What States Need to Do upon Return to their Home Agencies

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Agenda

- State of Autonomous Vehicle Technology
- DOT Roles for a Successful CAV Deployment

Automated Vehicle Technology Evolution

- First RC vehicles used in 1930s
- FHWA's Automated Highway System in the 1990s, and demo in 1997.
- DARPA Urban Challenge (on-road automated driving) in 2007.
- Demonstration on the streets of Manhattan, NYC at the 2008 World Congress
- U.S. DoD Investment
- Google's Demos/Efforts
- *Aggressive Marketing Campaigns leading to announcements by OEMs of their plans for production.*

NHTSA / SAE Driving Levels

- **Partially Automated Driving exists today**
- **Autonomy limited to specific driving environments**
- **Requires human fallback**
- **SAE and NHTSA levels different**

Source: SAE

SAE level	SAE name	SAE narrative definition	Execution of steering and acceleration/ deceleration	Monitoring of driving environment	Fallback performance of *dynamic driving task*	System capability (*driving modes*)	BASt level	NHTSA level
Human driver monitors the driving environment								
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a	Driver only	0
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes	Assisted	1
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	System	Human driver	Human driver	Some driving modes	Partially automated	2
Automated driving system ("system") monitors the driving environment								
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task* with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	System	Human driver	Some driving modes	Highly automated	3
4	High Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	System	Some driving modes	Fully automated	3/4
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	All driving modes		

Semi-Autonomous Driving – available TODAY

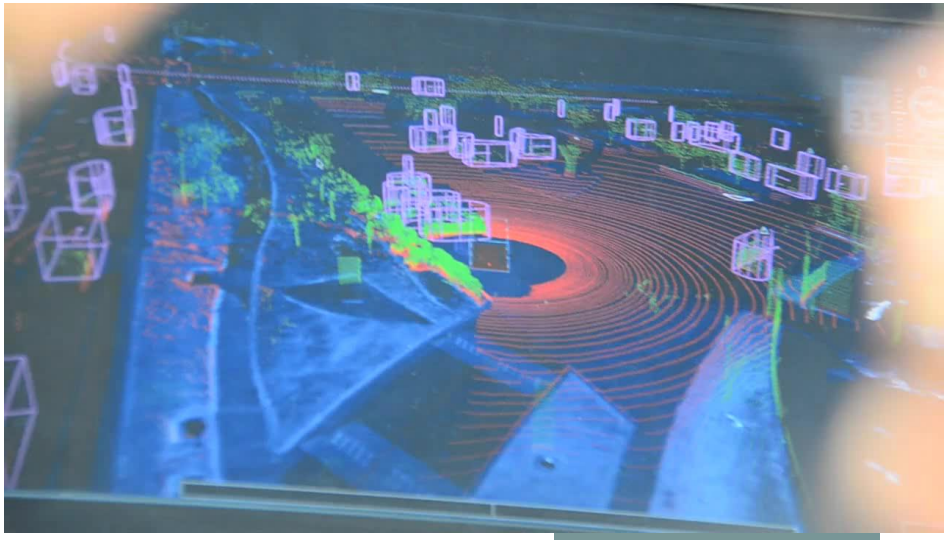
Who is Developing Autonomous Vehicle Capabilities

(list may incomplete because information is not openly shared – some proprietary efforts)

- **US OEMs:**
  - GM
  - Ford
  - Tesla
- **European:**
  - Mercedes
  - BMW
  - Audi
  - Volvo
  - Renault
  - Scania (trucks)
  - Jaguar Landrover
  - Deihl
  - RUAG
  - Rheinmetall Defence
- **Japan:**
  - Nissan
  - Honda
  - Toyota
  - Hino
  - Isuzu
  - Yamaha
  - Yanmar
- **Tier 1 Suppliers:**
  - Bosch
  - Continental
  - Delphi
  - Denso
- **Tech Companies:**
  - Google
  - Apple
- **US non-OEMs:**
  - Lockheed Martin
  - Southwest Research Institute (SwRI)
  - Smaller Defense Contractors:
    - TORC, GDRS, ASI, etc.
  - University Research:
    - CMU, Stanford, VTTI, California PATH, UMTRI/MTC, Princeton, and others
- **Government (non DoD)**
  - US:
    - Human Factors for Vehicle Highway Automation
    - USDOT Automation Program
  - European Union:
    - CitiMobil and CyberCars
    - Safe Road Trains for the Environment (SARTE)
  - Energy ITS Project (Japan)

State of the Practice: Commercial (Google)

- Pros
  - Well funded
  - Previously only freeway
  - Advancing arterial capability



Source: Google

Source: Google

- Cons
  - Expensive sensor suite
  - Must pre-drive route
  - Requires high precision map database
  - For the U.S. – less than 10,000 km of the 6.4M kms of highway "mapped"

Google's Change in Direction

- In May 2014 Google revealed a prototype of its latest driverless car:
  - No steering wheel
  - 25 mph
  - No breaks – start/stop button

- Platform developed from scratch
- Google says the car's most important feature is its safety.

- Development timeframe:
  - ~100 prototypes
  - Available for purchase by 2020

Other non-auto companies are developing

State of the Practice: Agriculture (John Deere)

- Constrained environment
- GPS effective in environment
- Limited obstacle avoidance

Source: John Deere

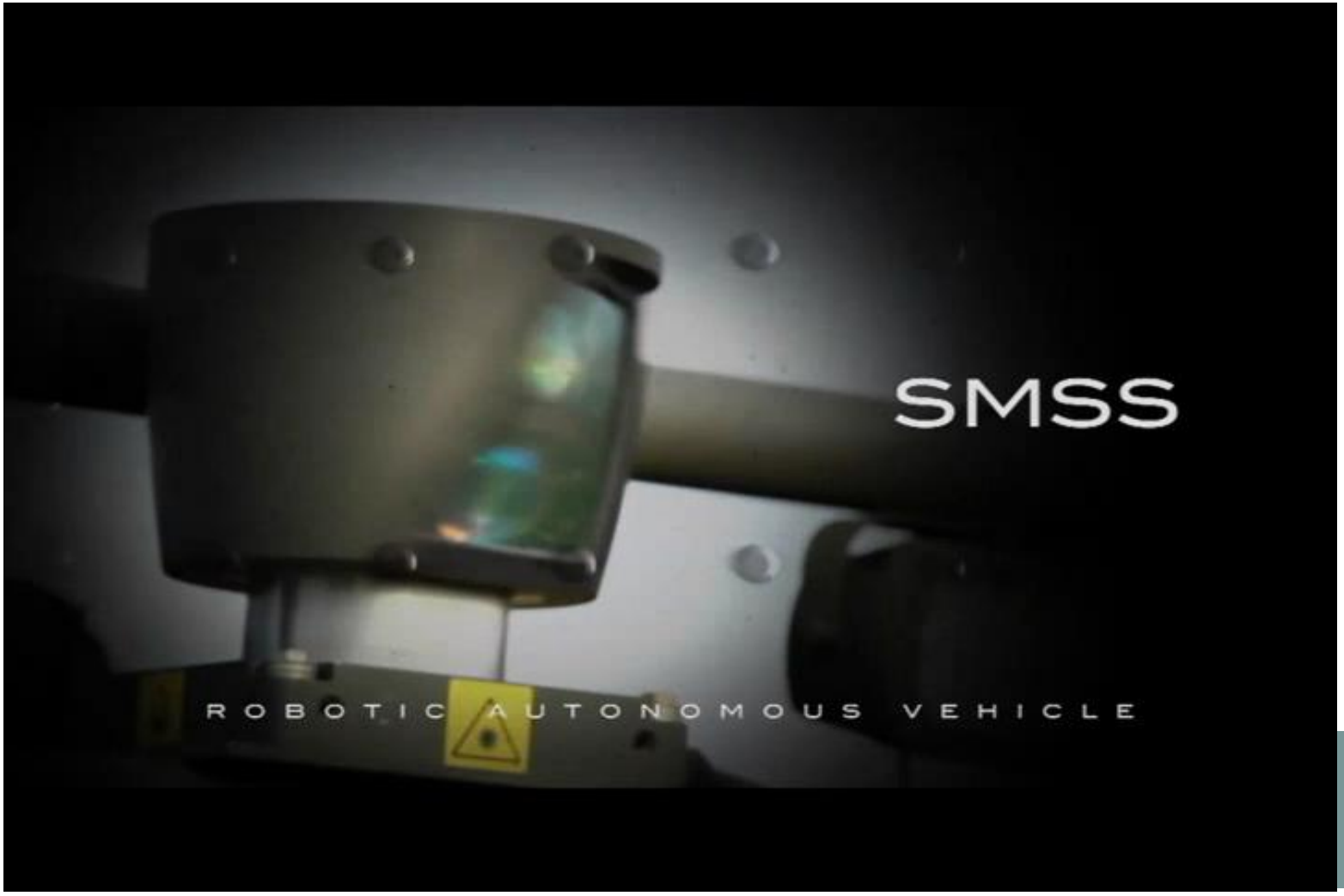
State of the Practice: Mining (Komatsu)

- Fixed route – GPS defined
- Obstacle detection
- Very dirty conditions

Source: Komatsu

State of the Practice: Military (Unmanned Support)

- 2000: Goal 1/3 automation in fleet by 2015
- Reduced exposure to unsafe environments
- Lighten soldier's loads
- Automate re-supply.



Source: Lockheed Martin

State of the Practice: Military (Oshkosh)

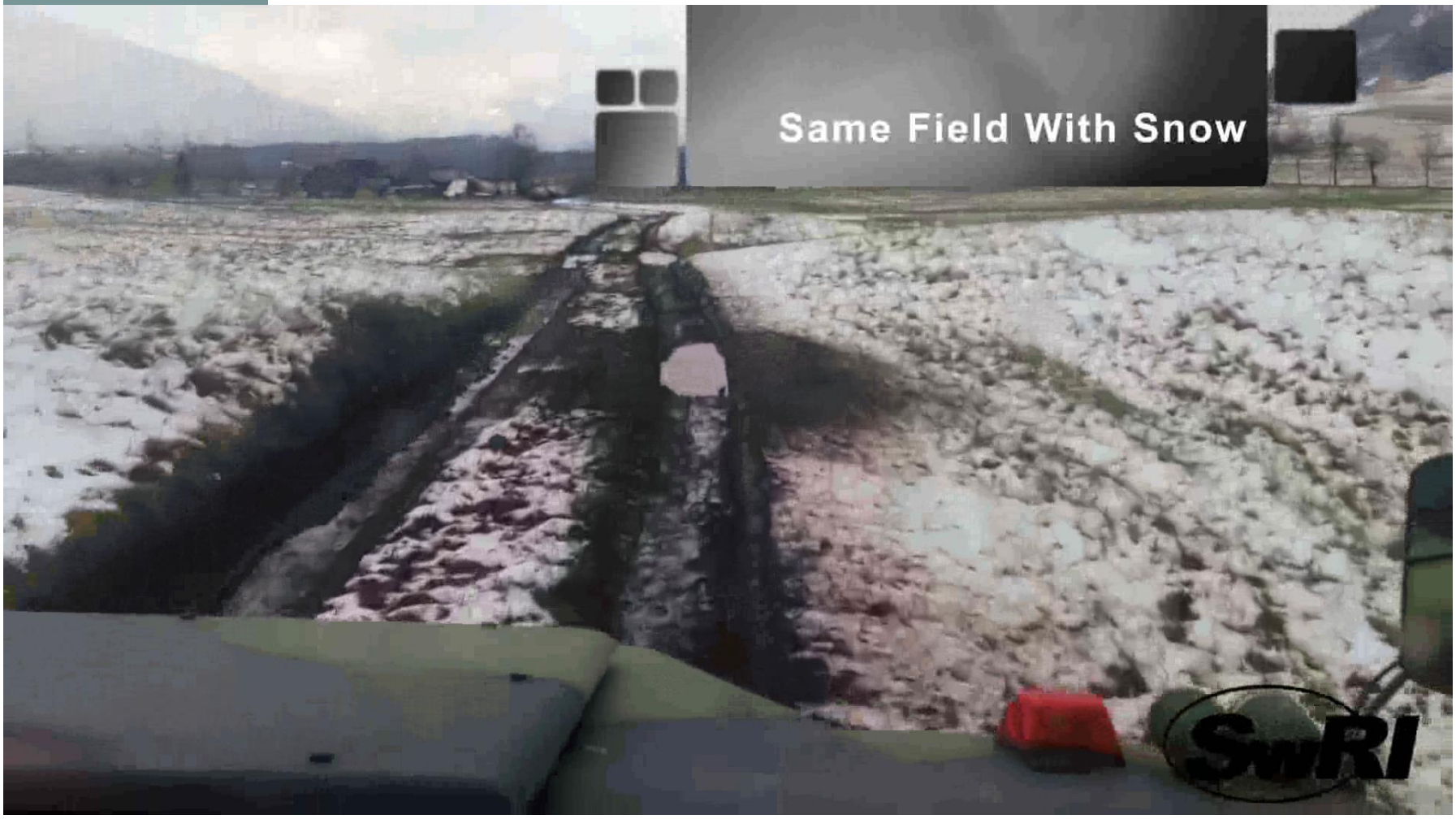
Source: Oshkosh

State of the Practice: Military (DSAT)

State of the Practice: Military (Weather)

- Material classification
- Snow and ice environments
- “New” environment to the system

Source: RUAG



Short Summary of AV Technology

- **State of Technology:**
  - **Semi-Autonomous: Available today**
  - **Full Autonomy: Not yet…**

- **Connected Autonomy: A likely reality**

- **Short Term: Adopting connected vehicles (V2V and V2X) is preparing for autonomous vehicles**

DOT Roles for a Successful AV Deployment

How will mapping data be handled?

- **New Road Construction**
  - Almost 14,000 miles of new roads built annually in the US

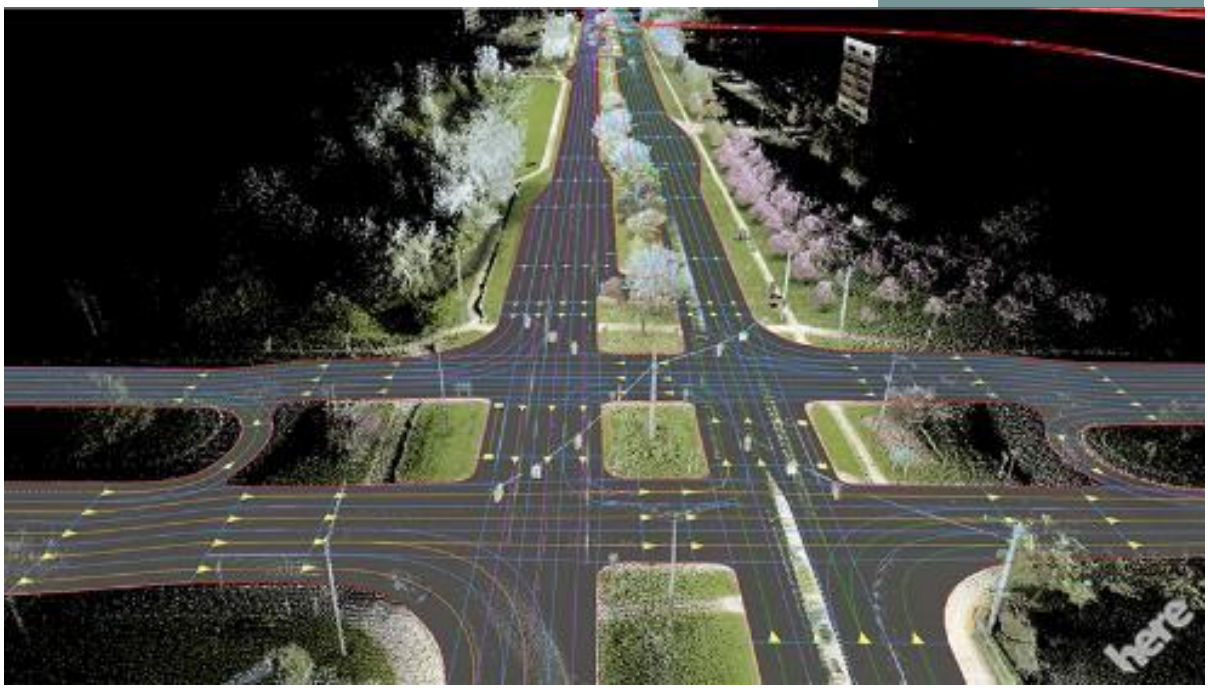
How will mapping data be handled?

- ***"It is clear that the industry needs a new kind of intelligent sensor – a "live map" that provides the vehicle with an awareness of the road environment beyond the reach of its other on-board sensors."* – HERE**

- **Rumor: Google's reason for advancing AV technology**

- **Roadway Data:**
  - Delivered in "real-time"
  - Centimeter lane level accuracy
  - GPS, photo, and point cloud
  - Petabytes of data

Source: HERE



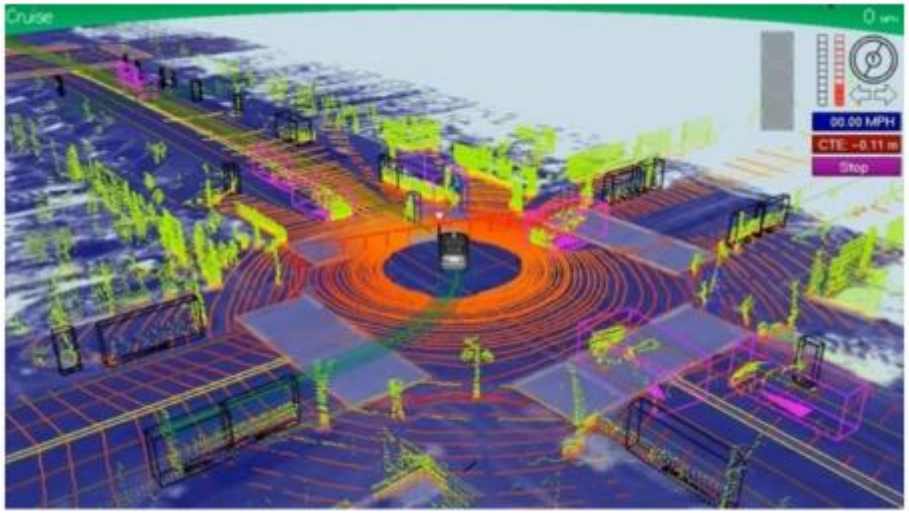
How will mapping be handled?

- **Challenges**
  - Real-time updates to:
    - Changes in roadway infrastructure
    - Road closures
    - Conditions
    - Construction lane changes
  - Distributing large data set on a national scale in real-time

- **HERE financially backed by Audi, BMW, and Daimler**

Source: HERE

Source: Google



How will mapping be handled?

Your Data Will Have Value

- Traffic data for public: *"Nice to have"*
- Roadway map data for AVs: *"Must have"*
- New roadways require pre-mapping
- Capturing and real-time distribution of map data:
  - Complex and expensive
  - Commercial sector moving
- Conclusion: Commercial sector managed

Actions to Consider:

- Short-term: Build relationships and partnerships
- Short-term: Commoditize or find a value proposition
- Medium-term: Plan to allow mapping providers advanced access to new roadways

How will Traffic Operations Change?

- **Negative Obstacle Avoidance**
  - Challenging for AV's to detect
  - Low-probability, high-impact problem
  - Technical need for a high fidelity observed world model that is dynamically *updated in real-time.*

How will Traffic Operations Change?

- Systems need to be capable of adapting to dynamic traffic patterns, construction/work zones, accidents, weather, etc.

How will traffic operations change?

- **Proposed HERE real-time environment data :**
  - Construction
  - Traffic congestion
  - Lane closures
  - Accidents
  - Weather-related changes
  - Variable traffic regulations

- **Who is the best source of this kind of data?**
  - You are! (DOTs)
    - Monitor for events
    - Verify events
    - Know when events clear

How will traffic operations change?

- **Autonomy Sensors dual-purposed**
  - Detect accidents
  - Report traffic conditions
  - Find potholes
- **Traffic operations information sources**
  - Current: DOT managed
    - 911, DOT sensor networks
  - Future: Vehicles as probes
    - Auto OEMs, Google (Waze), etc
    - CV Infrastructure (V2X)
- **Actions to Consider (All short-term):**
  - Be ready for more trends like Waze
  - A consortium of many states might get an auto OEM's attention (hint)
  - Research ways to communicate construction
  - Use analytics to parse big data

What changes need to be made to the roadway infrastructure?

- **Building our way out of congestion: Does this problem go away?**
  - Obtain 3,000, 4,000, or more vehicles/hour/lane?
    - Some say even more and some say no…
  - Can we narrow lanes?
  - Reduced accidents translates to less capacity to handle non-recurring congestion
  - Transition period: mixed autonomy and human driven vehicles
    - Efficiencies will be hard to gain
    - "Technology Lanes" – Next evolution to HOV and express-lanes
- **Actions to Consider:**
  - Medium-term: Planning to facilitate technology lanes
  - Long-term: Planning requires a full understanding of autonomous vehicle throughput / density
    - Research of autonomous vehicle throughput / density needs further funding

What changes need to be made to the roadway infrastructure?

- **What about roadway signage?**
  - Expensive
  - Delivery mechanism not verifiable
    - Perception in poor conditions (weather)
    - Visually occluded
    - Knocked over

- **"Connected autonomy" realistic**

- **Actions to Consider:**
  - Short-term:
    - Dynamic content: Adopt Connected Vehicles travel advisory messages (TAMs)
    - Static content: Likely handled by mapping firms. Will DOT deploy "virtual signs"?
  - Long-term: maybe no physical signs

What changes need to be made to the roadway infrastructure?

- **Does lane stripping, centerline markers, and other road markings matter?**
  - Now: Yes!
  - Future: Probably not…
- **Actions:**
  - Short-term: Road markings are important.
  - Long-term: a future of no markings (or barriers?)

What are the security implications?

- **Automobile Security**
  - 200+ electronic control units
  - 100M lines of code
  - Multiple suppliers
  - Cars are complex…
- **Attack Surfaces of AV/CV Environment**
  - Vehicle
  - Wireless communication
  - DOT infrastructure
- **Actions to Consider:**
  - Short-term: Build a culture of cyber-security into your agencies.
    - Treat it like Safety.
  - Short-term: Take steps to secure your ITS infrastructure

How do I handle the policy and legal issues?

- **Abusing autopilot functions**
  - Cannonball Run with a Tesla S
    - October 2015
    - L.A. to NY under 58 hours (including charging)
    - 96% autonomous mode
    - Speeds up to 90 mph
  - A matter of time…

- **Actions to Consider:**
  - November 7, 2000
  - For the Long-Term: Stay the course
    - begin with the end in mind.

How soon is full automation?

- Perception and behavior: 98% easy – last 2% is hard

How soon is full automation?

- "Deer in the headlights" (need 80 meters visibility)

- "Realistic" (aggressive) driving
  - June 2014 in DC
  - Taxi "strike"
  - How to "nose" into traffic (30 min)

- 50/50 odds my 2 year old could get an autonomous ride home from high school soccer practice

To prepare for a future of autonomy, embrace connected-vehicles

Thank you!

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