New York City's
Connected Vehicle Pilot Deployment Project

A Look at the Complexities and Challenges to
Deploying an End-to-End CV System
And Some Lessons Learned from NYC

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NEW YORK CITY DOT

NYC Connected Vehicle Project
For Safer Transportation

Outline

Traffic Controller → RSU → MAP/SPaT → Done?

This presentation will examine the complexity of CV deployment

- Overview of the NY project
- Overview of the end-to-end systems to support CV
- A more detailed look at the Intersection "systems"
- Lessons Learned
  - Data collection considerations
  - Over the air (OTA) updates
  - Security considerations
  - RSU installation
  - MAP message creation
  - Vehicle Interface
  - Location accuracy in the urban canyons
  - Standards
  - Transit vehicle installation

The Project

› NYC CV was a ***DEPLOYMENT*** project [driven by R&D]!

– *"After more than a decade in trials, proof of concept, etc. the pilots will leverage and deal with the issues of* ***practical deployment****"*

› **Ambitious plans:**

- Large fleets – many vehicle interactions
- Identify dense urban (canyon) solutions
- Assess CV technology's contribution to Vision Zero
- Develop approach for high intersection density (250 feet spacing)

Scale

- **8,000 fleet vehicles** with Aftermarket Safety Devices (ASDs/OBUs)
  - MTA Buses
  - Sanitation & DOT vehicles
  - DCAS vehicles
  - Taxis (Yellow Cabs)
- **100 Pedestrian Information Devices** (PIDs)
  - Visually Impaired Navigation
- **>400 Roadside Units (RSU)**
  - **Manhattan Avenues**
  - **Manhattan Cross Streets**
  - Flatbush Avenue
  - FDR
  - **Support locations** (where vehicles linger)
    - Airports,
    - River crossings
    - Terminal facilities
    - Additional to support location accuracy

Challenging Locations – Manhattan & Brooklyn

V2V applications work **wherever equipped vehicles** encounter one another.

V2I applications work where **infrastructure is installed** (highlighted streets).

Additional Sites not Shown: *Travel Times and OTA up/down*

- FDR north to Triboro Bridge
- Queensboro (59th St) Bridge Intersections (4) in Queens
- Williamsburg Bridge Intersections (2) in Brooklyn
- LGA and JFK airport
- Additional Locations to support OTA/SCMS access

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NYC CV Safety Applications

Vehicle-to-Vehicle

- Vehicle Turning Right in Front of Bus Warning
- Forward Collision Warning
- Emergency Electronic Brake Light
- Blind Spot Warning

- Lane Change Warning/Assist
- Intersection Movement Assist

Vehicle-to-Infrastructure

- Red Light Violation Warning
- Speed **Compliance**
- Curve Speed **Compliance**
- Speed **Compliance**/Work Zone
- Oversize Vehicle Compliance
  - Prohibited Facilities (Parkways)
  - Over Height warning
- Emergency Communications and Evacuation Information

Pedestrian Applications

- Pedestrian in Crosswalk (RSU)
- Visually Impaired Crossing (PID) ***Cellular Service***

Customized Applications

Operations, Maintenance, and Performance Analysis

Mobility Data Collection:

- CV Data for Intelligent Traffic Signal System (Travel Times)
- BSM for testing only

Other Applications

- OTA Firmware Update
- OTA Uploading of Data Collected
- Application Parameter Modifications (Tuning)

Evaluation Data Collection:

- RF Monitoring (ASD & RSU)
- Incident/Event activity
- System Logs - reliability

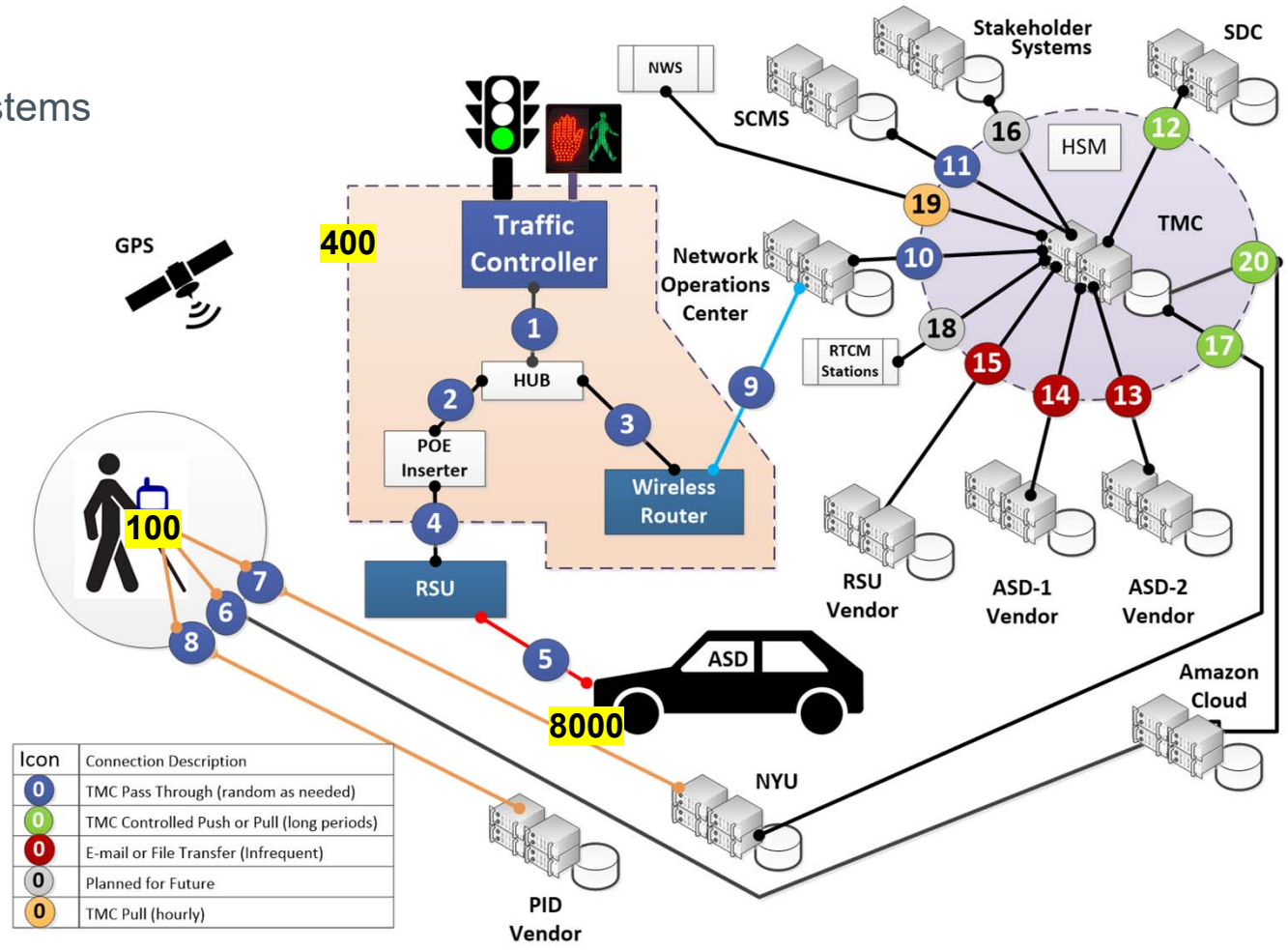
Connection Diagram for NYC CV Pilot System

Challenges

- Connections to external systems
  - Firewalls
  - Proxy Servers
- Wireless Backhaul
- Integration with ITS
- SCMS access and profiles

Development

- PED Application
- V2I Applications
- O&M Applications
- Asset Management
- Installation Procedures



Icon	Connection Description
0	TMC Pass Through (random as needed)
0	TMC Controlled Push or Pull (long periods)
0	E-mail or File Transfer (Infrequent)
0	Planned for Future
0	TMC Pull (hourly)

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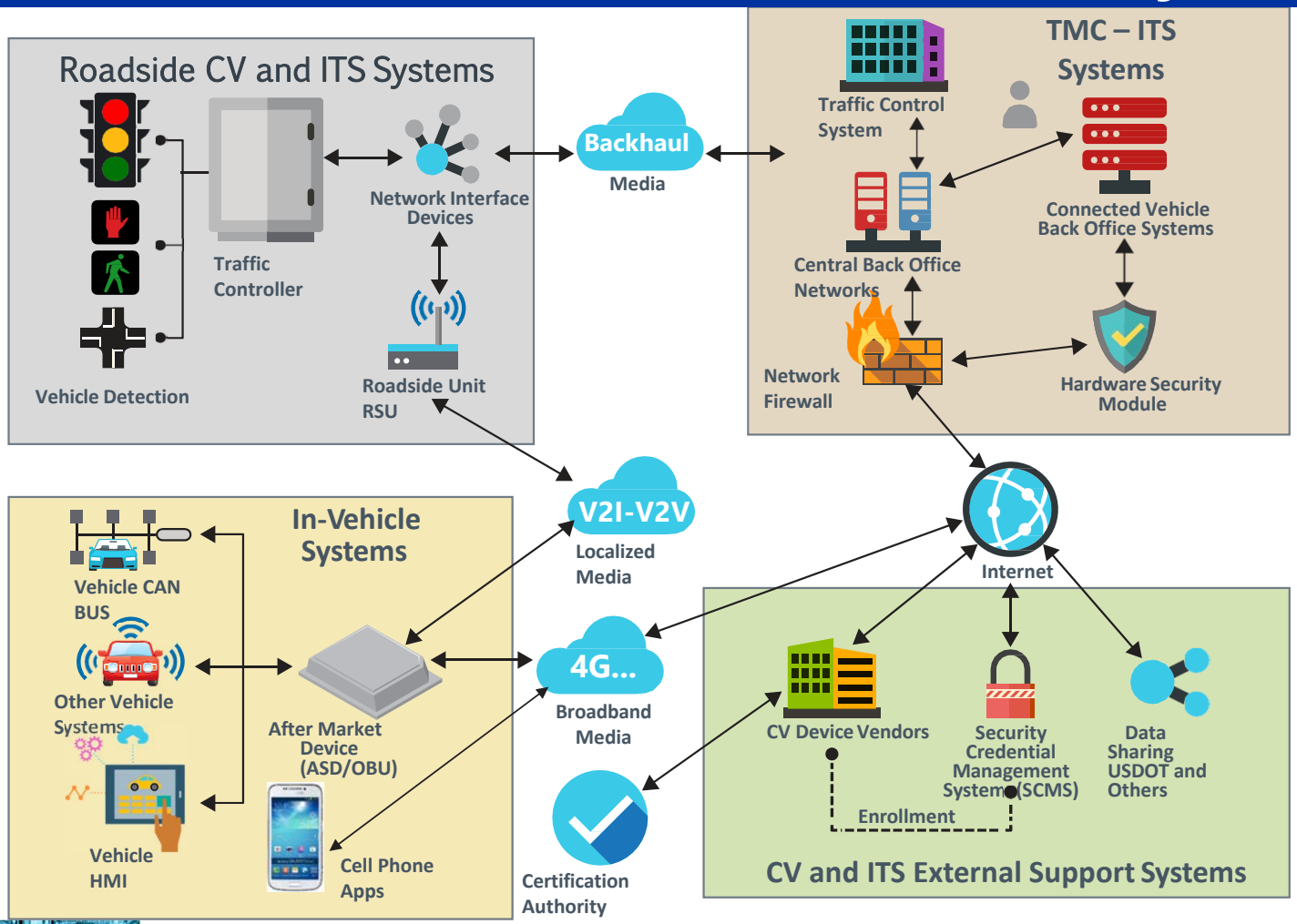
Connected Vehicle End-to-End ECO System



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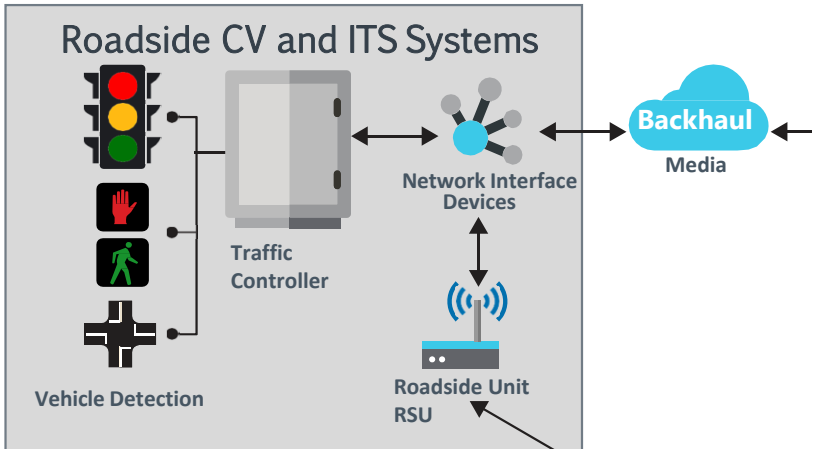
Focus on the Roadside Infrastructure



The Roadside Infrastructure

- ATC Software Upgrades
  - Export SPaT information – to TMC/RSU
  - NTCIP 1202v3 for RSU
  - Configure PED information (SPaT)
- Upgrade Security
  - TMC to ATC: (DTLS, TLS, VPN …)
  - ATC to RSU: DTLS – SNMPv1
  - TMC to RSU: DTLS – SNMPv3
  - Manage the certificates X.509
  - **Signed TIM & MAP at TMC**
- Pedestrian Detection for ***PED in crosswalk***
- PoE and "ethernet" for RSU
  - Cross intersection Wi-Fi (no conduit)
- Software updates (RSU – vendor proprietary)
- OTA Updates to ASDs
  - Parameters for algorithms
  - Firmware

- Managing WSA/PSID/ DSRC Channel usage
- OTA log files retrieval from ASD
  - RSU Store/Forward ASD upload data
    - Event data
    - RF Data
    - System log data
  - RSU Edge Computing
    - First and Last BSMs from passing ASDs
    - Reporting ASD entry to Travel Time Zone
- Privacy considerations
  - Encryption of backhaul
- Maintenance tracking and failure alerts
- Issues with the Standards
  - FHWA RSU 4.1 spec – needs update
  - NTCIP 1218 not finished - not addressing NYC needs
  - NTCIP 1202v3 new - untested

Consider - Practical Data Collection

Is this Deployment or R&D? . . . . .

What Data to collect

- What could you collect?
- What is the raw data available?

What do you need?

- What is the use of the data?
- Resolution and frequency

What should you collect?

- Need to justify the costs
- Protecting Personal Information
- Focus on the Metrics

Consider the costs

- Backhaul communications
- Storage (backup, recovery, etc.)
- Processing (using)
- **Supporting FOIA requests**
- **Supporting Subpoenas**

Consider Privacy Issues

- Prohibition of keeping PII
- Combination with other sources

- **Traceability to specific**
  - Driver
  - Vehicle
  - TOD
  - Location

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Practical Data Collection - NYC

› Practical and scalable data collection ?

- Each vehicle transmits ~25 MB /day (BSMs) *average vehicle operation – 10 hours/day*
- 8000 vehicles – aggregate is 230 GB per day
- With 36 Data Collection Stations - ~6 GB/Day/Site = 192 GB/Site/Month
- Total for these **36 collection sites**: ~7 TB per month in OTA network charges
- Add SPaT, MAP, TIM and everything everyone receives . . . . **Doesn't scale**
- ***NYC Project only uses DSRC (802.11p) for EVERYTHING***

Not enough "connection time" to upload this amount of data!
Monthly usage (carrier) is too costly
Not enough bandwidth to send over the wireless network

Backhaul wireless network

› NYC Approach

- Capture only data surrounding "events"
  - › 10 seconds before, 20 seconds after
- Only from vehicles within "X" meters of the HV

USDOT
Project Performance Metrics

- Capture only one BSM for travel time data per vehicle per intersection – Adaptive Control
- Collect first and last BSM/SPaT heard for each unique device – O&M

Security Challenges –NYC

- W/O mis-behavior detection and ***Certification Relocation List*** distribution

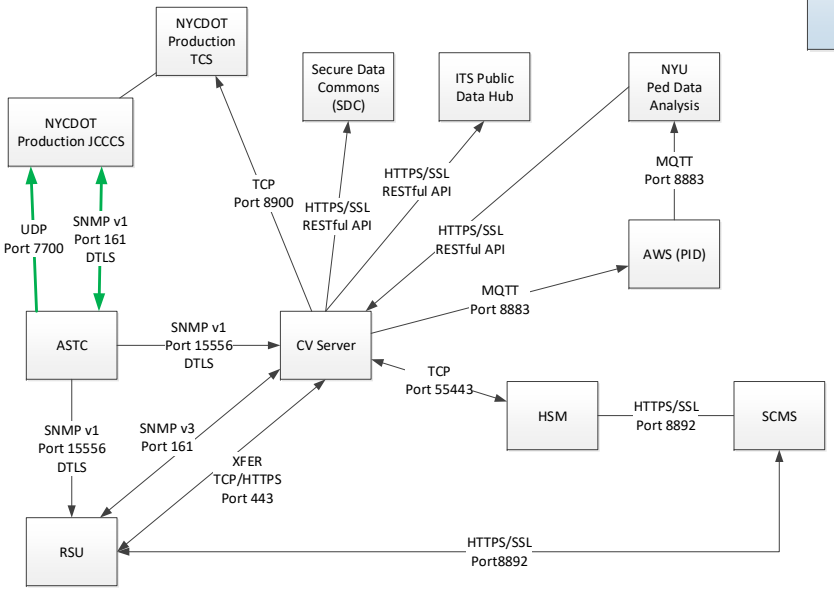
  NYC adopted proactive strategy
  - 1-week certificate life
  - **60 certificates per week** – Vehicles in service 14 hours per day not 1-2
  - **Weekly** "top-off" of certificates
    - ASD requires real-time access to SCMS
    - RSU requires real-time access to SCMS
- NYC required a "custom" security profile
- "Test Certificates" or "Production Certificates"?
  - Integration transition drives testing and schedule
- Challenge: secure access from ASD to SCMS
  - Proxy servers – NYC Networks – Cybersecurity Czars
- Re-enrollment of RSUs – transition from prototypes to production
- Initial startup for ATC – establish secure TMC-ATC link
- Need RSU at installers to provide valid certificates
  - W/O certificates – no broadcast (RSU or ASD)

Without IEEE 1609.2 Security,
- *Not a sustainable CV System*
- *Not interoperable with anything!*

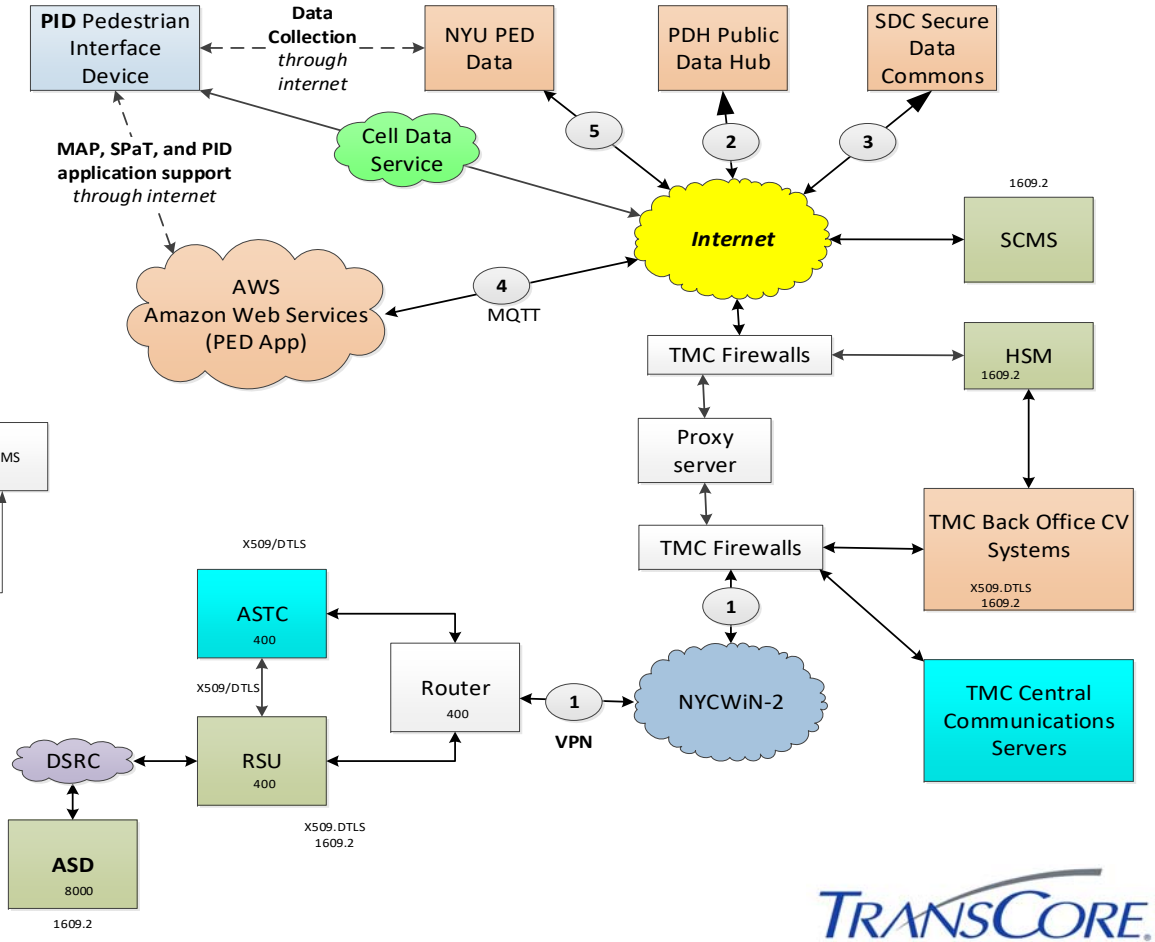
Certs have geographic limits for validity
Certs have time limits for validity

Security Challenges – NYC Architecture

Protocols



Functional Architecture



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OTA – Application Challenges

For NYC - DSRC (802.11p) is the only media - - -

- **OTA updates ASD (software & Config)**
  - Developed a network coding scheme
  - Broadcast for bulk of downloads
  - On demand for the “stragglers”
  - Maximize channel utilization
  - Target “groups” to manage options
  - Two Classes – “treatment” and “control”

- **Extensive System Testing & complexity**
  - ASD, RSU, Backhaul, Network, TMC
  - Large file sizes Up and Down – takes minutes
  - Takes multiple “sessions”

Keep in mind the cost to physically access the vehicle - - prohibitive

RSU Installation Challenges

- "Ideal Location" vs. what is available!
  - Line of sight – Avenues and Streets
  - Vendor requested alternate side of street
- No Conduit to Traffic Controller
  - Implemented cross intersection wireless ethernet link
- Mast Arms already "crowded"
  - Developed alternative mounting to avoid damage
- Changes After Installation
  - Scaffolding – compromised V2XLocate
- RSU – extensive testing (NY CVPD is different)
  - OTA upload (logs) OTA download (Firmware & parameters)
  - RF and travel time data collection
- Time sync Traffic controller (AC Line) vs. RSU/ASD (GPS)
  - Future goal – all GPS (with communications upgrade)

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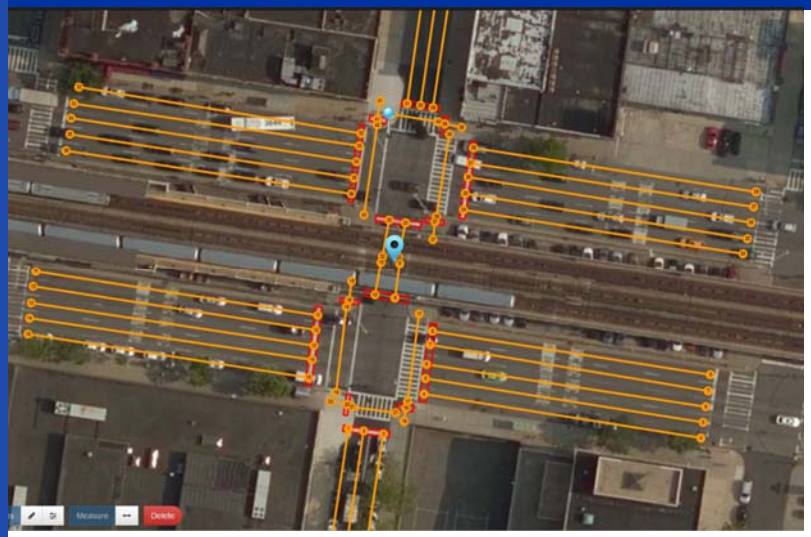
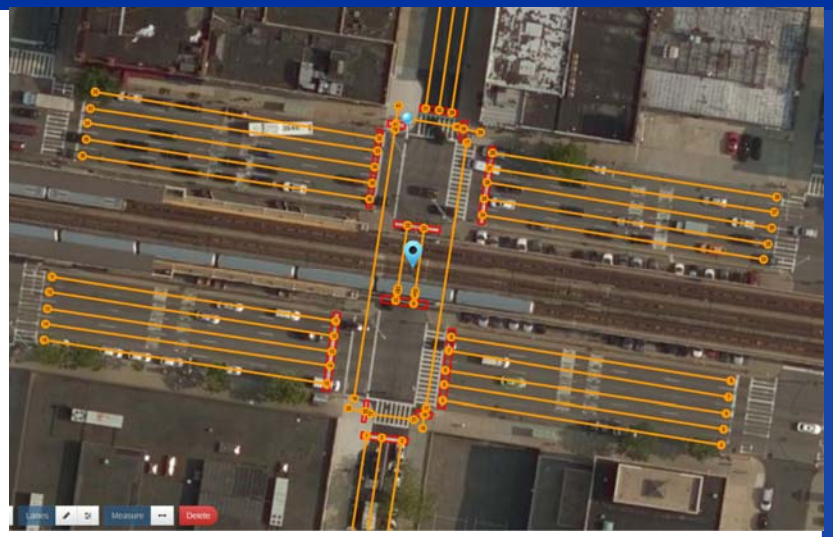
MAP Message Challenges



35th St. & Queens Blvd



- MAP message generation
  - Use USDOT tool
  - Max size – 1400 bytes with signature
  - Internal storage lane treatment
  - Ped applications need:
    - Crosswalk configuration
    - Crosswalk description
    - Landing zone configuration
    - Landing zone description
    - Text descriptions increase message size

- Adjustments Considered
  - Reduction in lane length
  - Aggregation for intersection egress
  - Removal of intermediate PED landings
  - Multiple MAP messages with layers

- Working cooperatively with vendors
  - Interoperable MAP operation
  - Consistent PED information (visually impaired)

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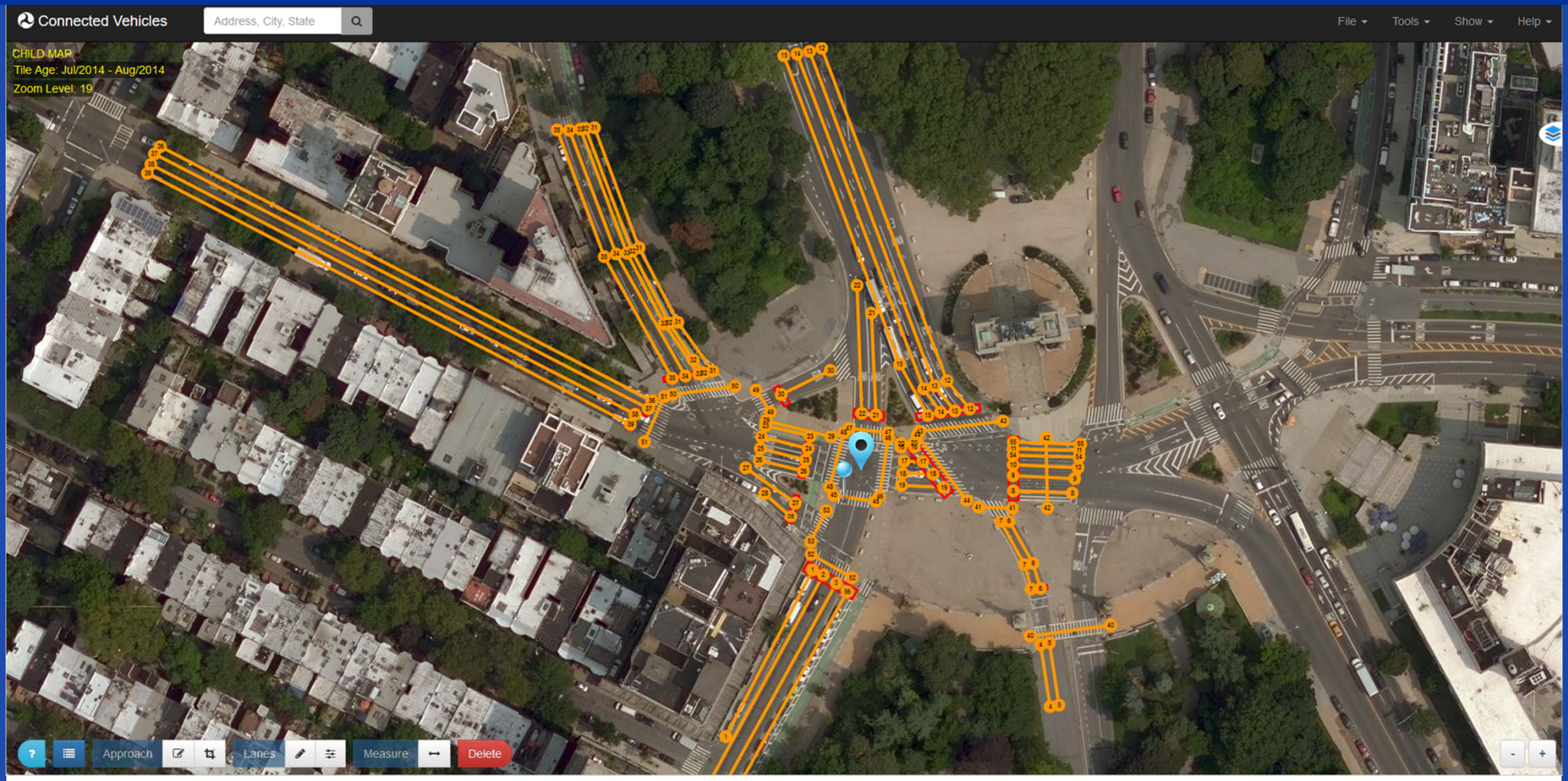
MAP Message Challenges



The tool is evolving based on user input

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Vehicle CAN Bus Interface

- **CAN Bus**
  - Interference from other devices (e.g. GeoTab)
  - Active retrieval – can create vehicle errors
  - Electrical interference issues
  - What data is available at OBD2 port
  - 10 Hz speed needed
  - Assistance provided by Toyota
- **Solution:**
  - Passive coupler
  - Not electrically connected

Downside: cannot read VIN – only what happens to be active on the CAN bus!

- **Power Consumption**
  - Quiescent power needed for GPS history
    - 25 microamps
  - Power needed to avoid Linux file corruption
  - Power needed to complete transfers
    - Upload & Download
  - Battery Preservation
- **Solution**
  - Mandatory step-down watchdogs
  - Time-out for “completion”
  - Lesson Learned
  - **ALWAYS DISCONNECT BATTERY BEFORE ANY INSTALLATION OR REPAIR**

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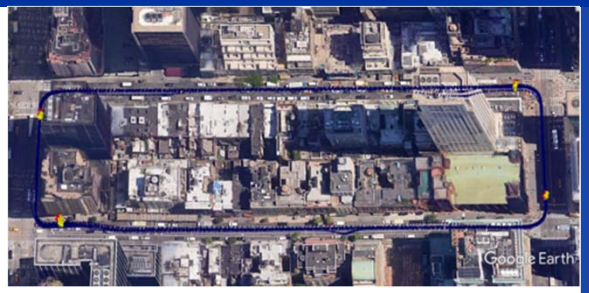
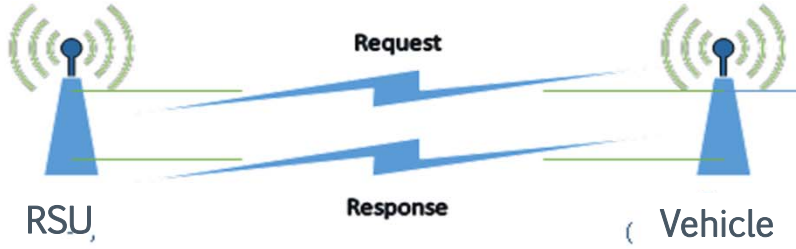
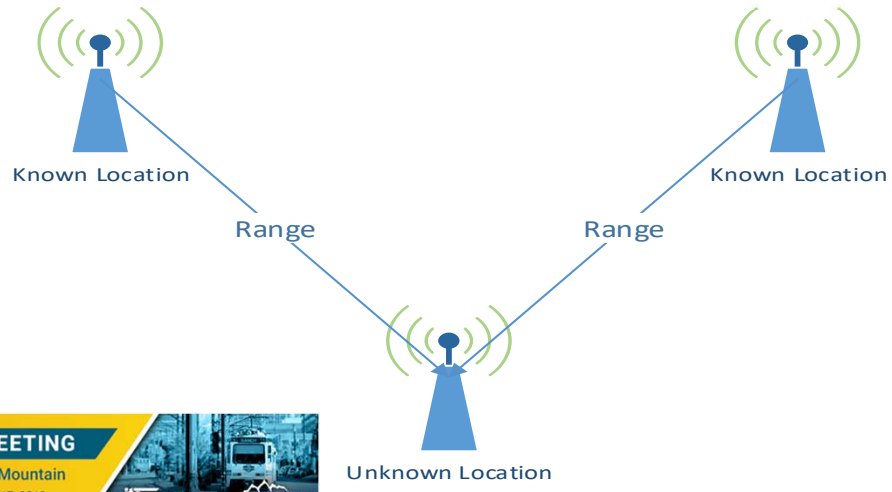
Location Accuracy Challenges

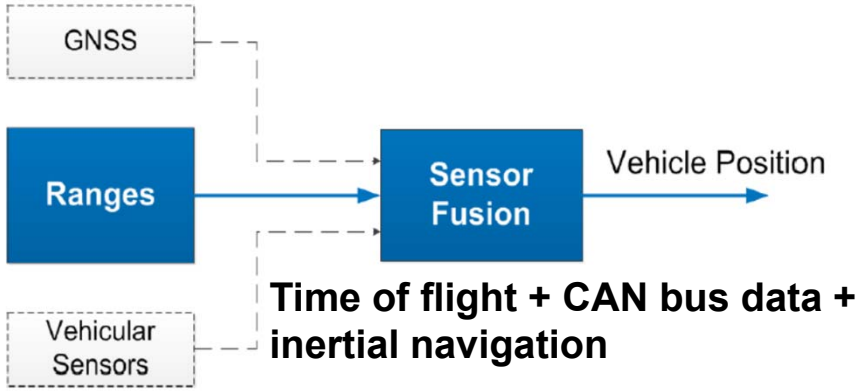
V2XLocate (Cohda)

*Uses **W**ave **S**ervice **A**dvertisement (WSA) – Channel 178*









Time of flight + CAN bus data + inertial navigation

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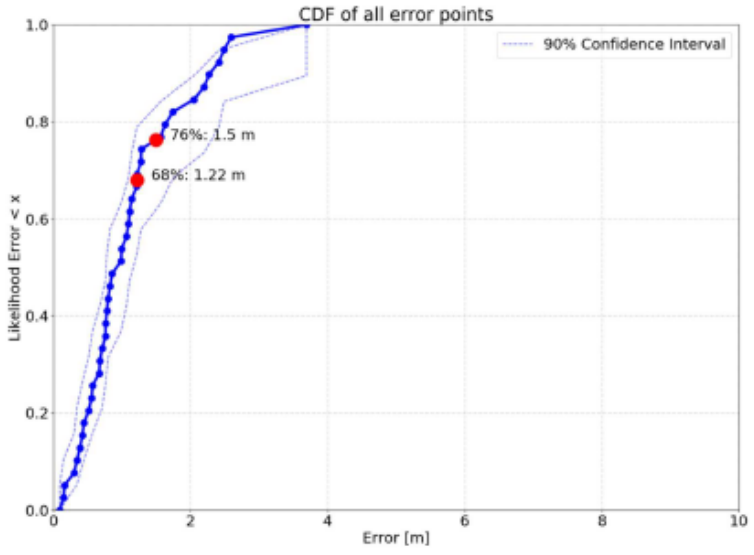
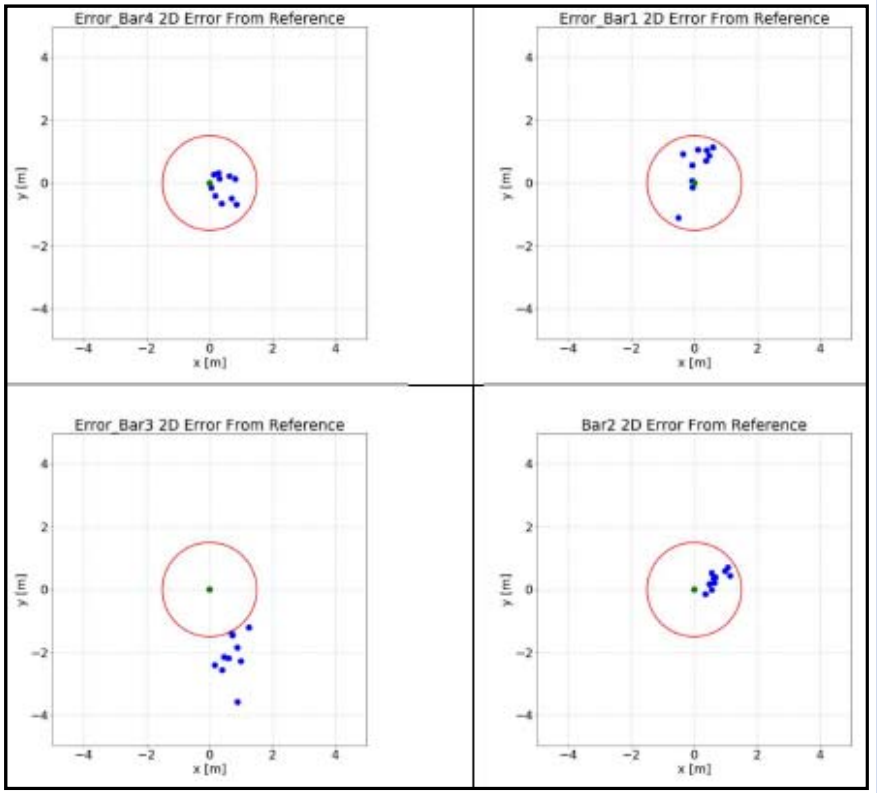
Other Challenges – Location Accuracy

2D Error (Absolute Stop Bar)*	
68th %	1.22m
1.5m	76%
CDF	

Cumulative Distribution Function



Stop Bar Error

SAE J2945/1 establishes 1.5 M at 1 sigma
Most applications work most of the time!

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Standards Issues

- Security
  - Understanding and managing 1609.2
  - Number of certificates
  - What PSIDs/SSPs apply to each Cert.
  - Guide coming from USDOT
  - Certificate Change criteria
- Security Library Performance Issues
  - Still testing
- WSA assignment and rules/limitations
- Channel Utilization
- NTCIP 1202v3 – needs work (NYC-first site)
  - Modified to transmit block object
  - Time-tick for RSU to track the LFC-GPS difference
- NTCIP 1218 – in process
- SAE J2735 3 CVPD Sites collaborated
  - Consistent interpretation of the meaning
  - Consistent use of optional elements
  - Consistent use of security
  - Issues with MAP message interpretation
  - Many areas need more guidance – for consistency

Challenge": INTEROPERABILITY – all vendors must be able to trust the data & unambiguously interpret the data **and** present a consistent user experience.

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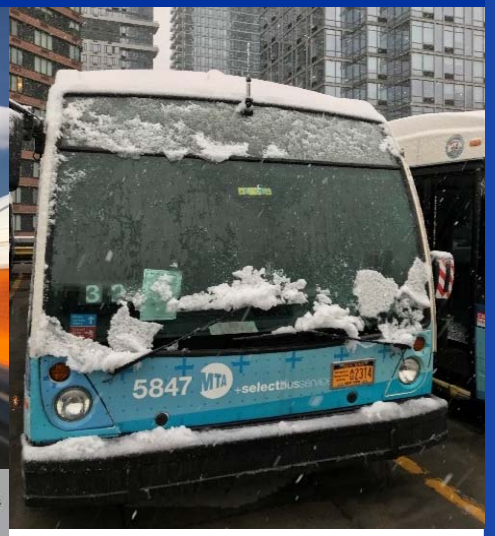
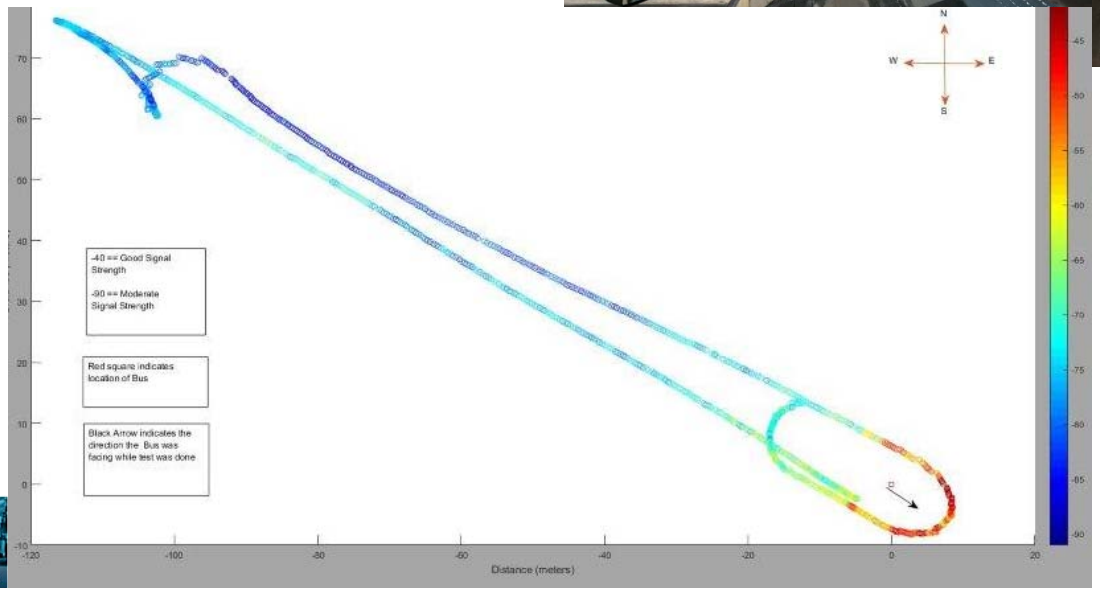
Bus Installation – NO HOLES ALLOWED

- Vendor (Danlaw) developed a through the glass antenna
- The buses were installed to test RF DSRC communication with light vehicles, and to develop an installation template





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Parting Comments

It takes more than installing an RSU & transmitting SPaT . . .
. . . to deploy a sustainable CV system.

Deploying CV without including security . . . is not secure **and**
. . . is not interoperable with anyone else.

Determine your real [useful] data needs . . .
Everyone wants "all" the data – what can you handle?

Is your system sustainable?
Is there a business case for your system?
What vehicles (fleets?) are you targeting
What vehicle applications are you supporting?

Questions

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USDOT CV
Contact Info

Contact for CV Pilots Program/Site AORs:

- Kate Hartman, Program Manager, Wyoming DOT Site AOR; Kate.Hartman@dot.gov
- Jonathan Walker, NYCDOT Site AOR; Jonathan.b.Walker@dot.gov
- Govind Vadakpat, Tampa (THEA) Site AOR; G.Vadakpat@dot.gov

Visit CV Pilot and Pilot Site Websites for more Information:

- CV Pilots Program: http://www.its.dot.gov/pilots
- NYCDOT Pilot: https://www.cvp.nyc/
- Tampa (THEA): https://www.tampacvpilot.com/
- Wyoming DOT: https://wydotcvp.wyoroad.info/


NYCDOT


Tampa (THEA)


WYDOT

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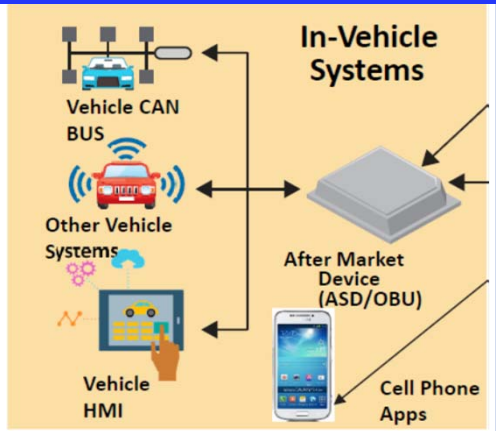
The following are supporting slides for consideration if you are planning a CV installation

Vehicle Equipment Considerations

- CAN Bus Interface
  - Existing devices (e.g. Geotab)
  - Interference with CAN bus
  - Passive vs. Active interface
  - Manufacturer's cooperation – *(Toyota helped us)*
  - What data is available – what do you need
  - Future Encryption – "right to repair"
- Device calibration (Inertial Navigation Parameters)
- Antenna Installation
  - Shark Fin - Drill vs. no drilling
  - Diversity (heavy vehicles)
  - Through the glass (Buses)
- Make sure the vehicle is OK **BEFORE** you start
  - Disconnect Battery **BEFORE** install
- Professional Installation Companies ?
  - Consider mobilization complexity
- Costs to "touch" the vehicles
- HMI – Audio, Visual, (both), Mounting, Speakers
  - Confirmation of alerts
  - Distraction issues – know your stakeholders
- Privacy & liability issues
  - Consent agreements
  - Public Agency Vehicles/Private Vehicles
  - 48 Hour self purge of log files (privacy)



- Connection to turn signals
- Power considerations
  - Ignition on/off
  - Quiescent Current Draw
  - Finishing "work in process"
  - Battery Disconnection
  - Inrush and fusing
  - Grounding
- Supporting Smartphone Apps.
  - DSRC or Cellular Service
- Control Group vs. Active
- Maintenance Tracking
- Fail-safe OTA survival

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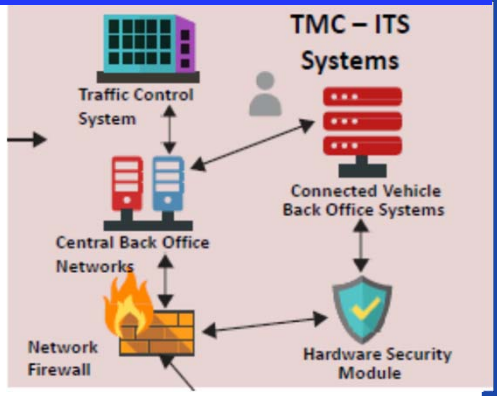
Central System Considerations

- Message Generation and Signing
  - MAP Message Management
  - TIM message Management
  - RTCM [not for NYC]
- Data Collection
  - Monitoring RSU health (RF)
  - Monitoring ASD health (RF)
  - Event Logs (performance measurement)
  - Travel Time (ISIG/MIM)
  - System Logs for troubleshooting
  - BSM – "breadcrumb" [not for NYC]
- Performance Measurements/Analysis
  - Project performance metrics
  - Report generation
- OTA download management
  - Configuration Management
  - ASD firmware upgrades
  - ASD Application Tuning
    - Application parameters
- User Interface/Database Management
  - RSU parameter management
  - ASD parameter management
- Privacy Protection
  - Obfuscated data
  - Aggregated data for export to SDC



- Management of CV and ITS devices
  - RSU – configuration files
  - RSU Firmware updates
  - Traffic Controller 1202v3 additions
  - Security enhancements (DTLS)
- Security management
  - Hardware Security Module
  - Security profiles for all messages
  - X.509 or TMC-RSU/ATC security
  - Firewall rules – external connections
- Tools for operations management
  - System logging
  - Operations alarms
  - Device status displays (visualization)
  - Security monitoring

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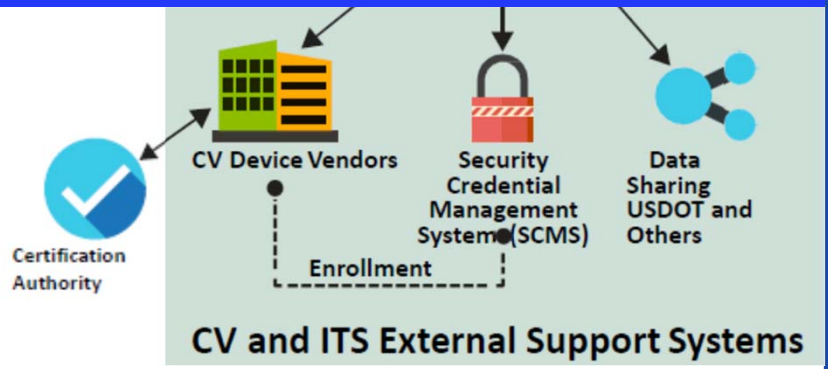
External System Connections

- Security Credential Management System SCMS
  - RSU acquires certificates
  - ASD acquires certificates
  - Product enrollment
  - Maintenance - re-enrollment
  - Test or Production certificates
  - CRL distribution
  - Misbehavior export
  - Disabling crypto content - “lost” devices
  - IPv4 or IPv6 – proxy server or direct firewall

- Secure Data Commons, RDE, etc. USDOT
  - Privacy issues
  - Reliability of the data
  - Metadata required
- Controlled Access (from vendors)
  - City receives firmware updates
  - City manages distribution
  - Vehicles assigned into groups
    - Testing
    - Upgrade management / Fleets



- Developed a Security Plan
  - Security Management & Operations Concept (SMOC)
  - Certificates per week? NYC 60
  - Life of certificates – NYC 7 days
  - Certs loaded onto a Device – 2 weeks
  - Security profile for messages
    - Pilots developed Profiles for each:
      - SPaT, MAP, BSM, TIM

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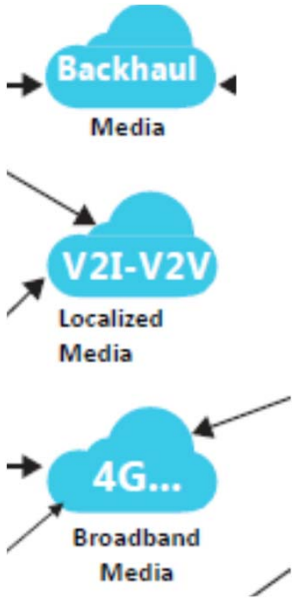
Communications Technology Considerations

- Data Requirements
  - Number of remotes
  - SCMS updates
  - Expected log file sizes
  - Number of vehicles
  - Frequency of encounters/alerts
- Media available
  - Wireless
    - Carrier
    - Trunk/microwave
    - Private network
    - 5G future
  - Fiber
  - Leased/Cable etc.
  - Mixed media
- IPv4/IPv6
  - ASD – IPv6
  - Backhaul is IPv4

NYC:
DSRC: V2V & V2I
4G SPaT Data for PED apps
4G Backhaul to TMC
IPv4 proxy to SCMS
MQTT to AWS

- "localized" communications V2V and V2I
  - 5G
    - Unproven in CAV
  - DSRC – 802.11p
    - 10 Years testing/trials
- Role of local communications
  - Smartphone apps
  - Pedestrian apps
  - In-Vehicle apps
  - ASD apps



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