Connected Vehicle Pilot Deployment Program Phase 1

Application Deployment Plan – New York City

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Final Application Deployment Plan — August 2016

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16. Abstract

This document is the Task 7 Application Deployment Plan deliverable for the New York City Connected Vehicle Pilot Deployment. It describes the process that the deployment team will follow to acquire and test the connected vehicle safety applications. This also includes the applications to support the system and applications to gather data for the performance evaluation. Most of the software applications will need specialized hardware, so the development and testing of both must be integrated.

The overall approach follows the standard "V" of system engineering. Specifications are developed at increasing levels of detail, and then elements are tested individually and together. Because of the large number of new subsystems that must work together, the plan provides for extensive testing as subsystems are integrated.

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Finally, the team wants to thank the USDOT for sponsoring this project and laying the foundation for future connected vehicle deployments.

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Chapter 1. Introduction

The New York City Connected Vehicle Pilot Deployment (CVPD) brings New York City another step towards reaching the Vision Zero goal—eliminating the injuries and fatalities due to traffic crashes. The project's concept introduces connected vehicle technology and communications to the New York City travel environment. Several large vehicle fleets will be equipped with connected vehicle technology, and selected corridors will be equipped with the corresponding connected vehicle infrastructure.

The first of the three phases of the project is to plan for the development and deployment in phase 2 and operation and evaluation in phase 3. The first phase will produce a number of documents, each of which is a plan for a particular aspect of the deployment. This Application Deployment Plan describes how the New York City team will develop and test the wide variety of hardware and software needed to run and evaluate the deployment.

1.1 Purpose of this Document

The scope of this document is the development and testing of the safety applications and the hardware and other applications (e.g. performance monitoring, maintenance analysis) needed to support them.

The safety applications are described in the Concept of Operations or "ConOps" (Galgano et al. 2016). In addition to the safety applications, the *Aftermarket Safety Devices* (ASDs) will run applications to support performance measurement. The safety applications will be supported by administrative applications, such as those to manage operating parameters, over the air software updates, and logging functions for real time and off-line performance analysis.

This document describes the processes that the New York City CVPD team will follow to procure and develop the applications. The document provides for extensive, iterative testing as the subsystems and systems are integrated in preparation for the pilot deployment. This document is the result of Task 7 in Phase 1 of the project.

As emerging technology, the connected vehicle safety applications will face new challenges in New York City. The deployment will enable significant advancement of the technology and produce lessons learned to facilitate future deployments. New challenges will include the "urban canyon" effect of tall buildings on the dedicated short range communication (DSRC) and Global Navigation Satellite System (GNSS) transmissions, and New York's drivers experiencing the applications as a new part of their work environment (versus the Safety Pilot Model Deployment, where drivers were primarily commuters). It is also an opportunity to deal with a roadway network with frequent underpasses and tunnels to see if the location tracking technology can be used for such situations which are a major part of one of the freeway segments covered.

1.2 Document Organization

This document lists the applications and then describes the effort planned to develop them and to test them. Chapter 2, the Overview of the Safety Applications, describes the background of each application and its relative maturity level.

Chapter 3 describes three distinct development approaches. The ASDs, integrated with the software for the project's connected vehicle applications, will be procured as part of a competitive bid from vendors. Likewise, the roadside units (RSUs) with their supporting applications will be procured as integrated devices. The New York City team will develop the back office applications to operate and manage the CVPD. The PED-SIG safety application and associated hardware for visually impaired users will be a separate effort by New York City.

Because the project will require custom hardware that does not currently exist and the majority of the connected vehicle applications will need to be developed or modified by the vendors, thorough verification and validation will be needed for acceptance of vendor's connected vehicle applications and so they operate as desired in the field. This is described in Chapter 4 – Verification and Validation.

1.3 Intended Audience

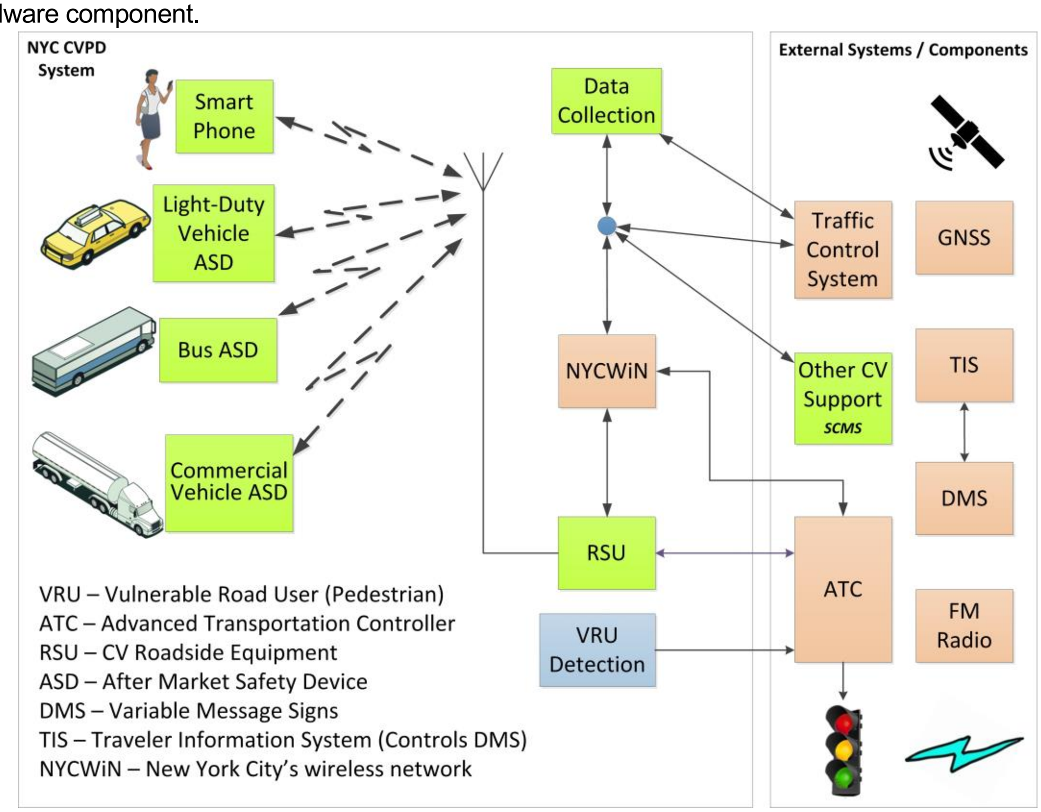
The primary audience of this document is the membership of the team working on the New York City Connected Vehicle Pilot Deployment project and the United States Department of Transportation (USDOT). The document will facilitate coordination of the team members and identify interfaces between their work products.

A secondary audience is future developers of connected vehicle systems in other urban areas.

Chapter 2. Overview of the Applications

New York City intends to deploy 14 safety applications as discussed in the *Concept of Operations*. The safety applications are listed in Table 2-1, which is adapted from Table 8 of the *Concept of Operations*. Figure 2-1, adapted from Figure 1 of the *Concept of Operations*, identifies the major hardware elements of the system. The safety applications run on the ASD in the vehicles, with the exception of the Mobile Accessible Pedestrian Signal System (PED-SIG), which runs on a personal intelligent device (PID). Note that most of the adaptations for the previously developed safety applications are associated with one or more of the following: 1) performance data collection to determine the benefits of the CV applications, 2) performance data collection for equipment and communications monitoring for maintenance support, 3) data collection for traffic management purposes, 4) application management including OTA software and parameter updates.

The V2I safety applications on the vehicles will be supported by information provided by the infrastructure. In addition to the safety applications will be applications to support administrative, security, and research purposes. Table 2-2 is a list of the software applications that reside on each hardware component.



Source: NYCDOT, 2016

Figure 2-1. NYC CVPD System Context

Table 2-1. Fourteen Safety Applications to be Deployed in New York City

	Application	Type	Taxi & Limousine	NYC DOT Sanitation	MTA NYCT Bus	Commercial Vehicle	Pedestrian
1	Speed Compliance (SPD-COMP)	V2I	Yes	Yes	Yes	Yes	No
2	Curve Speed Compliance (CSPD-COMP)	V2I	Yes	Yes	Yes	Yes	No
3	Speed Compliance in a Work Zone (SPDCOMPWZ)	V2I	Yes	Yes	Yes	Yes	No
4	Forward Crash Warning (FCW)	V2V	Yes	Yes	Yes	Yes	No
5	Emergency Electronic Brake Lights (EEBL)	V2V	Yes	Yes	Yes	Yes	No
6	Blind Spot Warning (BSW)	V2V	Yes	Yes	Yes	Yes	No
7	Lane Change Warning (LCW)	V2V	Yes	Yes	Yes	Yes	No
8	Intersection Movement Assist (IMA)	V2V	Yes	Yes	Yes	Yes	No
9	Vehicle turning right in front of a bus warning (VTRW)	V2V	No	No	Yes	No	No
10	Red Light Violation Warning (RLVW)	V2I	Yes	Yes	Yes	Yes	No
11	Pedestrian in Signalized Crosswalk (PEDINXWALK)	V2I	Yes	Yes	Yes	Yes	No
12	Mobile Accessible Pedestrian Signal System (PED-SIG)	Ped	No	No	No	No	Yes
13	Oversized Vehicle Compliance (OVC)	V2I	No	Conditional[1]	Conditional	Conditional	No
14	Emergency Evacuation	V2I	Yes	Yes	Yes	Yes	No

Source: NYCDOT, 2016

[1] Conditional: The OVC application will be triggered only when the vehicle enters designated roadways (i.e. FDR Drive)

Table 2-2. Software Applications in the Hardware Elements

Hardware➔ Software🡻	Aftermarket Safety Device (ASD)	PID	Roadside Unit (RSU)	Traffic Management Center
Support for Safety Applications	(13 vehicle apps listed in Table 2-1)	PED-SIG	SPAT MAP RTCM TIM PSM SSM	Parameter Management TIM Evacuation Notification Work Zone Roadside WSA Management
Administrative Applications	Vehicle Performance Monitor OTA Firmware Update Parameter Download	OTA Firmware Update	OTA Firmware Update IPV6/IPV4 Tunneling RF Monitoring	OTA Firmware Update RF Monitoring Operational Performance Measurement
Security	SCMS Certificate Use	SCMS Certificate use	SCMS Interface	SCMS Interface
Feasibility Test	(none)	(none)	Intelligent Traffic Signal System (I-SIGCVDATA)	Intelligent Traffic Signal System (I-SIGCVDATA)
Performance Measurement	Event History Recording Event History Upload RF Range and reliability	(none)	file upload services RF Range and reliability	Event History Upload Obfuscation Performance Measurement

Source: NYCDOT, 2016

2.1 Maturity Levels of the Safety Applications

The safety applications are listed again in Table 2-3, which indicates the relative maturity level of each application. The table also lists the source of each application or the prior application on which it will be based. All of the applications, whether mature, adapted, or new, will require some level of development work. For instance, the Speed Compliance, Curve Speed Compliance, Speed Compliance in a Work Zone, Mobile Accessible Pedestrian Signal System, and Oversize Vehicle Compliance applications will be adapted from the original CVRIA applications to meet the user needs of the system in the NYC pilot area. The development efforts will be based on the NYC CVPD requirements.

All applications will be applied to vehicles on which they have not previously been deployed. They will require tuning for alert thresholds and arbitration because the high density of traffic in New York City and the high number of applications in use. A novel audio-only driver-vehicle interface (DVI) will be developed. Through testing, demonstration, and shakedown periods, the nature of the tones (i.e. length, pattern, pitch) for each application will be determined to ensure clear interpretation of the alerts by the drivers.

Furthermore, work will be necessary to ensure interoperability of the hardware and software elements in the pilot deployment with one another and with the existing New York City infrastructure. Applications that are well established may need to be modified to perform with new interfaces.

The cross-cutting efforts necessary for deployment of all safety applications are in Chapter 3. Application-specific development efforts are in Development Approach, Chapter 4, where they are grouped according to how they will be developed.

The core V2V applications, as explained in Section 5.3.4 of the Concept of Operations will be little changed from prior work. Their function will be familiar to vendors in the field, although new alerts will be developed, parameters will be subject to adjustment, and use of the SCMS must be included. One V2I application, Red Light Violation Warning, will have minor modifications from its established function. The Pedestrian in Signalized Crosswalk, which has been previously deployed only in transit buses, will be deployed on all vehicles in the project but will only be fully supported at 10 intersections where ITS pedestrian detection equipment (e.g. video and/or infra-red detection TBD) will be installed. Work will be necessary for handling the lack of knowledge of the vehicle's path through an intersection.

Four V2I applications are similar to prior applications but are sufficiently different that they are given new names for this project. The concepts and requirements and test procedures for these applications can be adapted from prior work, but they will be treated as essentially new applications. These applications have a common deployment plan in Chapter 3.

The Mobile Accessible Pedestrian Signal System (PED-SIG) application will be adapted to the needs expressed by New York City stakeholders. A separate RFEI has been issued and this is part of a joint program with NYCDOT's IT department for the development of this application.

One application is unique to the New York City deployment. The Emergency Evacuation application will be developed from the concept level as outlined in the ConOps.

At this point, all of the applications will need to work with and develop some support for the SCMS and the implications of a full deployment of the security and privacy protection systems.

2.2 Components of the Applications

Every safety application is a software module running on an aftermarket safety device (ASD) mounted in the host vehicle (with the exception of PED-SIG which will run on a smartphone for the visually impaired). These applications will require input information provided by the ASD, which it acquires from external devices by DSRC radio, the vehicle bus, or GNSS. The information needs of the applications are listed in Table 2-4.

Table 2-3. Safety Application Sources and Maturity Levels

	Application	Name of the Original	Source of the Original	Maturity Level
1	Speed Compliance (SPD-COMP)	To be adapted from Speed Harmonization	FHWA-JPO-14-171	NYC CVPD requirements have been developed.
2	Curve Speed Compliance (CSPD-COMP)	To be adapted from Curve Speed Warning	FHWA-JPO-13-058	NYC CVPD requirements have been developed.
3	Speed Compliance in a Work Zone (SPDCOMPWZ)	To be adapted from Reduced Speed/Work Zone Warning	FHWA-JPO-13-060	NYC CVPD requirements have been developed.
4	Forward Crash Warning (FCW)	Unchanged (distinguished from CVRIA's Forward Collision Warning)	SAE J2945/1-2016	Saw limited deployment in the Safety Pilot
5	Emergency Electronic Brake Lights (EEBL)	unchanged	SAE J2945/1-2016	Saw limited deployment in the Safety Pilot
6	Blind Spot Warning (BSW)	unchanged	SAE J2945/1-2016	Saw limited deployment in the Safety Pilot
7	Lane Change Warning (LCW)	unchanged	SAE J2945/1-2016	Saw limited deployment in the Safety Pilot
8	Intersection Movement Assist (IMA)	unchanged	SAE J2945/1-2016	Saw limited deployment in the Safety Pilot
9	Vehicle turning right in front of a bus warning (VTRW)	minor changes	FHWA-JPO-14-117	Demonstration deployment in the Safety Pilot
10	Red Light Violation Warning (RLVW)	minor changes	FHWA-JPO-13-058	NYC CVPD requirements have been developed.
11	Pedestrian in Signalized Crosswalk (PEDINXWALK)	To be expanded from transit buses to other vehicles	FHWA-JPO-14-118	Demonstration deployment in the Safety Pilot
12	Mobile Accessible Pedestrian Signal System (PED-SIG)	To be adapted.	MMITSS System Design	Described in the MMITSS documents.
13	Oversized Vehicle Compliance (OVC)	To be adapted from Oversize Vehicle Warning	FHWA-JPO-13-060	NYC CVPD requirements have been developed.
14	Emergency Evacuation	New	NYC CVPD ConOps	New

Source: NYCDOT, 2016

Table 2-4. Safety Application Interfaces and Data Needs

	Application	Information needs External to the Vehicle	Information needs Internal to the Vehicle	Driver Alert Latency
1	Speed Compliance (SPD-COMP)	Statutory speed limits, from TIMs	Current speed	High
2	Curve Speed Compliance (CSPD-COMP)	Advisory speed limits, from TIMs	Current speed	High
3	Speed Compliance in a Work Zone (SPDCOMPWZ)	Temporary speed limits, from TIMs	Current speed	High
4	Forward Crash Warning (FCW)	Dynamics of remote vehicles, from BSMs	Current speed, brake pedal status	Low
5	Emergency Electronic Brake Lights (EEBL)	Dynamics of remote vehicles, from BSMs	Brake status, current speed, braking level	Low
6	Blind Spot Warning (BSW)	Dynamics of remote vehicles, from BSMs	Current speed	Low
7	Lane Change Warning (LCW)	Dynamics of remote vehicles, from BSMs	Current speed, steering angle status	Low
8	Intersection Movement Assist (IMA)	Dynamics of remote vehicles, from BSMs	Current speed, brake pedal status	Low
9	Vehicle turning right in front of a bus warning (VTRW)	Dynamics of remote vehicles, from BSMs	Brake pedal status	Low
10	Red Light Violation Warning (RLVW)	Intersection and signal data from MAP and SPaT.	Current speed and speed history, brake pedal status	Low
11	Pedestrian in Signalized Crosswalk (PEDINXWALK)	Pedestrian presence	Brake pedal status, current speed	Medium
12	Mobile Accessible Pedestrian Signal System (PED-SIG)	Intersection and signal data from MAP and SPaT.	(no vehicle)	Medium
13	Oversized Vehicle Compliance (OVC)	Road clearance, from TIMs	Height (static)	Medium
14	Emergency Evacuation	Route instructions	(none)	High

Source: NYCDOT, 2016

In the above table, high latency refers to advisories while low latency refers to crash-imminent warnings. This will impact the testing and determination of threat arbitration parameters and thresholds for each safety application. In addition, all applications need to know the vehicle's position while many need to know the current time.

Chapter 3. Overall Plan Information

This chapter presents the overview of the development and testing approach, and it contains several cross-cutting topics that apply to all applications.

3.1 NYC CVPD System Integration and Testing

While the NYC CVPD is a deployment program and not an experimental program, NYCDOT and TransCore recognize that new hardware and software will be developed for the deployment. Vendors' of existing CV products and components are continuing to upgrade, adapt and enhance these as new projects, needs, and features are identified. Accordingly, NYCDOT and TransCore will develop and integrate the multitude of components to be deployed systematically, in accordance with System Engineering principles. The steps in the System Deployment Plan are illustrated in the System Engineering "V" in Figure 3-1, and include

- NYC CVPD System Requirements and Procurement Specification Development
- NYC CVPD Subsystem Requirements and Procurement Specification Development
- NYC CVPD Hardware & Software Component Requirements and Procurement Specification Development
- NYC CVPD System, Subsystem, Hardware & Software Component Procurement
- Component Design Development, Verification and Acceptance Testing and Approval
- Subsystem Integration, Verification and Acceptance Testing and Approval
- Prepilot Deployment, Verification and Acceptance Testing and Approval
- Pilot Deployment, Verification and Acceptance Testing and Approval

NYCDOT and TransCore[2] plan to conduct pre-pilot deployments and acceptance testing prior to approval of full deployments throughout the CVPD area. These Pre-pilot deployments will first provide the opportunity for selected[3] vendors to demonstrate the robustness of their system and installations. Secondly, Pre-pilot deployments will also be used to test and verify the compatibility and interoperability of all vendor components and subsystems. NYCDOT will work with the selected vendors during Pre-pilot deployment tests to refine their respective systems to ensure more complete compatibility and interoperability.

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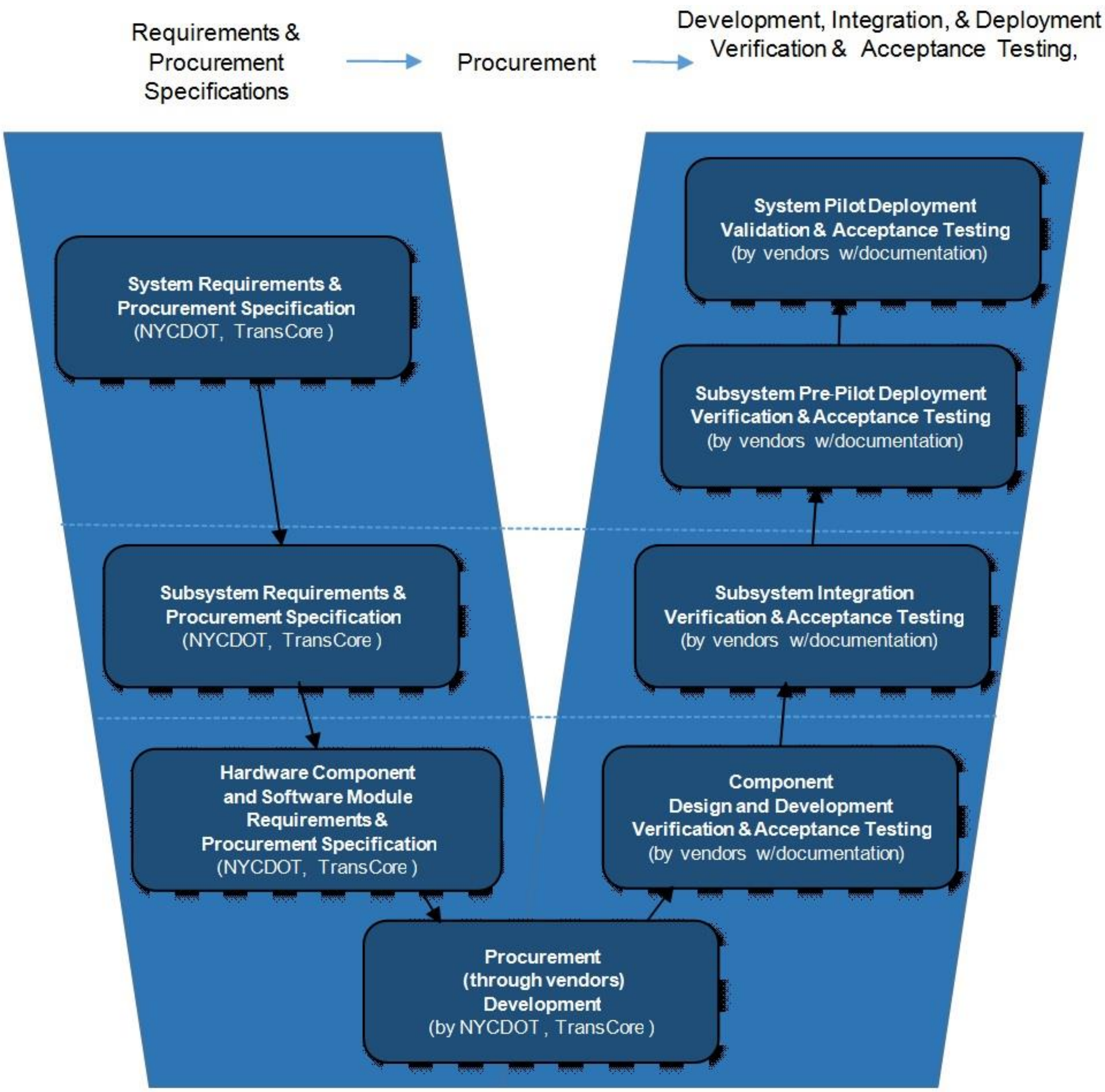
[2] Where TransCore is listed in this document, this will consist of representatives of TransCore and the continued support of the TransCore team responsible for deliverables in Phase 1 of the project. Notably this includes Security Innovations and Cambridge Systematics with consultant services from NYU and KLD.
[3] NYCDOT and TransCore have issued a Request for Expression of Interest to interview the vendors as part of the prequalification process and to better assess the practicality of some of the requirements within the identified budgets.



Source: NYCDOT, 2016

Figure 3-1. Standard System Engineering "V" Diagram for the NYC CVPD System Development, Integration, Deployment, and Testing

3.2 Security Credential Management System

All over-the-air communication among vehicles and between vehicles and RSUs will be protected by the Security Credential Management System (SCMS). Credential management may be implemented by hardware or by software on individual devices. Exactly how the SCMS is implemented, including how often actors are authenticated, has significant implications for bandwidth and cost. These decisions will be an integral part of the application development process. Dedicated tests of SCMS will be conducted, and security will be included from the early stages of integration testing as described in Chapter 5.

Note that it is assumed that we will be developing all software related to the use of the SCMS based upon the interface documents developed by USDOT. However, this would appear to be an area where considerable formal collaboration amongst the pilot sites would be of significant benefit since we will all be developing the same software support systems. USDOT should consider coordinating these efforts or funding [separately] the development of such tools as an API for encryption, authentication, decryption, acquisition of enrollment certificates, and acquisition of operating certificates.

3.3 Plan for Uploading Data to RDE

Some of the event data will be collected by the CV components (the ASDs and the RSUs), and other data will come from external sources (such as traffic control system data, crash databases and statistics, observed weather data, traffic counts, and travel times and speeds). All data will be scrubbed to remove any personally identifiable information (PII) using the data obfuscation protocols to be developed. Following this obfuscation process, the raw data will be destroyed[4], leaving only the obfuscated data. The obfuscated data will then be processed to develop performance metrics of the efficacy of the NYC CVPD application deployment and to calibrate microscopic simulation models to further estimate the effects of the NYC CVPD that cannot be directly observed in the field. Further details of the data sets, the obfuscation process to strip data of potential PII, the performance measures to be developed, and the evaluation plan are described in detail in the Task 5 Performance Measurement and Evaluation Support Plan Report.

The NYC CVPD data will be uploaded to the USDOT's Research Data Exchange (RDE) for use by the research community. This includes the ASD and RSU data that has been aggregated & obfuscated, the data from external sources, performance data from sources external to the CVPD, the possible confounding data (such as weather or work zones), and calculated performance metrics. As planning proceeds and particularly during the shakedown period, the anticipated volume of data will be estimated, and the team may decide, in cooperation with USDOT, whether to upload a representative subset of the data instead of the entire database.

While the ASD action log data will be obfuscated to prevent the matching of a driver action's to a specific time and location, the obfuscated data logs will be further reviewed before posting the data to the RDE to ensure that stakeholder and participant privacy is maintained. If some groupings of the obfuscated data and the confounding data have small numbers of samples, that data may be withheld from the RDE to prevent matching against other databases, such as crash records, that contain time and location details with PII.

[4] Refer to the Performance Document (Task 5); this is necessary to avoid problems associated with Freedom of Information Requests and Subpoenas for information held by NYCDOT that could be used against drivers or vehicle owners.

The disaggregated privacy-cleansed data will be uploaded in 24 to 48 hour time windows, as it becomes available. The processed aggregated data will be uploaded quarterly or more often depending on the volume and details worked out with USDOT in phase 2 of the project.

3.4 Intellectual Property Rights and Posting Code to OSADP

Intellectual property rights to the software will be negotiated as part of the ASD & RSU procurement. Ownership will depend on the origin of the designs for the code and equipment, the level of federal funding, and any data rights that may be asserted by the vendors in their proposals. The bid specifications will require this type of disclosure.

The New York City CVPD will have at least one application that is built from code found in the OSADP. The conditions for posting newly developed code to OSADP will be determined as part of the procurement process. This is anticipated to include elements from the data analysis and the extraction of mobility data (at the TMC) as well as selected PED applications from the MMITSS program.

3.5 Application Safety Plan Considerations

The Safety Management Plan from Task 4 has further provisions for system design, testing, and operation. The safety management function will continue independently and in parallel with the application deployment. As the architecture and design mature, the CVPD systems will continue to be reviewed for introducing new hazards and protecting against known hazards.

All of the vehicle safety applications provide the driver with additional cues to information that is already available. Should the applications fail to provide that cue, the driver has all ordinary sources of information. Thus, the CV applications will “do no harm” to the individual vehicles/drivers and are expected to provide additional alarms and warnings that should prevent or minimize the incidence and severity of crashes if/when they do occur.

In the event of missed warnings, drivers will not know whether they did not receive alerts from the ASD not being turned on or the applications failing to warn. However, the impact of false activations on drivers will increase the risk of crashes. If the applications send the wrong alerts, drivers will be confused and distracted. This potential malfunction will be investigated during testing and design to address the impact of false application triggers on safety.

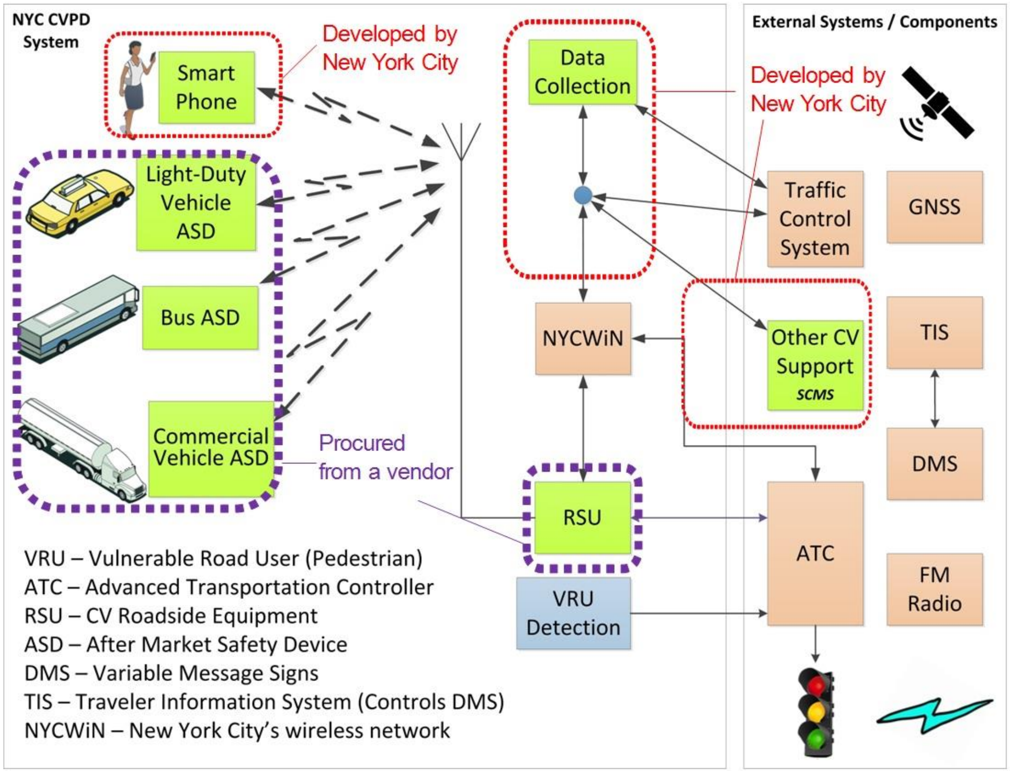
The PED-SIG application is unique in that it provides the visually impaired pedestrian with information that may not be otherwise available and will be difficult for the pedestrian to independently verify. This application will have further layers in all stages of development. Beginning with special reviews to ensure that the requirements are correct, individual staff members who are independent of the application development team will oversee all steps of development and testing to ensure that the safety goals are met. The ability of the hardware and the software to meet the safety goals will be verified. All decisions and results will be documented.

Chapter 4. Development Approach

The connected vehicle applications and supporting software that will run on the *Aftermarket Safety Devices* (ASDs) and the *Roadside Units* (RSUs) which will be procured as part of the ASD hardware. Additional software to enable the system to operate [i.e. CV support environment] will also be required at the Transportation Management Center (TMC), traffic signal controller, and mobile PED devices. The New York City team will be employing a variety of approaches to application development, depending on the hardware where the application is to reside and the maturity of the application. The software development approach has been divided into these categories representing the approach to the procurement:

Category	Approach
ASD	Turnkey procurement from one or more vendors, complete with all software and security enrollment certificate embedded application software/firmware.
RSU	Turnkey procurement from one or more vendors, complete with all software and security enrollment certificate embedded application software/firmware.
ASTC	Software modifications contracted to a single vendor to support data export to the RSU, and changes to support the security requirements, and time management.
TMC-CV	CV support software developed [and hardware procurement for additional servers and network equipment] based on the ConOps and requirements and detailed design developed during phase 2 to be developed by NYCDOT and the TransCore team. This is all of the CV support systems and interfaces specifically related to the CV systems including interfaces to the SCMS, RDE, and IE.
TMC-TCS	Includes minor modifications that are required to the existing traffic control system (TCS); there may be some additional data export for traffic controller status and/or software associated with time management since there are at least 4 time references used by the overall systems: UTC-line referenced for traffic control functions (e.g. offset relationships), UTC-GPS which is UTC referenced to absolute time (NIST) for the time points exported (SPaT), TAI which is the time reference for the SCMS and all security certificates.
PID	Personal Information Device used for the PED applications is being developed by a different NYCDOT project team in concert with the TransCore and it will include web applications and portable application for the implementation of the PED applications for the visually challenged.

This breakdown of the development and procurement is further shown in Figure 4-1.



Source: NYCDOT, 2016

Figure 4-1. Development and Procurement of ASDs and RSUs

Figure 4-1 is based on Figure 2-1, which is adapted from the ConOps. Green boxes indicate components that need to be developed for this deployment. Figure 4-1 indicates which components will be developed internally by the New York City CVPD team, and which will be procured from external suppliers. The figure also indicates the main interfaces in the equipment, with the exception of direct communication between vehicles for the V2V safety applications. The interfaces will be described more technically in Task 2-B, System Architecture and Design, and more thoroughly in the revised requirements in the specifications for each major system.

Table 4-1 lists all of the applications to be developed. They are grouped first by the hardware where they will run and secondly by the purpose. The column for development category lists the source where the software will originate

The column labeled Origin identifies the source of the code for the application, as was expressed graphically in Figure 4-1. Those labeled Project will need to be developed essentially from scratch for this project. Those labeled OSADP will be found originally in the OSADP and will be adapted as necessary for New York City. The label COTS (commercial off the shelf) indicates that the software is expected to be already in fairly mature form and can be incorporated with minor adaptation (e.g. . The final column of the table indicates whether the application will be written in-house by the New York City CVPD team (Develop) or by a vendor as part of a turnkey acquisition of hardware and software (Procure).

Table 4-1. Application Sources and Acquisition Methods

Hardware	Applications	Purpose	Origin	Acquisition
ASD	Speed compliance, curve speed compliance, speed compliance work zone, oversize vehicle compliance	V2I Safety	Project	Procure
ASD	FCW, EEBL, BSW, LCA, IMA, RLVW	V2V Safety	COTS	Procure
ASD	Vehicle Performance Monitor OTA Firmware Update Parameter Download	Administration	Project	Procure
ASD	SCMS	Security	COTS	Procure
ASD	Event History Recording Event History Upload	Performance Measurement	Project	Procure
Smart Phone	PED-SIG	Safety	OSADP	Develop
Smart Phone	OTA firmware update	Administration	Project	Develop
Smart Phone	SCMS	Security	Project	Develop
RSU	SPAT MAP RTCM TIM	V2I Safety	OSADP Vendor	Procure
RSU	PSM, SSM, OTA firmware update	Administration	Project	Procure
RSU	SCMS Interface IPv4/IPv6 Tunneling	Administration	COTS	Procure
RSU	Intelligent Traffic Signal System (I-SIGCVDATA)	Feasibility Test	OSADP Project	Procure
Traffic Management Center	Parameter Management TIM Evacuation Notification Work Zone Roadside WSA Management	Safety	Project	Develop
Traffic Management Center	OTA Firmware Update RF Monitoring Operational Performance Measurement	Administration	Project	Develop
Traffic Management Center	Intelligent Traffic Signal System (I-SIGCVDATA)	Feasibility Test	OSADP	Develop
Traffic Management Center	Event History Upload Obfuscation Performance Measurement	Performance Measurement	Project	Develop

Hardware	Applications	Purpose	Origin	Acquisition
Traffic Controller	Support for the export of the SPaT data Clock and time management Addition of security provisions for all exchanges	Safety Apps Support	Project Modifications to ASTC Firmware	Develop

Source: NYCDOT, 2016

The following provide additional detail for each platform.

4.1 ASD

The ASDs will be acquired through a turnkey procurement so that the specialized hardware can be developed in concert with the numerous safety and other applications it needs to run. The project team will monitor the progress of the vendors of the ASDs during their design and testing to ensure that performance requirements are met.

The detailed hardware and software specifications will be developed for this device and will be advertised for public bid offering based on vendor input during the RFEI[5] during July, 2016. NYCDOT has arranged for the availability of a test track to provide a suitable space for vendor demonstrations and discussions. This has been sent to all vendors known to have provided product in this domain or who have expressed interest in providing equipment to NYC for the CV pilot deployment project.

The NYCDOT will announce the available of the bid documents and follow their routine bidding procedures for this procurement. The bids will include the normal submittal review process, and will require both environmental and performance testing for communications throughput and proper use of the DSRC protocols and the SCMS. The vendor will be required to submit test procedures and such procedures will be reviewed by NYCDOT for completeness; the test procedures and all submittals will be shared with USDOT. The project team continues to monitor the certification programs and will incorporate those elements which are mature at the time of the bid letting and available at a reasonable and practical cost.

It is also expected that the vendor will self-certify many aspects of the conformance to the specifications and standards – and NYCDOT and its consultants will review their certification program which is subject to our review and approval. Note that members of the NYCDOT team are directly involved in the NTCIP, DSRC, SCMS, IEEE, and ISO development teams.

NYCDOT hope to award to more than one vendor, but recognizes that this may introduce significant cost increases to cover the required software/hardware development, testing (both by the vendor and the project team), and certification. However, the bid will be structured to support the supply of a

[5] A Request for Expression of Interest was issued by the project team to start a vendor review and qualification process which is intended to culminate in vendor presentations and demonstrations such that NYCDOT can establish the maturity of their applications and products and to refine our estimates for the installation and maintenance of this equipment. Our stakeholders will be invited to this “show and tell” to assist them and the project team in understanding the complexities and implications of the ASD installation in their fleet vehicles.

prototype phase and then production deployment of at least 5,000 units with additional units [thereafter] in lots of 500. This will allow NYCDOT and USDOT to make a determination of whether to award to one or 2 vendors based on the cost of the bid items.

The vendor will be required to develop detailed submittals for the application software and hardware including software architecture, module structure, operation to be provided by each module, interaction of modules, the operating platform and task management, watchdog management and recovery, encryption and authentication plan, data collection and event detection, CAN/J Bus interface, interface timing, radio characteristics, memory utilization, processor loading, OTA firmware updates and process management, and all of the MIB objects for the management of the unit and the applications. These submittals will be reviewed by the City and will be made available to USDOT for their review and comment. Once the submittals have been accepted, the vendor is expected to begin the submittal process for the test procedures and test environment which will likewise be reviewed and submitted to USDOT. Thus, the detailed design documents etc. for Phase 2 for the ASD will be developed by the turnkey vendor(s). Note that the City may award to more than one vendor depending on the budget.

4.2 RSU

The RSUs will be acquired through a turnkey procurement so that the specialized hardware can be developed in concert with the data collection and other applications it needs to run and additional provisions that we expect to be adding to the existing USDOT RSU Specifications. Note that there are significant changes to the software of the RSU to support the OTA updates for parameters, applications, and configuration of the performance monitoring system. The project team will monitor the progress of the vendors of the RSUs during their design and testing to ensure that performance requirements are met.

The detailed hardware and software specification will be developed for this device and will be advertised for public bid offering based on vendor input during the RFEI (see footnote 3) during July, 2016. NYCDOT has arranged for the availability of a test track to provide a suitable space for vendor demonstrations and discussions. Like the ASD, this has been sent to all vendors known to have provided product in this domain or who have expressed interest in providing this equipment to NYC for the CV pilot deployment project.

The NYCDOT will announce the available of the bid documents and follow their routine bidding procedures for this procurement. The bids will include the normal submittal review process, and will require both environmental and performance testing for communications throughput and proper use of the DSRC protocols and the SCMS. The vendor will be required to submit test procedures and such procedures will be reviewed by NYCDOT for completeness; the test procedures and all submittals will be shared with USDOT. The project team continues to monitor the certification programs and will incorporate those elements which are mature at the time of the bid letting and available at a reasonable and practical cost.

It is also expected that the vendor will self-certify many aspects of the conformance to the specifications – and NYCDOT and its consultants will review their certification program which is subject to our review and approval.

NYCDOT plans to award the RSU supply to a single vendor due to the small volume and software development required to support the extended operation support and monitoring applications.

The RSU vendor will be required to develop detailed submittals for the application software and hardware including software architecture, module structure, operation to be provided by each module, interaction of modules, the operating platform and task management, watchdog management and recovery, encryption and authentication plan, data collection and event detection, ASTC interface, interface timing, radio characteristics, memory utilization, processor loading, OTA firmware update management and downloadable firmware and parameters, and process management, and all of the MIB objects for the management of the unit and the applications. These submittals will be reviewed by the City and will be made available to USDOT for their review and comment. Once the submittals have been accepted, the vendor is expected to begin the submittal process for the test procedures and test environment which will likewise be reviewed and submitted to USDOT. Thus, the detailed design documents etc. for Phase 2 for the RSU will be developed by the turnkey vendor.

4.3 Discussion - Procured Applications: ASDs and RSUs

The ASDs for many vehicles with numerous applications represent the biggest advancement in technology in this deployment. Therefore, the ASDs will have the greatest number of design and test iterations of all the components of the NYC CVPD system. A limited acquisition, based on the requirements as they are currently understood, will begin with a Request for Information (RFI) in the summer of 2016. Following and concurrent with this activity and evaluation of the RFI and demonstrations (Week of July 11), the City will start the development their procurement specifications for both the RSU and ASD. Because of the time delays inherent in the NYCDOT procurement processes, it is expected that it will take several months (see project schedule) to gain approval to issue these bid documents. During Phase 2, NYCDOT will finalize the procurement documents and will then proceed with the bidding process.

The normal bidding process will lead to a bid “opening” after which one or more selected vendors will be invited to contract to build a small number of ASDs (100) and RSUs (10) to demonstrate they have adequate computing resources for the communication, security, and safety application needs. These initial “prototype units” are also intended to demonstrate all of the required applications and include benchmarking applications to demonstrate their processing capability (including location accuracy and management of location information in the urban canyons and under roadways). They will enable New York City and vendors alike to identify development needs for localization, BSM handling, security management, and safety application processing. After approval of the prototypes by both NYCDOT and USDOT, NYCDOT will authorize the start of the “production” and delivery of the ASDs and RSUs. It is assumed that at this point the vendor should be comfortable with the hardware designs – such that further changes necessary would be software – not hardware; this approach allow the vendor to accelerate its construction and supply of the hardware for the production installation and testing while continuing to perfect the application software including the additions for data collection and device management. The prototype bid item allows the vendor to recover some of their costs for engineering, however, award of the prototype is not a guarantee of continued participation; if the City or USDOT feel that the prototype has not sufficiently demonstrated the vendors ability to complete the project, the City may proceed with a single vendor.

It should be noted that working with 2 suppliers for the ASD’s (only one supplier will be selected for the RSU’s) means that the project costs could be considerably higher due to the potential investment required of the vendor to produce a working prototype and the additional engineering support needed from the consultant team to manage and monitor the delivery from two entities. The bid documents will allow the City to procure from 2 vendors and separate the RSU and ASD purchases as well as the PED applications for the PID. Once the bids have been received, the city will work with USDOT to determine the best approach for the project considering the budget, risks, and schedule.

As noted above, the ASDs and RSUs will be acquired directly by New York City through its regular equipment procurement system. The process typically begins with the release of a preliminary bid package. To allow as much development time as possible, the team will be prepared to release this package shortly after the authorization for Phase 2 is received. Requirements are finalized while potential bidders are analyzing the package and the city is preparing the formal procurement. A final bid package will be released approximately three months into Phase 2, with an award announced two months later. The city anticipates awarding contracts to multiple vendors, with one award for at least 4,000 units. Vendors will be asked to proceed at risk on the detailed design and prototype development and delivery while contract negotiations are finalized. During this time, the project team will monitor technical progress with a preliminary design review (PDR) and a critical design review (CDR), which will include both hardware and code reviews. As is explained in the next chapter, the ASDs will be part of rigorous testing of the entire system, and production of ASD hardware will begin only when it has been demonstrated to meet the performance requirements.

Task 6 of Phase 1 produced a system requirements document. Those requirements will be flowed down and expanded as necessary to the specifications for the separate units.

New requirements will be derived for various groups of ASDs. As shown in Table 2-1, the ASDs will be mounted in four classes of vehicles, Taxis and Limousines, NYCDOT Sanitation trucks, MTA NYCTA buses, and private commercial vehicles. As a practical matter, more than four models of vehicle will need to be fitted with ASDs. The team anticipates that five to ten separate taxi companies will be involved, each with a number of makes and model years. The private commercial vehicles are expected to include more than model of truck. Each of these vehicle models will be a separate engineering for where to mount the ASD, how to mount the DSRC antennas (a concern particularly on trucks and buses), and how to interface with the vehicle data bus. Testing will be needed to set the thresholds for the various safety applications, and possibly the order of priority of the alerts. Also, vehicle fleets such as buses and trucks have already deployed advanced safety devices that communicate with their vehicle data bus and alert the drivers. The ASDs will be tested to prevent interference and ensure interoperability with such existing advanced safety systems.

The NYC CVPD team will encourage the suppliers to develop modular hardware with common components to facilitate adaptation to different types of vehicles. Developing modular software following clear interface specifications will allow applications to be developed in parallel. The ASDs will be more efficient if safety applications can share common information such as target locations and accuracy of the host vehicle’s location. However, the project team will limit its direct involvement in the detailed design of the devices – and deal with the requirements since the vendor is solely responsible for their design and for conformance to the specifications.

Good programming practice isolates adjustable parameters from the code. To the extent possible, the system requirements in Task 6 have been written with explicitly adjustable parameters for thresholds for alerts in the safety applications and triggers for recording in the data applications. The applications must also allow flexibility in the sounds to be produced for the alerts. The alerts may be tones, or spoken words, or a combination of the two. The ASDs must allow flexibility to test various alert sounds during the iterative development and testing described in Chapter 5. The detailed specifications will include this additional level of requirements.

Task 4 of Phase 1 produced a safety management plan. Safety management continues throughout deployment. Some of the safety needs became safety-related requirements in the system requirements document. Other safety needs led to safety management practices that need to be documented and implemented. A safety manager, independent of the development personnel, will continue to oversee work so that the safety requirements are met during system development and that the testing of safety-related requirements meets proper standards.

It is unknown at this time if or how much of the ASD application software will be funded under this project or how much will consist previously developed vendor code representing the intellectual property of the vendor. In this latter case, the resulting application will not become public (through the OSADP). We will be requesting a detailed report by the bidders as to which applications are “public” and will be available through the OSADP and which are considered proprietary. It is possible that some of the specific data logging and configuration mechanisms may be considered work for hire, but that is currently unknown.

4.4 Development of the PED-SIG Application

This application will reside on smart phones or other types of Personal Information Device (PID) that is carried by visually impaired pedestrians. The application will not permit the pedestrian to call for a walk signal. The application could, in principle, be handled by one-way communication from the traffic signal to the device in the pedestrian’s hand. The only reason that part of the application’s function might be on the signal controller is to provide redundancy in determining the smart phone’s position and the pedestrian’s intended crossing direction. This will be resolved during the initial phases of the PED-SIG application development.

This application may be developed specifically for the New York City project, or the code may be obtained and adapted from MMITSS.

An early decision for this application will be smart phone platform where it runs--iOS or Android or both. Testing for this application will be different than for other applications. This application runs independently of the other safety applications, so it does not need to be tested with them. Because of this application’s safety implications, testing will be overseen by a safety team that is part of the project team but independent of the application developers.

This application is being procured by a separate group within NYCDOT – which plans to issue an RFEI seeking firms interested in supplying the device and developing the applications. The preliminary requirements have been developed for this PED program and it includes web based applications for enrollment and the development and testing of the PID and its applications.

At the moment, the RFEI has been delayed in the City’s legal department but is expected to be released in July with closure in late July or early August.

4.5 Development of the PED in Roadway Application (ASD)

This application will run on the ASD based on information in the SPaT message and will require close coordination between the RSU and the ASD. While the SPaT message includes a PED in crosswalk indication, this can be based on information collected from the local ITS pedestrian detection equipment at 10 signalized intersections, it may also rely on location information provided by the PED device depending on accuracy. It is not clear what accuracy can be achieved with the PED device, and this location accuracy has posed a problem for other deployments.

The application (RSU) will notify the upstream vehicle (SPaT) of the current signal phase and whether there is a pedestrian (or bicycle) currently in the crosswalk. The ASD is expected to use this information along with its current location and speed to determine if and when a driver alert/notification is appropriate. In the event that the intersection or the crosswalk is blocked by vehicles because of queue spillback, whether the application gets activated will be determined during testing and verification.

This will be a difficult application to make effective because of the density of pedestrians in the NYC area of interest, but is expected to be effective during hours with low pedestrian density. The specific parameters for operation such as times of operation will be determined during testing and verification. In the NYC CVPD system, the application is intended to reduce the risk of vehicle-to-pedestrian crashes especially in the night-time hours.

4.6 Development of the Back Office Applications

Figure 4-1 shows that the deployment equipment has a number of interfaces with the existing traffic control infrastructure in New York City. These systems are best modified by the personnel at New York City and its contractors who maintain them. Responsible personnel will work with the project principles as the existing ConOps and needs are developed into interface documents. Those who maintain these systems will design the support applications, and design reviews will be held before coding begins.

The NYCWiN network will provide the flow of data to and from the New York City traffic management center. The network will carry parameters and security certificates to the vehicles, and it will bring event data to the back office for analysis.

New applications at the back office will operate mostly independent of one another and can be developed independently. The security functions must be kept separate and protected. Parameter setting, work zone scheduling, Intelligent Traffic Signal System (I-SIGCVDATA), and performance evaluation, and others share only their need to communicate with the vehicles. After interface documents are established, these applications can be developed separately. All will follow New York City's common process for developing traffic applications. Following independent testing, they will be subject to integration testing as described in the next chapter.

The back office application development breaks down into 2 general cases: modifications to the existing traffic control system, and new applications to manage the CV infrastructure; the new applications and support software includes:

- Hardware monitoring (network, RSU, ASD)
- Data collection – includes event data, RF monitoring data, BSM mobility data
- Data obfuscation, normalization, & aggregation to protect privacy
- Security system support including interfaces to the SCMS and management of certificates
- Report generation for system operation, dash boards, etc.
- Data development for travel time input to the midtown-in-motion adaptive control system,
- RDE export support,
- Data export to the IE
- Misbehavior detection and CRL distribution (*if required in the future*)
- Support for the IPv4 to IPv6 conversion where necessary
- Management of the RSUs including WSA, channel usage, IP addressing
- MAP data distribution
- OTA parameter and firmware management
- Message management for the distribution of the emergency messages for our evacuation system.

The Back office support also includes the ***development*** of the MAP [message] database to be used for the V2I and the PED-SIG applications; this information must be developed using either the USDOT tool (previously demonstrated) or a service company; at this time, HERE (a company) has offered to develop this database, but that is still a point of discussion. Our project plan (for budgeting and scheduling purposes) assumes this will be done by NYCDOT personnel using the USDOT tool and precision location tools to identify the reference location at each intersection. The data will be stored and signed at the TMC such that it can be authenticated by the ultimate recipient; it will be held at the RSU until requested. It will not be developed for the “garage” RSUs – only for RSUs where there is a traffic controller.

This software will be developed in a modular fashion, and the individual modules will be placed onto the OSADP where their development if funded by the project.

Modifications to the existing TCS will remain the property of the original developer since they are expected to be integral to the systems for NYC. These software modifications will not be placed into the OSADP.
The design of the back office CV software is expected to be an interactive process with the RSU vendor and the ASD vendor. As the software is designed, it will be reviewed within the team and will be delivered to USDOT in accordance with the documentation schedule. However, note that the delivery of the detailed design and architecture will need to be accelerated to ensure that the software can be delivered and tested as the initial prototypes for the ASD and RSU become available.

4.7 ASTC

There will need to be modifications to the traffic controller firmware to support the changes to the existing firmware to support data export for the SPaT message, to support the requirements identified in the SMOC (Task 3), and to support the time management to ensure it can support the SCMS, the logging, and the proper time reference for the SPaT information.

This software will be developed by the original vendor, Peek Traffic, based on detailed requirements to be developed in Phase 2 and will not be placed in the public domain. This firmware is owned by Peek Traffic; the source code for the firmware is available to NYCDOT for 3rd party modifications – which have been performed by another traffic controller manufacture, but all rights rest with the original vendor. It is our expectation that we will work closely with the ICD previously developed for the Controller to RSU interface, and the new RSU vendor to ensure that all requirements are met. Depending on the schedule, NYCDOT may be able to bid out this set of software development and testing, but that will be determined during the early days of Phase 2. Note that this software will be extensively tested to ensure that the data provided is accurate, timely, and unaffected by any type of timing disruption including communications loading, transition, parameter updates, adaptive control, transit signal priority control, preemption, time changes, power interruptions, schedule changes, maintenance activities, and Monitor failures that cause the cabinet to a flashing condition.

Note that the traffic controller software was extensively tested by NYCDOT before installation and will be tested by NYCDOT and TransCore to ensure that the software modifications do not affect the existing operation.

4.8 Software Development Process

The TransCore Software Development Process (SDP) starts at the detailed design stage of the system engineering model and continues into the system integration phase. The TransCore SDP is dependent on delivery of the system requirements and high level design from the system engineering process.

When the high-level design and sub-system requirements have reach a stable version the software lead for the project develops the detailed design as a prelude to the actual software development. TransCore anticipates that minor changes or adaptations to the high-level design will be required based on findings during the detailed design phase. A key product of the detailed design phase is a baseline configuration for all sub-system interfaces.

In addition to the baseline configuration for sub-system interfaces a list of software modules and any database design will also be generated. These will serve as input to the actual software development. The software development is based on an Agile Software Process with 2-3 week software builds to verify progress. TransCore uses the JIRA Software to track the development of new software as well as any issues that are identified with the software. Each JIRA issue is assigned to a developer and progress is tracked.

Once initial development has been completed the software is installed in a test environment in the TransCore Tech Center and a test procedure developed from the high-level design is executed to verify that the software meets the requirements. Any issues are resolved and the software is placed under configuration management. An installer is defined and the software is ready for distribution.

Chapter 5. Testing and Verification Approach

Applications are one component of the overall NYC CVPD System, and the Application Deployment Plan is a subset of the overall NYC CVPD System Deployment Plan. Figure 2-1 provides a high-level example breakout of the hardware and software components and subsystems that makeup the overall NYC CVPD System.

5.1 Application Development, Integration and Deployment Process

Figure 5-1 shows the iterative and overlapping plan for development, integration, and deployment of the NYC CVPD applications. At the highest level, the key elements of the process are

- Development of requirements and procurement specifications
- Procurement
- Application design, development, and integration
- Requirements verification and acceptance testing
- Approval to proceed.

The figure separates the right side of the "V" into the steps of development, testing, and approval.

In accordance with the tenets of System Engineering, the development, integration, and deployment process will be performed incrementally.

In the initial stage of procurement, application developers (vendors) will design, develop, and refine the applications. They will then conduct and document requirements verification and acceptance testing, including both laboratory bench top testing using sample input data and track testing on a simulated NYC CVPD environment. Development testing will be performed with the applications installed on an example or simulated ASD while final hardware is developed by the same vendors. The outcomes will be reviewed and approved, noting exceptions, by NYCDOT and TransCore. Developers will refine the applications and resolve identified exceptions.

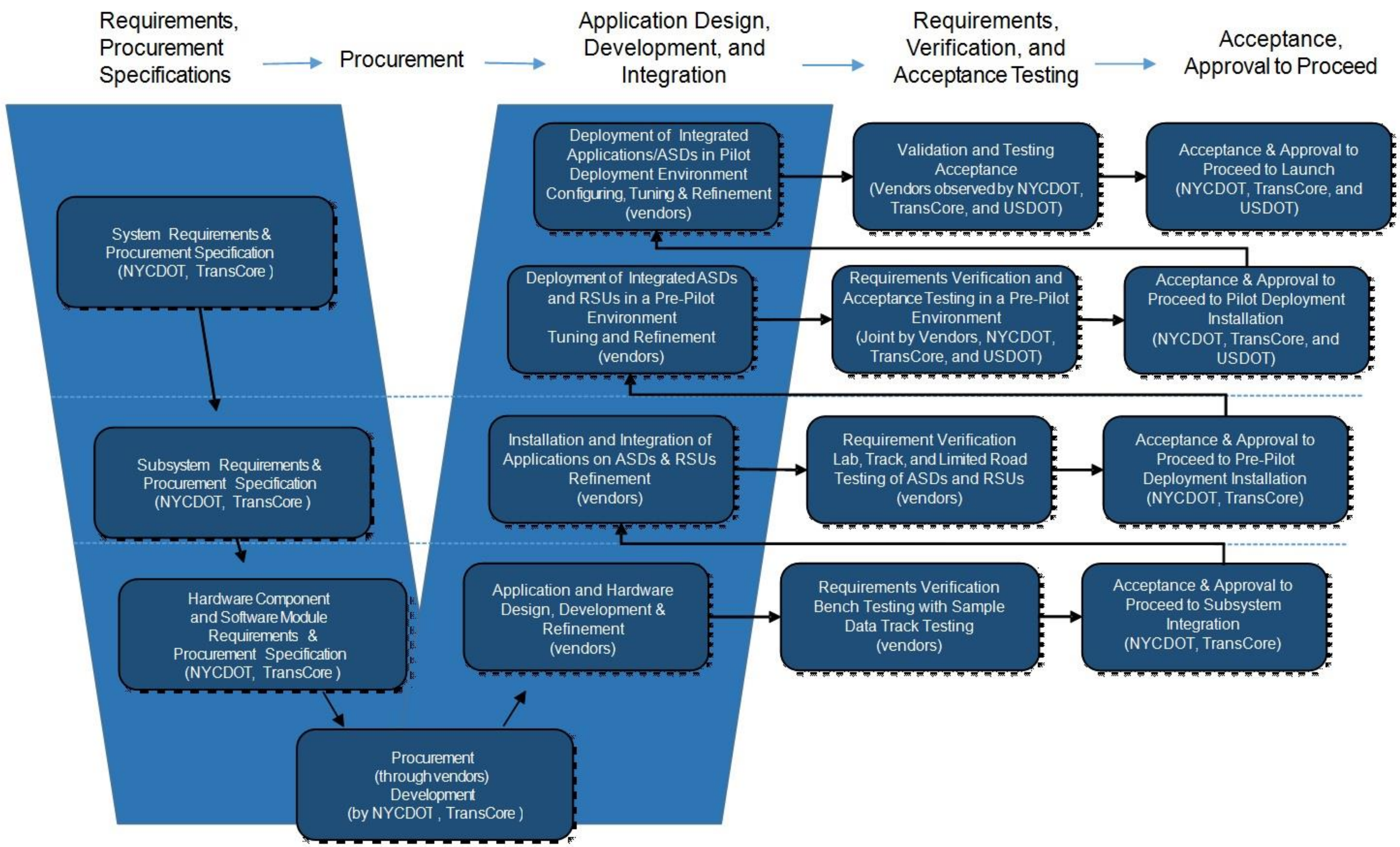
In subsystem integration, application developers will install and integrate applications on ASDs. They will conduct and document requirements verification and acceptance testing, including laboratory bench top testing, track testing, and on-road testing in a simulated NYC CVPD environment at a facility approved by NYCDOT. Similar to the RFEI demonstration performed by the vendors, all active testing will be done at a location in NYC with appropriate simulated curves, speed zones, and crash scenarios that represent the conditions in the pilot corridors. Some of the testing may be conducted at the vendor's or a third-party facility to verify the requirements listed in Operational Testing.

The outcomes will be reviewed and approved, noting exceptions, by NYCDOT and TransCore. Again, developers will refine the applications and resolve identified exceptions.

For pre-pilot deployment, application developers and other team members will integrate ASDs with applications in the Pre-Pilot deployment environment. They will conduct testing to refine, configure, and tune the applications for NYC CVPD. Some applications may need to be tuned differently based on the vehicle types. Light-duty vehicles such as taxis can stop more quickly than heavy vehicles such as a bus or truck. As a result, the timing of the warnings for certain applications will vary. More details can be found in Section 2.3.1.2 and Appendix E of the Systems Requirements Specification (SyRS) document, FHWA-JPO-16-303.

Requirements verification and acceptance testing will be conducted by all team members, including vendors, NYCDOT, TransCore. They will be observed by the USDOT and the independent evaluator. The outcomes will be reviewed and approved, noting exceptions, by NYCDOT, TransCore, and the USDOT. As in the earlier stages, developers will refine the applications and resolve identified exceptions.

Finally, in pilot deployment, application developers will collaborate with ASD vendors and other team members to integrate ASDs with applications in the Pilot deployment environment.



Source: NYCDOT

Figure 5-1. Application Development, Integration, & Deployment, Verification & Accept Testing Process.

5.2 Application Requirements Verification and Acceptance Testing

A critical component of deployment is verification and acceptance testing of the CV systems and applications. Vendors must demonstrate to NYCDOT that their applications meet their requirements and that they will perform well during the deployment and following. The NYC CVPD team anticipates four phases of application acceptance testing.

- Bench Acceptance Tests conducted by the Vendor with documentation provided to NYCDOT
- Controlled Environment (Test Track) Acceptance Tests conducted by the Vendor with documentation provided to NYCDOT
- On-Road Design Shakedown Testing conducted by the Vendor with documentation provided to NYCDOT
- Integrated Pre-Pilot Infrastructure and Vehicle Fleet Interoperability Acceptance Testing conducted jointly by the Vendor, TransCore and NYCDOT
- Integrated Pre-Pilot Infrastructure and Vehicle Fleet Interoperability Acceptance Testing conducted jointly by all Vendors, TransCore, NYCDOT, USDOT, and the Independent Evaluator

5.3 Sample Input Data and Simulated Test Environments

Sample Application Input Data. Vendors will be expected to traverse the NYC CVPD routes as early as practical to record sample input data, including GNSS, MAP, and SPaT files, for laboratory testing and demonstration of their applications. This will be done during pre-deployment for operational testing, demonstration, and verification of the system before full deployment.

Portable Infrastructure Components. NYC CVPD infrastructure component vendors will provide portable infrastructure systems which can be deployed in controlled environments for application testing. These portable systems will include traffic signal controllers and RSUs capable of broadcasting MAP and SPaT files for receipt by test vehicles for application verification testing.

5.3.1 Test Phases

Bench Acceptance Tests. Vendors will be expected to perform laboratory benchtop testing of the applications using simulated inputs. Vendors will provide sample data, output data logs with annotation and descriptions to the NC team for review and verification that the applications meet requirements.

This phase of testing will be performed during

- Component Design Development, Verification and Acceptance Testing and Approval, and
- Subsystem Integration, Verification and Acceptance Testing and Approval

Controlled Environment Acceptance Tests. Vendors will be expected to perform controlled environment (i.e., test track) tests and demonstrations to verify application requirements are met during simulated driving scenarios. While it is expected that most moving vehicle applications will be demonstrated during this test phase, controlled environment testing will specifically address requirements verification testing that cannot be conducted safely, reliably or repeatedly on NYC CVPD streets with traffic. Representatives of NYCDOT, USDOT, and the Independent Evaluators will be invited to observe controlled environment tests. Vendors will provide captured input data, output data logs with annotation and descriptions to the NYC CVPD team for review and verification that all 14 safety applications meet their requirements.

This phase of testing will be performed during

- Component Design Development, Verification and Acceptance Testing and Approval, and
- Subsystem Integration, Verification and Acceptance Testing and Approval

On-Road Design Shakedown Testing. In this phase of testing, vendors will be expected to perform live test and demonstrations along simulated NYC CVPD routes to verify application performance requirements are met during actual driving and to refine, configure, and tune the applications, prior to Pre-pilot deployment. This phase of testing will address requirements verification testing that can be conducted safely, reliably and repeatedly on simulated or actual NYC CVPD streets with traffic. This phase is also intended to be used by the application developers to “tune” their configuration to achieve intended performance on roadway conditions specific to the NYC CVPD.

This phase of testing will be performed during

- Subsystem Integration, Verification and Acceptance Testing and Approval

Integrated Pre-Pilot Infrastructure and Vehicle Fleet Interoperability Acceptance Testing. In this phase of testing, vendors will be expected to perform live test and demonstrations along NYC CVPD routes to verify application requirements are met during actual driving. TransCore will be invited to participate as both drivers and passengers in the demonstration vehicles. At least ten vehicles will be deployed simultaneously during the demonstration. Vendors will provide captured input data, output data logs with annotation and descriptions to the NYC CVPD team for review and verification that the applications meet requirements.

During this phase, vendors will conduct tabletop demonstrations of the applications which specifically address requirements verification testing that cannot be conducted safely, reliably or repeatedly on NYC CVPD streets with traffic. Vendors will use input data recorded during controlled environment tests to conduct the demonstrations.

For those requirements with statistical performance requirements, vendors will deploy at least ten representative vehicles in the NYC CVPD routes for at least 40 hours each of live testing sufficient to capture a statistically representative data set sufficient to verify applications meet statistical performance requirements.

This phase of testing will be performed during

- Prepilot Deployment, Verification and Acceptance Testing and Approval

Integrated Pre-Pilot Infrastructure and Vehicle Fleet Interoperability Acceptance Testing with the USDOT. These tests are conducted jointly by all selected Vendor(s), TransCore, NYCDOT, USDOT, and Independent Evaluator. In this phase of testing, TransCore and NYCDOT, with support of vendor(s), will perform live test and demonstrations of the applications for the USDOT and its Independent Evaluator along NYC CVPD routes to verify application requirements are met during actual driving. USDOT and its Independent Evaluator will be invited to participate as both drivers and passengers in the demonstration vehicles. Vendors will provide captured input data, output data logs with annotation and descriptions to the USDOT and the Independent Evaluator for review and verification that the applications meet requirements.

During this phase, TransCore and NYCDOT, with support of vendors, will conduct tabletop demonstrations of the applications (i.e. PEDINXWALK, PED-SIG, VTRW applications) which specifically address requirements verification testing that cannot be conducted safely, reliably or repeatedly on NYC CVPD streets with traffic. Vendors will use input data recorded during controlled environment tests to conduct the demonstrations.

This phase of testing will be performed during

- Prepilot Deployment, Verification and Acceptance Testing and Approval

5.4 Operational Readiness Testing vs. Demonstrations

The NYCDOT will plan to conduct a series of tests prior to the live demonstrations with the AOR and federal team. The test results will be documented and reported to USDOT prior to holding the demonstrations. The operational tests will include a set of selected integrated, end-to-end system capabilities central to the deployment concept of operations. The operational demonstration will be a live, real-time activity for the AOR and federal team wherein success and failure of the demonstration are directly observable.

5.5 Operational Testing

The testing program will be coordinated between the NYC team members - developing test procedures for, data collection testing, performance testing, and services testing (OTA updates, SCMS, Maintenance tracking), end-to-end system testing and overseeing vendor test procedures for the applications – both in-vehicle and RSU that connect to the back office CV systems. The ASD and RSU test procedures will be developed by the vendors, reviewed by the project team, and then conducted by the vendor (witnessed by the NYC team) based on the approved test procedures at a facility agreed to by the City. Note that NYCDOT plans to require all “active” testing be done at a location within the City such as that used for the RFEI demonstration with appropriate simulated curves, speed zones, and crash scenarios. Some of the testing may be conducted at the vendor’s facility or a third party facility to verify requirements such as the following:

- Temp, humidity, vibration, voltage variations, power interruptions and noise, ESD, etc.
  - Use automotive standards and NEMA references
- Verify the RF output levels for various antenna placements etc.
- Verify HSM

- Verify [secure] Boot
- Verify Watchdog features
- Verify sample installations (vendor provided)
  - Speakers, sound, PoE,
- Verify all I/O features
- GPS accuracy and time to connect (preliminary – inspection and demonstration)
- Location accuracy (ASD)
- Crystal clock accuracy
- CAN/J-bus interface
- Memory and Processor capabilities and “head room” for future additions and to meet our logging requirements.

In all cases, the test procedures will be developed to demonstrate the requirements based on the final requirements document and/or the procurement specifications. Our intent is to construct a master testing plan that deals with evaluating conformance to the relevant standards and compliance with the relevant procurement and requirements documents. This is the same process we have followed for the City of NY for their central systems and field ITS hardware for NYC over the past 25 years – which has included their traffic controllers (12,700), their wireless communications (to all controllers), their central systems (full featured adaptive system), variable message signs, RFID readers, TMC systems (video, audio, telephone, networks), and their Manhattan communications network. In all of these projects, test cases were established and documented to demonstrate compliance with all aspects of the specifications. Each test is evaluated based on pass fail criteria; when failures did occur, a change control board determined what regression testing was required depending on the nature of the failure and the corrective action. All testing is fully documented and cross checked to ensure that all requirements are verified.

Once the testing described above is completed, we will be performing rigorous evaluation of the ASD and RSU “platforms” to ensure that they always start, continue, and that the watch dog mechanism and process management meet the requirements. This is essential since once we start the installation, it is no longer practical to “push a reset” button on each unit or to visit each unit to update firmware. The goal of the “factory” and preliminary system testing is to ensure that OTA software updates and process management is “solid” and not affected by any power interruptions, faulty application software, or communications “anomalies” of any sort. This will require both positive and negative testing as well as adverse and “loaded” condition testing (flooded communications, OTA updates, all applications active, and maximum event and normal data recording – plus uploading – all with security fully active). In addition to testing of the individual application’s performance, we will have tests with many vehicles concurrently interacting to address requirements related to threat arbitration, BSM scheduling and congestion control, and location accuracy in a multi-lane environment.

We expect this round of testing to include the following in Table 5-1:

Table 5-1: Operational Testing Approach

Device	Test Areas
For the RSU	Boot process
	Process management
	MIB elements
	Data collection
	Parameters and control
	OTA updates
	Overall reliability
	IP support
	IPv4-IPv6 exchanges
	Security for RSU-TMC exchanges
	Channel congestion control
For the ASD	Boot process
	Process management
	MIB elements
	Data collection
	Parameters and control
	Mobility, performance, maintenance
	OTA updates
	Overall reliability
	IP support
	Security for ASD-TMC exchanges
	Channel congestion control
	CAN/J-Bus interface
	Accelerometers

As noted above, the test procedures will be developed during the procurement process for the ASD and RSU in concert with the vendors – by the vendor. The NY team will review and modify the required adjustments to ensure a thorough testing of the safety applications under both “lab” conditions and actual field conditions, and may (depending on schedule and costs) use institutional testing for verifying DSRC PHY, MAC layer, message content (J2945/1, J2735), and security (SCMS) where appropriate depending on schedule. Our testing program is focused first on ensuring a reliable and updatable field platform (RSU & ASD) then verifying the accuracy and reliability of the various applications. This is essential such that we can continue application evaluation, testing, and tuning concurrent with the production installation program expected to require 22 weeks. The last 8.5 weeks prior to Phase 3 will be spent tuning and working with the application developers, the IE, and our own evaluators to endure we are collecting the right accurate data and tuning the applications (with sample subjects) to minimize the false alarms without compromising the benefits intended.

5.5.1 Test Descriptions & Requirements Matrix

Each test case will have a written description that includes a description of the individual verification and validation processes that will occur as part of the effort to ensure that the system was built correctly and that the correct system was built. Safety and security requirements, clearly marked as such, will be among those tested.   A requirements-test matrix will be developed to link each test descriptions to the related System Requirement(s). This matrix will depict the test coverage relationship among the tests and the requirements. Every requirement will have at least one test case associated with it and each test case will have at least one requirement associated with it.

5.5.2 Test Cases, Procedures & Results

Each test case will include a set of test inputs, execution conditions, and expected results developed for a particular objective. Test procedures will describe the verification and validation process used to determine that the system functions as intended. If it is determined that test data will be used as part of the verification and validation process in this step, the test procedures will also spell out how one will determine that the system actually performed the correct transformations on the data entered. The verification method will be identified for each test.

The ORP will also describe how test results will be summarized and documented across all test and the remediation procedures that will be employed for any failed tests.

5.6 Operational Demonstrations

Operational Demonstrations will cover:

- Key use cases illustrating the capability of the system to perform in accordance with the Phase 1 Concept of Operations.
- Safety-focused demonstration elements illustrating the capability of the system to address key scenarios identified in the Phase 1 Safety Management Plan.
- Security-focused demonstration elements illustrating the capability of the system to successfully interact with the SCMS and carry out key security-related capabilities identified in the Phase 1 SMOC. One or more demonstration elements will explicitly consider misbehavior detection.
- Privacy-focused demonstration elements illustrating key aspects of the Phase 1 Privacy Operational Concept and the Phase 2 Privacy Management Plan.
- Performance measurement and evaluation support demonstration elements (e.g., a dry run) illustrating key aspects of the Phase 1 Performance Measurement Plan, including data collection and processing.
- Institutional coordination and successful execution of governance frameworks, management processes, and financial arrangements, illustrating key aspects of the Phase 1 Partnership Status Summary.
- Maintenance-oriented demonstration elements related to the management concepts for over-the-air management of data and firmware updates, as well as radio frequency range monitoring

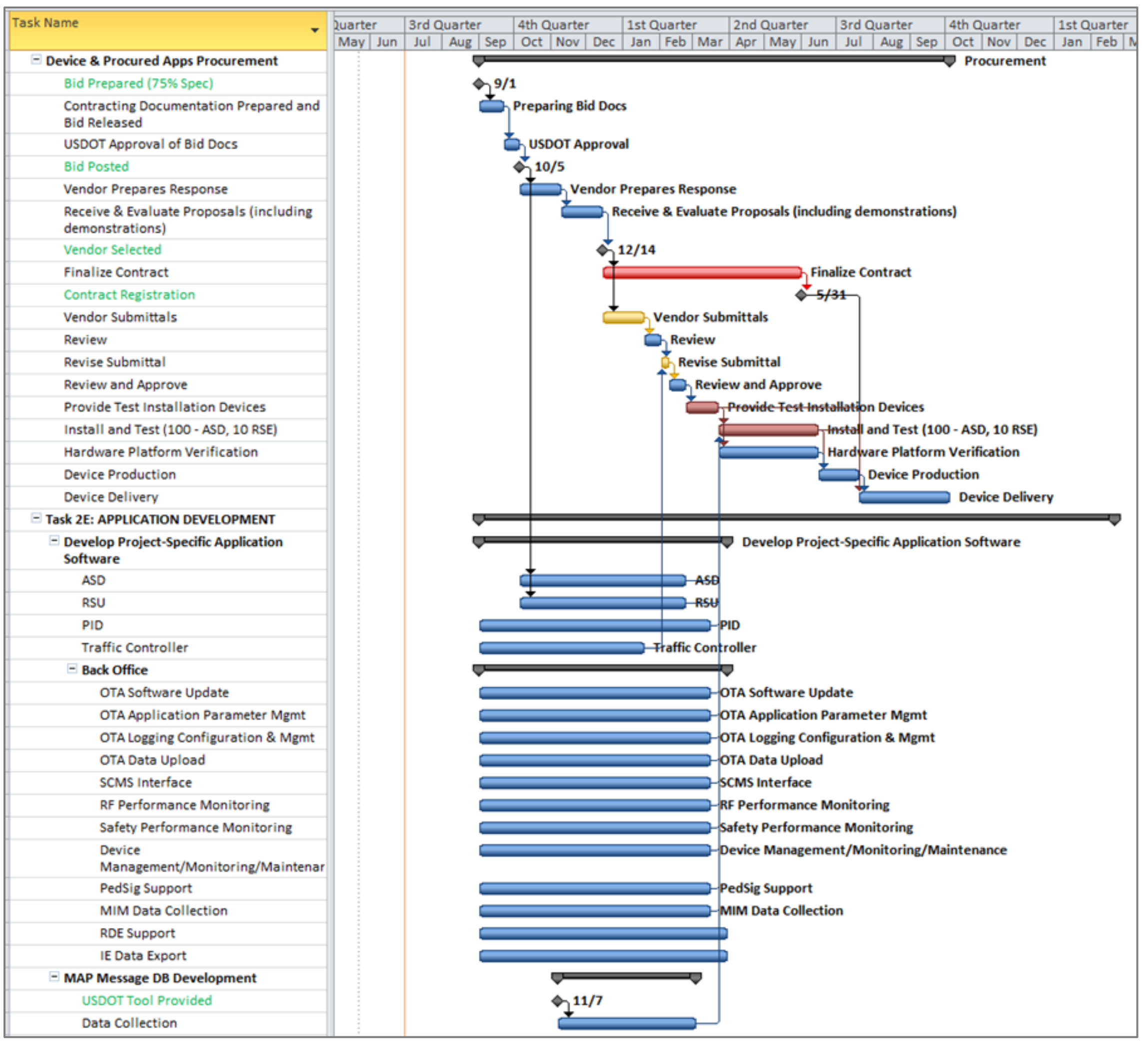
The ORP will describe the objective, general location, participants, equipment, and actions to be taken within the demonstration to illustrate the successful deployment of key use cases. It will also detail the sequence of events expected to be demonstrated and observable validation criteria associated with the overall purpose of the demonstration. The plan will describe how data will be collected before, during, or after the demonstration to support the observable demonstration validation criteria related to demonstration success (e.g., pass or fail). The ORP describe how demonstration results will be summarized and documented across all demonstrations.

Chapter 6. Cost and Schedule

This chapter has the development and integration schedule at a high level. The Task 12 report will have a more extensive cost and schedule.

6.1 Schedule

The schedule shows considerable overlap between the development and the integration testing.



Source: NYCDOT, 2016

Figure 6-1. Schedule for Development and Testing

The schedule shown above is for the development and deployment of the applications for the CV pilot project. This schedule represents a compression to what is typically needed for a development effort, and is dependent on cooperation from the vendor(s) for the equipment. Based on the general survey of the market place, most of the vendors have developed virtually some form of all of our safety applications; hence, the software development and testing phases are shown above. It is assumed that the vendors have a commitment to this market place, and will continue to develop their products and that the NYC CVPD is the first opportunity to provide a significant quantity of both ASDs and RSUs. The schedule shown above assumes a September 1 start data – with the preparation of the final bid documents (15 business days) followed by a 10 day approval cycle with USDOT. The vendors will have 25 days to prepare their final bid documents including pre-bid conference and questions – no extensions. The schedule allows 25 days for review of bids and selection and notification of award. The project team expects to collaborate with USDOT and then notify the apparent one or two low bidders (at risk) within the first week following the receipt of the bids; the official notification will be provided after the 5 week evaluation period. At that point contract office begins the arduous process of developing a contract – allocated to take 6 months. Armed with the knowledge that they have been selected, the vendors are expected to start their schedule immediately and prepare their submittals and designs and submit same to the project team and USDOT at the same time. Note that the NYCDOT will issue a notice of award and a notice to proceed at risk. Within 25 days of the formal notification to proceed at risk, the vendor is expected to provide the first submittals; the schedule allows 10 days for review and we have assumed that a revision may be required (5 days) and resubmit and review cycle is likely (10 days). USDOT and NYCDOT will be involved in all reviews and will receive the documents at the same time. 10 days is allowed for concurrent reviews by both parties.

At this point, the vendor's submittals have been approved, and we have allowed 20 days for the vendor to deliver and install (with City assistance) the prototypes (or at least a few) to be used for early testing and demonstrations of any issues. The project team will then work through a 60 day hardware and software testing and review period – including integration and testing of the back-office systems, SCMS, etc.

Our schedule for the back office software development will follow the processes indicated herein and has been allocated 140 days for the development and installation of all of the software except the actual evaluation software. This same software will be used during the initial prototype testing; what is critical is the management of the security aspects and the OTA process and application updates and loading. With these operational, and proven, both the application developers (RSU and ASD) and the back office developers can continue their testing and debugging and evaluation development throughout the 60 day platform testing and the following 110 day deployment program as the field equipment (ASD and RSU) is installed and tested. We have allocated a final 43 day silent shakedown period for the total system testing for the applications and management systems as well as the database systems. The exact number of units finally installed to start the 18 month operation and evaluation period remains to be determined based on the bid and the number of stakeholder vehicles that can be outfitted during this period.

6.2 Budget

The budget for the development of the software for the RSU and ASD is included in the bid price for the units and hence not shown here.

The budget for the back office support software is roughly 4660 Man Hours with a breakdown as follows:

Table 6-1. Budget for the Back Office Support Software

Task Description	Labor Estimate (Man Weeks)
Detailed Design	15
RSU configuration screens	7.5
ASD configuration screens	7.5
Event data – retrieve and store	10
RF Quality Data – retrieve and store	10
Travel Time – retrieve, calculate, store summary	30
Travel Time – configuration screens	5
Reports (develop reports to budget)	15
OTA update process	4
Testing	5
Tech PM	7.5
Total	116.5
Total Man hours	4660

Note that a large portion of this budget is devoted to the data collection for performance measurements. The balance is devoted to developing the operation and maintenance tools and reports that can be used to track the equipment operation.

Chapter 7. Assumptions

Successful execution of this plan depends on a number of external factors. Each of these assumptions represents a risk to the project that will affect the ability to meet the schedule or performance goals.

(a.) The *Security Credential Management System* version 1.1 will need to be available and stable by November 1, 2016. USDOT will need to define the specific protocols for all users to incorporate and the certification processes required to ensure equipment meets the standards for security and interoperability.

The protocols and their implementation will need to be able to handle messages at the rate needed for the traffic density in New York City. The response times for the SCMS will have an impact on the system design as to whether credentials need to be managed as store and forward due to the demands for service. Note that this is an important consideration based on the future of the use of the SCMS.

This is a deployment with actual **users in revenue service**; the security must be in place before testing moves to drivers outside the project team.

Mitigation: There is no mitigation for this risk; the project schedule will slip and costs will increase since the BAA explicitly told us to use the SCMS, we did not design or make provisions for the absence of a working SCMS. The only alternative is to run without security and for such a deployment this is far more risky.

(b.) How well the DSRC and GNSS will perform in the urban canyon. The team already knows some of the issues from prior projects and preliminary testing. The early acquisition of ASDs will enable continued testing and development throughout Phase 2.
It is also clear that the location “tracking” mechanism needs to continue in an active mode in the urban environment where possible – or many of the freeway applications will be turned off. There are large areas of NYC where there is “something” overhead – it is unfortunate that every time GPS is lost, they all become inactive?

Mitigation: We believe this can be solved, and during the RFEI demonstrations, this was discussed with each of the vendors. One of the reasons we had them drive Manhattan and collect GPS “bread crumbs” was to make sure they understood the situation. Each vendor indicated they had been developing alternatives including data from the CAN bus, accelerometers, and even RSU triangulation. We plan to require prospective vendors to demonstrate prior to award of the procurement contract and will include extensive testing for this specific problem.

(c.) The Schedule will be met by the selected vendors. The demands on the hardware and the complexity of the software will be unprecedented for connected vehicle equipment. The team will work with vendors to establish realistic schedules and enable as much work in parallel as possible. After development is complete, manufacturing and installing the units will take time.

Mitigation: We plan on awarding to two (2) vendors and evaluating prototypes early in the project (See the schedule). With two vendors, we can fall back to a single vendor and disqualify the non performing vendor and continue with the performing vendor for the full complement of units. All vendors interviewed during the RFEI indicated they could meet the schedule.

(d.) The contracting delays and schedule will require that the vendors start much of their work "at risk"; if the city takes 6 months after announcement of award, the vendors will need to proceed with the development and hardware design "at risk" in order to even come close to meeting the proposed schedule. That is – much of the development, certification, and testing must, of necessity, begin before the City issues a billable contract. It is also likely that the prototypes will be delivered and installed before the contract is issued! Will all of the vendors accept such conditions?

Mitigation: During the RFEI and the live demonstrations by the vendors that was held at the aqueduct racetrack parking lot, all vendors were asked if this was a problem; without exception, all of the vendors indicated this would not be a problem; the specifications for the RFQ will also indicate that this will be a limitation of contracting process with NYCDOT, and that their submission of a bid indicates their acceptance of this situation and that they will proceed with the project including engineering, and delivery of the prototypes and applications to meet our project schedule.

(e.) Review & approval by USDOT of all aspects of the Phase 2 work must be done very quickly and the existing "approvals" of the ConOps, requirements, performance evaluations, SMOC must be used to jump start the development and procurement specifications. Delays in the review and approval of such documents and completion of promised resources may extend the project schedule and budget.

Mitigation: We have allowed the 10 day approval by USDOT in our project schedule, and have encouraged the USDOT to instruct the IE to work alongside NYCDOT during the early phases of the deployment to ensure that our data collection would meet their needs.

(f.) Data collection in the "Before" period begins May 2018 at the start of Phase 3, i.e., formal data collection of any type of data collected using the deployed CV devices or that could be influenced by the CV deployment or other confounding factors will not start until Phase 3. . If the Independent Evaluator (IE) has issues with the type of data being collected and the processing, then the changes may be requested [by USDOT] and such changes may extend the project schedule and budget.

Mitigation: Knowing this, we will make the raw data available at our site (TMC) for the IE's evaluation and testing prior to Phase 3. If the IE works side-by-side with the real raw data, the risk that the data being collected is reduced or eliminated and we can adjust both the expectations and software early in the project.

(g.) There is inadequate time [schedule] and budget to deal with a vendor pre-qualification phase and bake-off. We will rely on the responses to the RFEI; the vendor chosen may not be the low bid as we will require further demonstrations prior to award. However, once the vendors have been chosen, the project is at significant risk until the completion of the 100 ASD/10 RSU pre-pilot installation and testing program is successfully completed; if the vendor is ultimately unable to complete this phase successfully, the schedule is at serious risk because of the time required to start with an additional vendor. If we move forward with 2 vendors, the risk is mitigated, but the development costs and integration costs may as much as double.

Mitigation: If we move forward with 2 vendors, the risk is mitigated, but the development costs and integration costs may double. We have assumed two bidders and two awards in our cost model.

(h.) USDOT completes its promised tools and utilities – especially for the development of the MAP message (including PED crossings) by the end of 2016. Delays in the delivery of such tools may delay the project schedule.

Mitigation: We can hire this to be done but at a considerably higher cost than shown in our budget.

(i.) The FCC does not change the use patterns for the DSRC band – as this could necessitate a re-design and re-engineering of both the hardware and software – and jeopardize the funding since this project is intended to lead to permanent deployment.
Mitigation: There is no mitigation strategy. Our solutions are dependent on the use of DSRC, and changes to the channel availability and use will increase costs and cause project delays. It is up to USDOT to strongly support the current channel allocation and to ensure that any channel sharing is done in a manner that does not compromise the current channel allocations and usage. Further mitigation would mean redesign of the radios and channel usage plans and reliance on alternate media – which could delay the project.

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APPENDIX A. List of Abbreviations and Acronyms

Acronym / Abbreviation	Definition
ASD	Aftermarket Safety Device
BSM	Basic Safety Message
BSW	Blind Spot Warning
CDR	Critical Design Review
ConOps	Concept of Operations
COTS	Commercial Off the Shelf
CSPD-COMP	Curve Speed Compliance
CVPD	Connected Vehicle Pilot Deployment
CVRIA	Connected Vehicle Reference Implementation Architecture
DSRC	Dedicated Short Range Communications
DVI	Driver Vehicle Interface
EEBL	Emergency Electronic Brake Lights
FCW	Forward Crash Warning
FHWA	Federal Highway Administration
GNSS	Global Navigation Satellite System
IMA	Intersection Movement Assist
IMU	Inertial Measurement Unit (to assist navigation)
LCW	Lane Change Warning
MMITSS	Multi-Modal Intelligent Traffic Signal System
MTA	Metropolitan Transportation Authority
NYCDOT	New York City Department of Transportation
NYCT	New York City Transit
OSADP	Open Source Application Development Portal
OTA	Over the Air
OVC	Oversized Vehicle Compliance
PDR	Preliminary Design Review
PEDINXWALK	Pedestrian in Signalized Crosswalk
PED-SIG	Mobile Accessible Pedestrian Signal System
PII	Personally Identifiable Information
PSM	Personal Safety Message
RDE	Research Data Exchange

Acronym / Abbreviation	Definition
RF	Radio Frequency
RLVW	Red Light Violation Warning
RSU	Roadside Unit
RTCM	Radio Technical Commission for Maritime (Services)
SCMS	Security Credential Management System
SPaT	Signal Phase and Timing
SPDCOMPWZ	Speed Compliance in a Work Zone
SPD-COMP	Speed Compliance
SSM	Signal Status Message
SyRS	System Requirements Specification
TIM	Traveler Information Message
USDOT	United States Department of Transportation
VTRW	Vehicle Turning Right in Front of a Bus Warning
V2V	Vehicle-to-Vehicle
V2I	Vehicle-to-Infrastructure
WSA	WAVE (Wireless Access in Vehicular Environments) Service Advertisement

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