 100 ms each. Each sync period consists of one CCH interval followed by one SCH interval. The default division is 50 ms for each.

Each CCH and SCH interval begins with a 4 ms guard interval, which is used by a switching device to transfer control from one virtual MAC to another. The device may begin receiving frames as soon as it is ready within the guard interval, but it normally will not transmit until the guard interval is complete because it will assume that its neighbors are still performing their own transitions. The guard interval also accounts for small errors in a device's representation of UTC. A device that does not switch channels is permitted to send at any time, including a guard interval. However, it cannot assume that a channel switching neighbor will be capable of receiving its transmissions during a guard interval.

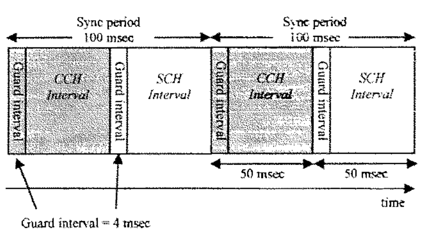


Fig. 8. ***Division of time into CCH intervals and SCH intervals. (Reproduced by permission of © 2010 John Wiley and Sons Ltd.)***

Switching to an SCH: If a device determines via a WSA that it is interested in accessing an advertised service (more on this process in the next subsection), it will switch to the relevant SCH. Normally it will switch at the end of the CCH interval and return to the CCH at the start of the next CCH interval. However, IEEE 1609.4 provides for an *immediate* departure option, in which the switch to the SCH can occur as soon as the WSA is received. It also provides for an *extended access* departure option in which the device remains on the SCH through one or more sync periods until service delivery is completed.

A device might also remain on the CCH during the SCH interval, e.g., if there is no WSA or the services advertised in a WSA are not currently of interest. A device tuned to the CCH during the SCH interval may transmit and receive, but in general its neighbors cannot be assumed to hear any transmissions, because they may be tuned to an SCH.

Synchronized Frame Collisions: The rendezvous time on the CCH is the 46 ms from the end of the CCH guard time to the end of the CCH interval. If a frame intended to be sent during the rendezvous time is enqueued during the other 54 ms of the sync period (i.e., during the SCH interval or CCH guard time), IEEE 1609.4 requires that the frame treat the channel as busy and enter back-off when the guard time expires. Within a transmission area, any two devices whose frames choose the same back-off time slot (by default a 1 in 16 probability) will experience a frame collision. If there are many such devices, the probability that any given time slot is chosen by exactly one frame will be quite small. This problem is referred to as "synchronized collisions." This is a significant concern if BSMs are constrained to be sent on the CCH during the CCH interval, since there could be hundreds of devices in a given area. However, synchronized collisions are relatively easy to avoid if the message generation function in the higher layers is provided with a signal indicating the start of a sync period. Then it can choose to enqueue its message at the MAC layer during a random time within the 46 ms interval. It may still find the channel busy and enter back-off, but at reasonable channel loads it is far less likely to suffer a collision. Synchronized collisions can also occur on an SCH at the start of the SCH interval. Annex B of IEEE 1609.4 recommends, but does not require a device to take steps to avoid this phenomenon.

Channel Switching and Safety Communication: An early version of IEEE 1609.4 required all DSRC devices to participate in channel switching, and in particular to visit the CCH during the CCH interval. Under that paradigm, V2V safety messages would also be exchanged during the 46 ms rendezvous time, and the capacity of the system for safety messages would be less than half that of a system that utilized a full-time channel. Concerns about the reduced capacity for safety messages prompted research into other approaches, and led to the decision to make IEEE 1609.4 optional. An analysis of the performance associated with the channel switching safety paradigm and with several alternatives can be found in [31].

A consensus is developing in the industry to send all collision avoidance safety messages (specifically the BSM, Map Data, and Signal Phase and Timing messages, see Section VI-A) on Service Channel 172, with no time division. However, this implies that a vehicle desiring to participate in both safety and non-safety applications will require two DSRC radios, one that remains tuned to Channel 172 and one that participates in IEEE 1609.4 channel switching. A single-radio safety system will only send and receive on Channel 172. Congestion remains a concern even with a dedicated safety channel [31], and congestion control is one of the most important open research problems for DSRC [13], [32]–[35]. Since some vehicles might have only one DSRC radio, one can imagine that many stakeholders will desire their applications to also use Channel 172. The U.S. FCC has designated Channel 172 "exclusively for vehicle-to-vehicle safety communications for accident avoidance and mitigation, and safety of life and property applications" [12]. The balance between Channel 172 congestion and access is an outstanding DSRC policy issue, which must be addressed in future standards (e.g., SAE J2945.1) and government regulation (U.S. DOT and FCC).

Notwithstanding the removal of safety messages, there are still concerns about CCH congestion. Due to these concerns, only WSMs, WSAs, and other management frames are allowed on the CCH; IP packets are not allowed. The IEEE 1609 standards impose no packet-type restrictions on the SCHs, but constraints might be added in other standards (e.g., SAE J2945.1) or in FCC regulations, if necessary to protect high priority applications like V2V safety.

B. Network Services for DSRC: Network and Transport Layers, IEEE 1609.3

The Internet Protocol (IP) has become the default Layer 3 protocol in many networks today, especially those that are interconnected with other networks as part of the public Internet. The primary service that IP offers to higher layers is connectivity, i.e., the ability to find a path to a node anywhere, based only on its public IP address. The IP connectivity service is achieved via a set of highly successful IP routing protocols.

In the vehicular environment, however, many packets are sent directly over the air from the source to the destination, so routing is less of an issue. In order to avoid the packet overhead associated with internet protocols, a minimum of 52 bytes for a UDP/IPv6 packet, the IEEE 1609 WG defined a new Layer 3 protocol that is efficient for these 1-hop transmissions: the *WAVE Short Message Protocol (WSMP)*. Packets sent using WSMP are referred to as *WAVE Short Messages (WSMs)*. The minimum WSM overhead is 5 bytes, and even with options and extensions it will rarely exceed 20 bytes. Channel congestion is a significant concern in DSRC, especially on the channel used for BSMs, so the efficiency of WSMP is quite valuable.

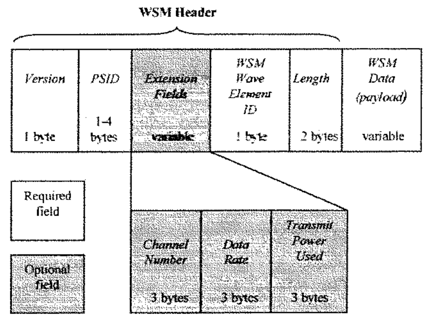


Fig. 9. *WAVE Short Message format. (Reproduced by permission of © 2010 John Wiley and Sons Ltd.)*

1) WAVE Short Message Format: The WSM format consists of a variable-length header followed by a variable-length payload, as shown in Fig. 9. The message format includes both mandatory and optional fields, defined later.

WSMP version: This mandatory one-byte field contains a 4-bit WSMP version number and 4 reserved bits. The version number associated with the current 1609.3 standard [4] is 2. A receiver will discard a WSM with a version number higher than it was designed to support.

Provider Service IDentifier (PSID): The mandatory PSID identifies the service that the WSM payload is associated with. A device creates a list of PSIDs that have active receive processes at higher layers. When a WSM arrives, if the PSID matches one of those on the list, the WSM payload is forwarded to that process. In this way, the PSID serves a purpose that is similar to a TCP or UDP Port.

For bandwidth efficiency, PSIDs are defined in a variable-length format. Leading bits are used to indicate the number of bytes in the PSID, as shown in Table 6.

Table 6 Provider Service Identifier (PSID) Lengths and Ranges

Leading bits in first byte of PSID	Length of PSID (bytes)	Range of PSID values for this length (hex representation)	Number of PSID values for this length
0	1	0x00-0x7F	2^7
10	2	0x8000-0xBFFF	2^{14}
110	3	0xC00000-0xDFFFFF	2^{21}
1110	4	0xE0000000-0xFFFFFFFF	2^{28}

A leading bit of 0 indicates a 1-byte PSID. Similarly, leading bits of 10, 110, and 1110, respectively, indicate a 2-byte, a 3-byte or a 4-byte PSID.

PSIDs are currently administered by the IEEE 1609 WG, with some values assigned at the request of other standards organizations (e.g. SAE). There is an effort underway to harmonize the PSID and a similar identifier used in some European standards, so that identifiers will be drawn from a common number space. The IEEE 1609.12 draft standard [30] was recently started to document allocations that have been made by IEEE 1609 and other standards organizations from this number space. The current draft IEEE 1609.12 reflects nine PSID values requested by SAE for application areas associated with the J2735 messages.

WSM Extension Fields: In IEEE 1609.3 there is a facility for including an optional "extension field" in a WSM or WSA header. This facility provides flexibility for the protocol to omit or include a field considered optional. It also provides extensibility so that new extension fields can be defined in future revisions.

An extension field consists of three fields: a one-byte *identifier*, a one-byte *length*, and a variable-length *contents* field whose size (in bytes) is indicated in the *length* field. Since a given extension field may or may not be present, its presence needs to be explicitly signaled. The *identifier* provides that indication, distinguishing one extension from another; *identifiers* are unique and are defined in the 1609.3 standard. The *length* field also supports flexibility and extensibility. An explicit *length* indicator allows the *contents* field to be variable length, which promotes bandwidth efficiency in longer fields. More importantly, the *length* indicator allows a legacy device to skip over an extension whose *identifier* it does not understand, and continue parsing the rest of the message. This will be important when extension fields are added in the future, after devices are deployed.

The current version of IEEE 1609.3 defines three extension fields for the WSM. The *contents* field of each uses one byte, so with the *identifier* and *length* each extension is three bytes long. Note that since each is fixed length and is defined in the original revision of the WSMP version 2 protocol, the *length* field could have been omitted as redundant, but it is included for consistency with future extensions, at the cost of one byte. The three WSMP extensions are:

- **Channel Number**: Interpreted in the context of a particular regulatory domain, e.g., see Fig. 4 for U.S. 5.9 GHz band channel numbers.
- **Data Rate**: Using an IEEE 802.11 format with resolution 500 Kbps.
- **Transmit Power Used**: A signed integer with resolution 1 dBm

WSMP WAVE Element ID: This mandatory one-byte field marks the end of the extension fields and indicates the format of the WSM Data field.

Length: This mandatory two-byte field is the final byte of the WSM header. Its value is equal to the number of bytes in the WSM Data field, which follows immediately. The valid range is 0–4095, but a smaller maximum length may be defined in the Management Information Base (MIB). The upper four bits of this field are reserved.

WSM Data: This is the payload of the WSM. Some or all of this data is provided by higher layers at the sender and is passed to higher layers at the receiver. In some cases additional protocol information is inserted in a "shim header" at the sending device. The format of the WSM Data field is indicated by the WSMP WAVE Element ID value. In the current version of IEEE 1609.3 three formats are defined, indicated by WSMP WAVE Element ID values 128, 129, and 130. In one format (ID = 128) all of the WSM Data belongs to the higher layer. The other two formats include a shim header pre-pended to the higher layer data. One of these shim headers (ID = 130) relates to remote management and is defined in IEEE 1609.1. The other shim header option (ID = 129) is the so-called WSMP Safety Supplement (WSMP-S) Control field. The use of WSMP WAVE Element ID 129 is optional if the higher layer data is safety-related; if ID 129 is not used then ID 128 is used and the WSMP-S Control field is not inserted. As noted above, there is an ongoing debate about which channel will be used for V2V safety messages. Some of the alternatives outlined in [31] rely on extra protocol information, and the WSMP-S Control field was defined to convey that information. However, the WSMP-S Control field is itself extensible. In the long term its utility may expand to include support of other functions related to improving DSRC safety, e.g., conveying information useful to an adaptive congestion control algorithm.

2) WAVE Service Advertisement Format: The WSA includes information about one or more DSRC services that are offered in an area. A service can be almost any information exchange that provides value to a vehicle's occupants. Example services include traffic alerts, tolling, navigation, restaurant information, entertainment, and Internet access. Most services are provided by an RSU, but a vehicle could also send a WSA. The information exchange within a service can be unidirectional or bidirectional. WSAs are sent on the CCH during the CCH interval. The services they advertise are offered on one or more of the SCHs. One type of DSRC communication that is not considered a service is the broadcast of Basic Safety Messages from a vehicle to its neighbors. Those broadcasts are not advertised via a WSA.

A WSA-sender may support more than one service offering. For efficiency, it can provide information about up to 32 services in a single WSA. Services can be supported by either the IPv6 or WSMP part of the protocol stack. The information passed in the WSA will vary depending on the service protocol, as shown below. The WSA is intended to

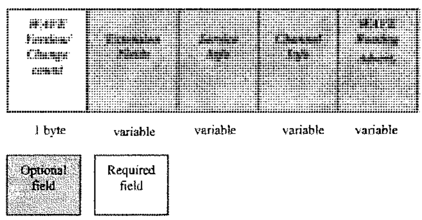


Fig. 10. ***WAVE Service Advertisement format.***

be carried within an IEEE 802.11 Vendor Specific Action (VSA) management frame. The WSA is a management message; it originates in the management plane of the sender and is processed in the management plane of the receiver. The decision to access an advertised service is not standardized; typically it depends on factors including the type of service (indicated by PSID), the quality of the link to the service provider, the time since the vehicle most recently accessed this service, the availability of competing services, the cost of the service, etc. The WSA format is shown in Fig. 10.

WAVE version/Change count: This mandatory one-byte field conveys the 4-bit version number that defines the format of this WSA. The version number associated with the current standard is 1. This serves the same purpose for a WSA as the WSMP version serves in a WSM. The remaining four bits are a modulo-16 content change counter. The sender increments the counter when it updates the content of the WSA. This provides an efficient way for a receiver to filter out duplicate WSAs.

WSA header extension fields: As with the WSM, optional extension header fields are allowed in the WSA header, and they are encoded using the same *identifier/length/contents* format. The aggregate length of the WSA header extensions must not exceed 254 bytes. In the current standard six extensions are defined as follows.

- *Repeat Rate*: An 8-bit unsigned integer indicating the number of WSA broadcasts per five seconds. Monitoring the success rate of repeated broadcasts, along with other measures like received power level, provides a way to estimate link quality.
- *Transmit power used*: An 8-bit signed integer indicating the power with which the WSA's frame was transmitted, with resolution 1 dB.
- *2D Location*: An 8-byte field conveying the location of the transmitting device, encoded as a 32-bit latitude and 32-bit longitude, with 1/10 micro-degree resolution.
- *3D Location and confidence*: A 15-byte field conveying the 3D location of the transmitting antenna (32-bit latitude, 32-bit longitude, and 16-bit elevation), the position and elevation confidence (4 bits each), and a 4-byte position accuracy indication.
- *Advertiser Identifier*: a text string of 1 to 32 bytes associated with the WSA sender.
- *Country String*: a 3-byte field using a format defined in IEEE 802.11 to convey the country regulatory domain of the sender.

Service Info: The WSA header extensions are followed by 0 to 32 instances of a Service Info field. This is where services are actually advertised. Each Service Info field advertises one service. Each Service Info field has the following content.

- One-byte WSA WAVE Element ID. Value 0x01 indicates Service Info.
- 1-to-4-byte Provider Service Identifier (PSID), indicating the type of service being advertised, see WSM format above.
- One-byte Service Priority, with values restricted to the range 0–63 (0 is lowest priority). This priority is associated with the higher layer process initiating the advertisement. It is used to help arbitrate access to competing advertised services.
- One-byte Channel Index. Indicates which of the Channel Info fields that follow (see below) is associated with this service.
- Variable length Service Info Extension Fields. These extensions are specific to a service info field, and they utilize the same encoding format as other extensions. The Service Info Extensions defined in the current standard are as follows.
  - Provider Service Context (PSC)—a string of up to 31 bytes that provides additional information about the service. Each PSID has a unique PSC format, which is defined by the organization to which the PSID is assigned.
  - IPv6 address—a 16-byte address of the entity hosting the service, if the service is provided using IPv6 rather than WSMP.
  - Service Port—a two-byte port number for the transport layer protocol (UDP or TCP) if the service is provided using IPv6.
  - Provider MAC Address—a six-byte IEEE MAC address of the device hosting the advertised service, if different from the MAC address of the device sending the WSA.
  - RCPI Threshold—a one-byte Received Channel Power Indicator value indicating the minimum WSA received power recommended prior to attempting to access the service, with range 0 to −110 dBm.
  - WSA Count Threshold—a one-byte count indicating the minimum number of WSAs recommended to be received prior to attempting to access the service, with range 0 to 255 WSAs.

- WSA Count Threshold Interval—a one-byte time interval over which the WSA Count Threshold is measured, with range 0.1 to 25.5 seconds. If absent, the WSA Count is measured over 1 second.

Channel Info: The Service Info fields are followed by 0 to 32 instances of a Channel Info field. There is one Channel Info field for each channel on which an advertised service is offered. A Service Info field is linked to a Channel Info field by the Channel Index in the Service Info field. Each Channel Info field has the following content.

- One-byte WAVE Element ID. Value 0x02 indicates Channel Info.
- Two-byte Operating Class and Channel Number. These follow a format defined in IEEE 802.11. Together they indicate the channel to which the remaining information applies. In the U.S. this would normally be one of the channels shown in Fig. 4.
- One-byte Adaptable field, of which only one bit is used, as a bit flag. If the flag is 0, then the Data Rate and Transmit Power Level (see directly below) are fixed. If the flag is 1, then the Data Rate is a lower bound and the Transmit Power Level is an upper bound. In that case higher rates and/or lower power levels are allowed when accessing the service.
- One-byte Data Rate, a signed integer with resolution 500 Kbps, the allowed range is 1.0 to 63.5 Mbps.
- One-byte Transmit Power Level, applied to transmissions on the indicated channel. The resolution is 1 dB and the range is −128 dBm to +127 dBm.
- Variable length Channel Info Extension Fields: These extensions are specific to a Channel Info field, and they utilize the same encoding format as other extensions. There are two Channel Info extension fields in the current standard as follows.
  - EDCA parameter set: The format of the EDCA parameter set is defined in IEEE 802.11. The default EDCA parameter set for OCB communication is defined in IEEE 802.11p. This extension field provides an opportunity to advertise a non-default set for up to four different priority classes. Note: the IEEE 1609 WG plans to issue a corrigendum (correction) to [4] to clarify that when the EDCA extension field is included it may consist of parameters for between one and four EDCA access categories.
  - Channel Access: A bit flag within a one-byte field. The value 0 indicates that the service is available all the time, and the value 1 indicates that the service is available only during SCH intervals.

WAVE Routing Advertisement (WRA): This is an optional field within the WSA. It is only used when an advertising device offers a service that utilizes the IPv6 part of the protocol stack. The WRA provides information about how to connect to the Internet, which a receiver (e.g., a vehicle) can incorporate in its network configuration. Each WSA includes at most one WRA. If present, the WRA consists of a fixed-length mandatory part followed by a variable-length optional extension. Each extension includes an explicit length indicator, so it is not necessary to also explicitly indicate the length of the entire WRA.

- **WAVE Element ID**: a mandatory one-byte field set to 0x03. This distinguishes the WRA from a Channel Info field.
- **Router Lifetime**: a mandatory two-byte field indicating how long, in seconds, the Default Gateway information that follows is valid.
- **IpPrefix**: a mandatory 16-byte IPv6 subnet prefix.
- **Prefix Length**: a one-byte value indicating how many of the 128 bits in the preceding IpPrefix are significant.
- **Default Gateway**: a mandatory 16-byte IPv6 address of the default router used to achieve internet connectivity.
- **Primary DNS**: a mandatory 16-byte IPv6 address of a device that can serve as a Domain Name Server;
- **WRA Extension Fields**: optional extension fields using the normal format; the current standard defines two extension fields:
  - Secondary DNS: 16-byte IPv6 address
  - Gateway MAC address: 6-byte IEEE MAC address, if different than the MAC address of the WSA transmitter.

C. Middle Layer Security Services: IEEE 1609.2

The general topic of security in vehicular networks is a complex subject. This subsection explains how the basic principles are applied in the specific case of the IEEE 1609.2 [3] standard: Security Services for Applications and Management Messages. As this paper is being written the IEEE 1609.2 standard is in draft stage. Some changes are likely during the balloting process, which is expected to be completed in 2011. IEEE 1609.2 defines standard mechanisms for authenticating and encrypting messages, especially WSMs and WSAs. This subsection focuses on authentication of a vehicle safety message, i.e. a Basic Safety Message (BSM) carried in a WSM. In addition to the algorithm and frame formats currently defined in IEEE 1609.2, the general area of "DSRC security" involves other issues as well. A cooperative U.S. DOT and automotive industry project called V2V-Communications Security [36] is developing solutions related to the following open questions: a) type of wireless communication to be used between a vehicle and the security infrastructure [i.e., Certificate Authority (CA)], b) type of Public Key Infrastructure (PKI), e.g., policy regarding certificate validity, certificate encryption, and certificate revocation, c) protecting the privacy of vehicle drivers and owners, d) physical security of DSRC devices, and e) detection and reporting of misbehaving DSRC devices. Some of the solutions to these open issues may eventually be reflected in the IEEE 1609.2 standard, while others will likely be documented in government regulations.

IEEE 1609.2 Authentication: An authenticated message carries a *digital signature* that can be used to verify that the sender had the authority to send the message and that the content has not been altered. IEEE 1609.2 authentication uses the Elliptic Curve Digital Signature Algorithm (ECDSA), which is an asymmetric cryptographic algorithm. Two different key lengths are specified, 224 bits and 256 bits. ECDSA is a relatively processor-intensive algorithm, which is a concern in the cost-sensitive vehicle market, especially given that a receiver might receive hundreds of safety messages per second. Signing or verifying a message with the 224-bit version of ECDSA takes about 60–80% as much processing time as the 256-bit version [37], so it has been the plan to sign BSMs using the 224-bit key. However, the emergence of the implicit certificate option (see below) has called that plan into question recently.

Certificate Content: To sign a message a sending device must have a private signing key and a certificate containing the public key associated with that private key. The receiver uses the public key to verify the signature. The certificate also includes information about how a receiver can check if the certificate has been revoked. For privacy reasons, the certificate a vehicle will use to sign safety messages will not carry information that is easily linked to permanent identifiers for that vehicle. The issuing Certificate Authority (CA) can identify the certificate holder, but even that capability can be split among multiple authorities to prevent abuse.

In addition, the certificate carries various scoping restrictions with regard to time, content, and location (location is more important in the case of an RSU certificate). With privacy again in mind, the vehicle will typically use a given certificate for a limited time (e.g., 5 to 10 min), so that the vehicle's movements cannot easily be tracked by its safety broadcasts over long intervals. When the vehicle changes certificates it also changes other identifiers in its safety messages, e.g., source MAC address, Temporary ID and Sequence Number in the BSM (see Section VI-A). A vehicle will typically be reloaded with new certificates infrequently (e.g., annually). To prevent a so-called Sybil attack in which an attacker gains access to multiple valid certificates and uses them simultaneously, only one certificate will be valid at any given time. For example, a vehicle might carry on the order of 100 000 certificates, each of which is valid for a different five minute period in the coming year. Even if all of those certificates are stolen, the attacker can only use one at a time to impersonate the certificate owner. This principle can be relaxed to allow a short (e.g., 30 second) overlapping validity interval between consecutive certificates, so that certificate transitions can be randomized for privacy, and so that a vehicle will have some flexibility to defer a transition during a critical safety event.

The certificate carries a list of PSIDs that the sender is authorized to use in its WSM transmissions. For example, a vehicle will have certificates authorizing it to send a WSM with the PSID that is associated with the Basic Safety Message. The certificate may also indicate content-specific permissions that the sender has. For example, an SAE J2735 emergency vehicle alert message (EVAM) might be sent by a number of emergency vehicle types, including police cars, ambulances, and tow trucks. A siren indication within the EVAM is permissible for an ambulance or police car, but not for a tow truck. The certificate attached to an EVAM will authorize the PSID value with which the EVAM is associated, and in addition will include a service specific permissions (SSP) field indicating which content within the message the sender is authorized to set. The format of the SSP field consists of a 1-byte length indicator followed by up to 31 additional bytes. The format of the SSP is specific to a given PSID value, and is defined by the organization that defines the meaning of that PSID value (i.e., defined by SAE in the case of the PSID associated with the J2735 EVAM). The SSP field can be absent, indicating that there are no content-specific restrictions for that PSID value.

Finally, the certificate carries its own authentication field, signed by the CA using the CA's private key. A recipient of the certificate can use the CA's public key to authenticate the certificate itself. The CA's public key is usually well known, and thus it does not need to be disseminated using DSRC. Since a CA's public key has a much longer lifetime than a DSRC sender's public key, it will normally utilize the 256-bit version of ECDSA for stronger security.

The sender's public key and the CA's authentication can be provided by a certificate in two ways. In an *explicit certificate* these are supplied in separate fields within the certificate, for example a 224-bit sender public key field and a 256-bit CA signature.

Alternatively, in an *implicit certificate* the sender's public key and the CA's authentication are supplied implicitly via a *reconstruction field*. A receiver can use the CA's public key and the reconstruction field value to recover the sender's public key, and in the process it can authenticate the certificate itself. An implicit certificate requires that the sender and CA use the same length key, so in the case of BSM certificates it would likely revert to the higher security 256-bit key. The length of the reconstruction field is equal to the key length. The replacement of explicit sender public key and CA signature fields with a single reconstruction field allows an implicit certificate to save on the order of 50 to 60 bytes compared to an explicit certificate. This is a significant saving, and the IEEE 1609 WG is thinking about specifying this approach as an option [3]. The implications for processing burden depend somewhat on implementation choices, but generally implicit certificates are expected to represent roughly the same processing requirement as explicit certificates.

Certificate Digest: An explicit certificate can be on the order of a hundred bytes or more in length. Even the smaller implicit certificate is significant compared to the vehicle state content in a BSM (which varies between about 50 and 150 bytes). In order to reduce the security overhead, a WSM might carry a *certificate digest*, which is a short (e.g., 8 byte) hash of a certificate, in place of the certificate itself. A digest can be used in place of either an explicit or an implicit certificate. If a vehicle has once received a full certificate from another vehicle, it can recognize a certificate digest in a subsequent message and use the cached certificate to verify the signature. On the other hand, a vehicle cannot begin to verify messages from a given sender until it sees a full certificate. A sending vehicle might interleave BSMs carrying full certificates and BSMs carrying certificate digests, trading off the bandwidth consumed against the latency to verify a first message from that sender. The interleaving schedule is one of many open security issues for vehicle safety security. Use of certificate digests does not impact security processing significantly because the hash operation is very simple.

Other Security Overhead: In addition to the digital signature and the certificate (or certificate digest), a signed message may also include other security overhead. For example, it may optionally include a message generation time and validity period, or a location and validity region. These can be used, respectively, to prevent temporal or spatial replay attacks. In the case vehicle safety, the BSM already includes absolute generation location, and the recipient is able to judge whether the transmitter location is close enough to be relevant, so there is no need for location security overhead. Generation time in the BSM is only modulo-one minute, so an absolute generation time is included in the certificate.

IEEE 1609.2 Encryption: Though the focus of this subsection is authentication for vehicle safety messages, the IEEE 1609.2 standard also defines an encryption algorithm, which uses a combination of symmetric and asymmetric cryptography. In the current standard, one symmetric algorithm and one asymmetric algorithm are specified. The symmetric algorithm is the Advanced Encryption Standard with 128-bit keys in Counter with CBC MIC mode, i.e. AES-CCM. The asymmetric algorithm is the Elliptic Curve Integrated Encryption Scheme (ECIES). Since symmetric cryptography requires less processing, the sender will encrypt the message with a symmetric key, and then will encrypt the symmetric key using the asymmetric algorithm. The receiver does the inverse, decrypting first the symmetric key, and then the message. The bulk of the cryptography is done using the efficient symmetric algorithm. It is also possible for a message to be both signed and encrypted, in that order. IEEE 1609.2 security services will normally be invoked by the message sublayer (see Fig. 2), and the secured message will become the payload of a 1609.3 WSM.

VI. DSRC MESSAGE SUBLAYER

At the top of the protocol stack in Fig. 2, the Application Layer includes application processes and additional protocols that provide direct support to applications. An example of the latter is the SAE J2735 DSRC Message Set Dictionary standard, which defines fifteen messages that collectively enable a core set of DSRC applications. This section describes these messages, and examines the Basic Safety Message in detail. The SAE DSRC committee is also developing a complementary standard, J2945.1 [7], which defines additional rules for using BSMs to implement V2V safety systems.

A. SAE J2735 DSRC Message Set

In this section the names of data structures defined in the J2735 standard are represented in this font: `Sample`. Table 7 lists the fifteen message types that are defined in the SAE J2735 standard [6].

The SAE DSRC committee is developing additional message types that will appear in a future revision of J2735, for example a message to enable cooperative cruise control. In addition, the U.S. DOT is planning to propose additional content in SAE J2735 to solidify the systems engineering behind the standard, for example content related to concept of operations and development of requirements. That proposal is expected to be provided to the SAE in early 2012.

SAE J2735 defines the format of each of the message types listed in Table 7. Each message is defined as a collection of constituent data structures called *data elements* and *data frames*. A data element is the most basic data structure in the J2735 standard. A data frame is a more complex data structure, composed of one or more data elements or other data frames. The J2735 standard defines the syntax (length, format) and semantics of each data element and data frame.

An example of the relation between data elements and data frames can be seen in the `ApproachesObject` data frame, which is used as part of the description of an intersection. The `ApproachesObject` frame is made up of four constituent parts: a `Position3D` frame, a simple `LaneWidth` element, and two instances of a frame called `Approach`, one each for ingress and egress lanes. The `Approach` frames are each in turn composed of a collection of several data elements and data frames that describe a set of lanes. The `ApproachesObject` data frame is itself a constituent of a larger frame called `Intersection`. Ultimately, messages are composed of

Table 7 SAE J2735 DSRC Standard Message Types

Message Type	Purpose
A La Carte Message	Generic message with flexible content
Basic Safety Message	Conveys vehicle state information necessary to support V2V safety applications
Common Safety Request	A vehicle uses this to request specific state information from another vehicle
Emergency Vehicle Alert Message	Alerts drivers that an emergency vehicle is active in an area
Intersection Collision Avoidance	Provides vehicle location information relative to a specific intersection
Map Data	Sent by RSU to convey the geographic description of an intersection
NMEA Corrections	Encapsulates one style of GPS corrections – NMEA style 183
Probe Data Management	Sent by RSU to manage the collection of probe data from vehicles
Probe Vehicle Data	Vehicles report their status over a given section of road; aggregated to derive road conditions
Roadside Alert	Sent by RSU to alert passing vehicles to hazardous conditions
RTCM Corrections	Encapsulates a second style of GPS corrections – RTCM
Signal Phase and Timing Message	Sent by RSU at a signalized intersection to convey the signal's phase and timing state.
Signal Request Message	A vehicle uses this to request either a priority signal or a signal preemption.
Signal Status Message	Sent by RSU to convey the status of signal requests.
Traveler Information	Sent by RSU to convey advisory and road sign types of information

collections of data elements and data frames. The hierarchical structuring of data elements, data frames, and messages encourages reuse of data structures. A given message can be decomposed in a tree structure, with each branch ultimately ending in a data element. SAE J2735 defines approximately 150 data elements and 70 data frames.

The data elements, data frames, and message types in J2735 are defined in *Abstract Syntax Notation One (ASN.1)*, which is defined in the ITU-T X.680 series of standards. SAE J2735 also specifies the use of the *Distinguished Encoding Rules (DER)* to translate the ASN.1 into over-the-air bits and bytes. DER, a subset of the Basic Encoding Rules (BER), is defined in the ITU-T X.690 standard [38]. DER encodes each data item (element or frame) in a three-part structure consisting of an *identifier*, a *length*, and the *contents*. The encoding is recursive, i.e., the *contents* field of one frame consists of the entire *identifier*, *length*, and *contents* of each of the constituent parts. The use of ASN.1 and DER encoding has three principal advantages: interoperability of data types, efficient parsing using the *identifier, length, contents* structure, and extensibility while providing backward compatibility for legacy implementations. The DER encoding can also impose a data size (and therefore bandwidth) penalty, however. Each tag and length represents overhead, and if the value fields are short the overhead can be significant. In some cases, notably the `Basic Safety Message`, some of the flexibility of DER encoding is sacrificed in the name of bandwidth efficiency. The next subsection describes the Basic Safety Message use case in more detail.

Case Study—The Basic Safety Message: The BSM is perhaps the most important message in the J2735 standard. It conveys core state information about the sending vehicle, namely its position, dynamics, system status, and size. It also has the flexibility to convey additional information as needed. There has been extensive research into the content of safety messages for collision avoidance [9]. This research demonstrated that although there are many distinct collision avoidance applications, there is a significant overlap in the state information that each application in a receiving vehicle needs from its neighbors. This commonality led to the definition of the BSM for support of all V2V safety applications, rather than defining a group of application-specific messages.

The common requirements only go so far, however. The BSM has two parts. Part I includes critical state information that must be sent in every BSM. The data structure for Part I emphasizes compactness and efficiency. Part II is an optional area where additional data elements and frames can be included. Part II provides three forms of flexibility: 1) inclusion of some data types at a frequency less than the overall BSM rate; 2) evolution in the definition of new state information (e.g., from new types of sensor) and new applications; and 3) customization of messages to include company-specific features.

Table 8 lists the content of the BSM Part I, which is present in every BSM transmission. The first column of the table uses the official data structure terminology from the standard. The constituents of Part I are an exception to the recursive encoding rule mentioned above. There is a heightened sensitivity to the bandwidth consumed by BSMs in general and Part I of BSMs in particular. For that reason, the constituent pieces of the BSM Part I are not individually DER-encoded, since the identifier and length would add at least two bytes for each. The content shown in Table 8 consumes 39 bytes, and DER-encoding the individual items would add approximately equal overhead. So, instead DER-encoding is applied to just two items. The `DSRC_MessageID` must be separately DER-encoded because it is parsed independent of the rest of the content. The remainder of Part I is defined as one complex element (called the `BSM_blob`), to which one DER tag and length are applied. The components of the `BSM_blob` are of fixed length and known order, so there is no need for each component to have an explicit *identifier* and *length*.

Table 8 SAE J2735 DSRC Basic Safety Message Part I

Data item name, Element/Frame, and length	Description
DSRC_MessageID element, 1 byte	The first element in every message, used by the parser to determine how to parse the rest of the message
MsgCount element, 1 byte	A sequence number, incremented with each successive transmission of a **BSM** by a given vehicle, used primarily to estimate packet error statistics.
TemporaryID element, 4 bytes	A value chosen randomly and held constant for a few minutes, it helps a receiver correlate a stream of **BSMs** from a given sender.
DSecond element, 2 bytes	The current time, modulo one minute, with resolution 1 millisecond.
Latitude, Longitude 2 elements, 4 bytes each	Geographic latitude and longitude, with resolution 1/10 microdegree.
Elevation element, 2 bytes	Position above or below sea level, resolution 0.1 meter.
PositionalAccuracy frame, 4 bytes	Conveys the one-standard-deviation position error along both semi-major and semi-minor axes, and the heading of the semi-major axis.
TransmisionAndSpeed frame, 2 bytes	3 bits encode vehicle transmission (gear) setting. 13 bits convey unsigned vehicle speed, resolution 1 cm/second.
Heading element, 2 bytes	Compass heading of vehicle's motion, resolution 1/80 degree.
SteeringWheelAngle element, 1 byte	Current position of the steering wheel, resolution 1.5 degree. Clockwise rotation is a positive angle.
AccelerationSet4Way frame, 7 bytes	Provides longitudinal acceleration, lateral acceleration, vertical acceleration, and yaw rate.
BrakeSystemStatus frame, 2 bytes	Conveys whether or not braking is active on each of four wheels, also conveys the status of the following control systems: Traction Control, Anti-Lock Brakes, Stability Control, Brake Boost, and Auxiliary Brakes.
VehicleSize frame, 3 bytes	Vehicle length and width, resolution 1 cm.

There are four data items that are most often discussed for inclusion in Part II of the BSM. These are collected in a data frame called VehicleSafetyExtension, which is shown in Table 9. A given BSM may include the VehicleSafetyExtension frame or not, and a given VehicleSafetyExtension frame may be composed of any combination of the four data items shown. The first item reports the occurrence of one or more "events," and is included in the message only when there is at least one event. The remaining three items are considered necessary for the operation of some safety applications (see Annex C.8 of [6]), but they are not required to be updated as frequently as the Part I data, so they are not included in every BSM. The PathHistory and RTCMcorrections fields can also be quite lengthy. The sub-rate necessary for each of these items is an open research question, and is expected to be addressed in SAE J2945.1 (see below).

Table 9 VehicleSafetyExtension Data Frame, Required for Some Safety Applications, Sent in Part II of Some BSMs

Data item name, Element/Frame, and length	Description
EventFlags element, 2 bytes	An optional set of bit flags, each of which can convey the occurrence of a given "event." A given event may be flagged only if a set of minimum activation criteria are met. Examples include: Hard Brake, Hazard Lights, Emergency Response Vehicle, Stop Line Violation
PathHistory frame, variable length (typically on the order of 20 bytes for a straight path and less than 100 bytes for a curved path)	Used to convey where a vehicle has been, in the form of individual data structures sometimes called "Bread Crumbs." Each bread crumb includes a prior position, and optionally time and position accuracy. **PathHistory** is useful in identifying lane level information in the absence of map data. The number of bread crumbs in a frame is a function of the degree to which the actual path can be represented in piecewise linear fashion.
PathPrediction frame, 3 bytes	Indicates the path that a sender expects to traverse. 2-byte radius of curvature and 1-byte prediction confidence.
RTCMPackage frame, variable	Conveys GPS correction data in the RTCM style. Variable length depends on number of satellites in view.

B. SAE J2945.1 Minimum Performance Requirements

The SAE DSRC committee realized that specification of the message format was not sufficient to ensure interoperability of V2V safety applications. Additional rules are required, and the SAE J2945.1 *DSRC Vehicle BSM Communication Minimum Performance Requirements* (MPR) draft standard [7] is being developed to document those rules. This work is in its early stages. A first version is expected to be published as a "recommended practice" in 2011, with more complete "standard" versions to follow as V2V safety systems approach deployment. In the long term this is expected to be part of a series of J2945.x standards, each of which addresses MPR for a given message or group of similar messages.

The motivation for J2945.1 is to define additional constraints on a BSM sender, beyond syntax and semantics, such that a receiver will know enough to provide effective driver warnings for collision prevention. The initial areas that J2495.1 is expected to address are:

BSM Sending Rate: A key question is how often a vehicle should send BSMs. BSMs that are sent too frequently add to channel load with little marginal benefit. BSMs that are sent too infrequently may fail to provide information in a timely manner needed to provide driver warnings. Constraints may be needed for both a maximum and minimum message rate. This is complicated for a number of reasons:

- Ideally these constraints would be a function of safety application performance, but 1) there are no standardized safety applications, and 2) even for prototype applications it is very difficult to translate application level performance into message rates (or into other J2945.1 constraints, like sensor accuracy). For example, some simple applications may be able to provide an effective driver warning based on the reception of a single message in a critical time window, while others may require receipt of two or more messages before providing a warning.

- The optimal message rate will depend on the physical characteristics of the communication channel, which vary widely and change rapidly.
- The optimal message rate will also depend on the ability of a receiver to model the sender's position between messages, and thus on the sender's dynamics. An approach to varying sending rate based on dynamics is described in [33].
- If a vehicle is running a standardized adaptive message rate control algorithm to control congestion [34], [35], it would be desirable to allow a wider range of rates than if the vehicle is permitted to choose any allowed rate at any time.

As noted in the J2735 discussion, Part I is included in every BSM, but Part II elements are optional in SAE J2735. The elements in the `VehicleSafetyExtension` (Table 9) are considered necessary for inclusion on either an event basis or at a rate below the nominal 10 Hz BSM rate. SAE J2945.1 will separately address the minimum and maximum constraints for including these elements in BSMs.

BSM Transmit Power: This is somewhat analogous to message rate in that it affects channel loading (and potential congestion) and application performance. The SAE J2945.1 standard will provide constraints for transmit power, ideally in a way that accounts for the operating environment (e.g., vehicle speed, relevance of application requirements as a function of road type, etc.)

Sensor Accuracy: Most of the data in a BSM represents the output of a sensor, e.g., speed, acceleration, three-dimensional position, time. The receiver uses this to model the sender's relative position. Constraints on sensor data accuracy are needed in order to enable the receiver to provide timely warnings with a sufficiently high probability while avoiding false negatives. This is again complicated by the fact that application performance is difficult to translate to individual sensors. A particularly challenging issue is the absolute accuracy of GPS position data, given that GPS errors may be expected to be correlated near a given location and that relative position is more critical than absolute position for collision prevention. It may also be necessary to specify requirements related to the maximum latency between the capture of sensor data and the transmission of a BSM that conveys that data.

Some additional requirements that may be included in later versions of J2945.1 include Security and Privacy, Certificate Management, BSM PSID assignments, BSM SSP definition, QoS (relative message priority and EDCA parameter selection), and Adaptive Congestion Control. As new interoperability requirements are discovered in other parts of the protocol stack, the J2945.1 standard will be a candidate document for addressing them.

Another open issue is whether J2945.1 will represent a single set of constraints for all BSM-sending devices, or whether it will recognize classes of devices some of which have greater capability (e.g., because they are factory installed and have greater sensor availability) than others. The U.S. DOT and automakers are investigating at least three classes of device in the Safety Pilot Model Deployment [39]: fully integrated, aftermarket, and "Here I Am" (HIA). The HIA devices have no access to internal vehicle state, and derive their safety message contents primarily from GPS signals; they do not have receivers or provide driver warnings. The aftermarket devices will both transmit and receive BSMs, and will have a variety of sensor data capabilities. The aftermarket and HIA devices are expected to accelerate the penetration of DSRC equipment compared to a new-car-only deployment approach, and thus to accelerate the benefits of DSRC.

One final note is that some aspects of V2V safety will likely not be standardized. In particular, automobile manufacturers will define and implement proprietary versions of the safety applications, including the threat assessment algorithms and the important driver-vehicle interface.

VII. CONCLUSION

DSRC technology in the 5.9 GHz band has the potential to support many different types of applications, including collision avoidance applications that can save tens of thousands of lives and billions of dollars in the United States. This technology depends fundamentally on standards-based interoperability. The core standards expected to be used in the U.S. are reaching a critical level of maturity. Several have been published within the past 12 months: IEEE 802.11p, IEEE 1609.3, and IEEE 1609.4 (see Fig. 2). The IEEE 1609.2 Security Services standard is likely to be published near the end of 2011. A preliminary version of SAE J2945.1 Minimum Performance Requirements may also be published in 2011, with more substantial revisions expected soon after. Recent testing of basic interoperability among independent DSRC implementations is encouraging [14].

NHTSA plans to decide in 2013 whether to use regulations to require or encourage deployment of DSRC safety systems in new vehicles in the United States [8]. That decision will be based on a variety of factors, including an objective benefits assessment. While the status of standards today is healthy, a number of challenges remain. Some of the most critical are as follows.

- Development of SAE J2945.1 Vehicle BSM Communication Minimum Performance Requirements, to specify BSM rate and power constraints, as well as position and sensor accuracy requirements.

- Development of a "communications security" framework to supplement the algorithms and frame formats specified in IEEE 1609.2. This framework will define aspects of the public key infrastructure (PKI) over which vehicles will be provided security certificates and certificate revocation notices, as well as a means by which the security infrastructure can be notified if a vehicle detects a misbehaving device. Some aspects of this framework may be documented in IEEE 1609.2, while others will be captured in government regulations. The V2V-Communications Security project is investigating these issues and proposing solutions [36]. The proposals will be tested in the V2V-Interoperability project [13].
- Development of a Channel Congestion Control algorithm, especially for the safety channel. While DSRC congestion will not be a problem in the early stages of deployment, the long life cycle of vehicles suggests that even the initial in-vehicle devices have a capability to react to channel congestion by mitigating their own contribution. This capability can then be refined with experience. Congestion control is likely to be standardized eventually, perhaps in SAE J2945.1.
- Policy and Business issues, many of which will not require technical standardization but which nevertheless are important for deployment, including: enforcement of regulations and standards, certification of devices, clarification of use of Channel 172 (see Section V-A), field testing and analysis of field data to prove benefits, a decision regarding the potential subsidy of equipment to promote fast market penetration, and harmonization of standards between the United States and other regions of the world. ■

REFERENCES

[1] *Vehicle Safety Communications Project—Final Report*, U.S. Dept. Trans., Nat. Highway Traffic Safety Admin., Rep. DOT HS 810 591, Apr. 2006.

[2] *IEEE Standard for Information Technology—Telecommunications and Information Exchange Between Systems—Local and Metropolitan Area Networks—Specific Requirements; Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications; Amendment 6: Wireless Access in Vehicular Environments*, IEEE Std. 802.11p, Jul. 2010.

[3] *Draft Standard for Wireless Access in Vehicular Environments—Security Services for Applications and Management Messages*, IEEE P1609.2/D9.0, May 2011.

[4] *IEEE Standard for Wireless Access in Vehicular Environments—Networking Services*, IEEE Std. 1609.3-2010, Dec. 2010.

[5] *IEEE Standard for Wireless Access in Vehicular Environments—Multi-Channel Operation*, IEEE Std. 1609.4-2010, Dec. 2010.

[6] *Dedicated Short Range Communications (DSRC) Message Set Dictionary*, SAE Std. J2735, SAE Int., DSRC Committee, Nov. 2009.

[7] *Draft DSRC Message Communication Minimum Performance Requirements—Basic Safety Message for Vehicle Safety Applications*, SAE Draft Std. J2945.1 Revision 2.2, SAE Int., DSRC Committee, Apr. 2011.

[8] R. Resendes, "Vehicle-to-vehicle and safety pilot," in *Proc. U.S. Department of Transportation Safety Workshop*, Jul. 20, 2010. [Online]. Available: http://www.its.dot.gov/presentations/Safety_workshop2010/Vehicle-toVehicle%20and%20Safety%20Pilot%20-%20R%20Resendes.pdf

[9] *Vehicle Safety Communications—Applications VSC-A, First Annual Report*, U.S. Dept. Trans., Nat. Highway Traffic Safety Admin., Rep. DOT HS 811 073. [Online]. Available: http://www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/2008/811073.pdf

[10] *Intelligent Transportation Services Report and Order*, U.S. Federal Communications Commission, R&O FCC 99-305, Oct. 21, 1998.

[11] *Dedicated Short Range Communications Report and Order*, U.S. Federal Communications Commission, R&O FCC 03-324, Dec. 17, 2003.

[12] *Amendment of the Commission's Rules Regarding Dedicated Short-Range Communication Services in the 5.850–5.925 GHz band (5.9 GHz band)*, U.S. Federal Communications Commission MO&O, FCC 06-110, adopted Jul. 20, 2006.

[13] *Interoperability Issues of Vehicle-to-Vehicle Based Safety Systems Project (V2V-Interoperability), Project Order 0004, Technical Proposal Statement of Work*, U.S. Dept. Trans., Nat. Highway Traffic Safety Admin., Cooperative Agreement DTNH22-05-01277, Dec. 2009.

[14] *Draft First Annual Report: Interoperability Issues of Vehicle-to-Vehicle Based Safety Systems Project (V2V-Interoperability); Vehicle Safety Communications 3 (VSC3) Consortium*, submitted to U.S. Dept. Trans., Jan. 2011.

[15] H. Hartenstein and K. Laberteaux, Eds., *VANET: Vehicular Applications and Inter-Networking Technologies.* Wiley, 2010.

[16] *IEEE Standard for Information Technology—Telecommunications and Information Exchange Between Systems—Local and Metropolitan Area Networks—Specific Requirements; Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications*, IEEE Std. 802.11-2007, Jun. 2007.

[17] *Standard Specification for Telecommunications and Information Exchange Between Roadside and Vehicle Systems—5 GHz Band Dedicated Short Range Communications (DSRC) Medium Access Control (MAC) and Physical Layer (PHY) Specifications*, ASTM E2213-03, ASTM International, Aug. 2003.

[18] *Code of Federal Regulations, Title 47, Part 90, Private Land Mobile Radio Services*, U.S. FCC, CFR 47 Part 90. [Online]. Available: http://www.access.gpo.gov/nara/cfr/waisidx_08/47cfr90_08.html

[19] *Code of Federal Regulations, Title 47, Part 95, Personal Radio Services*, U.S. FCC, CFR 47 Part 95. [Online]. Available: http://www.access.gpo.gov/nara/cfr/waisidx_08/47cfr95_08.html

[20] D. Jiang, Q. Chen, and L. Delgrossi, "Optimal data rate selection for vehicle safety communications," in *Proc. 5th ACM Int. Workshop on Veh. Inter-NETworking (VANET 2008)*, San Francisco, Sep. 2008.

[21] F. Bai, D. Stancil, and H. Krishnan, "Toward understanding characteristics of Dedicated Short Range Communications (DSRC) from a perspective of vehicular network engineers," in *Proc. Sixteenth Annu. Int. Conf. Mobile Comput. Networking (MobiCom)*, Chicago, IL, Sep. 2010.

[22] V. Rai, F. Bai, J. Kenney, and K. Laberteaux. (2007, Jul.). *Cross-Channel Interference Test Results: A Report From the VSC-A Project*, IEEE 802.11 WG submission 11-07-2133-00-000p. [Online]. Available: https://mentor.ieee.org/802.11/dcn/07/11-07-2133-00-000p-cross-channel-interference-test-results-a-report-from-the-vsc-a-project.ppt

[23] *IEEE Standard for Information Technology—Telecommunications and Information Exchange Between Systems—Local and Metropolitan Area Networks—Specific Requirements; Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Amendment—Fast Initial Link Setup*, IEEE P802.11ai, Dec. 2010, Project Authorization Request (PAR).

[24] J. Hui and M. Devetsikiotis, "A unified model for the performance analysis of IEEE 802.11e EDCA," *IEEE Trans. Commun.*, vol. 53, no. 9, pp. 1498–1510, Sep. 2005.

[25] A. Banchs, A. Azcorra, C. Garcia, and R. Cuevas, "Applications and challenges of the 802.11e EDCA mechanism: An experimental study," *IEEE Network*, vol. 19, no. 4, pp. 52–58, Jul.–Aug. 2005.

[26] *IEEE Standard for Information Technology—Telecommunications and Information Exchange Between Systems—Local and Metropolitan Area Networks—Specific Requirements: Part 2: Logical Link Control*, IEEE Std. 802.2, May 1998, 1998 Edition (R2003), Also adopted by the ISO/IEC and redesignated as ISO/IEC 8802-2:1998.

[27] *IEEE Standard for Local and Metropolitan Area Networks: Overview and Architecture*, IEEE Std. 802-2001, Feb. 2002.

[28] J. Postel and J. Reynolds, *A Standard for the Transmission of IP Datagrams Over*

IEEE 802 Networks, Internet Engineering Task Force RFC 1042, Feb. 1988.

[29] *Draft Standard for Wireless Access in Vehicular Environments—Architecture*, IEEE P1609.0/D0.9, Apr. 2010.

[30] *Draft Standard for Wireless Access in Vehicular Environments—Provider Service Identifier (PSID) Allocations*, IEEE P1609.12/D0.3, May 2011.

[31] K. Hong, J. Kenney, V. Rai, and K. Laberteaux, "Evaluation of multi-channel schemes for vehicular safety communications," in *Proc. 3rd IEEE Int. Symp. Wireless Veh. Commun. (WiVEC 2010)*, Taipei, May 2010.

[32] M. Torrent-Moreno, J. Mittag, P. Santi, and H. Hartenstein, "Vehicle-to-vehicle communication: Fair Transmit Power Control for safety-critical information," *IEEE Trans. Veh. Technol.*, vol. 58, no. 7, Sep. 2009.

[33] C. Huang, H. Krishnan, R. Sengupta, and Y. Fallah, "Implementation and evaluation of scalable vehicle-to-vehicle transmission control protocol," in *Proc. Second IEEE Veh. Networking Conf. (VNC 2010)*, Dec. 2010.

[34] D. Jiang and T. Tielert, "PULSAR: A rate adaptation based congestion control protocol for vehicle safety communication," submitted to *8th ACM Int. Workshop on Veh. Inter-NETworking (VANET 2011)*, Las Vegas, Sep. 2011.

[35] A. Weinfield, J. Kenney, and G. Bansal, "An adaptive DSRC message transmission interval control algorithm," accepted for *Proc. ITS World Congr. 2011*, Oct. 2011.

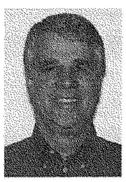
[36] *V2V-Communications Security Project Technical Proposal Statement of Work*, U.S. Dept. Trans., Cooperative Agreement DTFH61-01-x-00014, Dec. 2009.

[37] *Security in VSC-A, Submission to IEEE 1609 WG from Vehicle Safety Communications 2 (VSC2) Consortium*, Jun. 2009. [Online]. Available: http://vii.path.berkeley.edu/1609_wave/jun09/presentations/VSC/VSCA-1609_ecdsa_privacy_final_6_15_2009.ppt

[38] *Information Technology—ASN.1 Encoding Rules: Specification of Basic Encoding Rules (BER), Canonical Encoding Rules (CER) and Distinguished Encoding Rules (DER)*, ITU-T Recommendation X.690, Nov. 2008.

[39] *Connected Vehicle Safety Pilot Frequently Asked Questions*, U.S. DOT Res. Innovative Technol. Admin. [Online]. Available: http://www.its.dot.gov/research/safety_pilot_faq.htm

ABOUT THE AUTHOR



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He joined the Tellabs Research Center in 1983, where he was a Senior Research Engineer until 2007. He was Adjunct Assistant Professor of Electrical Engineering at Notre Dame from 1989 to 2010. From 2007 to 2010, he was a Consultant for Toyota Motor Engineering & Manufacturing North America (TEMA) and Toyota InfoTechnology Center, USA. He joined Toyota InfoTechnology Center USA in 2010 (Mountain View, CA), where he is Senior Research Manager in the Network Group. He represents Toyota in cooperative projects between the Vehicle Safety Communication (VSC) consortium and the U.S. Department of Transportation: VSC-Applications (2007–2009), VSC-Interoperability (2010–2012), and VSC-Communications Security (2010-12). He also represents Toyota in DSRC-related standards groups: IEEE 802.11 Working Group (WG), IEEE 1609 DSRC WG, SAE DSRC Technical Committee, and ETSI TC ITS. He is the author of the "Standards and Regulations" chapter in *VANET: Vehicular Applications and Inter-Networking Technologies* (Hartenstein and Laberteaux, Eds., Wiley, 2010). He is Co-General Chair of the Eighth ACM VANET Workshop (part of MobiCom 2011). His current research is in wireless congestion control and performance of vehicular networks. His prior research interests include adaptive systems, high speed packet switch architectures, and packet network quality of service.

Dr. Kenney was recognized by the IEEE Standards Association for his contributions to IEEE Standards 802.11p-2010, 1609.3-2010, and 1609.4-2010.

Responses by Dr. Christopher P.L. Barkan

HOUSE COMMITTEE ON SCIENCE, SPACE, AND. TECHNOLOGY
SUBCOMMITTEE ON RESEARCH AND TECHNOLOGY

"The Future of Surface Transportation"
June 18, 2014 Hearing

Christopher P.L. Barkan, PhD, Professor and George Krambles Faculty Fellow
Executive Director, Rail Transportation and Engineering Center-RailTEC
University of Illinois at Urbana-Champaign

Questions for the Record from Rep. Larry Bucshon
Chairman, Subcommittee on Research and Technology

1) What are any proposed changes you would recommend to the existing UTC program, including how UTC program competitions are administered? Why would you recommend these changes?

Questions for the Record from Rep. Dan Lipinski
Ranking Member, Subcommittee on Research and Technology

This Committee has long been concerned with the balance of long-term versus short-term transportation research. While short-term R&D is essential for addressing current needs and opportunities, the big breakthroughs in safety and efficiency won't happen without a dedicated source of funding for longer-term, exploratory research. Universities such as your own are the place where longer-term research happens, but because of your partnerships with the public and private players on the operational side, you also face pressures to address short-term R&D needs.

2a) Where does your own match come from? How does the matching requirement influence your discretion to pursue long-term research projects that may not be in-line with your partners' applied research priorities?

2b) Do you have any general recommendations for how the UTC program can best address the balance between the shorter and longer-term research needs? Are they doing a good job of that already?

Questions for the Record from Zoe Lofgren
Member, Subcommittee on Research and Technology

Unfortunately, I was unable to attend this important hearing. As we approach a Surface Transportation reauthorization, a sustained effort on Transportation research and development will help inform and improve our transportation policy. The Mineta Transportation Institute, at San Jose State University in my district, has been providing high quality research and training in focusing on multimodal surface transportation policy and management since 1991.

3) As an expert in rail transportation and research, what elements would you recommend be considered or included in possible Surface Transportation Reauthorization legislation, to ensure a vibrant and effective rail network in this country in the coming decades?

Responses to Questions for Christopher P.L. Barkan
University of Illinois at Urbana-Champaign

Questions for the Record from Rep. Larry Bucshon
Chairman, Subcommittee on Research and Technology

1) What are any proposed changes you would recommend to the existing UTC program, including how UTC program competitions are administered? Why would you recommend these changes?

The strictly competitive process for UTC selection should be continued. It helps ensure that UTC awards are based on merit and that the best quality research and educational programs are being supported, thereby maximizing the value provided to the US DOT and taxpayers. This has obvious near term benefits in terms of the quality of the research and educational results provided, but there are longer-term benefits as well. Merit-based selection encourages the most talented faculty to develop expertise in transportation and develop career-long programs of research and teaching, and through them, it similarly encourages their students, with the attendant benefits from their career paths. A high-caliber body of intellect among both faculty and students, many of whom will enter the transportation field, will prepare us to address present and future transportation challenges and offer benefits for decades to come.

The UTC legislative language should clearly support a multi-modal focus. The US passenger and freight transportation system is a complex, multimodal system. Each mode has important individual characteristics, technologies and operational factors that must be mastered in order to use them to maximum advantage. Furthermore, each mode interacts with and indeed may depend on others in a variety of important ways. In addition, the transportation system operates and interacts at multiple scales – urban, regional, national and international – with challenges at each. The UTC legislative language should recognize this as well. Finally, there are numerous transportation principles that transcend individual modes. The UTC system should have the flexibility to address all of these approaches by encouraging centers to focus on individual modes, intermodal interaction and/or transportation principles. All are valid approaches to advancement of US transportation technology, infrastructure, operations and policy. These varied approaches to transportation research and education should not be viewed as dichotomous alternatives, but rather as complementary parts of an integrated transportation system.

Related to this, the UTC program should allow centers the latitude to take maximum advantage of their strengths addressing the often inter-related U.S. DOT strategic goals, rather than artificially partition them according to specific DOT strategic goals. It should also allow for additional centers beyond the core program to be funded by other government agencies.

UTCs should be funded on six-year contracts, rather than two year, as has been the case in the past two competitions. Competing every two years places substantial "overhead" on both center consortia members and US DOT review staff alike. Even more important in terms of achieving UTC program goals, this would allow universities to take a strategic view of their programs including development of faculty expertise, research deliverables and other "value added" products of the centers.

Development of a quality UTC proposal is a substantial undertaking for faculty and staff in UTC consortia, and conducting thorough reviews is an equally burdensome activity for US DOT staff. In the last competition approximately 150 proposals were submitted, all of which had to be prepared and then reviewed in a relatively short period of time. The administrative burden associated with this process is substantial for all parties involved.

A better approach would be to stagger the competition so that in any two-year cycle only one third were being prepared and reviewed. Some have suggested organizing the competitions according to the three current types: Regional, National and Tier 1, with each group competing every two years; however, an alternative approach that might allow better flexibility and responsiveness to changing transportation dynamics and needs of the nation would be to hold a competition for one third of each type every two years. However, either approach would be a considerable improvement over the recent pattern.

Apart from the "traditional" pattern of UTC proposal competitions, Congress should consider expansion of the program, but not necessarily with more of the same. Rather, it might consider two new (to DOT at least) approaches to take better advantage of the intellectual resources of the academic community it is helping to develop.

One is to further incentivize centers to succeed by offering follow-on or expanded resources for centers that are particularly successful in some important or high-impact aspect of their stated mission. So a center that was having particular success forming a successful coalition and achieving objectives in an area that DOT believes is particularly important would have the opportunity to submit a proposal for additional funding to expand its activities in that area.

A second additional approach would be for US DOT to have the discretion to offer special additional funding for work on particular, focused topic areas that are a major problem or opportunity for an individual mode, or some cross-modal topic. These would be highly goal-oriented with a clear focus on solving some problem of great significance in some aspect of transportation. These might be short or long term projects.

In both of the two approaches above, the funding might come from the US DOT OST, or from one of the specific modal agencies as appropriate to the opportunity or problem being addressed.

The UTC program will yield better results if constraints on partnerships were relaxed or removed. Universities often have highly diverse talent and expertise in different departments. A successful UTC program will enable the very best expertise to be brought to bear on specific DOT goals by any given UTC coalition. Inter-university collaboration that takes full advantage of complementary expertise amongst faculty from different colleges and universities should be encouraged, rather than artificially interfered constrained.

Somewhat related is that the role, mission and goals of the different types of centers – Regional, National and Tier 1 – should be more clearly articulated by DOT. What is the vision for each type of center? How do they relate to one another? Why should consortia pursue one type of center versus another? In short what is the philosophy of the three types and how do they fit into the larger goals of the US DOT?

Questions for the Record from Rep. Dan Lipinski
Ranking Member, Subcommittee on Research and Technology

This Committee has long been concerned with the balance of long-term versus short-term transportation research. While short-term R&D is essential for addressing current needs and opportunities, the big breakthroughs in safety and efficiency won't happen without a dedicated source of funding for longer-term, exploratory research. Universities such as your own are the place where longer-term research happens, but because of your partnerships with the public and private players on the operational side, you also face pressures to address short-term R&D needs.

Academic research should be broad in its coverage, ranging from short-term to long-term projects, and along the spectrum from applied to basic. These two axes for research (short-term/long-term and applied/basic) are not synonymous and each has a vital role to play that Congress should recognize. I will address both in my reply.

With regard to basic versus applied research, an intellectually diverse academic research community is beneficial to all, faculty, students, sponsors and society in general. This does not mean that all faculty are involved in all types and ends of the spectrum; what it means is that a strong academic research environment will include significant elements of both, and all things in between. Exposure to applied problems often inspires new insights that advance basic science, and as a complement to this, basic scientific advancements have a rich history of providing solutions to applied problems. The US has a distinguished history of post-war support for basic research that is a critically important part of our ascendency to the top echelon of global science, technology and engineering. Our nation has prospered because of this position of international leadership for the past 70 years. For much of this time, global competition for this position was relatively limited; however, this is no longer the case and our academic and research programs must be cognizant of these challenges and continue to invest in both the advancements and the intellects that will be needed if the US is to remain in the forefront.

By its nature, transportation is multi-disciplinary so it draws from many different fields. It has benefited both directly and indirectly from US research investments in a broad range of scientific, engineering and other fields. When one considers the spectrum of basic to applied research, many of the challenges being addressed in transportation are adapting knowledge developed elsewhere to solve problems or exploit opportunities unique to transport, rather than inventing wholly new fundamental knowledge. Therefore, research funding is generally closer to the applied end of the spectrum than the purely fundamental. That said, research funded by modal agencies, state DOTs and much of the private sector is often constrained to be at the highly applied end of the spectrum, and often requires short-term returns on investment. Research closer to the middle of the spectrum between purely basic and purely applied is where the funding gap exists.

Filling this gap is a critically important role of the UTC program. UTC funding should allow researchers to explore concepts that address important topics that may not have obvious near-term payoffs but may have longer-term potential. It should also be used where there are opportunities to advance more fundamental principles of transportation, even if the ultimate application is not yet obvious, as long as the questions being addressed can be demonstrated to be of fundamental importance to our understanding of how transportation systems function from a technological and institutional viewpoint and how they relate to critical contemporary issues (energy and environmental issues, economic development and so forth)

With regard to short-term vs. long-term projects, this speaks to the scale of the problem being addressed. Some major problems are so complex that they may require years of focused work by highly skilled experts. Rather than address these through "conventional" research programs, specifically targeted, multi-year research programs with the goal of solving these problems should be instituted in transportation, as has successfully been done in other disciplines.

2a) Where does your own match come from? How does the matching requirement influence your discretion to pursue long-term research projects that may not be in-line with your partners' applied research priorities?

Within the NURail consortium, our matching funds come from a variety of external private and public sector sources, as well as internal campus resources. Each of our partners has different options and campus policies governing how they meet the match requirement in compliance with US DOT requirements. Some of the match comes from gifts, endowments, donations or other campus resources that generally do not constrain the use of the funds toward near-term, applied research. In other cases, funds may come from state DOT or private sector funds. Depending on the specific source of these funds and the objectives of the particular sponsor, they may or may not constrain their use.

It should be mentioned that although the UTC requirement for matching funds may sometimes constrain research for some researchers, there are benefits as well. For example, some focus on near-term, applied projects helps strengthen the bond between the academic and the transportation practitioner communities for reasons discussed above. It enhances the practitioner community's perception of the value of academic contributions to transportation in general and the UTC program in particular. Furthermore, faculty and student exposure to practical problems may inspire new insights and research on more fundamental problems. Engagement with the practitioner community is also consistent with the UTC's work force development objectives because it supports and encourages broadening of faculty understanding of the field, thereby making them more effective as researchers and teachers. It also encourages student engagement with the practitioner community, making them more knowledgeable and competitive for employment in the transportation work force after they complete their studies.

I cannot speak for the UTC program in general but a poll of the NURail consortium member principal investigators had no significant problems with DOT constraints imposed by the match requirements. It was also evident that how individual school administrations respond to the match requirement from DOT varies widely and some approaches are more advantageous to the UTC member, its faculty and achievement of UTC goals than others.

2b) Do you have any general recommendations for how the UTC program can best address the balance between the shorter and longer-term research needs? Are they doing a good job of that already?

Probably the best way to address this is for DOT (and whatever legislation that governs their approach) to be as flexible as possible in how UTC schools can apply and use matching funds. A specific example might be if federal funds from another agency whose mission is focused on basic research, such as the National Science Foundation, are being used for more fundamental research directly related to a particular UTC project, then these might be a permissible match.

It would be helpful to clarify that longer-term, basic research is a valid, stated objective as part of a spectrum of research activities for UTCs. A lot of emphasis is placed on performance goals at the applied end of the spectrum, such as Technology Transfer. Although some projects should be able to respond to the applied aspect of the UTC mission, not all should be required to and indeed, by definition, some basic, longer term research will not. If the DOT and Congress wish to have a diverse portfolio along a broad spectrum of applied versus basic research (as I believe that they should), then that should be unambiguously stated in solicitations for proposals and in the metrics used to assess UTC performance.

Questions for the Record from Zoe Lofgren
Member, Subcommittee on Research and Technology

Unfortunately, I was unable to attend this important hearing. As we approach a Surface Transportation reauthorization, a sustained effort on Transportation research and development will help inform and improve our transportation policy. The Mineta Transportation Institute, at San Jose State University in my district, has been providing high quality research and training in focusing on multimodal surface transportation policy and management since 1991.

3) As an expert in rail transportation and research, what elements would you recommend be considered or included in possible Surface Transportation Reauthorization legislation, to ensure a vibrant and effective rail network in this country in the coming decades?

Let me begin by briefly addressing the importance of transportation research in general. As the Committee understands, transportation is fundamentally important to the US. Approximately 10% of our nation's economy is directly related to transportation activities, which have a major impact on public safety, economic competitiveness, energy efficiency and environmental sustainability. Yet despite its magnitude, research expenditures to improve transportation are far lower than other major sectors of the economy as a percentage of revenues. Because of its size, even small improvements in the transportation system can be quite important, and the impact of breakthrough improvements can be substantial

Within transportation, rail has an even smaller ratio of research expenditures to revenues than other modes. In light of its current importance, and anticipated growth, the first thing that is needed is substantial expansion of the nation's rail research program. This should be a well-crafted, strategic rail research program that thoroughly engages stakeholders at all levels including the private and public sector rail industry, state DOTs, academia and others.

The US DOT has defined 'high-performance rail' as *"a passenger and freight rail network that is designed to meet the current and future market demands for transportation of people and goods, in terms of capacity, travel times, reliability, and efficiency."* I agree with this definition and its emphasis on both freight and passenger rail transport, and would underscore the importance of achieving this with a very high level of safety. The US lags behind much of the rest of the world in its passenger rail system, but is a world leader in rail freight transport. The most important technical and policy challenge facing US railroads is how to continue to improve our economically healthy, self-sustaining freight rail system, while at the same time increasing the ability to provide high-quality, sustainable passenger rail transport. Development of both incremental (passenger trains on track shared with freight trains) and very High-Speed Rail (HSR) lines (with right-of-way dedicated to high-speed passenger trains, such as California is developing) in the US poses a number of new challenges related to shared use of infrastructure, operation and policy. Despite more than 50 years of international experience planning, designing, building and operating high-speed passenger rail infrastructure and rolling stock elsewhere in the world, there are numerous questions unique to the North American environment that must be answered if advanced rail technologies are to be successfully implemented.

Consequently, the US has an increasingly urgent need for a substantially expanded body of expertise in rail transport and engineering. We need individuals who understand the fundamental principles of both high-speed (passenger) and heavy axle load (freight) railroading and when and how they may be combined, and when not. This will require a new generation of skilled employees, and the faculty members and programs to educate them and conduct research to further advance the field. As with the Mineta Center, this is a major thrust of the NURail Center, but the efforts of these two centers, and the very limited number of others around the nation are far less than are needed if the nation is to take full advantage of what rail has to offer.

Some specific recommendations include:

1) Congress should support and fully fund the Federal Railroad Administration's (FRA) proposed High-Performance Rail Research and Development (HPRRD) program to ensure that the US advances to the forefront of passenger rail technology, while at the same time maintaining its global leadership in safe and efficient freight rail transport. This includes the National Cooperative Rail Research Program (NCRRP) that launched an important group of projects in 2012 and developed a strategic research plan intended to improve short and long term rail transport (see recent NCRRP Research Results Digest 1). And it should expand FRA's mandate so that it specifically includes rail workforce development at a variety of levels including support for additional or expanded rail-focused UTCs.

2) The Hazardous Materials Cooperative Research Program (HMCRP) was previously authorized and funded and conducted a number of useful projects to improve hazardous materials transportation safety across all modes, including rail. However, it was not reauthorized in MAP-21. Ironically, in an era when newly tapped domestic petroleum energy reserves are offering significant economic and energy independence benefits, but are also raising major questions about how to safely transport these products, the HMCRP no longer has funds to conduct research to address these questions.

3) Beyond what is included in the HPRRD, the FRA and the Association of American Railroads (AAR) have developed strategic research plans that identify many of the most pressing rail safety and technology research needs in the 5 to 20-year time frame. These, along with passenger rail research priorities identified by the American Public Transportation Association (APTA), should be integrated and prioritized to launch a substantially expanded and accelerated FRA research program in cooperation with these organizations and academia. This should not simply include more of the same, but would encompass more research in the intermediate range of the basic-to-applied spectrum, and new, targeted approaches to development of solutions to the most important challenges facing North American rail transport.

Related to this, Congress should recognize that there are some complex, high impact problems and opportunities in rail that are not well addressed by the current programmatic research structure and time constraints. It should consider establishing a new research and development program specifically and exclusively focused on such high impact topics and conducting the research needed to develop and implement solutions. The concept would be to bring together an expert, interdisciplinary team from academia, industry and government and provide them with a clear mandate. They would be given sufficient resources to devote themselves to solving the problem without the distraction of other regular duties. Such big, important projects might take a number of years to complete, but their objective would be to finally solve problems that have lingered for decades. Their long-term impact on safety, productivity or sustainability would make the effort well worth it. Where appropriate, these projects would also have a mandate to develop solutions to eliminate institutional or regulatory barriers that could interfere with implementation.