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November 19, 2015
Entrepreneurship and Transportation
Intelligent Transportation Systems

- What is ITS?
# History of ITS

<table>
<thead>
<tr>
<th>ITS Initiative</th>
<th>Year</th>
<th>Brief description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comprehensive Automobile Traffic Control System (CACS)</td>
<td>1973</td>
<td>Develop and test an in-vehicle dynamic route guidance</td>
</tr>
<tr>
<td>Road/Automobile Communication System (RACS)</td>
<td>1980s</td>
<td>Research, development, and operations for near-term deployment of ITS</td>
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<tr>
<td>Advanced Mobile Traffic Information and Communication System (AMTICS)</td>
<td>1980s</td>
<td>Research, development, and operations for near-term deployment of ITS</td>
</tr>
<tr>
<td>Advanced Road Transportation System (ARTS)</td>
<td>1989</td>
<td>Apply RACS technology to develop next generation traffic systems</td>
</tr>
<tr>
<td>Vehicle Information &amp; Communication System (VICS)</td>
<td>1990</td>
<td>Achieve intelligent coordination between cars and road infrastructure</td>
</tr>
<tr>
<td>Super Smart Vehicle System (SSVS)</td>
<td>1990</td>
<td>Explore concepts and develop technology for fully automatic driving 20 to 30 years</td>
</tr>
<tr>
<td>Vehicle, Road, and Traffic Intelligence Society (VERTIS)</td>
<td>1994</td>
<td>Government supported public-private partnership organization was formed in the ITS</td>
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<td>Prototype dynamic route-guidance system</td>
<td>1980s</td>
<td>Demonstration of route-guidance system in Germany and Britain</td>
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<td>Program for a European Traffic with Highest Efficiency and Unprecedented Safety (PROMETHEUS)</td>
<td>1986</td>
<td>Achieve intelligent vehicle-highway systems through a 8 year program with emphasis on vehicle systems</td>
</tr>
<tr>
<td>Dedicated Road Infrastructure for Vehicle Safety in Europe (DRIVE)</td>
<td>1980s</td>
<td>Advanced transport telematics (ATT) through road infrastructure projects (smart highways)</td>
</tr>
<tr>
<td>System of Cellular Radio for Traffic Efficiency and Safety (SOCRATES)</td>
<td>1989</td>
<td>Delivering ATT services via cellular radio communications</td>
</tr>
<tr>
<td>European Road Transport Telematics Implementation Coordination Organization (ERTICO)</td>
<td>1990s</td>
<td>Public-private organization to coordinate ongoing ATT projects and support implementation in</td>
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<td>Smart Corridor Project</td>
<td>1980s</td>
<td>Demonstration of computer and communication technologies on a freeway corridor</td>
</tr>
<tr>
<td>Pathfinder Experiment</td>
<td>1980s</td>
<td>Measure driver response to real-time in-vehicle traveler information system</td>
</tr>
<tr>
<td>Mobility 2000 Group</td>
<td>1987</td>
<td>Promote the field of Intelligent Vehicle Highway System (IVHS)</td>
</tr>
<tr>
<td>IVHS America</td>
<td>1990</td>
<td>Federal advisory committee to US DOT for the emerging national IVHS program</td>
</tr>
<tr>
<td>IVHS Act</td>
<td>1991</td>
<td>Authorized federal funding to support IVHS programs</td>
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</table>
What is a traffic detector?

- Traffic detector is....

- What parameters it collects:
What is a traffic detector

- Traffic detector is….
  - an integral part of ITS that automatically collects traffic parameters
- Which parameters are collected?
  - Flow
  - Speed
  - Occupancy (Density)
  - Time Headway
  - Vehicle Classification
Occupancy

\[
\% OCC = \frac{\sum_{n=1}^{N} (t_{occ})_n}{T} \times 100
\]

Where \%OCC = percent occupancy time
\[(t_{occ})_n = (t_{off})_n - (t_{on})_n\]
N = number of vehicles detected in time period T
T = selected time period (seconds)

\[
k = \frac{52.8}{\overline{L}_V + L_D} \% OCC
\]

Where k = density (vehicle per lane-mile)
\[\overline{L}_V = \text{average vehicle length (feet)}\]
\[L_D = \text{detection zone length (feet)}\]
\%OCC = percent occupancy time
Examples of Detector Data Applications

- Travel Time Estimation
- Congestion Maps
- Incident Detection
- Traffic Signals
- Ramp Metering
- Enforcement Equipments
- HPMS Program
- Traffic Studies
Modern Traffic Detectors

- **IN-ROADWAY SENSORS** (Intrusive)
  - Embedded in the pavement of the roadway,
  - Embedded in the subgrade of the roadway,
  - Taped or otherwise attached to the surface of the roadway.

- **OVER-ROADWAY SENSORS** (Non-Intrusive)
  - Above the roadway or
  - Alongside the roadway, offset from the nearest traffic lane by some distance.
Modern Traffic Detectors

- Pneumatic
- Magnetic
- Inductive Loop
- Microwave
- Video Image Processing
- Piezoelectric
- Acoustic
- Ultrasonic
- Infrared
Inductive Loop Detectors (ILD)
Inductive Loop Detectors (ILD)

- Presence or passage of a vehicle causes an increase in the oscillation frequency, controller unit logs presence or passage.
Speed Measurement with ILD

Trade-offs for space between detectors:
Speed Measurement with ILD

Trade-offs for space between detectors:

- Long distance:
  - Vehicle Lane Change
- Short distance:
  - Sensor Cross Talk
Magnetic Detectors

- Magnetic sensors are passive devices that indicate the presence of a metallic object by detecting the perturbation (known as a magnetic anomaly) in the Earth’s magnetic field created by the object.
Perturbation of Earth’s magnetic field by a ferrous metal vehicle

(Drawing courtesy of Nu-Metrics, Vanderbilt, PA)
Pneumatic Tube

Changes in tube air pressure, results in an electrical signal, which is used to count axles.
Pneumatic Tube Configuration

Photograph courtesy of Time Mark, Inc., Salem, OR
Microwave Radar (RTMS)

- The Remote Traffic Microwave Sensor (RTMS) is a radar vehicle detector. Capable of measuring the distance to objects by radiated and reflected microwave signals.
Image Processing Detectors
Image Processing Detectors
Modern Traffic Detectors

- Pneumatic
- Magnetic
- Inductive Loop
- Microwave
- Video Image Processing
- Piezoelectric
- Acoustic
- Ultrasonic
- Infrared
Other detection methods

- Cell phones
- GPS
- AVI/AVL
- Connected Vehicles

- Pedestrian detectors
- Bike detectors
Detector Selection Factors

- Traffic Parameters Needed
- Cost
- Maintenance
- Accuracy
- Environmental Conditions
- Power and Communication Needs
References

- The Vehicle Detector Clearinghouse, “A Summary of Vehicle Detection and Surveillance Technologies used in Intelligent Transportation Systems”, August 2007
Connected Vehicles
- http://youtu.be/lXGGu6wj_f8
Learning Objectives

1. Provide an overview of the connected vehicle program
2. Understand history, evolution, and future direction of connected vehicle program
3. Understand partnership and roles of government and industry
4. Understand basic technologies and core systems
5. Understand key policy, legal, and funding issues
Definition of a Connected Vehicle Environment

Wireless connectivity among vehicles, the infrastructure, and mobile devices, resulting in transformative change to:

- Highway safety
- Mobility
- Environmental impacts

Source: USDOT
Wireless Communications for Connected Vehicles

Core technology for Connected Vehicle applications

- Safety-related systems to be based on Dedicated Short Range Communications
- Non-safety applications may be based on other technologies

- DSRC characteristics:
  - 75 MHz of bandwidth at 5.9 GHz
  - Low latency
  - Limited interference
  - Performance under adverse conditions

Source: USDOT
Connected Vehicle Benefits

Connected Vehicles will benefit the public good by:

- Reducing highway crashes
  - Potential to address up to 81% of unimpaired crashes
- Improving mobility
- Reducing environmental impact

Additional benefits to public agency transportation system management and operations
Historical Context

Current program results from more than a decade of research:

- 2003 – Vehicle Infrastructure Integration (VII) program formed by USDOT, AASHTO, and carmakers
- 2006 – VII Concept of Operations published by USDOT
- 2008-2009 – VII Proof-of-Concept in Michigan and California
- 2010-2011 – VII renamed to Connected Vehicle program
Connected Vehicle Program Today

Current research addresses key strategic challenges:

- Remaining technical challenges
- Testing to determine actual benefits
- Determining if benefits are sufficient to warrant implementation
- Issues of public acceptance
Key Decision Points

- Decisions to be made on core technologies:
  - 2013 NHTSA agency decision on implementation of DSRC in light vehicles
  - 2014 decision regarding DSRC in heavy vehicles
  - Information to support the decision will come from multiple sources, including the Safety Pilot Model Deployment
Connected Vehicle Safety Pilot

- 2,800 vehicles (cars, buses, and trucks) equipped with V2V devices
- Provide data for determining the technologies’ effectiveness at reducing crashes
- Includes vehicles with embedded equipment and others that use aftermarket devices or a simple communications beacon

Image source: USDOT
Safety Pilot V2V Applications

- Applications to be 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

Source: USDOT
V2I Safety Applications

- Use data exchanged between vehicles and roadway infrastructure to identify high-risk situations and issue driver alerts and warnings
  - Traffic signals will communicate signal phase and timing (SPaT) data to vehicles to deliver active safety messages to drivers

Source: USDOT
Typical V2I Safety Applications

- Candidate applications under development include:
  - Red Light Warning
  - Curve Speed Warning
  - Stop Sign Gap Assist
  - Railroad Crossing Violation Warning
  - Spot Weather Impact Warning
  - Oversize Vehicle Warning
  - Reduced Speed/Work Zone Warning

Source: USDOT
Connected Vehicle Mobility Applications

- Provide an interconnected, data-rich travel environment
- Used by transportation managers to optimize operations, focusing on reduced delays and congestion
Potential Dynamic Mobility Applications

- EnableATIS – support sharing of travel information
- IDTO – support transit mobility, operations, and services
- MMITSS – maximize arterial flows for transit, freight, emergency vehicle, and pedestrians
- INFLO – optimize flow with queue warning and speed harmonization
- R.E.S.C.U.M.E. – support incident management and mass evacuations
- FRATIS – freight-specific information systems or drayage optimization
Connected Vehicle Transit Applications

- Three Integrated Dynamic Transit Operations (IDTO) applications developed:
  - Dynamic Transit Operations (T-DISP)
  - Connect Protection (T-CONNECT)
  - Dynamic Ridesharing (D-RIDE)

- Additional transit safety applications in the Safety Pilot:
  - Emergency Electronic Brake Lights (EEBL)
  - Forward Collision Warning (FCW)
  - Vehicle Turning Right in Front of Bus Warning (VTRW)
  - Curve Speed Warning (CSW)
  - Pedestrian in Crosswalk Warning (PCW)
Connected Vehicle Environmental Applications

- Generate and capture relevant, real-time transportation data to support environmentally friendly travel choices for:
  - Travelers
  - Road operating agencies
  - Car, truck, and transit drivers
USDOT AERIS Program

- Research on connected vehicle environmental applications conducted within the AERIS program

Cleaner Air Through Smarter Transportation

AERIS: Applications for the Environment Real-Time Information Synthesis
Connected Vehicle Environmental Applications

- Generate and capture relevant, real-time transportation data to support environmentally friendly travel choices
  - Travelers avoid congestion, take alternate routes or transit, or reschedule their trip to be more fuel-efficient
  - Operators receive real-time information on vehicle location, speed, and other operating conditions to improve system operation
  - Drivers optimize the vehicle's operation and maintenance for maximum fuel efficiency
Potential AERIS Concepts

- **Eco-Signal Operations** – Optimize roadside and traffic signal equipment to collect and share relevant positional and emissions data to lessen transportation environmental impact.

- **Dynamic Eco-Lanes** – Like HOT and HOV lanes but optimized to support freight, transit, alternative fuel, or regular vehicles operating in eco-friendly ways.

- **Dynamic Low Emissions Zones** – Similar to cordon areas with fixed infrastructure but designed to provide incentives for eco-friendly driving.
Connected Vehicle Technology

- Onboard or mobile equipment
- Roadside equipment
- Communications systems
- Core systems
- Support systems

Source: USDOT
Dedicated Short-Range Communications

- Technologies developed for vehicular communications
  - FCC allocated 75 MHz of spectrum in 5.9 GHz band
  - To be used to protect the safety of the traveling public
- A communications protocol similar to WiFi
  - Derived from the IEEE 802.11 standard
  - DSRC includes WAVE Short Message protocol defined in IEEE 1609 standard
- Typical range of a DSRC access point is 300 m
  - Typical installations at intersections and other roadside locations
Key DSRC Functional Capabilities

- DSRC is the only short-range wireless technology that provides:
  - Fast network acquisition, low-latency, high-reliability communications link
  - An ability to work with vehicles operating at high speeds
  - An ability to prioritize safety messages
  - Tolerance to multipath transmissions typical of roadway environments
  - Performance that is immune to extreme weather conditions (e.g., rain, fog, snow)
  - Protection of security and privacy of messages
DSRC for Active Safety Applications

![Graph showing latency requirements and technologies](image)

**ACTIVE SAFETY LATENCY REQUIREMENTS**

- Traffic Signal Violation warning: 0.1s
- Curve Speed Warning: 1s
- Emergency Electronic Brake Lights: 0.1s
- Pre-Crash Sensing: 0.02s
- Cooperative Forward Collision Warning: 0.1s
- Left Turn Assistant: 0.1s
- Lane Change Warning: 0.1s
- Stop Sign Movement Assistance: 0.1s

Least stringent latency requirement for Active Safety (1 sec)

Most Stringent latency requirement for Active Safety (0.02 sec)

Source: USDOT
Cellular Communications

- USDOT committed to DSRC for active safety, but will explore other wireless technologies
- Cellular communications is a candidate for some safety, mobility, and environmental applications
  - LTE technologies can provide high-speed data rates to a large number of users simultaneously
  - Technologies are intended to serve mobile users
  - Good coverage – all urban areas and most major highways
Security Credential Management

- Connected Vehicle Environment relies on the ability to trust the validity of messages between users
  - Accidental or malicious issue of false messages could have severe consequences
- Users also have expectation of appropriate privacy in the system
- Current research indicates use of PKI security system and exchange of digital certificates
Policy and Institutional Issues

- May limit successful deployment
- Collaborative effort among USDOT, industry stakeholders, vehicle manufacturers, state and local governments, associations, and citizens
- Policy issues and associated research fall into four categories:
  - Implementation Policy Options
  - Technical Policy Options
  - Legal Policy Options
  - Implementation Strategies
Implementation Policy Options

Topics to be addressed:

- Viable options for financial and investment strategies
- Analysis and comparisons of communications systems for data delivery
- Model structures for governance with identified roles and responsibilities
- Analyses required to support the NHTSA agency decision
Technical Policy Options

- Analysis of technical choices for V2V and V2I technologies and applications
  - Identify if options require new institutional models or can leverage existing assets and personnel
- Technical analyses related to Core System, system interfaces, and device certification and standards
Legal Policy Options

- Analysis on the federal role and authority in system development and deployment
- Analysis of liability and limitations to risk
- Policy and practices regarding privacy
- Policies on intellectual property and data ownership
Implementation Strategies

- AASHTO conducted a Connected Vehicle Field Infrastructure Deployment Analysis
  - Infrastructure deployment decisions by state and local transportation agencies depend on nature and timing of benefits
  - Benefits depend on availability of Connected Vehicle equipment installed in vehicles
    - Original equipment
    - After-market devices
Connected Vehicle Market Growth

Source: USDOT
Funding for Infrastructure Deployment

- Key task facing state and local DOTs is the need to identify a funding mechanism.
  - Capital and ongoing operations and maintenance costs
- Agencies can consider various funding categories to support deployment.
  - ITS budget or federal/state funds with ITS eligibility
  - Safety improvement program
  - Funds set aside for congestion mitigation or air quality improvement projects
  - Public–private partnerships
Summary

- The Connected Vehicle Environment:
  - Wireless connectivity among vehicles, infrastructure, and mobile devices
  - Transformative changes in highway safety, mobility, and environmental impact
  - Broad stakeholder base – government, industry, researchers

- Potential benefits
  - Use of V2V and V2I may address 81% of unimpaired crashes in all vehicle types
  - Reduce congestion and vehicle emissions
Summary (cont’d)

- Current strategic challenges – technical, benefits, deployment, public acceptance
- Connected Vehicle Safety Pilot to support NHTSA agency decisions in 2013 and 2014
- Applications allow systems and technologies to deliver services and benefits to users in three broad categories
  - Safety applications (including those based on V2V or V2I communications)
  - Dynamic mobility applications
  - Environmental applications
Summary (cont’d)

- DSRC technologies developed specifically for vehicular communications
  - Reserved for transportation safety by the FCC
- DSRC will be used for V2V and V2I active safety
  - Cellular communications can be explored for other safety, mobility, and environmental applications
- A Public Key Infrastructure (PKI) security system, involving the exchange of digital certificates among trusted users, can support both the need for message security and provide appropriate anonymity to users.
Summary (cont’d)

- Policy and institutional issues are topics that may limit or challenge successful deployment.
- An AASHTO Connected Vehicle field infrastructure deployment analysis indicates:
  - Infrastructure deployment decisions of state and local transportation agencies will be based on the nature and timing of benefits
  - Benefits will depend on the availability of Connected Vehicle equipment installed in vehicles, either as original equipment or as after-market devices.
References

- AASHTO Subcommittee on Systems Operations and Management Web site: http://ssom.transportation.org/Pages/default.aspx
Autonomies Vehicles
<table>
<thead>
<tr>
<th>Level</th>
<th>Automation Level</th>
<th>Description</th>
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</table>
| Level 0 | No Automation                     | - Driver is in full control of the vehicle  
- All the control functions require driver’s input  
- Safety features available to warn driver about road hazards but will not take any control action (e.g. blind spot monitoring system) |
| Level 1 | Function-specific Automation      | - Driver is responsible for safe operation and has overall control of the vehicle  
- One or more control functions could be automated e.g. adaptive cruise control, electronic stability control, or dynamic brake support in crash eminent situations  
- Driver is constantly engaged in physically controlling the vehicle using steering wheel and pedals |
| Level 2 | Combined Function Automation      | - Two or more primary control functions are automated.  
- Driver is responsible for monitoring roadway and is in charge of safe operation of the vehicle  
- Driver is expected to be available to take control all the time and on short notice.  
- Unlike level 1, driver could be disengaged from physically controlling the vehicle using steering wheel and pedals during specific operating conditions |
| Level 3 | Limited Self-Driving Automation   | - Under certain traffic and environmental conditions driver can ceded control of safety-critical functions to the vehicle  
- Driver is expected to be available for occasional control; however, the transition occurs at a comfortable transition time  
- Unlike level 2, driver is not responsible for constantly monitoring the roadway conditions |
| Level 4 | Full Self-Driving Automation      | - Vehicle performs all safety-critical driving functions and monitors the road conditions during the entire trip  
- Driver only has to provide destination or route preference information  
- Driver is not expected to be engaged in any control task during the trip |
Potential impacts

- Safety
- Congestion and traffic operations
- Travel-behavior impacts
- Freight transportation
- Changes in VMT and vehicle ownership
- Discount rate and technology costs
- https://youtu.be/r7_lwq3BfkY
Barriers to Implementation

- Vehicle costs
- AV certification
- Litigation, liability and perception
- Security
- Privacy