



Self-Driving Cars: The Next Revolution

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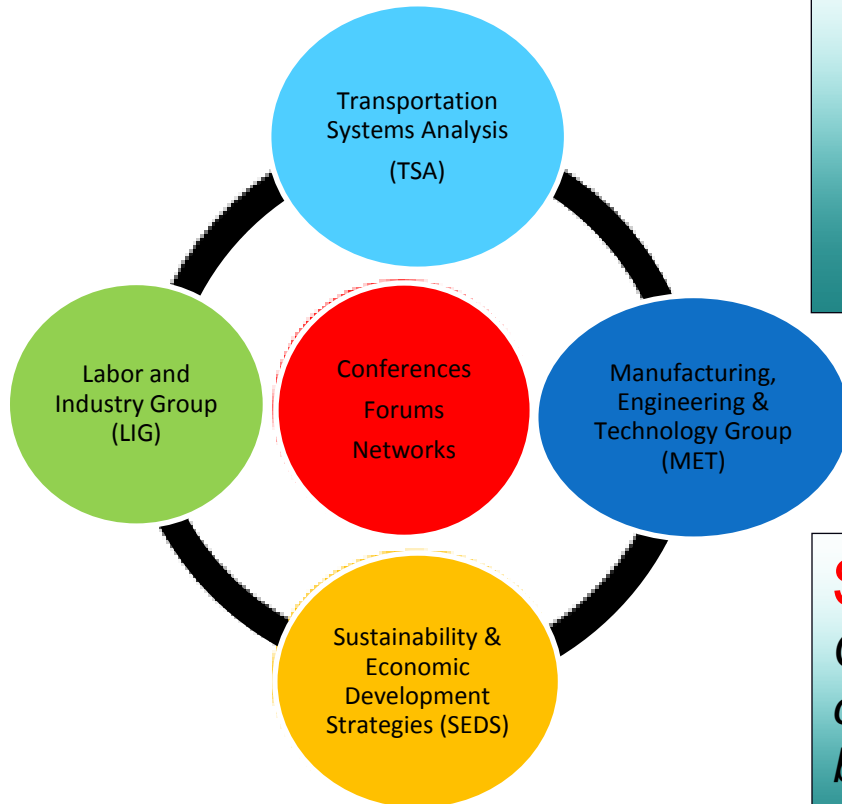
Center for Automotive Research

Executive Insights in the Automotive Industry

November 28, 2012

Center For Automotive Research (CAR)

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Mission

“..... To assist the global automotive industry’s competitiveness and technological advancement through unbiased research and support”

CAR
CENTER FOR AUTOMOTIVE RESEARCH

Success

CAR’s success relies on maintaining close industry relationships while balancing independent and unbiased research

CAR is an independent, not-for-profit organization with research activities in manufacturing, economics, and transportation systems.

CAR was formerly OSAT with a 25-year history at the University of Michigan prior to spinning off in 2000 and becoming independent.

Management Briefing Seminars



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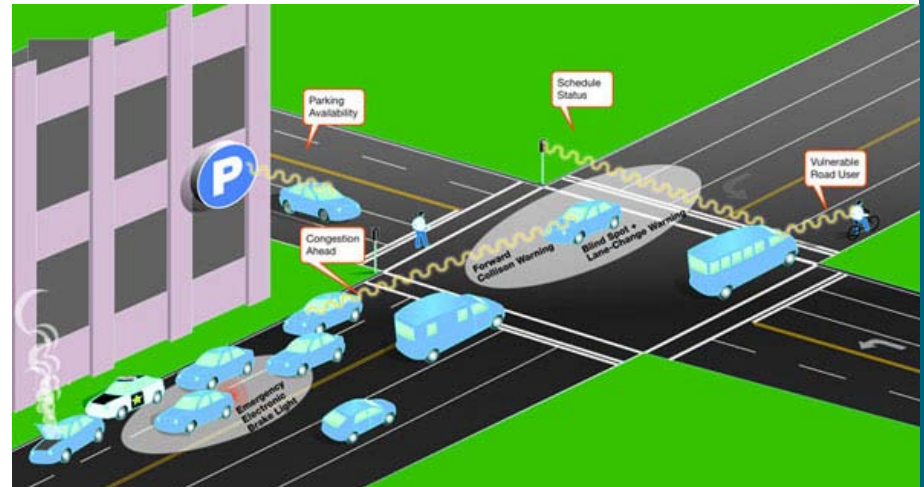
Vehicles Evolving Quickly along Several Dimensions

- Growth in vehicle communications and connectivity
 - Increase in electronic content
 - Proliferation of sensor-based safety systems
 - Vast potential for aftermarket products
 - Electrification of the powertrain
 - Changing fuel economy standards
-
- In our white paper *Self-Driving Cars: The Next Revolution*, CAR and KPMG propose that vehicle communication and sensor-based safety technologies, rooted in electronics and software, are converging to enable vehicles that drive themselves, with enormous implications.

Connected Vehicles Defined

- Connected vehicles use any of a number of different wireless communication technologies to communicate with:

- Each other
- Roadside infrastructure
- The “Cloud”

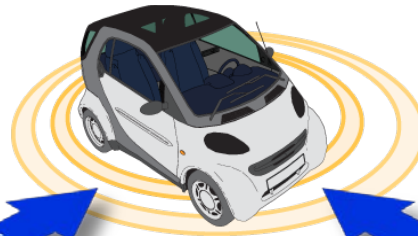


- Goals for connected vehicles are to enhance
 - Vehicle and roadway safety
 - Mobility
 - Environment (e.g., reduced fuel consumption)

Evolving Vehicles in an Evolving Environment

Automotive Industry

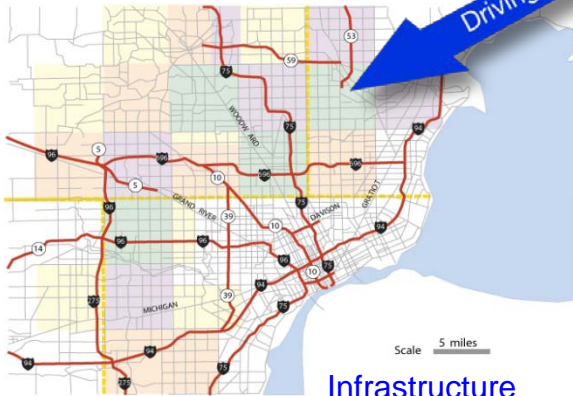
Mechanical \Rightarrow Electronic and Connected



Vehicles

Driving & Traffic

Wireless



Infrastructure

Local, state, &
federal agencies

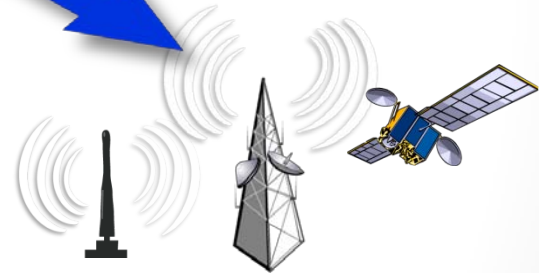
Construction \Rightarrow Operations and Jobs



Driver

Mobile, Safe, and Connected

Traffic Operations



Infostructure

Telecommunications,
Consumer Electronics

Wired \Rightarrow Seamless Connectivity

Three Components of Vehicle Connectivity

- Information broadcast from vehicles (mobile)
- Information broadcast from fixed locations (e.g., intersections)
- Ability to complete transactions with security and confirmation to both parties (a record made)
 - May be monetary (e.g., paying a toll)
 - Or not (e.g., signal pre-emption for emergency vehicles or wireless roadside inspections for trucks)

Primary Options for Vehicle Communications

- Dedicated Short-Range Communications (DSRC)
 - Operates at 5.9 GHz in U.S.
 - Especially promising for applications that require very fast, highly reliable transmission, such as cooperative safety with active braking (V2V)
 - Range up to 300 m
 - Could require fairly extensive and expensive build out
- Cellular
 - Much infrastructure already in place, but many planned applications require third generation (3G) or beyond network (4G, LTE, WiMax)
 - Works well for OnStar and like applications; also works for traffic probe data collection (as done by companies such as INRIX)
- Wi-Fi
 - Mobile Wi-Fi networks beginning to emerge that use 3G (increasingly 4G) for backhaul; could have utility for mobile ad-hoc networks (but not for safety?)
- Bluetooth
 - Useful for communication within a vehicle and some attempts underway to measure traffic via passive roadside units

Sample Connected Vehicle Applications

Safety
Electronic Brake Lights
Traffic Signal Violation Warning
Stop Sign Violation Warning
Curve Speed Warning
Display Local Signage
Electronic Payment
Tolling
Parking
Automotive
Vehicle Diagnostics
Software Updates

Mobility
Traveler information
Weather Information
Navigation
Ramp Metering
Signal Timing Optimization
Corridor Management
Infrastructure Management
Weather Information
Winter Maintenance
Pothole Detection
Automated Mapping

DARPA Urban Challenge (2007)

Tartan Racing is united to catalyze a technical, cultural and industrial revolution for a new class of robotics to advance the state-of-the-art in driver safety.

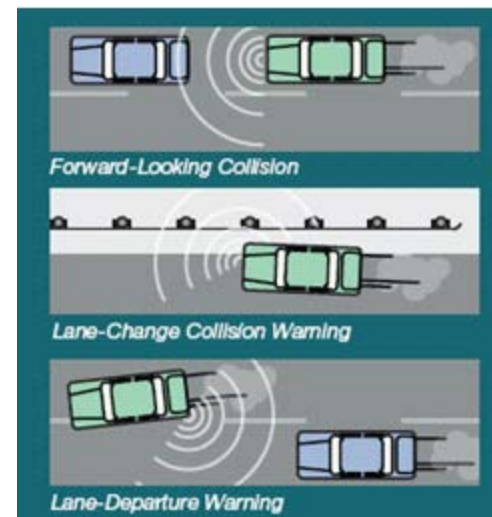


And Available Today

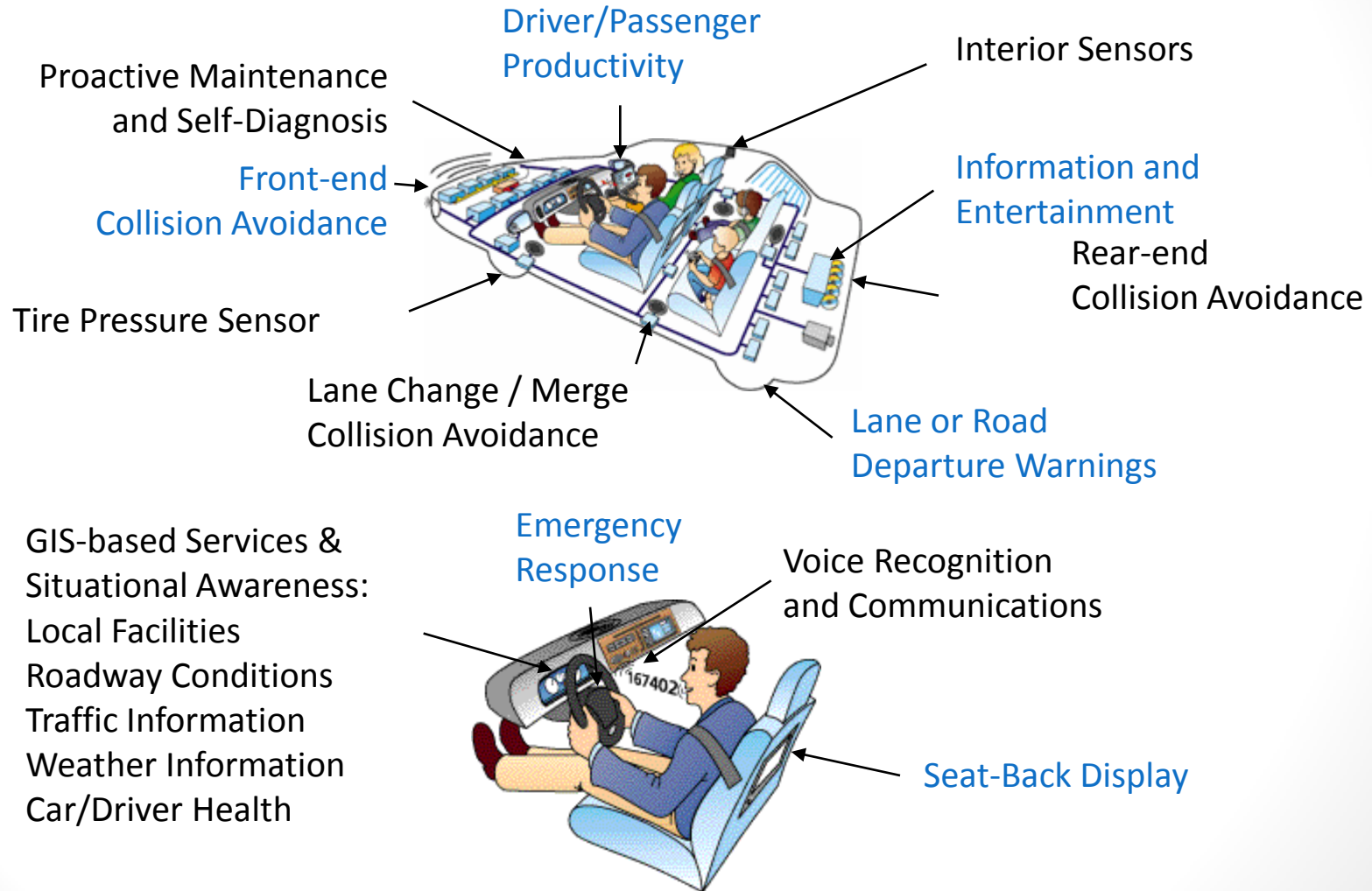


Lane Departure Warning Systems Go Mainstream: \$14.3 Billion Market by 2016

--ABI Research, February 2011



The Vehicle as a Communications Hub

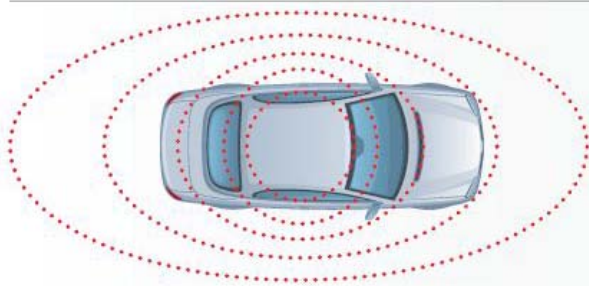


So Why Convergence?



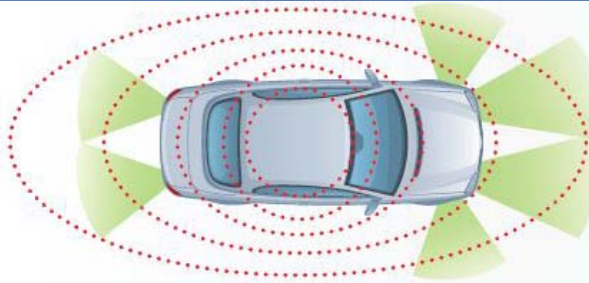
Sensor-based Solution Only

- Cannot sufficiently mimic human senses
- Not cost-effective for mass market adoption
- Lack of adequate 360° mapping of environment in urban grids



Connected Vehicle Solution Only

- Dedicated Short Range Communication (DSRC) does not currently work with pedestrians, bicyclists, etc.
- DSRC-based Vehicle to Infrastructure (V2I) might require significant infrastructure investment
- Vehicle to Infrastructure (V2V) requires high market penetration

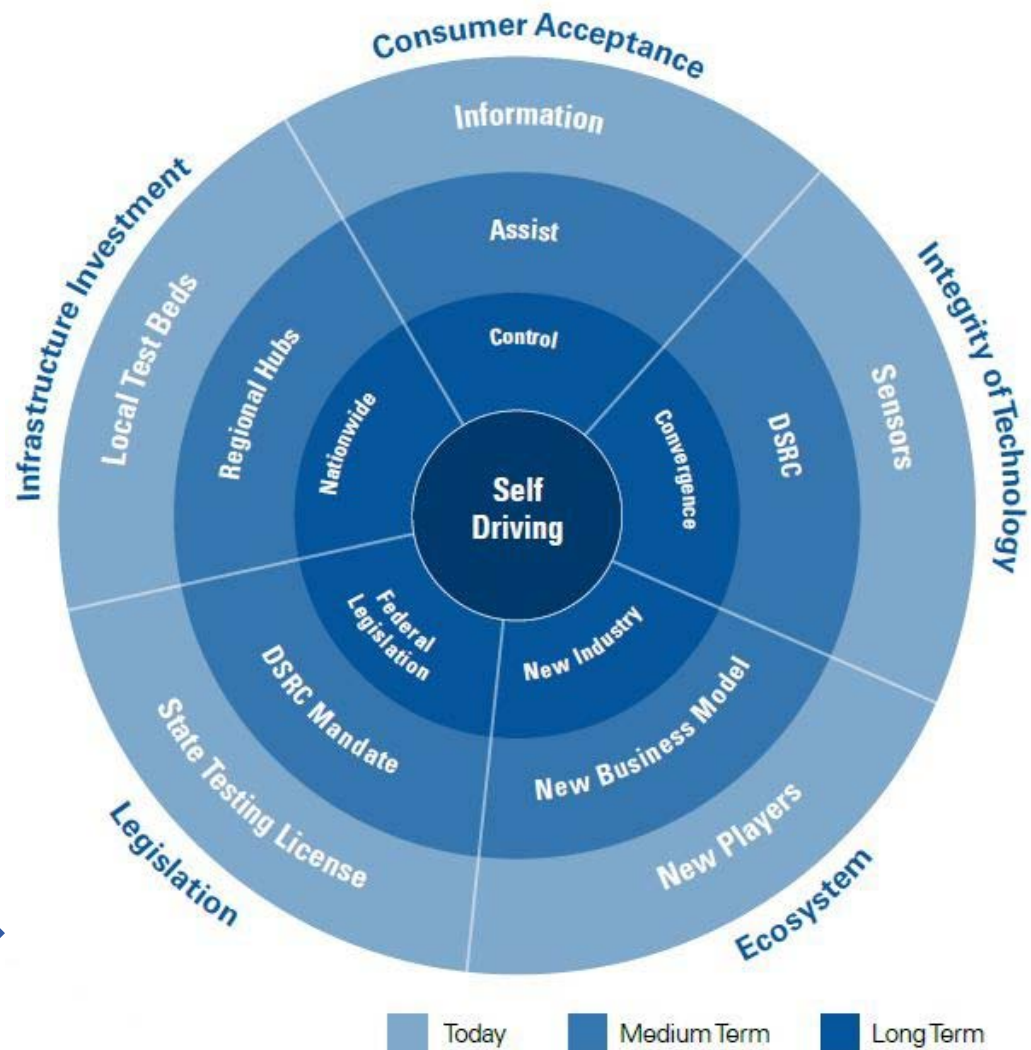


Converged solution

- Convergence will facilitate adequate mimicking of human senses
- Convergence will reduce need for an expensive mix of sensors and reduce the need for blanket V2I investment
- Convergence provides functional redundancy to ensure that the technology will work 100 percent of the time

The rate of adoption of self-driving solutions will depend on various factors and forces coming together

- The convergence of sensor-based and connected-vehicle technologies will happen and there will be a positive effect on the adoption of both systems — drivers will take the leap.
- Convergence will bring enhanced mobility and safety and reduced environmental impacts
- Automotive and technology companies are already investing in connected and autonomous technologies and applications.



Various facets and forces that must come together to enable self-driving

Regulatory Environment Is Critical

- Automotive companies do not necessarily want connected-vehicle safety applications (in-vehicle signage, cooperative crash avoidance, etc.), or sensor-based ones, to be mandated anytime soon (based on CAR studies)
 - NHTSA has set 2013 decision date on proposed rule-making for vehicle-to-vehicle safety (crash avoidance) for light vehicles
 - 2014 for heavy vehicles
 - Numerous sensor-based approaches under regulatory review
 - Blind-spot detection, pedestrian detection, etc.
- Market forces also critical

Implications for Investment of Convergence and Self-Driving Vehicles



Crash elimination: Crash-free driving and improved vehicle safety could change the concept of a vehicle as we know it



Improved energy efficiency: Reduced energy consumption in at least three ways: more efficient driving; lighter, more fuel-efficient vehicles; and efficient infrastructure



Reduced need for new infrastructure: Self-driving can reduce the need for building new infrastructure and reduce maintenance costs



Data challenges: Issues related to data security, privacy, and data analytics and aggregation could crop up due to abundance of data in vehicles



Travel time dependability: Convergence can substantially reduce uncertainty in travel times via real-time, predictive assessment of travel times on all routes



New models for vehicle ownership: Self-driving vehicles could lead to a major redefinition of vehicle ownership and expand opportunities for vehicle sharing



Productivity improvements: Convergence will allow travelers to make use of travel time productively



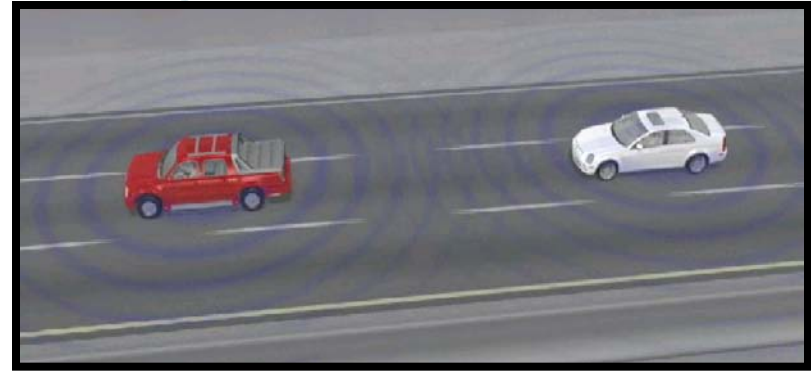
New business models and scenarios: Convergence of technologies may realign industries such that ecosystem participants need to compete and collaborate at the same time

Vehicles That Cannot Crash

- Both communication- and sensor-based systems are providing crash avoidance
- Together, the two can result in vehicles that simply cannot crash
 - Eliminate crash fatalities and injuries, property damage, emergency room visit, etc.
- This requires convergence—neither sensors nor communications alone can accomplish this outcome

Connectivity for Safer Driving

- Greater situational awareness
 - Your vehicle can “see” nearby vehicles and knows roadway conditions that you cannot see
- Reduce or even eliminate crashes through:
 - Driver advisories
 - Driver warnings
 - Vehicle control



Connected vehicle technology has the potential to address 82% of the vehicle crash scenarios involving unimpaired drivers.



Work Zone
Notification



Vehicle-to-Vehicle Safety Starts with Data Broadcast

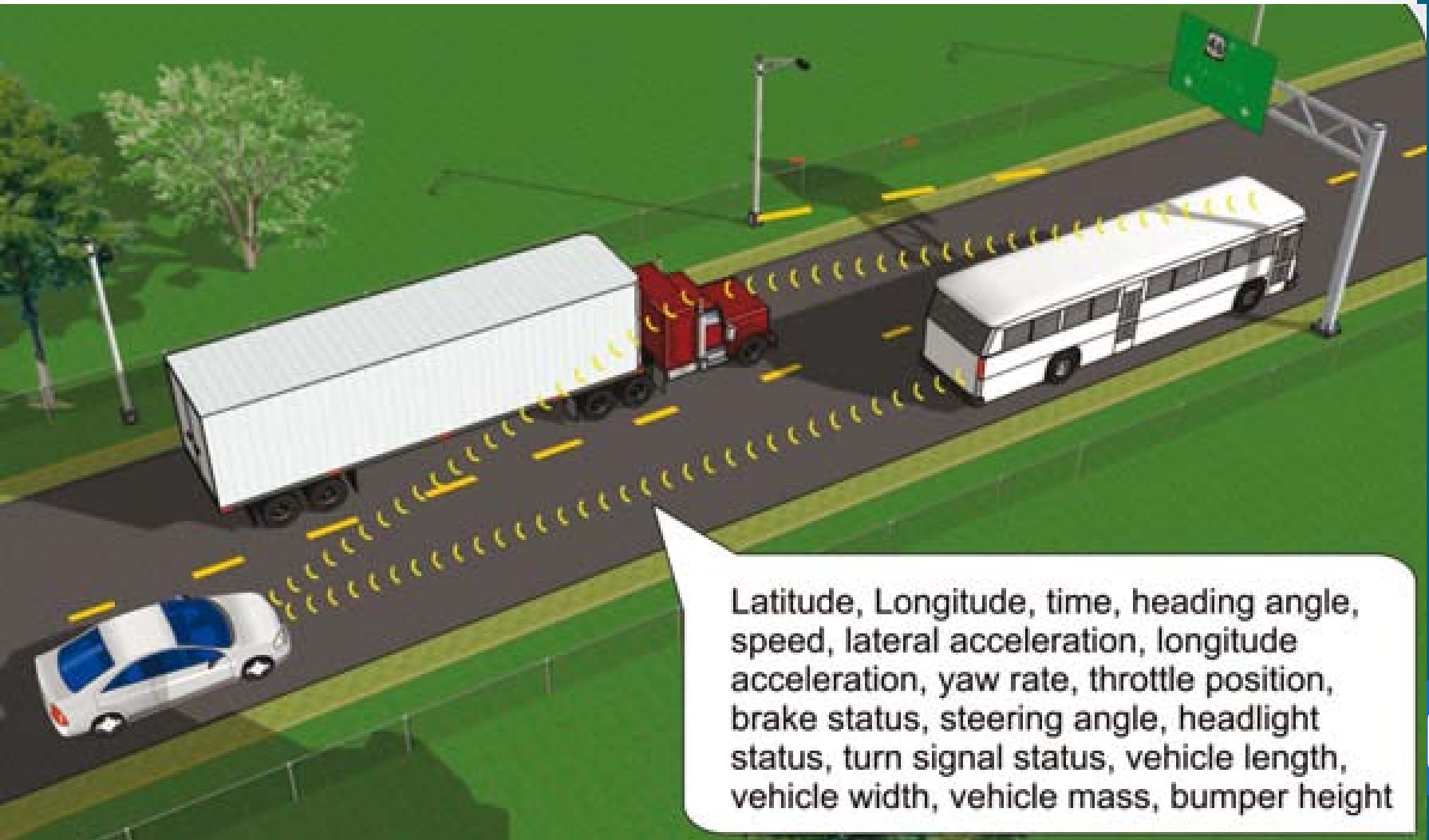


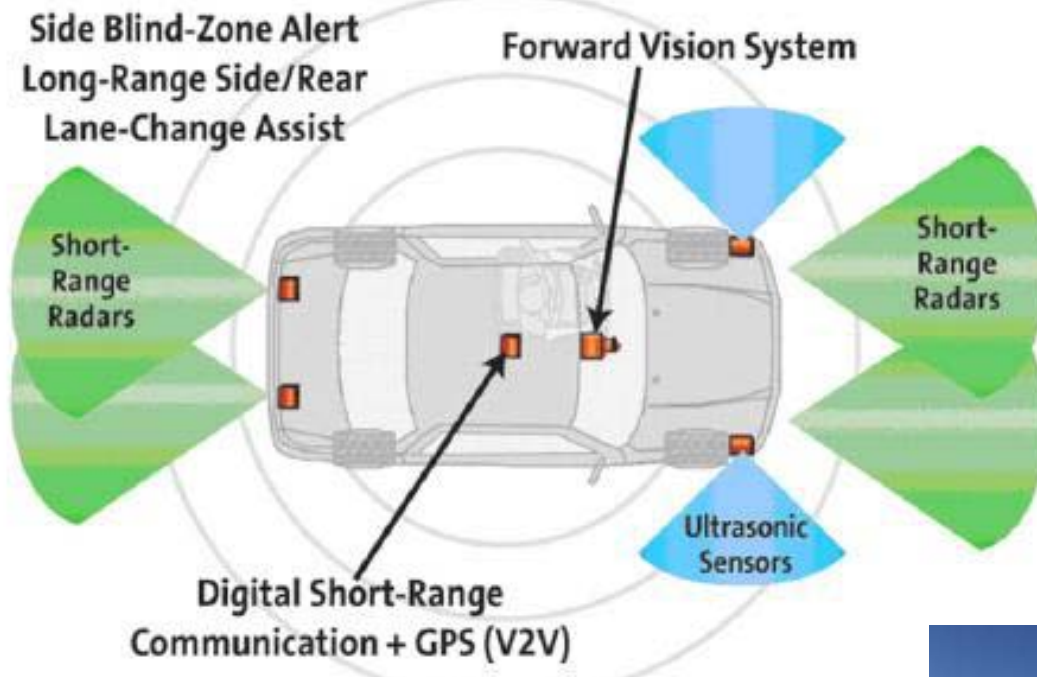
Image source: USDOT RITA

V2V Safety Pilot to Support Regulatory Decision-making

- V2V Driver Safety Clinics
 - Provided opportunity for non-professional drivers to test connected vehicle safety systems and provide feedback to the USDOT and industry (6 locations)
- V2V Safety Pilot Field Test
 - Underway in Michigan
 - Thousands of equipped vehicles concentrated in Ann Arbor
 - Includes light vehicles, heavy truck, buses, etc.; more than 2,000 already fielded
- Both will provide important input to NHTSA's planned 2013 decision on regulatory intent



And Coming Tomorrow: Autonomous and Connected



Reduced Need for New Infrastructure

- Currently, we spend about \$75 billion annually in the U.S. on roads, highways, bridges, etc., in support of human drivers with all their (our) shortcomings
 - Thus, we have rumble strips, wide lanes, significant gaps between vehicles, etc.
 - Self-driving vehicles could be tightly spaced into platoons with up to 500 % more capacity than we have today with no additional space
 - Intersections could achieve 200 times more throughput through intelligent signal control based on “flight path” through the intersection

Data Challenges & Opportunities

- Data security
- Threats to personal privacy
- Data analytics and aggregation

Security and Standards

- Data security (like for any wireless communication system) may be challenging
 - Black Hat conference already has included a briefing entitled “Hacking the Fast Lane: Security Issues with 802.11p, DSRC, and WAVE”
- Standards regime is fairly mature and includes many active organizations, but standards are still incomplete
 - ASTM, IEEE, SAE, Most Cooperation, OmniAir,...
 - US DOT, FCC, AASHTO, TIA, others
- DSRC standards
 - ASTM E2213-03 provides for wireless, high bandwidth, short-range communication
 - SAE J2735 covers message set dictionaries and strives for interoperability
- Wireless Access in Vehicular Environments (WAVE)
 - IEEE 1609 includes four specific standards under development
- Shortcomings remain that hinder full interoperability
 - When standards are “complete,” CV market will boom (like cable)

Connectivity and Communications Concerns

- Privacy
 - Always an issue when information is shared or tracked over a network
 - Solutions seems to be available (cellular phone providers face similar challenges)
- Driver distraction
 - Clearly, this is a significant challenge, and U.S. Secretary of Transportation Ray LaHood has been very vocal about this issue
 - Not to mention a recent NTSB report
 - Communications are not the only distraction
 - Hands-free technology becoming more common
 - Could the vehicle drive itself?



Data Are Critical (and Potentially Lucrative)

- Data drive connected-vehicle applications and services

Entities Interested in Data...	May Create Markets for
DOTs	Probe data, asset management data, road-weather information
Auto manufacturers	Vehicle diagnostics and prognostics, driver behavior
OE Suppliers	Component diagnostics and prognostics
Drivers and passengers	Real-time route guidance, map updates, media downloads, infotainment...
Marketers and providers of location-based services	Driver behavior, vehicle location
Insurance industry	Driver behavior

New Models of Vehicle Ownership

- Beyond ZipCar on steroids, can lead to “mobility as a service” as the next dominant paradigm in U.S. transportation
- Technology will support instant personalization of whatever vehicle you happen to be in through user profiles, reconfigurations, etc.

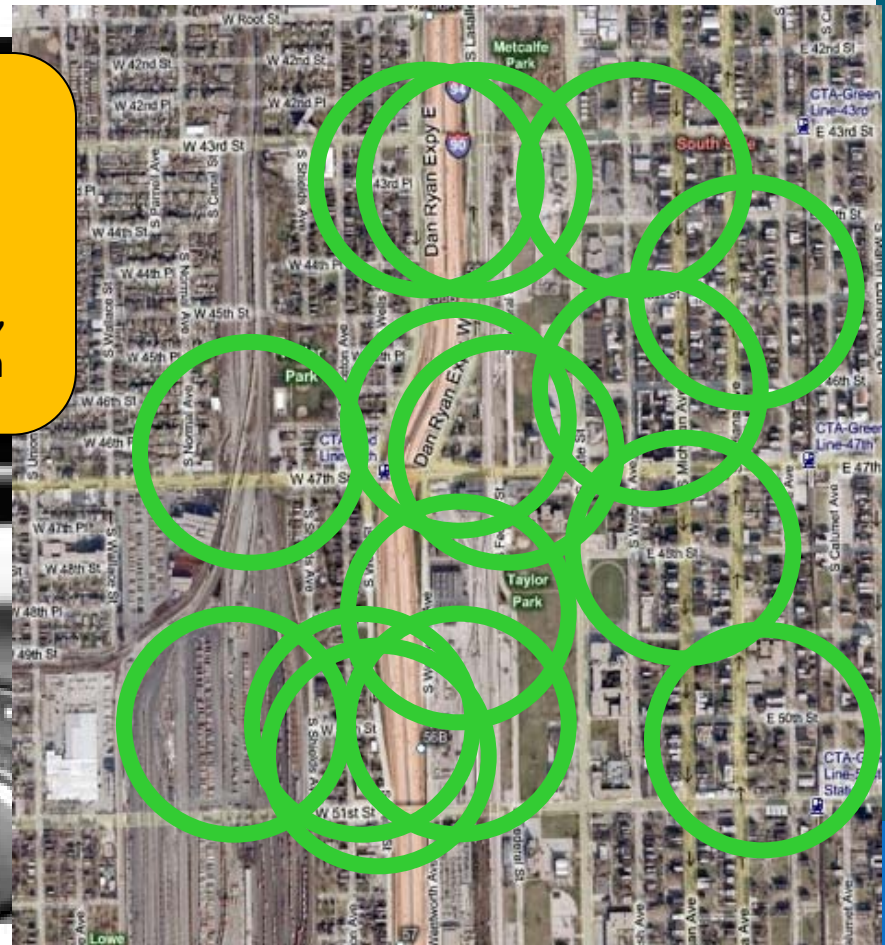


Increased Travel Time Dependability

- Driven by real-time data and enhanced predictive algorithms based on rich data environment
- Fewer to zero crashes further enhances travel time estimates

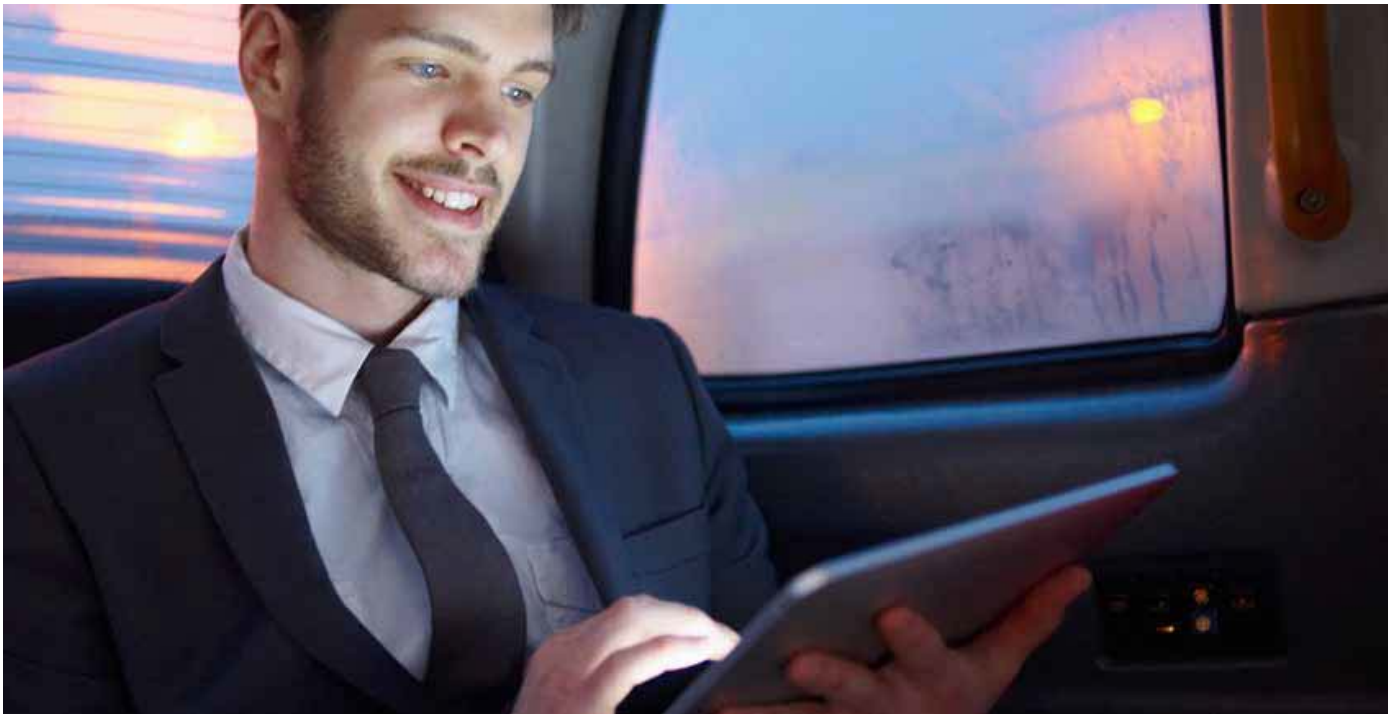


Traffic Reports of the Future



Improvements in Productivity

- Less time lost to commuting
- Commuting time more predictable
- Can work while you commute by car



Improved Energy Efficiency

- Improved traffic flow, fewer (to zero) crashes, etc., all contribute to enhanced fuel economy, reduced emissions, etc.
- Connectivity provides additional benefits in a world of electrified powertrains

Synergies Created by Trends in Connectivity and Electrification

- Simultaneous development of these two technologies is not merely coincidental
- These technologies each make the other better in interesting ways
- Can define at least three dimensions of synergy
 - Transportation Energy Planning and Mapping
 - Grid-Enabled Communication
 - Integrated Energy-Transportation System
- CAR white paper available at:
<http://www.cargroup.org/pdfs/green.pdf>

Basic Green Application: Transportation Energy Planning and Mapping

- Limited range of BEVs limits appeal to large number of potential customers
- Vehicle communications can help allay potential driver anxiety by providing drivers with up-to-the-minute info on locations of charging stations within range
- Can also use real-time traffic info to avoid congestion

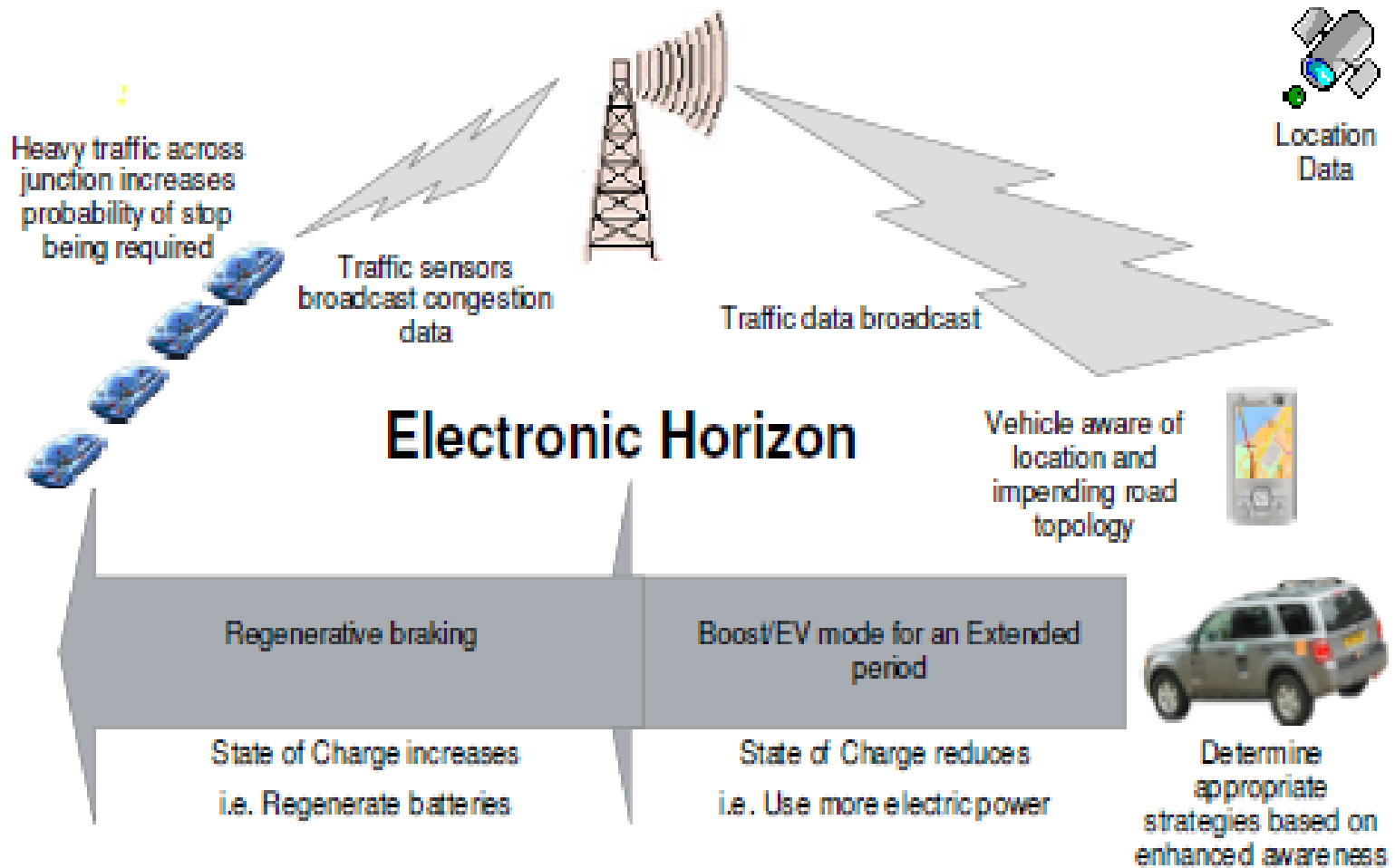
The screenshot displays a web application interface. On the left, a map shows the United States with green pins indicating charging stations. A pop-up window for a specific station provides details: Name: INTERMID / INTERMID2, Address: 321 S. State St, Chicago, IL 60601, USA, Description: 321 S. State, Chicago, IL, Traders, Hours: 10:00 AM - 10:00 PM, Status: on air, 2010-09-16 15:18:53 (GMT), Port: 8, 1234, 15A, 15B, 15C, 15D, 15E, 15F, 15G, 15H, 15I, 15J, 15K, 15L, 15M, 15N, 15O, 15P, 15Q, 15R, 15S, 15T, 15U, 15V, 15W, 15X, 15Y, 15Z, 16A, 16B, 16C, 16D, 16E, 16F, 16G, 16H, 16I, 16J, 16K, 16L, 16M, 16N, 16O, 16P, 16Q, 16R, 16S, 16T, 16U, 16V, 16W, 16X, 16Y, 16Z, 17A, 17B, 17C, 17D, 17E, 17F, 17G, 17H, 17I, 17J, 17K, 17L, 17M, 17N, 17O, 17P, 17Q, 17R, 17S, 17T, 17U, 17V, 17W, 17X, 17Y, 17Z, 18A, 18B, 18C, 18D, 18E, 18F, 18G, 18H, 18I, 18J, 18K, 18L, 18M, 18N, 18O, 18P, 18Q, 18R, 18S, 18T, 18U, 18V, 18W, 18X, 18Y, 18Z, 19A, 19B, 19C, 19D, 19E, 19F, 19G, 19H, 19I, 19J, 19K, 19L, 19M, 19N, 19O, 19P, 19Q, 19R, 19S, 19T, 19U, 19V, 19W, 19X, 19Y, 19Z, 20A, 20B, 20C, 20D, 20E, 20F, 20G, 20H, 20I, 20J, 20K, 20L, 20M, 20N, 20O, 20P, 20Q, 20R, 20S, 20T, 20U, 20V, 20W, 20X, 20Y, 20Z, 21A, 21B, 21C, 21D, 21E, 21F, 21G, 21H, 21I, 21J, 21K, 21L, 21M, 21N, 21O, 21P, 21Q, 21R, 21S, 21T, 21U, 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The interface includes a map of the United States with green pins indicating charging stations. A pop-up window for a specific station provides details: Name: INTERMID / INTERMID2, Address: 321 S. State St, Chicago, IL 60601, USA, Description: 321 S. State, Chicago, IL, Traders, Hours: 10:00 AM - 10:00 PM, Status: on air, 2010-09-16 15:18:53 (GMT), Port: 8, 1234, 15A, 15B, 15C, 15D, 15E, 15F, 15G, 15H, 15I, 15J, 15K, 15L, 15M, 15N, 15O, 15P, 15Q, 15R, 15S, 15T, 15U, 15V, 15W, 15X, 15Y, 15Z, 16A, 16B, 16C, 16D, 16E, 16F, 16G, 16H, 16I, 16J, 16K, 16L, 16M, 16N, 16O, 16P, 16Q, 16R, 16S, 16T, 16U, 16V, 16W, 16X, 16Y, 16Z, 17A, 17B, 17C, 17D, 17E, 17F, 17G, 17H, 17I, 17J, 17K, 17L, 17M, 17N, 17O, 17P, 17Q, 17R, 17S, 17T, 17U, 17V, 17W, 17X, 17Y, 17Z, 18A, 18B, 18C, 18D, 18E, 18F, 18G, 18H, 18I, 18J, 18K, 18L, 18M, 18N, 18O, 18P, 18Q, 18R, 18S, 18T, 18U, 18V, 18W, 18X, 18Y, 18Z, 19A, 19B, 19C, 19D, 19E, 19F, 19G, 19H, 19I, 19J, 19K, 19L, 19M, 19N, 19O, 19P, 19Q, 19R, 19S, 19T, 19U, 19V, 19W, 19X, 19Y, 19Z, 20A, 20B, 20C, 20D, 20E, 20F, 20G, 20H, 20I, 20J, 20K, 20

Advanced Green Application: Integrated Energy-Transportation System

- Consists of high integration between the energy system and the transportation system
- Uses large fleet of grid-enabled vehicles to manage flow of power, e.g., to meet peak power needs and as a buffer for renewable, but less than 100 % reliable, power generation
- Uses communications to provide considerable situational awareness to the vehicle for optimized powertrain control and management
 - For example, knowledge of upcoming topography or traffic conditions can influence current power consumption, aggressiveness of regenerative braking, etc.

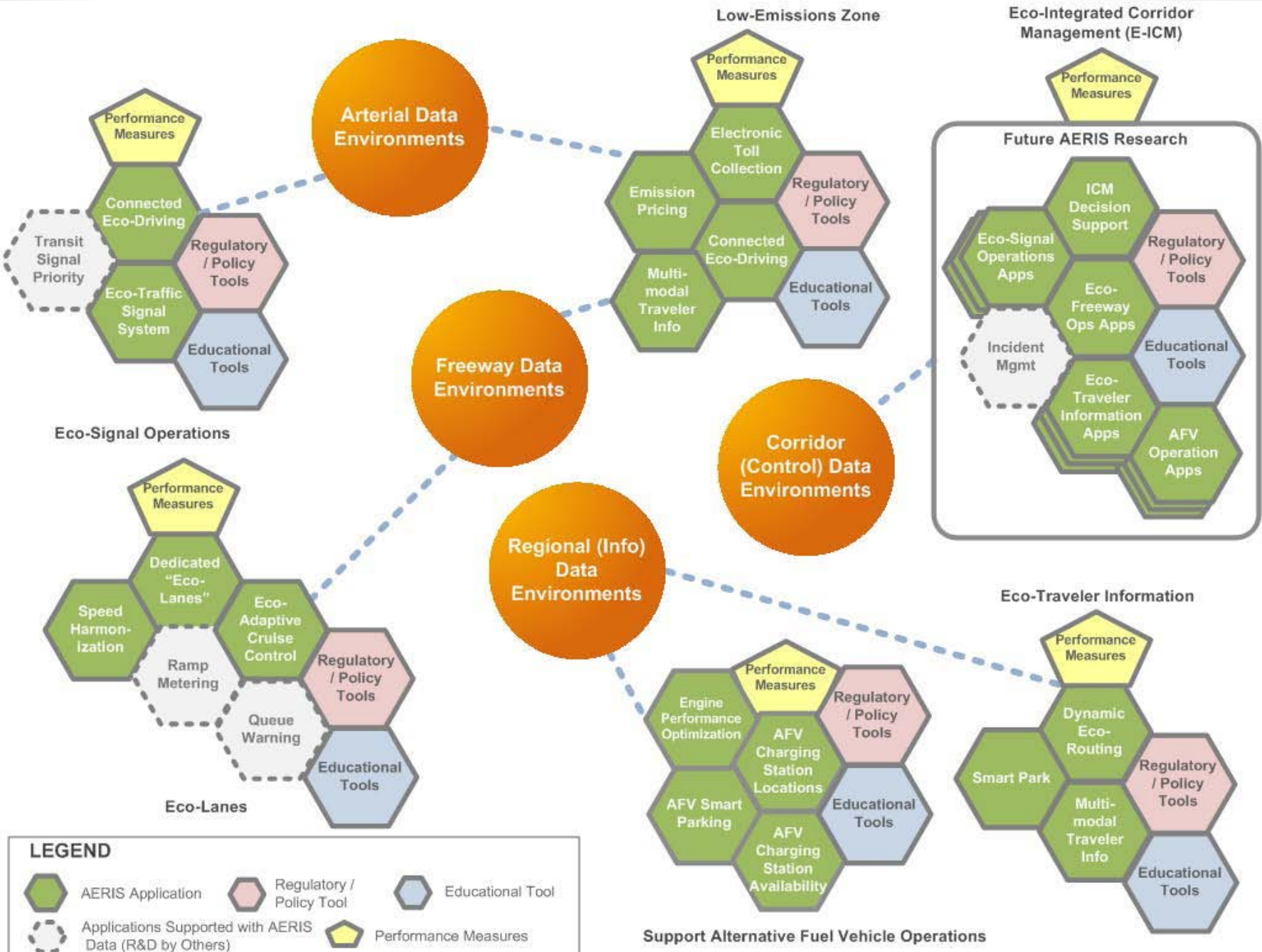
Situational Awareness Optimizes Powertrain Control



USDOT Applications for the Environment: Real-Time Information Synthesis (AERIS)

- Has identified six “transformative concepts” that use connected vehicle technology for enhanced environmental performance
 1. Eco-Integrated Corridor Management
 2. Support Alternative Fuel Vehicle Operations
 3. Eco-Signal Operations
 4. Low Emissions Zones
 5. Eco-Traveler Information
 6. Eco Lanes





When Will This Happen?

- Vehicles with some self-driving capability already exist
- We foresee vehicles that can smoothly maintain their lane and safe headway control by 2018 or so
- V2V and V2I built in about the same time, maybe 2019
- Vehicles can go driveway to destination self-driving: 2025 or later
- And what might the industry look like then, Gary?