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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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)
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
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
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
Focus on the Roadside Infrastructure

Roadside CV and ITS Systems

Vehicle Detection

Traffic Controller

Network Interface Devices

Roadside Unit RSU

Backhaul Media

Data Sharing

USDOT and Others

CV Device Vendors

Security Credential Management System (SCMS)

4G Broadband Media

V2I-V2V Localized

Certification Authority Enrollment

CV and ITS External Support Systems

Backhaul Media

Vehicle CANBUS

Other Vehicle Systems

Vehicle HMI

After Market Device (ASD/OBU)

In-Vehicle Systems

Cell Phone Apps

Connected Vehicle Back Office Systems

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

ATC Software Upgrades
- Export SPaT information – to TMC/RSU
- NTCIP 1202v3 for RSU
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Upgrade Security
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Pedestrian Detection for *PED in crosswalk*
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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?
  o What is the use of the data?
  o Resolution and frequency

What should you collect?
  o 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
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

NYC Approach
- Capture only data surrounding “events”
  - 10 seconds before, 20 seconds after
- Only from vehicles within “X” meters of the HV
- 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

Backhaul wireless network

USDOT Project Performance Metrics
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)

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**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**
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)
MAP Message Challenges

- 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)
The tool is evolving based on user input
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**
Location Accuracy Challenges

V2XLocate (Cohda)

Uses **Wave Service Advertisement (WSA)** – Channel 178

Vehicular Sensors

Ranges

Sensor Fusion

Vehicle Position

Time of flight + CAN bus data + inertial navigation

Known Location

RSU

Request

Response

Timestamped Channel Estimates

Local Processor (V2X-Locate Engine)

Unknown Location

Vehicle

Known Location

Range

Range

GNSS
SAE J2945/1 establishes 1.5 M at 1 sigma
Most applications work most of the time!
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.
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.
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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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/
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
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
External System Connections

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

• Secure Data Commons, RDE, etc. USDOT
  o Privacy issues
  o Reliability of the data
  o Metadata required

• Controlled Access (from vendors)
  o City receives firmware updates
  o City manages distribution
  o Vehicles assigned into groups
    - Testing
    - Upgrade management / Fleets

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

- **“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

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