Connected Vehicles – Improving Safety, Mobility, and the Environment

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U.S. Department of Transportation
Intelligent Transportation Systems Joint Program Office

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Presentation Overview

- Overview of Intelligent Transportation Systems
- Transportation Challenges
- Overview of Connected Vehicle Environment
- Connected Vehicle Research
- Deployment of Connected Vehicle Technology
- Exploratory Research
- Vehicle Automation Research
Overview of Intelligent Transportation Systems
What is ITS?

Information and communications technology to manage and operate surface transportation systems.

- Transaction Automation
- Decision Information
- System Control
The ITS JPO has Department-wide authority in coordinating the ITS program and initiatives among the following DOT Offices:

- Federal Highway Administration (FHWA)
- Federal Motor Carrier Safety Administration (FMCSA)
- Federal Transit Administration (FTA)
- Federal Railroad Administration (FRA)
- National Highway Traffic Safety Administration (NHTSA)
- Maritime Administration (MARAD).
Transportation Challenges

Safety
32,367 highway deaths in 2011
5.3 million crashes in 2011
Leading cause of death for ages 4, 11–27

Mobility
5.5 billion hours of travel delay
$121 billion cost of urban congestion

Environment
2.9 billion gallons of wasted fuel
56 billion lbs of additional CO₂
Overview of Connected Vehicle Systems
Connected Vehicle Concept

Today Show Segment
Connected vehicles have the potential to address approximately 80% of vehicle crash scenarios involving unimpaired drivers.

- Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication technology and standards
- Enables crash avoidance and other safety applications
- Testing and pilot deployments
- USDOT regulatory decisions
Fully Connected Environment

Vehicle Data:
- Latitude, Longitude, Speed, Brake Status, Turn Signal Status, Vehicle Length, Vehicle Width, Bumper Height

Infrastructure Data:
- Signal Phase and Timing, Speed Guidance, Parking Spaces Available, etc.
Dedicated Short Range Communications Technology

- 5.9 GHz DSRC
- Wi-Fi radio adapted for vehicle environment
- Inexpensive to produce in quantity
- Original FCC spectrum allocation in 1999
- FCC revised allocation in 2004 and 2006
Connected Vehicle Communications Technology: DSRC

- Data is transmitted 10 times/sec (300m range – line of sight)
- Privacy is protected (vehicle location is NOT recorded or tracked)
Benefits of V2V communications....

Uses a single sensor (radio) to receive threat data from all directions

Compared with non-cooperative detection systems (e.g., radar, camera), V2V offers potentially lower cost for more comprehensive situational awareness
**Connected Vehicle Communications Technology: Other Options**

- 4G and older 3G cellular networks provide high-bandwidth data communications over widely deployed commercial networks.
- Increasingly available in vehicles.
- Not suitable for safety applications that require low latency.
- Other wireless technologies such as Wi-Fi, satellite, and HD radio may have roles to play.
### Safety Applications: V2V

**V2V Safety Applications**

<table>
<thead>
<tr>
<th>Application</th>
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<tbody>
<tr>
<td>Forward Collision Warning</td>
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<tr>
<td>Emergency Electronic Brake Light</td>
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<tr>
<td>Blind Spot/Lane Change Warning</td>
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<tr>
<td>Do Not Pass Warning</td>
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<tr>
<td>Intersection Movement Assist</td>
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<td>Left Turn Assist</td>
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</table>
Forward Collision Warning & Lane Change Warning

**FCW**
- Lead Vehicle Stopped
- Lead Vehicle Slower
- Lead Vehicle Decelerating

**LCW**
- Changing Lanes/Same Direction
- Drifting/Same Direction
- Turning/Same Direction

FCW: Forward Crash Warning
LCW: Lane Change Warning
## Safety Applications: V2I

<table>
<thead>
<tr>
<th>V2I Safety Applications</th>
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<tr>
<td>Curve Speed Warning</td>
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<tr>
<td>Red Light Violation Warning</td>
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<tr>
<td>Spot Weather Information Warning</td>
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<tr>
<td>Reduced Speed Zone Warning</td>
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<tr>
<td>Stop Sign Gap Assist</td>
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<td>Smart Roadside</td>
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<td>Transit Pedestrian Warning</td>
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</tbody>
</table>
Curve Warning & Spot Weather Information Warning

Curve Warning

RSE Geometric/Weather Data

Driver Vehicle Interface (DVI) Example

SWIW

Driver Infrastructure Interface (DII) (static or dynamic sign)

RWIS and RSE

Driver Vehicle Interface (DVI) Examples
### Dynamic Mobility Applications

<table>
<thead>
<tr>
<th>Category</th>
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<tbody>
<tr>
<td>Enable Advanced Traveler Information Systems</td>
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<tr>
<td>Intelligent Network Flow Optimization</td>
</tr>
<tr>
<td>Response, Emergency Staging and Communications, Uniform Management, and</td>
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<tr>
<td>Evacuation</td>
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<tr>
<td>Integrated Dynamic Transit Operations</td>
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<tr>
<td>Multimodal Intelligent Traffic Signal Control</td>
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<tr>
<td>Freight Advanced Traveler Information Systems</td>
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</table>

In addition:
- Analytics Test Bed
- Program Evaluation

![Map Image]

*U.S. Department of Transportation*
Dynamic Speed Harmonization

1. Vehicles slowing down at recurrent bottleneck broadcast speed, location, etc.
2. TMC identifies impending congestion and initiates speed harmonization plan for upstream vehicles
3. TMC relays appropriate speed recommendations to upstream vehicles
4. Upstream vehicles implement (or alert drivers to) the recommended speed
Queue Warning

1. Queue condition forms

2. Vehicles broadcast their rapid changes in speed, acceleration, position, etc.

3. Host Vehicle receives data and provides driver with imminent queue warning

4. Driver provided sufficient time to brake safely, change lanes, or even modify route
### Environment Applications: AERIS

<table>
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<tr>
<td>Eco-Signal Operations</td>
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<tr>
<td>Eco-Lanes</td>
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<tr>
<td>Low Emissions Zones</td>
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<tr>
<td>Eco-Traveler Information</td>
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<tr>
<td>Eco-Integrated Corridor Management</td>
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</table>
Eco-Signal Operations

1. SPaT Data
2. I2V Communications: SPaT and GID Messages
3. V2V Communications: Basic Safety Messages
4. Vehicle Equipped with the Eco-Approach and Departure at Signalized Intersections Application (CACC capabilities optional)

Source: USDOT, November 2013

U.S. Department of Transportation
Connected Vehicle Research
# USDOT’s Connected Vehicle Research Program

<table>
<thead>
<tr>
<th>Applications</th>
<th>Safety</th>
<th>Mobility</th>
<th>Environment</th>
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<tr>
<td></td>
<td>V2V</td>
<td>V2I</td>
<td>AERIS</td>
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<td></td>
<td>Safety Pilot</td>
<td>Real Time Data Capture &amp; Management</td>
<td>Road Weather Applications</td>
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### Technology
- Harmonization of International Standards & Architecture
- Human Factors
- Systems Engineering
- Certification
- Test Environments

### Policy
- Deployment Scenarios
- Financing & Investment Models
- Operations & Governance
- Institutional Issues
The purpose of the Ann Arbor test bed was to gather 1 year of data to support the NHTSA decision.

- **Assets**
  - More than 2,800 vehicles (cars, commercial trucks, transit)
  - Integrated Safety Systems, Vehicle Awareness Devices, and Aftermarket Safety Devices
  - 73 lane miles of roadway instrumented with 29 roadside-equipment installations

Source: U.S. DOT/UMTRI
Applications that were tested include:

- Forward Collision Warning
- Electronic Emergency Brake Lights
- Blind Spot Warning/Lane Change Warning
- Intersection Movement Assist
- Do Not Pass Warning
- Left Turn Assist

Safety Pilot: Ann Arbor, MI
The vision is to have multiple interoperable locations as part of one connected system moving toward nation-wide deployment.

- Common architecture
- Common standards
- Independent operations
- Shared resources
Key Objectives of the Affiliated Test Beds

- Harness the abilities of existing researchers and installations to move the technology toward full deployment.
  - Create an organizational structure
  - Share deployment lessons learned
  - Develop a common technical platform
  - Expand test bed options for users
  - Share tools and resources across all facilities
  - Serve as models for future deployments
USDOT Connected Vehicle PlugFests

- Events where devices are tested for interoperability with emerging standards.
- Provide essential feedback to standardization organizations as well as to the developer community.
- Events in 2014:
  - Midwestern PlugFest: March 12-13, 2014, Novi, MI
  - Western PlugFest: June 2014, Palo Alto, CA
  - Bimonthly World Congress Mini-Fests tentatively scheduled for:
    - May 2014 – Novi, MI
    - July 2014 – Detroit, MI
    - Mid-August 2014 – Detroit, MI
  - Hackathon: Early November 2014/January 2015, Novi, MI
Connected Vehicle Pilot Deployment Program

- Synergy among technologies, messages, and concepts
- In pre-deployment development since July 2013
  - First wave of deployments in 2015
  - Program runs through 2020
- Pilots will be *pilot deployments*, that is, real-world environment
  - If successful, deployed technologies are expected to remain as permanent operational elements
- There will be *multiple* pilot deployment sites across the nation
  - Each site may have different needs, focus and applications
  - Performance-driven deployment concepts will *address integrated objectives* related to mobility, safety, and environmental impacts
  - Sites will deploy *multiple applications* drawing on current research
Example Application Bundle to Explore in CV Pilots

- Eco-Traffic Signal Timing
- Dynamic Parking Guidance
- Enhanced Maintenance Decision Support
- Transit Connection Protection
- Drayage Optimization

Results:

- Reduced Emissions
- Reduced Fuel Consumption
- Reduced public agency spending
- Increased Transit Use
- Reduced Emissions from Idling at Ports
Deployment of Connected Vehicle Technology
NHTSA Decision to Move Forward with V2V communication for light vehicles

Safety Pilot in 2013

FHWA Deployment Guidelines

Path to Deployment

Defined V2V Apps
Defined Safety (V2I), Mobility (V2V & V2I), AERIS and Weather Apps
Application Development
Pilots/Early Deployments

2011
2012
2013
2014
2015
2016
USDOT/NHTSA Decision on V2V

- Announced on February 3, 2014 for light vehicles
  - Primary purpose: enable collision warnings to drivers prior to a crash
  - Based on several years of research including the safety pilot model deployment – 3000 vehicle road test in Ann Arbor, Michigan
    - Report pending
  - Security and privacy protections built into contemplated system
    - No exchanging or recording of personal information
    - No tracking of vehicle movements
  - After circulating the research report for public comment, NHTSA will then begin working on a regulatory proposal to require V2V devices in new light vehicles in a future year
  - Decision on heavy vehicles planned at end of 2014
Infrastructure Deployment Planning

- National Connected Vehicle Field Infrastructure Footprint Analysis
- Standardized interfaces
- Certification processes for equipment and systems
- Nationwide Security Credential Management System (SCMS)

2015 FHWA Deployment Guidance
<table>
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<tr>
<th>Deployment Challenges</th>
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<tbody>
<tr>
<td>▪ Aftermarket Devices</td>
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<td>▪ Security</td>
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<td>▪ Spectrum Demands</td>
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<tr>
<td>▪ Communications Congestion Potential</td>
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Aftermarket Devices

- Developed and demonstrated devices that can bring the technology to the existing vehicle fleet in Safety Pilot Model Deployment
  - Aftermarket Safety Devices (Light Vehicles)
  - Vehicle Awareness Devices (Light Vehicles)
  - Retrofit Safety Devices (Trucks/Buses)

- Aftermarket devices allow for the acceleration of benefits
Security Challenges

- Message validity
- Security entity
- Network
- Business models for security operations
Privacy Challenges

- A user cannot be tracked along his journey or identified without appropriate authorization.

- User privacy can be protected further through policy means. We’ve done initial privacy analysis of the system and will have privacy experts do a comprehensive review of any final system proposed for implementation.
5.9 GHz Spectrum Issue

• Federal Communication Commission’s (FCC) Notice of Proposed Rulemaking (NPRM); The FCC is seeking to open up additional spectrum for unlicensed Wi-Fi devices within the 5.9 GHz band which serves as the platform for connected vehicle technology.

• 5.9 GHz Spectrum: The connected vehicle environment that is being researched is based on reliable access to the 5.9 GHz wireless spectrum.

• Spectrum Sharing: Any changes to the 5.9 GHz spectrum may jeopardize crash avoidance capabilities.
Communications Scalability

- Ensure that V2V safety communication protocol(s) that will support large-scale deployment level of vehicles while preserving the performance of V2V safety applications in congested environments
- Tested impacts of 100, 200, and 400 devices all transmitting on the safety applications
- Developing simulations to estimate impacts of larger numbers of devices all within communication range.
Exploratory Research

- Vehicle to Motorcycle
- Vehicle to Pedestrian
- Vehicle Automation
  - Can proceed independently of connectivity to a point
  - Greatly enhanced with connectivity to other vehicles and infrastructure

Benefits of Connectivity
- Increases availability, speed, and reliability of information
- Enables coordination of automated traffic streams

The full potential benefits of road vehicle automation can only be achieved through a connected environment

Source: Continental Automotive Group
Vehicle Automation Research
Some Previous Federal Automated Vehicle Programs

Summer of 1997…

Buicks in San Diego

Sojourner in Ares Vallis
Facilitate development and deployment of automated transportation systems that enhance safety, mobility, and sustainability

Identify benefit opportunities in automated vehicle technology

Invest in research areas that further industry investments and support realization of benefit opportunities

Establish Federal Motor Vehicle Safety Standards (NHTSA)

Ensure a safe transitional period during mixed traffic operations
NHTSA Levels of Automation

- **Level 0**: No-Automation
- **Level 1**: Function-specific Automation
- **Level 2**: Combined Function Automation
- **Level 3**: Limited Self-Driving Automation
- **Level 4**: Full Self-Driving Automation

**Vehicle Control**

**Operator Control**
**Connected and Automated Vehicles**

- **Autonomous Automated Vehicle**
  - Operates in isolation from other vehicles using internal sensors

- **Connected Vehicle**
  - Communicates with nearby vehicles and infrastructure
  - Not automated (level 0)

- **Connected Automated Vehicle**
  - Leverages autonomous automated and connected vehicles
L1 example: Integrate CACC with applications

- Driver advisory and warning applications (presented earlier) with limited control functionality added.

<table>
<thead>
<tr>
<th>CACC</th>
<th>SPD-HARM</th>
<th>Q-WARN</th>
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<tbody>
<tr>
<td><img src="image1" alt="CACC Diagram" /></td>
<td><img src="image2" alt="SPD-HARM Diagram" /></td>
<td><img src="image3" alt="Q-WARN Diagram" /></td>
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</table>

- CACC initiated for upstream traffic in order to maximize carrying capacity of the road as crash is cleared.
- Dynamic speed harmonization initiated for upstream traffic to reduce speed.
- Queue alert immediately provided to following vehicles to prevent secondary crashes.
- Freeway collision occurs and queue forms.
L1 Example: Truck Platooning Research

- Three truck platoon
- 5.9 GHz DSRC Communication
- Longitudinal control only (throttle and brakes) driver, steers the truck
- Vehicles already equipped with production ACC
- Lead truck either manually or automatically (ACC) driven
- Gap is based on time headway – consistent with driver preference

![Diagram of truck platooning with speed and command connections.]
L2/L3 Example: Human Factors Research

Project Objective

- Addresses human factors research questions focused on drivers transitioning into and out of automated driving states enabled by Level 2 and Level 3 automated driving concepts.

Project Deliverable

- Driver-Vehicle Interface Design Principles
Summary

- Connected vehicle technologies have been extensively tested
- Large potential safety benefits
- DSRC radios in all new cars in a few years
- Options for other vehicles and pedestrians
- Partial connected automation offers near term safety, mobility and environmental benefits.
- Research continuing toward vision of fully automated vehicle operations
Questions / Follow-up

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