Connected Vehicle Pilot Deployment Program Phase 2

Performance Measurement and Evaluation Support Plan – New York City

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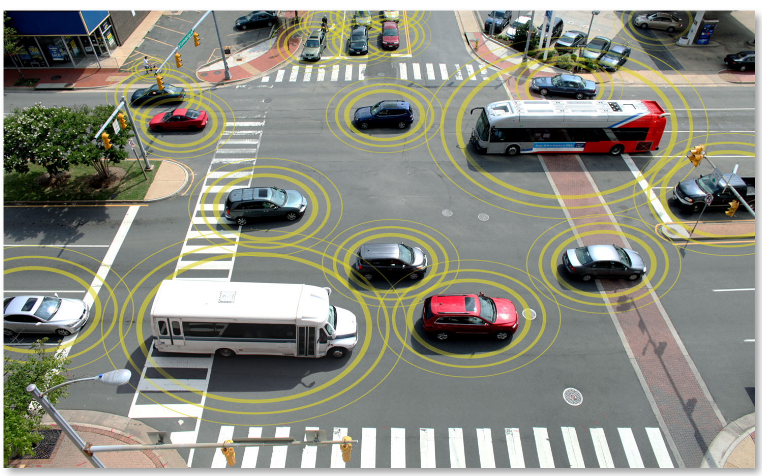

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7. Author(s) Steve Galgano, NYCDOT; Mohamad Talas, NYCDOT; Keir Opie, Cambridge Systematics; Michael Marsico, NYCDOT; Andrew Weeks, NYCDOT; Yixin Wang, NYCDOT, David Benevelli, TransCore; Robert Rausch, TransCore; Kaan Ozbay, NYU; Satya Muthuswamy, KLD		**8. Performing Organization Report No.**
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16. Abstract

This document describes the Performance Measurement and Evaluation Support Plan (PMESP) for the New York City Department of Transportation New York City (NYC) Connected Vehicle Pilot Deployment (CVPD) Project Phase 2. The report updates the Phase 1 report and presents the performance metrics that will be used to assess the success of the NYC CVPD project, the targets for improvement in those performance metrics, the data collection process, and the analytical processes that will be undertaken to show the impacts of the NYC CVPD project. It also documents the data elements that will be provided to support the United States Department of Transportation (USDOT) independent evaluator (IE) and the data elements that will be provided to the research community via the ITS DataHub.

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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.

Table of Contents

List of Tables

List of Figures

1 Introduction

The NYC CVPD project area encompasses three distinct areas in the boroughs of Manhattan and Brooklyn. The following describes these deployment areas in terms of their roadway characteristics.

The first area includes Franklin D. Roosevelt (FDR) Drive in the Upper East Side and East Harlem neighborhoods of Manhattan. The second area includes four one-way corridors of 1st Avenue, 2nd Avenue, and 5th Avenue from 14th Street to 67th Street and 6th Avenue from 14th Street to 59th Street in Midtown and Upper East Side neighborhoods of Manhattan. The segment lengths are 2.6 miles for 1st, 2nd, and 5th Avenues and 2.2 miles for 6th Avenue, respectively. The third area consists of the five two-way, bi-directional cross streets in Midtown Manhattan: 14th, 23rd, 34th, 42nd, and 57th Streets. The fourth area covers a 1.6-mile segment of Flatbush Avenue in Brooklyn from Tillary Street on the north and Grand Army Plaza near Prospect Park to the south. While FDR Drive is a freeway without signalized intersections, the four avenues in Manhattan include 281 signalized intersections and Flatbush Avenue in Brooklyn includes 28 signalized intersections. These locations are shown in Figure 1 below.

1.1 Purpose of the Report

This document describes the Phase 2 Performance Measurement and Evaluation Support Plan for the New York City Department of Transportation New York City (NYC) Connected Vehicle Pilot Deployment (CVPD) Project. The report documents the performance metrics that will be used to assess the success of the NYC CVPD project, the targets for improvement in those performance metrics, the data collection process, and the analytical processes that will be undertaken to show the impacts of the NYC CVPD project. It also documents the data elements that will be provided to support the United States Department of Transportation (USDOT) independent evaluator and the data elements that will be provided to the research community via the ITS DataHub.

This report is an update to reflect in the performance measurement and evaluation plan for the NYC CVPD project. As the project as evolved through the Phase 2 detailed design and initial deployment steps, some changes were made to the original Phase 1 plans to improve on the overall project and to overcome and address potential issues that were not envisioned during Phase 1. This report should supersede the Phase 1 report.

1.2 Organization of the Report

The report is organized according to the following sections:

Section 1 presents an overview of the NYC CVPD and the role of this report in the project.

Source: NYCDOT, 2017

Figure 1. NYC CVPD Deployment Corridors

Section 2 presents an overview of the Needs justifying the NYC CVPD project. It also addresses stakeholder identified needs specifically related to the performance measurement.

Section 3 highlights the NYC CVPD goals and objectives. If also presents an overview of the NYC CVPD deployment plan and presents some estimates as to the potential average market penetration of CV vehicles that can be expected from the pilot deployment.

Section 4 introduces the use cases for the CV applications and the various performance metrics that will be produced to assess the impacts of the deployed CV pilot on improving conditions in those use cases. It also discusses the potential targets for improvement in either reducing the number and/or the severity of crashes of the NYC CVPD.

Section 5 presents a list of the identified potential confounding factors that may need to be considered in the evaluation plan of the CVPD. It also lists the planned methods for tracking and quantifying these confounding factors and the methods to include these confounding factors in the CV performance evaluation.

Section 6 outlines the needs and use cases specifically related to performance evaluation and presents the considered experimental design options, including the advantages and disadvantages of each. The recommended experimental design is presented and the factors that will be considered in selecting the size of the planned control group is discussed. Finally, the usage of simulation for performance evaluation is introduced.

Section 7 presents the data collection plan and documents the methods and sources of data that will be collected, including both detailed trajectory data surrounding CV application warnings collected from the deployed ASDs, crash records, weather conditions data, and non-CV related mobility data. The section also presents the methods that are being used to merge the confounding factor data sets to the ASD data while still scrubbing the ASD sourced data of potential PII-revealing data in the form of precise time and location details prior to storage on the NYC CVPD data servers.

Section 8 presents the system impact evaluation plan and discusses the planned analysis methodologies that are planned to evaluate the collected data and to compute the performance measurements for with and without the CVPD deployment, thus providing an evaluation of the impacts of the NYC CVPD on the identified use cases. The section discussed in some detail the methods that will be used for the before and after analysis of crash records and the use of simulation modeling that will be undertaken as part of the evaluation plan for both safety impact assessment and for non-safety system performance evaluation.

Section 9 presents an overview of the performance reporting mechanisms that will be utilized during Phase 3 of the CVPD to inform various stakeholders, including potential online dashboard reporting mechanisms and more traditional analysis reports.

Section 10 provides a discussion of the NYC CVPD team's commitment to work with and support the USDOT's Independent Evaluation contractor through Phase 3 of the NYC CVPD.

Section 11 describes the data sharing framework that the NYC CVPD team will operate under. This describes the data elements and possible transmission protocols that can be shared with both the USDOT and their independent evaluator. The section also discusses the options and privacy concerns for sharing data with the larger research community via data distribution on the ITS DataHub.

Section 12 summarizes the contents of and concludes the report.

Following these sections, appendices present a glossary of abbreviations included in the report as well as supporting documentation referenced in the report.

2 NYC CV Pilot Needs

In 2014, NYC began its Vision Zero program to reduce the number of fatalities and injuries resulting from traffic crashes. The Mayor's Office developed the Vision Zero action plan which highlighted a set of initiatives for multiple city agencies to support the goal of improving street safety. One of the major ongoing initiatives has been the citywide speed limit reduction from 30 mph to 25 mph. According to the National Highway Transportation Safety Administration (NHTSA), speeding was a factor in more than one in four deaths. Also, human factors were the critical cause in about 94% of all crashes while vehicle-related factors only apply to about 2% of all crashes.

The Borough Pedestrian Safety Action Plans is another Vision Zero initiative for tackling the different safety challenges of each borough. The safety action plans have identified a priority list of streets based on historical accident frequencies, pedestrian fatalities, and severe injuries. Based on these findings, engineering and design modifications have been recommended for implementation. Despite these efforts, dangerous driving behavior still remains as the primary cause of pedestrian fatalities in crashes. In Manhattan, 73% of all crash fatalities involve pedestrians while this figure is only 14% nationwide. After pedestrian fatalities in NYC reached an all-time low in 2011 with 249, it surged to 297 in 2013. Senior citizens over age of 65 comprise of 12% of the population in NYC but about 33% of all pedestrian fatalities. Also, the primary reason for crash-related deaths of children under 14 was from being struck by a vehicle. The New York City Connected Vehicle Pilot Deployment (NYC CVPD) is another tool that can be used to further the city's Vision Zero goals.

While the NYC CVPD ConOps presents a complete list of needs for the system design and function for traffic managers, fleet owners, roadway users, and independent evaluators, the needs as they related to the performance measurement of the pilot generally directly related to the primary goals of the CVPD; to improve the operating conditions for safer roadways and to reduce the number of and severity of accidents on the roadways.

While not the primary goal of the pilot, the performance evaluation plan must also be capable of measuring the impacts on the mobility and reliability of travel in the city and on improving the environmental impacts of the transportation system as targeted secondary goals of the deployment.

2.1 Additional Stakeholder Identified Needs

A specific identified stakeholder need that was identified which has significant impacts on the design of the performance evaluation plan is the need for retaining privacy as it relates to the CV operations and data. The NYC DOT held an initial introductory meeting on 10/27/2015 with key stakeholders regarding the overall NYC Connected Vehicle Pilot Deployment (CVPD) project. The purpose of the meeting was to brief stakeholders on the Connected Vehicle (CV) applications, project goals, and timelines. A second round of stakeholder meetings were held with small groups of representatives of the NYC DOT fleet operations, MTA fleet operations (for Manhattan), UPS fleet operations (for Manhattan), the Taxi and Limousine Commission (for Manhattan), and Sanitation Operations (for Manhattan) in November and December 2015; these meetings included technical, operations, and legal personnel to address a wide range of issues including device installation, maintenance requirements, operating hours, operator selection, geographic coverage areas, stakeholder responsibilities, system operation, driver interface, and data collection activities.

The major concern expressed by all of the stakeholders was the potential that any data collected could be used for driver evaluation and/or enforcement or that such data could be subpoenaed or the subject of a freedom of information act (FOIA) request for any and all records available that could then be merged with other records (e.g., police accident reports) and used in legal proceedings, disciplinary proceedings, or insurance negotiations. Concerns were also expressed by the labor unions and legal departments that if such records were known to exist, they would be subpoenaed for criminal and/or civil suits and would be subject to FOIA requests – which are very frequent in NYC.

What is important to note is that although collected CVPD data will not identify the specific vehicle or the driver, it could be merged with other data sources such as accident records to provide extensive information regarding what happened in the case of an “incident” because it includes a specific time and place. As such, the need to preserve the anonymity of the data records, including the identification of a precise time and location, is a primary stakeholder need.

3 CV Pilot Goals and Objectives

The NYC CVPD project is primarily focused on improving safety through the reduction of vehicle and pedestrian crashes, injuries, and fatalities. This is consistent with the City's focus and dedication of resources to achieve its Vision Zero goals.

The fundamental message of the NYC Vision Zero initiative is that death and injury on City's streets is not acceptable. These tragedies happen in every community within NYC, to families from every walk of life – from the Upper East Side to the Lower East Side; from Park Slope to Edenwald. They happen to people who drive and to those who bike, but overwhelmingly, the deadly toll is highest for pedestrians – especially children and seniors. The goal of Vision Zero is to eliminate traffic deaths by 2024. The NYC CV Pilot Deployment project will focus on safety improvements for both motorists and non-motorists. In particular, the crash risks increase during nighttime hours when vehicle speeds tend to be higher and it becomes more difficult for vehicle drivers to see pedestrians crossing the roadway.

As the safety statistics indicate, surface improvements on city streets alone will not mitigate the number of crashes, fatalities, and severe injuries long-term. While no "Silver Bullet" will end all crashes, multiple supplemental tools are needed that can work together to attain Vision Zero's goal. The CV technology is one of these tools and it presents a systematic approach in alerting vehicles of unsafe roadway conditions and prevents collisions with other vehicles, pedestrians, and bicyclists. It will provide numerous safety benefits that facilitate Vision Zero's goals and initiatives.

In addition to the safety benefits which are anticipated from the deployment of connected vehicles, more minor benefits and improvements can be expected in system mobility and travel time reliability, along with associated improvements in the environmental impacts related to congestions. The non-safety improvement objectives are, however, directly related to improved safety conditions and a reduction in the number and severity of accidents.

3.1 Pilot Deployment Details

While many more details are available in the other NYC CVPD documents, to frame the context of the pilot deployment as it relates to the performance measurements, the planned deployment of the applications is shown in Table 1, along with which CV device the applications will run on. Devices include Aftermarket Safety Device (ASDs) for vehicles, smartphone based Pedestrian Interface Devices (PIDs) for pedestrians, and Roadside Units (RSUs) for signalized intersections and roadside locations.

Table 1. Planned CV Application Deployment by Device

CV Application	Category	NYC City Agency Fleet Vehicles (3000 ASDs units)	Pedestrian Information Devices / Cell Phones (10 PIDs)	Signalized Intersections and Other Infrastructure (450 RSUs)
Forward Crash Warning (FCW)	V2V	Yes	No	No
Emergency Electric Brake Light (EEBL)	V2V	Yes	No	No
Blind Spot Warning (BSW)	V2V	Yes	No	No
Lane Change Warning (LCW)	V2V	Yes	No	No
Intersection Movement Assist (IMA)	V2V	Yes	No	No
Vehicle Turning Right Warning (VTRW)	V2V*	Yes	No	No
Speed Compliance (SPDCOMP)	V2I	Yes	No	No
Curve Speed Compliance (CSPD-COMP)	V2I	Yes	No	No
Speed Compliance in Work Zone (SPDCOMPWZ)	V2I	Yes	No	No
Red Light Violation Warning (RLVW)	V2I	Yes	No	No
Pedestrian in Crosswalk Warning (PEDINXWALK)	V2I	Yes	No	No
Oversize Vehicle Compliance (OVCCLEARANCELIMIT)	V2I	Conditional	No	No
Emergency Communications and Evacuation Information (EVACINFO)	V2I	Yes	No	No
Mobile Accessible Pedestrian Signal System (PED-SIG)	I2P (Ped)	No	Yes	No
Intelligent Traffic Signal System Data (I-SIGCVDATA)	Mobility	No	No	Yes

*Note: VTRW also requires messages from an RSU.

The above plan is revised from the original plan outlined in the earlier Phase 1 documents. While the original plan was primary targeting installation of ASDs in yellow taxis, the revised plan instead equips fleet vehicles from various NYC city agencies in their place. Changes in the for-hire vehicle marketplace in New York City have led to significantly reduced market share for the yellow taxis1. With this changing landscape, the yellow taxi industry removed themselves from the pilot study.

[1] Improving Efficiency and Managing Growth in New York's For-Hire Vehicle Sector, NYC TLC & DOT, June 2019

Additionally, the changing focus of the transit operators MTA and NYCT resulting from impacts of the COVID-19 pandemic have reduced their participation in the pilot as well.

The deployment will install ASD units into various vehicles used by numerous city agencies. Table 2 presents the targeted installations of ASDs into different agencies, including the types of vehicles that are being equipped. Of the approximate 2,100 vehicle installations completed to date, approximately 5% are buses (including transit and non-transit buses), 27% are pickups or work trucks, 7% are vans, and the remaining 61% are passenger cars and SUVs.

Table 2. ASD Deployment Plan by Agency and Vehicle Type

Agency	Passenger Car	Pickups and Trucks	Vans	Buses	Planned Vehicle Installations
NYC Dept. of Transportation (DOT)	●	●	●		1,359
NYC Dept. of Correction (DOC)	●	●	●	●	293
NYC Dept. of Parks and Recreation Dept. (Parks)	●	●			200
NYC Dept. of Environmental Protection (DEP)	●	●	●		132
NYC Taxi and Limousine Commission (TLC-DCAS)	●	●	●		104
NYC Dept. of Homeless Services (DHS)	●		●		100
NYC Human Resources Administration (HRA)	●		●		84
NYC Dept. of Citywide Admin. Services Fleet (DCAS)	●				76
NYC Administration for Children's Services (ACS)	●	●	●		65
NYC Dept. of Design and Construction (DDC)	●				50
NYC Dept. of Buildings (DOB)	●				50
NYC Housing Preservation & Development (HPD)	●				50
NYC Dept. of Health and Mental Hygiene (DHMH)	●	●	●		18
NYC Office of Chief Medical Examiner (OCME)	●	●	●		17
MTA Bus & NYCT				●	11
NYC Emergency Management (OEM)	●				11
MTA Bridges and Tunnels (TBT)	●				10
NYC Dept. of Information Technology and Telecommunications (DOITT)	●				9
Still to be Allocated (TBD)					361
Total					**3,000**

The targeted equipped vehicles are used by the various agencies for conducting their daily business for the city. Some vehicles are housed in common facilities located across the city and are used by numerous agency staff on an as-needed basis fleet of vehicles, while some vehicles are assigned to one individual staff member, some of whom may also be authorized to use the vehicle to commute to and from work in addition to conducting their work activities throughout the day. Some vehicles will be used as simple transportation from point to point in the city, while others are used in various field inspection, maintenance, and operations for the city's roads, signals, buildings, parks, and other infrastructure.

To help assess how the equipped vehicles are utilized, the city's existing fleet management system Geotab which is installed on the majority of the city's vehicles can be leveraged. While the city's Geotab system does not allow full GPS tracking of the vehicles, some measures of the vehicles use can be extracted from the system, including odometer readings, hours of operation, excessive use violation reporting. Those reports together with some basic geofencing abilities added by the CVPD team, a general sense of the equipped vehicles usage can be developed.

From this data, it can be seen that the equipped vehicles are predominantly focused on the standard business hours on weekdays. However, the 24-7 nature of some of the city agency's activities does extend into the overnight and weekend hours and on weekends. Vehicles can also be seen moving across the city in all five boroughs using all road types, although activities do concentrate on areas of the city which are not predominantly residential.

Appendix B provides more information about the typical operations of the targeted fleet of vehicles.

4 Performance Measures and Targets

The goal of the performance evaluation of the NYC CVPD project is to demonstrate the impacts of the deployed CV applications that will help advance the City's existing Vision Zero program, which aims to reduce the number of fatalities and injuries on NYC's roadways.

To assess the safety impacts of the NYC CVPD program, NYCDOT has identified needs which encompass managing speed and reducing the number of crashes and their severity to improve safety. As a secondary goal, by reducing crashes and incidents that disrupt travel, improvements can be made in travel mobility and reliability in the heavily congested area.

While the NYC CVPD program is directly focused on safety, secondary mobility improvements are intertwined with safety improvements because fewer crashes will reduce crash related delays. Meanwhile, improvements to mobility can improve safety as well. For example, fewer stops may mean fewer occasions for rear end crashes.

Other improvements such as environmental improvements will not be measured directly, but they will be estimated indirectly from mobility improvements that are directly measurable such as travel time savings, queue reduction, and braking as impacts on emissions.

Through the work in developing the NYC CVPD's Concept of Operations, seven use cases for user needs have identified for improvement in the system performance. The following sections present these seven use cases, the CV applications being deployed in an attempt to improve conditions, and the performance metrics listed in Table 3 which have been identified to measure the impacts of the NYC CVPD on each use case.

Table 3. Identified Performance Metrics by CV Application

User Need	Category	NYCDOT Needs	CV Application	No.	Performance Measure Metrics	Question for Evaluation
Manage Speeds	Safety, Mobility	Discourage Spot Speeding	Speed Compliance	1	1a. Number of stops (average and distribution measures) 1b. Speeds (average and distribution measures) 1c. Emissions 1d. Reduction in speed limit violations 1e. Speed variation 1f. Vehicle throughput (average and distribution measures) 1g. Driver actions and/or impact on actions in response to issued warnings	Does speed limit adherence increase and speed variability decrease within the vehicle fleet on a given study roadway segment for a given time period (cycle length basis) from the Before period to the Pilot period, and from control group to the treatment group? Is this accompanied by an overall increase, decrease or no change in average segment speed?
Manage Speeds	Safety	Improve Truck safety	Curve Speed Compliance	2	2a. Speed related crash counts, by severity 2b. Vehicle speeds at curve entry 2c. Lateral acceleration in the curve 2d. Driver actions and/or impact on actions in response to issued warnings 2e. Number of curve speed violations at each instrumented location	Do the number of curve speed violations on each applicable studied roadway segment decrease from the Before period to the Pilot period, and from control group to the treatment group?

User Need	Category	NYCDOT Needs	CV Application	No.	Performance Measure Metrics	Question for Evaluation
Manage Speeds	Safety	Improve Work Zone Safety	Speed Compliance / Work Zone	3	3a. Speed in work zone (average and distribution measures) 3b. Speed variation (distribution) at work zone 3c. Number of vehicle speed limit violations in variable speed zone areas 3d. Driver actions and/or impact on actions in response to issued warnings	Do the number of work-zone speed violations on each applicable studied roadway type decrease from the Before period to the Pilot period, and from control group to the treatment group?
Reduce Vehicle to Vehicle Crashes	Safety	Reduce Vehicle to Vehicle Accidents	FCW EEBL BSW LCW IMA	4	4a. Fatality crash counts 4b. Injury crash counts 4c. Property damage only crash counts 4d. Time to Collision (vehicle to vehicle)	Do the number of reportable crashes decrease from the Before period to the Pilot period, and from control group to the treatment group?
Reduce Vehicle to Vehicle Crashes	Safety	Reduce Accidents at High Incident Intersections	Red Light Violation Warning	5	5a. Red light violation counts 5b. Time To Collision (vehicle to cross vehicle path) at the intersection 5c. Driver actions and/or impact on actions in response to issued warnings	Do the number and severity of red-light violations at each studied intersection decrease from the Before period to the Pilot period, and from control group to the treatment group?
Reduce Vehicle to Vehicle Crashes	Safety	Reduce Bus Incidents, Improve Safety	Vehicle Turning Right in Front of Bus Warning	6	6a. Right-turning related conflicts 6b. Time to collision (vehicle to bus) 6c. Number of warnings generated 6d. Driver actions and/or impact on actions in response to issued warnings	Do the number of bus / right turn vehicle crashes decrease from the Before period to the Pilot period, and from control group to the treatment group?

User Need	Category	NYCDOT Needs	CV Application	No.	Performance Measure Metrics	Question for Evaluation
Reduce Vehicle to Pedestrian Crashes	Safety	Improve Pedestrian Safety on Heavily Traveled Bus Routes	Pedestrian in Signalized Crosswalk Warning	7	7a. Pedestrian related crash counts, by severity 7b. Number of warnings generated 7c. Pedestrian-related conflicts/hard braking events 7d. Time to collision (vehicle to pedestrian) 7e. Driver actions and/or impact on actions in response to issued warnings	Do the number of pedestrian related crashes decrease from the Before period to the Pilot period, and from control group to the treatment group?
Reduce Vehicle to Pedestrian Crashes	Safety	Improve Safety of Visually and Audibly-impaired pedestrians	Mobile Accessible Pedestrian Signal System (PED-SIG)	8	8a. Qualitative Operator Feedback 8b. Pedestrian Crossing Speed and Crossing Travel Time 8c. Times Out of Crosswalk 8d. Waiting time at intersection for crossing	Does the mobile app improve participants' perceived safety when crossing signalize intersection?
Reduce Vehicle to Infrastructure Crashes	Safety	Address Bridge Low Clearance Issues/Enforce Truck Route Restriction	Oversized Vehicle Compliance	9	9a. Number of Warnings generated 9b. Number of truck route violations	Do the number of low clearance violations decrease from the Before period to the Pilot period, and from control group to the treatment group?
Inform Drivers of Serious Incidents	Mobility	Inform Drivers	Emergency Communications and Evacuation Information	10	Number of vehicles receiving information when generated	Do CV vehicles receive the information warnings when generated?

User Need	Category	NYCDOT Needs	CV Application	No.	Performance Measure Metrics	Question for Evaluation
Provide Mobility Information	Mobility	Replace Legacy Measurements	Intelligent Traffic Signal System Connected Vehicle Data (I-SIGCVDATA)	11	11a. Segment speed (average and distribution measures) from CV compared to legacy detection systems 11b. Travel time (average and distribution measures) from CV compared to legacy detection systems	Do the CV based mobility metrics compare favorably to legacy detection systems or provide better information?
Manage System Operations	System Operations	Ensure Operations of the CV Deployment	NA	12	System performance statistics (system activity, down time, radio frequency monitoring range on ASD's and RSU's, number of event warnings by app)	Does the system operate reliably?

4.1 Use Case 1: Manage Speeds

There are several CV technologies aiming to manage speeds on surface streets.

These CV apps send alert to driver when their speed exceeds the posted speed limit within a special zone, such as a curve or a work zone, or when their speed exceed the 25 mph speed limit implemented in the early stages of NYC's Vision Zero program. By reducing spot speeding, it is aimed to improve both safety and mobility. It could also reduce emissions by reducing hard braking events. The CV technologies that will be used to improve speed compliance for this use case are:

- Speed Compliance (SPDCOMP)
- Curve Speed Compliance (CSPD-COMP)
- Speed Compliance in Work Zone (SPDCOMPWZ)

4.1.1 Speed Compliance

The Speed Compliance (SPDCOMP) application notifies drivers when their speed exceeds the posted limits by a given threshold amount (potentially zero) to discourage spot speeding. To measure the effectiveness of the speed compliance application, the following metrics are measured:

- Number of stops (including both average and measures of the range and distribution)
- Speeds (including both average and measures of the range and distribution)
- Emissions
- Reduction in speed limit violations
- Speed variation
- Vehicle throughput (including both average and measures of the range and distribution)
- Driver actions and/or impact on actions in response to issued warnings

4.1.2 Curve Speed Compliance

The Curve Speed Compliance (CSPD-COMP) application allows connected vehicles to receive information that they are approaching a curve with a reduced recommended speed. This capability allows the vehicle to provide a warning to the driver regarding the curve if the driver is exceeding its recommended speed. To measure the effectiveness of curve speed warning application, the following metrics will be collected at the instrumented locations:

- Speed related crash counts, by severity of crash
- Vehicle speeds in excess of the curve speed
- Lateral acceleration in the curve
- Driver actions and/or impact on actions in response to issued warnings
- Number of curve speed violations at each instrumented location

4.1.3 Speed Compliance in Work Zone

The Speed Compliance in Work Zone (SPDCOMPWZ) provides connected vehicles that are approaching a reduced speed work zone with information on the zone's reduced speed limit, and warns the drivers if their speed is above the zone speed limit. To measure the effectiveness of application, the following metrics will be measured at the instrumented locations:

- Speed in work zone (including both average and measures of the range and distribution)
- Speed variation at work zone
- Number of vehicle speed limit violations in variable speed zone areas
- Driver actions and/or impact on actions in response to issued warnings

4.2 Use Case 2: Reduce Vehicle to Vehicle Crashes

The ultimate goal of Vision Zero program is to reduce the number of fatalities and injuries on roadways including vehicle-to-vehicle crashes. To reduce vehicle-to-vehicle crashes, the following CV technologies will be applied for this use case:

- V2V safety applications warnings
- Red light violation warning
- Vehicle turning right in front of bus warning

4.2.1 V2V Applications

Vehicles equipped with connected vehicle technology (i.e., aftermarket safety devices or ASDs) will travel throughout the City's transportation network. Thus, the connected vehicle technology that supports Vehicle-to-Vehicle (V2V) applications will function anywhere two equipped vehicles are within range of one another. The large fleet size means that there will be many opportunities for the connected vehicle technology to perform over a large geographic area and diverse roadway environments.

V2V safety application aim to improve overall vehicle-to-vehicle safety by deploying the following V2V applications in the NYC CVPD:

1. Forward Collision Warning (FCW): Warns the driver of the host vehicle in case of an impending rear-end collision with a remote vehicle ahead in traffic in the same lane and direction of travel.
2. Emergency Electronic Brake Light Warning (EEBL): Enables the equipped vehicles to broadcast a self-generated emergency brake event to other surrounding connected vehicles. Upon receiving such event information, the receiving vehicle determines the relevance of the event and provides a warning to the driver if appropriate.
3. Blind Spot Warning / Lane Change Warning (BSW/LCW): Warns the driver of the host vehicle during a lane change attempt if the blind spot zone into which the host vehicle intends to switch is, or will soon be, occupied by another connected vehicle traveling in the same direction.
4. Intersection Movement Assist (IMA): Warns the driver of a host vehicle when it is not safe to enter an intersection due to high collision probability with other remote connected vehicles at stop sign controlled and uncontrolled intersections.

The following performance metrics will be measured for the effectiveness of V2V applications:

- Fatality crash counts
- Injury crash counts
- Property damage only crash counts
- Time to collision (vehicle to vehicle)

It is important to note the number of crashes to be measured depends on the targeted type of crash each V2V application aims to prevent. For example, rear end crash counts will be measured to estimate the effectiveness of forward collision warning application, while left turn across path from opposite direction or straight crossing paths at non-signalized junction will be measured to estimate the effectiveness of the intersection movement assist application. USDOT's research "*Depiction of Priority Light-Vehicle Pre-Crash Scenarios for Safety Applications Based on Vehicle-to-Vehicle Communications*" published by National Highway Traffic Safety Administrations (NHTSA) lists pre-crash scenarios for potential vehicle-to-vehicle (V2V) safety applications, as indicated in Table 4 below.

Table 4. Mapping of Target Light-Vehicle Pre-Crash Scenarios to VSC-A Applications

Target Pre-Crash Scenarios	EEBL	FCW	IMA	BSW/LCW
Rear-end crash/LVS[1]		√		
Rear-end crash/LVM[2]		√		
Rear-end crash/LVD[3]	√	√		
Rear-end crash/LVA[4]		√		
Rear-end crash/following vehicle making a maneuver		√		
Opposite direction/no vehicle maneuver				
Opposite direction/vehicle making a maneuver				
LTAP/OD at signalized junctions[5]				
LTAP/OD at non-signalized junctions[5]			√	
SCP at non-signalized junctions			√	
Turning at non-signalized junctions			√	
Turning right at signalized junctions				
Running red light				
Running stop sign			√	
Changing lanes/both vehicles traveling in same direction				√
Drifting/both vehicles traveling in same direction				√
Turning/ both vehicles traveling in same direction				√

Source: Table 2 from USDOT's "Depiction of Priority Light-Vehicle Pre-Crash Scenarios for Safety Applications Based on Vehicle-to-Vehicle Communications" published by NHTSA

Notes:
1. Rear-end crash/lead vehicle stopped (LVS)
2. Rear-end crash/lead vehicle moving at slower constant speed (LVM)
3. Rear-end crash/lead vehicle decelerating (LVD)
4. Rear-end crash/lead vehicle accelerating (LVA)
5. Left Turn Across Path / Opposite Directions (LTAP/OD)

As the information detailing the crash type is required to evaluate the above specific V2V safety applications, crash-based evaluation largely depends on the sample size and actual data availability specifying each crash type. Unfortunately, within the crash record databases available in a timely enough manner to evaluate changes during the deployment period (the NYPD crash database, see section 7.2.1 for more details), both rear-end crashes with a leading vehicle decelerating and all types of crashes that correspond to the IMA warning are not reliably identifiable in the available databases. Thus, a crash-based evaluation specifically regarding EEBL and IMA will not be feasible. More details on evaluation of the V2V applications are included in section 8).

4.2.2 Red Light Violation Warning

The Red Light Violation Warning (RLVW) application enables a connected vehicle approaching an instrumented signalized intersection to receive information from the infrastructure regarding the signal timing and the geometry of the intersection. The application in the vehicle uses its speed and acceleration profile, along with the signal timing and geometry information to determine if it appears likely that the vehicle will enter the intersection in violation of a red traffic signal. If the violation seems likely to occur, a warning is provided to the driver. To measure the effectiveness of Red Light Violation Warning application, the following metrics will be measured at the instrumented intersections:

- Red light violation counts
- Time To Collision (vehicle to cross vehicle path) at the intersection
- Driver actions and/or impact on actions in response to issued warnings

4.2.3 Vehicle Turning Right in Front of Bus Warning

The Vehicle Turning Right in Front of a Bus Warning (VTRW) application determines the movement of connected vehicles near to the host transit vehicle stopped at a transit stop and provides an indication to the transit vehicle operator that a nearby vehicle is pulling in front of the transit vehicle. This application will help the transit vehicle determine if the area in front of it will not be occupied as it begins to pull away from a transit stop. To measure the effectiveness of application, the following metrics will be measured:

- Right-turning related conflicts
- Time to collision (vehicle to bus)
- Number of warnings generated
- Driver actions and/or impact on actions in response to issued warnings

4.3 Use Case 3: Reduce Vehicle to Pedestrian Crashes

One new area of connected vehicle applications to be assessed within the project involves assisting/protecting pedestrians and cyclists. This area is significant in the NYC environment due to the nature of heavy pedestrian and bike presence and the nature of vehicle-pedestrian crashes under the current conditions.

The NYC CVPD will deploy two pedestrian oriented applications: 1) a generalized warning to vehicles of pedestrians in the crosswalks and 2) support for visually impaired (blind) pedestrians at signalized crossings.

4.3.1 Pedestrian in Signalized Crosswalk Warning

This Pedestrian in Signalized Intersection Warning (PEDINXWALK) application will use pedestrian detection equipment to inform the roadside unit (RSU) at an equipped intersection of the presence of pedestrians in a crosswalk at a signalized intersection. Nearby the connected vehicles will receive this information from the infrastructure that indicates the presence of pedestrians in the signalized intersection crosswalks. The application will then, as appropriate, warn the driver of the pedestrian's presence. To measure the effectiveness of application, the following metrics will be assessed at the instrumented locations:

- Pedestrian related crash counts, by severity
- Number of warnings generated
- Pedestrian-related conflicts/hard braking events
- Time to collision (vehicle to pedestrian)
- Driver actions and/or impact on actions in response to issued warnings

4.3.2 Mobile Pedestrian Signal System (PED-SIG)

To support visually impaired pedestrians, PED-SIG will be implemented using a portable personal device (e.g., smartphone) so that the pedestrian can receive messages from equipped traffic signals regarding the pedestrian signals (walk / do not walk) status of nearby crosswalks to assist them in making crossing decisions. The deployment includes ten portable personal devices to be used by approximately 25 visually impaired pedestrians during the limited field tests. Due to the safety concerns for the visually impaired participants, all field test of the PED-SIG in this pilot will be directly overseen by at least one IRB approved researcher. To measure the effectiveness of application, the following metrics will be measured at the test locations:

- Qualitative Operator Feedback
- Pedestrian Crossing Speed and Crossing Travel Time
- Times Out of Crosswalk
- Waiting time at intersection for crossing

4.4 Use Case 4: Reduce Vehicle to Infrastructure Crashes

To reduce vehicle to infrastructure crashes, the application of Oversize Vehicle Compliance will be deployed to address low clearance issues for oversized vehicles and enforce truck route restrictions.

4.4.1 Oversize Vehicle Compliance

The Oversize Vehicle Compliance (OVC) application will be used for connected trucks and other commercial vehicles to reinforce drivers of the vehicle restrictions, for example the low 9'6" height restrictions on the FDR. The focus of this application is on preventing oversize vehicle from entering roadways to which they are restricted to prevent such over-height crashes and support the safety goals of Vision Zero. To measure the effectiveness of application, the following metrics will be measured:

- Number of warnings generated
- Number of truck route violations

4.5 Use Case 5: Inform Drivers of Serious Incidents

As the traffic manager and roadway infrastructure owner, NYCDOT needs to provide notification to drivers that an area is to be avoided and why. To inform drivers of serious incidents, the CV application of Emergency Communications and Evacuation Information will be deployed.

4.5.1 Emergency Communications and Evacuation Information

The Emergency Communications and Evacuation Information (EVAC) application will help transmit the information from NYC Office of Emergency Management (OEM) and from NYCDOT Office of Emergency Response (OER) to the connected vehicles near or within affected areas during incidents. When incidents occur, emergency response information will be transmitted to the connected vehicles through the roadside equipment (RSUs) and drivers will be notified if they are within the designated warning zone. To measure the effectiveness of the application, the following metric will be measured:

- Number of vehicles receiving information when generated

4.6 Use Case 6: Provide Mobility Information

To balance mobility and provide information in heavily congested areas, the NYC CVPD project is deploying the application of Intelligent Traffic Signal System Connected Vehicle Data (I-SIGCVDATA).

4.6.1 CV Data for Intelligent Traffic Signal System

The CV Data for Intelligent Traffic Signal System (I-SIGCVDATA) application uses the RSU's to monitor connected vehicle movements and to ultimately provide RSU to RSU travel time data for use in other NYCDOT systems, in particular the award-winning Midtown in Motion (MIM) adaptive traffic signal system. Travel time and speed data currently collected by toll tag reader system is used as an input to the existing Adaptive Control Decision Support System (ACDSS). It is the intent of the project to determine if the CV technology provides input that is equivalent to the existing data collection mechanism such that expansion of the ACDSS adaptive control system can rely on only the CV data collected. To measure the effectiveness and accuracy of I-SIGCVDATA, the following metrics will be measured:

- Segment speed (including both average and measures of the range and distribution) collected from CV vehicles compared to legacy detection systems
- Travel time (including both average and measures of the range and distribution) collected from CV vehicles compared to legacy detection systems

4.7 Use Case 7: Manage System Operations

The NYCDOT will need to manage and track the CV system operations. While not directly related to CV applications on the ASDs, the following system performance statistics will be monitored and assessed to ensure the operation of CV deployment:

- System activity
- Downtime (number of events and duration)

- Radio frequency monitoring range on ASD's and RSU's
- Number of event warnings by application

4.8 Performance Measure Targets

As the performance evaluation of the NYC CVPD project aims to demonstrate the benefits that will help advance the City's existing Vision Zero program, the primary performance measures for the safety improvements will focus on reductions in the number of crashes and the crash rate (crashes per million vehicle miles travelled) due to the CV applications that will likely occur within the study limits. It is acknowledged that with the complexity of the traffic system in New York City, there are many factors that can potentially affect the crash and incident rates in addition to the CV applications.

The ultimate target of NYC's Vision Zero program is to eliminate traffic fatalities and serious injuries on the city's roadways. While this lofty target is admirable for an ultimate goal, establishing significant yet achievable targets for the NYC CVPD is challenging. It is difficult to set meaningful or useful targets for the parameters that are still under investigation, since the CV deployment on congested urban city streets of this scale is without precedent.

USDOT conducted a preliminary analysis in 2009 of the annual number of crashes that could be addressed by V2V technology. Based on this existing research on V2V benefit, "*Vehicle to Vehicle Communications: Readiness of V2V Technology for Applications*" published by National Highway Traffic Safety Administrations (NHTSA) indicates that as a primary countermeasure, a fully mature V2V system could potentially address 79 percent of all vehicle target crashes. It is estimated the application of Intersection Movement Assist (IMA) would help drivers avoid 41 to 55 percent of target intersection crashes. The application of Left Turn Assist (LTA) would prevent 36 to 62 percent of left turn crashes.

Despite the large number of vehicles being equipped with CV technology in NYC as compared to previously completed CV pilot studies, the number of CV vehicles will still be a very small minority of the overall traffic streams on the study corridors. The expected reduction accidents should therefore be lower than these values for V2I improvements, and even lower for V2V applications for the planned NYC CVPD study. The ultimate target value for improvement will be determined based on existing research of V2I and V2V benefits for the CV applications being deployed, the final market penetration rate achieved for the NYC CV program deployment and data on the actual frequency of the CV application warnings.

The target values for improved performance are initially identified in the 5% range for accident reduction as the current plan for NYC CVPD deployment. However, it is noted that some types of crashes which are expected to be more influenced by the V2V applications can only approach these levels of improvement under a relatively higher percentage of equipped vehicles interacting with each other. Error tolerance and confidence intervals will be determined based on the achieved sample sizes to arrive at statistically significant results. More detailed targets for improvement for performance metrics will be developed in Phase 3 where initial performance of the CV devices and the number of warnings generated can be observed and the actual market penetration of equipped vehicles is known.

The performance measure targets for non-safety improvements will depend on the efficiency of the baseline state of the traffic network and the number of prevented or severity-reduced accidents. Travel time savings of 5 to 15 percent would be considered quite effective in a carefully managed traffic signal system, as was indicated in the improvements in operating speeds generated from NYCDOT's signature adaptive signal control program Midtown in Motion (MIM). Mobility improvements, as the secondary goal in the NYC CV program, will focus to reduce travel time and delay as performance measure target, but will also be proportional to the number of reduced accidents.

5 Confounding Factors

In a city the size of New York City, the variety of factors which can affect the operational performance of the transportation and roadway network can be large. This chapter attempts to document the potential confounding factors that will need to be considered during the performance measurement and evaluation process for the NYC CVPD. For information and plans on how to track and account for these confounding factors during the CVPD performance measurement and evaluation plan, please refer to the later chapters in this report.

5.1 Identified Confounding Factors

The following confounding factors have been identified which impact the performance of the transportation network in New York City and could influence the results of comparisons of with and without CV deployment for performance reporting of the CVPD project.

5.1.1 Traffic Demand Variations

Traffic demands and the resulting observed vehicle volumes vary across the study area corridors by time of day and day of week. Because the study corridors are within a dense urban area, seasonal variation of demands is less pronounced. Along each corridor, volumes also vary, particularly for the four Manhattan Avenues. Vehicular traffic volumes within the Manhattan study area are especially variable in the vicinity of the East River crossings, such as the Queens-Midtown Tunnel and the Ed Koch (formerly Queensboro) Bridge, which deliver and attract significant volumes between Midtown and Queens. Observed traffic volumes can be intermittently affected by closures, incidents, or disabled vehicles on the approaches to or within those facilities. Similarly, Flatbush Avenue volumes can be influenced by operations on the Brooklyn and Manhattan Bridges, connecting Manhattan and Brooklyn. As a limited-access highway, the FDR Drive serves significant through traffic along the east side of Manhattan, connecting the East River Bridges, Queens-Midtown Tunnel, and highways further north.

Similar to vehicular volumes, pedestrian volumes vary by time of day and day of week. Unlike vehicular demands, pedestrian volumes do see seasonal surges marked by increased tourism and holiday time periods. Pedestrian volumes also vary spatially with increased volumes near transit hubs, especially during typical commute periods.

5.1.2 Weather

The humid continental climate of New York City is characterized by significant variation across seasons. Winter months can experience below freezing temperatures with frozen precipitation and snow accumulation; heavy rain totals can occur in other months; and severe storms such as nor'easters, blizzards, and even hurricanes are possible. Over the duration of the data collection period of the project, such weather events may occur, and such conditions can affect travel demand, vehicle operating characteristics, and roadway conditions.

5.1.3 Accidents and Incidents

Based on 2010-2014 data, the city's crash ranking (KSI, "killed or severely injured" metric) of the CV study corridors vary: 1st Avenue ranks in the top third of Manhattan corridors, while 2nd, 5th and 6th Avenues rank in the top 10 percent, and similarly, Flatbush Avenue ranks in the 10 percent for Brooklyn. Just as important, however, is the impact crashes have on adjacent streets and facilities can affect flows on the study corridors, due to the dense, congested nature of the city's network. Incidents can affect throughput, routing and driving patterns across large areas of the network. In addition, the interrelationship of accidents and observed traffic volumes on an hourly and daily basis (see section 5.1.1) is important.

In addition to accidents and crashes, regular very short-term lane blockage disruptions incidents, such as truck double-parking for loading and unloading or taxi pick-up/drop-off activity, regularly happen on the city's arterial roadways. These incidents are generally very short in duration, typically the range of less than a minute to a few minutes. Additionally, they occur frequently enough that they are almost common occurrence and part of the typical operations of the city's roadways, particularly on Manhattan avenues.

Transit service disruptions can also have impacts on both vehicular and pedestrian volumes. Disruptions may cause travelers to change their travel patterns. In a transit-rich environment like New York City, minor disruptions may cause changes travelers to shift from one transit route to another, transit riders may also shift between transit modes (e.g., subway to bus), to non-motorized modes (bike and walk), or to taxi or for-hire vehicles. In the case of major disruptions, the potential to shift to auto modes is also possible.

5.1.4 Traffic Signal Timing Updates

To maintain efficient and safe movement of vehicles and people through the network, the city periodically conducts reviews and, if needed, adjusts the time of day traffic signal timing plans, including phasing, splits and/or offsets. While the SPaT data will report the actual operations of the signals and capture these changes, large changes such as turn phase adjustments can creates changes in travel patterns.

In addition to periodic signal timing plan updates, adaptive signal control within the Midtown in Motion (MIM) area of Manhattan, plays an important role in managing congestion through real-time adjustment of corridor offsets (Level-1 control) and green time phase splits at select intersections (Level-2). MIM Level-1 control can affect the four study avenues in Manhattan and may indirectly affect travel conditions on adjacent avenues. Level-2 control can have more localized effects. While Level-1 and Level-2 control are limited to certain segments (1st, 3rd, Lexington, Madison, 5th, 6th, 8th and 9th Avenues) and intersections (15 in all), respectively, the overall coverage of MIM's real-time travel time monitoring system extends from 1st Avenue to the east, 11th Avenue to the west, 23rd Street to the south and 57th Street to the north, which includes monitoring of segment travel times in real-time. Segment travel times are observed through deployment of RFID tag readers at fixed locations.

5.1.5 Work Zones – Short Term or Unplanned

Short-term work zones – including lane closures for emergency utility work – can be omnipresent in the city and have a cumulative effect on travel conditions on the study corridors. Moreover, the nature of these work zones, particularly for emergency utility work, are difficult to track and account for in the observed traffic conditions.

5.1.6 Work Zones – Long Term or Planned

Long-term work zones on the study corridors are not anticipated, though building construction projects can affect availability of curb lanes and sidewalk space, instigating increased double-parking blockages, pedestrian spillover and intermittent street closures. In addition, a number of longer-term street construction projects and MPT-related changes to facilities/crossings may affect travel patterns and instigate volume increases or decreases on the study corridors. In general, the number of construction-related permits affecting street and/or sidewalk operations issued by the city has increased year over year since the end of the recession. The locations and details of these work zones can be tracked and documented throughout the study.

5.1.7 Planned Special Events

Special events occur with regularity, especially for the Manhattan study area, but are given advanced notice and can be documented. Events include the meeting of the United Nations General Assembly every September, which greatly affects travel on the east side of Manhattan, the New York City Marathon, and the Five Boro Bike Tour occur annually. Additionally, a number of street closures occur as a result of parades, seasonal, and community events (e.g., Summer Streets roadway closures, street fairs and plazas) and presidential or other dignitary visits.

5.1.8 Economic Conditions

As was apparent during and following the last recession, travel patterns, including volumes and modes, pedestrian and tourist demand, freight and construction activity, are closely tied with local, regional, and even national economic conditions. While these conditions can play a role on transportation activity, the effects of economic swings can be slow to materialize and dissipate.

5.1.9 Fuel Prices

Varying fuel prices can instigate changes in automobile trips and potentially create shifts between modes as well. Given that fuel prices can change based on both global economic and oil production disruptions, the effects large changes in fuel costs could have influences on vehicle demands and vehicle miles travelled. While fuel prices may adjust more quickly than general economic conditions, the effects of changing gas prices are may be more noticeable over a longer timeframe than the Phase 3 performance evaluation period.

5.1.10 E-Hail and For-Hire Vehicle (FHV) Services

The increase in E-Hail FHV services (e.g., Uber, Lyft, etc.) in New York City in recent years has corresponded with a drop in traditional street hail (yellow taxi) pick-ups, particularly in the Manhattan Central Business District south of 60th Street. In addition, the city's green "Boro" taxis, which provide street hail pick-ups in the four outer boroughs (excluding the airports) and northern Manhattan (north of East 96th Street or north of West 110th Street) and are allowed to drop off anywhere, have assumed some of the offset yellow taxi demand since their introduction in 2013. The changes in yellow and green taxi as well as FHV providers are apparent in the trip records which are provided by the TLC. Recent rule changes made by TLC to cap the number of FHV licenses and to encourage minimal levels of vehicle passenger occupancies, as well as ongoing lawsuit over those rules, may further influence the future changes within the for-hire market in NYC.

5.1.11 Citi Bike

Citi Bike, New York City's bikeshare program, has an expansive network of stations in Manhattan and Brooklyn. For short trips (less than 2 miles), Citi Bike can compete with for-hire modes in terms of relative trip time and cost especially in those areas. In addition, the increased bikeshare demand and expanded network can add to more bike traffic along study corridors and through intersections. While the program has been ongoing since 2013 and is generally mature, plans to introduce additional bikes and some electric bikes and to expand may evolve the impacts of Citi Bike during the pilot evaluation period.

5.1.12 Changes in Transit

While the addition of new Select Bus Service (NYC's branding of Bus Rapid Transit) routes along the study corridors is not anticipated during the CV pilot, service changes on some Manhattan cross streets (e.g., 23rd Street) and associated construction and roadway restriping for reserved bus lanes may occur. Other SBS service changes outside of the CV corridors may affect travel demand characteristics within the study area.

To rehabilitate damage incurred during Hurricane Sandy to the East River Canarsie Tunnel which carries the L train between Williamsburg, Brooklyn and 14th Street in Manhattan, an ongoing construction project is disrupting L train service and operations on nearby surface roadways, including the introduction of 14th Street Transit & Truck Priority which restricts movement on 14th Street for vehicles other than trucks and buses.

5.1.13 Vision Zero Projects

Initiated in January 2014 by Mayor Bill de Blasio and supported by a package of legislation in June 2014, Vision Zero's goal is to halve the number of traffic fatalities by 2025. Vision Zero includes a host of citywide and localized projects and initiatives such as enforcement, education, and outreach programs; speed limit reduction; neighborhood and arterial slow zones; use of speed cameras; and targeted safety and design treatments along corridors and at intersections.

As part of the program, the citywide speed limit was reduced from 30 mph to 25 mph – unless otherwise posted – on November 7, 2014. While Vision Zero (VZ) includes citywide enforcement programs, such as the potential for criminal charges for failure to yield to a pedestrian resulting in death or injury, and education programs that have been in effect for several years, VZ-related projects anticipated to be implemented during the CVPD evaluation period would predominantly be localized to intersection or corridor level design and safety improvements. Those projects are tracked by NYC DOT, as are related changes, such as overnight corridor signal retimings for the 25-mph speed limit. In addition, the deployment of enforcement measures, such as red light cameras and speed cameras, are included.

5.1.14 COVID-19 Impacts

The ongoing impacts of the COVID-19 pandemic is an additional confounding factor that has had dramatic impacts on the overall demand and nature of travel in the city, as well as the resulting operational conditions in the city. While the initial stay-at-home orders in the city have been lifted and many people are returning to work, certain restrictions are still in place in the city and the timeline to lift those restrictions is still uncertain at this point in time. Dramatic impacts were seen starting in March 2020, with some limited return towards normal conditions following in the Summer and Fall of 2020. Lingering impacts are still readily evident now in 2021 as restrictions are still in place and are likely to remain in place until a significant number of vaccinations are completed. Additionally, a true return to pre-COVID conditions may not ever be seen, as changes to telecommuting and other changes in travel behaviors are speculated to be permanently altered, at least to some degree.

Details of the overall impacts of COVID-19 and the ongoing impacts to transportation in the NYC region are available at https://c2smart.engineering.nyu.edu/covid-19-dashboard. The overall impacts of the pandemic make the use of 2020 data sets highly questionable, and the overall impacts on use of 2021 data and the comparison to pre-COVID conditions an element that must be factored into the deployment evaluation.

5.1.15 CV Fleet Size and Activity

As a result of the COVID-19 pandemic, ASD installations were put on hold for a large portion of 2020 during Phase 2. As the CVPD enters into Phase 3, approximately 30 percent of the ASD installations have yet to be completed. While installations are underway, the size of the CV equipped fleet will continue to grow during Phase 3 until installations are completed. The changing size of the equipped fleet itself then becomes a confounding factor that must be considered during the evaluation of the impacts of the NYC CVPD.

In addition to the size of the fleet, expected continued lifting of COVID-19 restrictions may have an impact on the typical activity levels of the CV equipped fleet. Throughout the late stages of Phase 2 as the city continued to recover from COVID-19 impacts, the average hour or miles driven per city fleet vehicles has not changed significant, mostly due to the essential nature of the city's workers and operations. While the majority of the city operations have needed to continue through the pandemic and city vehicles have been continually used, further lifting of restrictions with an increasing vaccinated population may increase the overall activity level of the CV fleet vehicles. Therefore, the activity levels of the CV fleet should be tracked throughput Phase 3 and considered in the evaluation of the NYC CVPD.

5.2 Impact Assessment of Confounding Factors

In order to help determine the impacts of the identified confounding factors on the performance evaluation of the CV pilot, the NYC team has evaluated the relative impact of each factor on the overall system performance of the city and the study are roadways. Table 5 lists both the assessed overall impact of the confounding factor on the system performance, and the relative difficulty to quantify those factors and their impacts given the current state of system monitoring in NYC. The relative difficulty to track assessment is a hybrid valuation that includes the overall difficulty in quantifying both (a) our ability to be aware that changes are occurring and (b) our ability to quantify the effects of those changes.

Table 5. Impact of Confounding Factors on Performance Evaluation

Confounding Factor	Impact on System Performance	Relative Difficulty to Quantify
Traffic Demand Variations	High	Medium

Confounding Factor	Impact on System Performance	Relative Difficulty to Quantify
Weather	Medium	Medium
Accidents and Incidents	Medium	High
Traffic Signal Timing Updates	Medium	Low
Work Zones (Short Term or Unplanned)	Medium	High
Work Zones (Long Term or Planned)	Medium	Low
Planned Special Events	High	Low
Economic Conditions	Low	Low
Fuel Prices	Low	Low
E-Hail and For-Hire Vehicles	Medium	Medium
Citi Bike	Low	Low
Changes in Transit	Medium	Medium
Vision Zero Projects	Medium	Low
COVID-19 Impacts	High	Medium
CV Fleet Size and Activity	High	Low

Those confounding factors rated 'low' in "Impact on System Performance" (Economic Conditions, Fuel prices, and Citi Bike) will neither be tracked nor accounted for in the performance assessment, as the overall impacts of these factors can be determined as minimal. Two of these factors (economic conditions and fuel prices) will be indirectly captured, since their influence is predominantly seen through changing the overall traffic demand, which will be independently tracked. Potential changes or increase usage in the Citi Bike program could be monitored through open data tracking the system usage, but the bikeshare program is already well established and active throughout the vast majority of the CVPD study area.

For the remaining identified factors, care will need to be taken to monitor the activity of these confounding factors during the CV pilot performance reporting period. Table 6 provides an overview of available and proposed data sources to be gathered specifically for the CV Pilot study, to monitor the confounding factors and their influence on the CVPD performance evaluation. Proposed data is recommended for factors where currently limitations in data availability resulted in a "High" rating for "Relative Difficulty to Quantify" in Table 6.

Further details on the data sets being collected are included in Section 7.

Table 6. Datasets to Track Confounding Factors

Confounding Factor	Current Data Available to NYC DOT	Supplemental Data Collection for CV Pilot
Traffic Demand Variations	• Semi-annual, two-week counts at NYC DOT screenlines, bridges and county crossings (coverage of continuous traffic monitoring devices is very limited in the study area)	• Count monitoring of key crossings within the study area

	• Traffic flow conditions along study corridors from segment travel time information (TRANSCOM, Midtown in Motion, MTA Bus Time, taxi GPS data)	• Potentially quarterly count program (tube counts) along CV pilot corridors
Weather	• National Weather Service (NWS) METAR station reports of current conditions at 4 NYC and 3 NJ stations • Snowplow clearing status from Department of Sanitation	None
Accidents and Incidents	• NYPD and NYS Crash Databases; including type, vehicle type(s), severity, location and time	None
Traffic Signal Timing Updates	• NYC DOT official timing sheets with retiming dates; periodic updates made	None
Work Zones (Short Term)	• Incident reporting in TRANSCOM OpenReach	None
Work Zones (Long Term)	• Incident reporting in TRANSCOM OpenReach; permit database (NYC DOT OCMC)	None
Planned Special Events	• City Hall Street Activity Permit Office (SAPO) calendar and event details; calendar of street closures (NYPD)	None
E-Hail and For-Hire Vehicles	• TLC trips and GPS trip data records, including spatial/temporal routing and activity patterns for all yellow and green taxis and FHV companies	None
Changes in Transit	• Project details, extents and implementation dates; ridership data (NYC DOT & MTA)	None
Vision Zero Projects	• Project details, extents and implementation dates for design/safety improvements (NYC DOT); locations and implementation dates of new enforcement measures (NYPD); findings of Years 1 and 2 “after” analyses (City Hall)	None
COVID-19 Impacts	• Tracking of various performance metrics aggregated and reported at https://c2smart.engineering.nyu.edu/covid-19-dashboard	None
CV Fleet Size and Activity	• CVPD system logs and CV installation records to track the number of installed and fully operational CV vehicles • NYC’s fleet vehicle management system (Geotab) to track general levels of fleet vehicle activity; can report hours of operations and miles traveled for fleet vehicles that are also equipped with the Geotab system	None

5.3 Relation of Confounding Factor Data to CV Data

Real-time data feeds such as weather, link condition data, and the Openreach events will be monitored and processed throughout the CVPD deployment period. To create as comprehensive as possible recording of the CV-related data and the influence of the confounding factors while still preserving spatial and temporal PII concerns, these real-time or near real-time data feeds will be fused to the CV data prior to the spatial and temporal obfuscation of the CV data items. This allows the status of these confounding factors to be considered while examining the obfuscated data feeds from the CV devices.

However, data that is not available in real-time, such as Vision Zero project-related changes, taxi activity patterns and speeds, crash records, etc., would be historical in nature and need to be processed and summarized outside of the CV data environment. These measures of confounding factors can be used to assess the state of the network operational profile for a given day, week, or month. The data can provide insight into network conditions throughout the evaluation periods and potentially identify network-level trends that may have influenced conditions on the study corridors, such as Vision Zero measures. However, since the data is not available in a real-time manner, or may introduce PII concerns if linked to the CV data records, these data sets will not be fused to the CV data sets.

Further details of the data fusion process are presented in Section 7.3 of this report.

6 System Deployment Impact Evaluation Design

First and foremost, the CVPD performance evaluation plan needs to be capable of measuring or otherwise estimating the degree to which the CV equipment and devices can encourage safer operations on the city's roadways and reduce crashes. This requires the measurement and comparison of the performance of the system both with the connected vehicle technology and without.

6.1 Needs for Performance Evaluation

The following needs for performance evaluation were determined to be needed as part of the design of the experimental design and evaluation of the NYC CVPD.

6.1.1 Need to Assess Impacts of CV Deployment on Reducing Number of Accidents or Accident Severity

The primary goal of the NYC CVPD is to further the city's Vision Zero initiative by reducing the number of accidents on the city's roadways, and specifically to reduce the number of fatalities and injuries occurring in those crashes. The performance measurement and evaluation plan must be able to monitor and report the number and nature of the accidents occurring with and without the CV deployment. In addition to the number of accidents occurring, the relative severity of the accidents must be measurable.

While the numbers of accidents are significant, they are still relatively rare and unpredictable events on a day-to-day basis. Determining the impacts of the CV deployment on the number of accidents observed during the pilot deployment is anticipated to be difficult to prove with sufficient statistical significance. The degree to which confounding factors change the probability of an accident occurring will vary not only day to day during the evaluation period, but minute to minute on the dynamic NYC streets.

Given this concern, additional evaluation methods need to be included in the performance measurement plan that allow for the analysis of the change in the likelihood of accidents created from the CVPD. The plan must also provide methods to isolate the impacts of the confounding factors that cannot be fully accounted from in a pure observation of accident occurrences. Finally, the plan must provide a mechanism that observable changes in both system performance and driver behavior between with and without the CV deployment drive the analysis, as opposed to more theoretical assessments of CV technology.

6.1.2 Need to Assess Impacts of CV Deployment on Mobility

A secondary goal of the NYC CVPD is to utilize CV technology to improve the overall mobility of the traveling public and to better monitor operating conditions on the city roadways. Most of the changes in the mobility of the system are secondary benefits to mobility created by fewer or less severe accidents across the roadway network.

6.1.3 Need to Assess Impacts of CV Deployment on Travel Reliability

Similar to mobility improvements, the improvement of the reliability of the roadway network is secondary goal as compared to the safety improvements from the NYC CVPD. Unlike mobility however, travel time reliability will be more directly impacted by prevention in the number of accidents on the city's roadways. The evaluation plan must be able to assess the changes in the overall travel time reliability from the CVPD and to address the impacts of confounding factors which would also have impacts on the system reliability.

6.1.4 Need to Assess Impacts of CV Deployment on Environment Pollutants

While none of the CV applications being deployed in the CVPD are directly aimed at improving the environmental impacts of the transportation system in NYC, it is understood that the impacts of the deployment may see environmental benefits or impacts on tailpipe emissions. While direct measurement of tailpipe emissions is not planned, the measurement of system performance metrics of vehicle motion (delays, speeds, travel times, idle time, etc.) can be used to compute estimates of the environmental impacts of the CVPD.

6.1.5 Need to Assess Level of False Alarms or Missed Alarms

The CV technology that will be deployed as part of the NYC CVPD is generally proven based on existing research, proof of concept, and small-scale pilot studies that have been previously completed. While all of the applications being deployed are based on previous studies, the maturity of some of the CV applications that will be deployed in this pilot are less than others, and the overall efficacy of the CV applications may be less than ideal. The question of efficacy of the CV applications is compounded by the operating environment of the study corridors, where GPS accuracy in urban canyons of buildings and can be problematic. The performance evaluation plan must consider the efficacy of the applications while considering the overall impacts of the deployment on the performance metrics.

6.1.6 Assess Impacts of ASD warnings on Behavior and Actions

The underlying aim of the installation of the ASD devices is modify driver behaviors to drive in a safer manner and to alert drivers of potential conditions that can lead to an accident. At this most basic level, this changing of driver behaviors and reactions to unforeseen or dangerous conditions is the first level impact that the CV deployment can be measured at. Some of these can be measured in aggregate or from outside the vehicles using non-CV technologies, such as the compliance to speed limits. However, the majority of the behavior changes must be measured from within the vehicle to assess the responses of the driver to the ASD warnings and what actions they take upon hearing the warning. The performance evaluation plan must be capable of assessing these microscopic changes in driver behaviors that are created by the addition of the in-vehicle ASD warnings.

6.2 Experimental Design Options

While there are different types of experimental designs that could be used to assess the performance of the NYC CVPD, the key to any experimental design requires the assessment of vehicles with addition of the installed CV technology and those without the CV technology. Regardless of the experimental design, the impacts of the previously identified confounding factors must be considered and included in the evaluation process. This is particularly the case given the timing of Phase 3 as the city continues to recover from the COVID-19 impacts and hopefully will continue to return closer to pre-pandemic levels of activity and operations.

Given the detailed nature of the CV technology being deployed for the NYC CVPD, no sufficient method for collecting comparable data sets for the with and without CV vehicles exists without involving the data collection methods that the installation of an ASD permits. Therefore, two different functioning states of the ASDs in a fully tested and deployed CV system must be considered as part of the experimental design: a silent mode, and an active mode. These modes are defined as follows:

- Silent Mode (or Without CV): System fully deployed and operational but ***without*** user notification of ASD perceived warnings. In silent mode, the ASDs will record normal driver behaviors and reactions during conditions that the ASDs would have issued a warning if active.
- Active Mode (or With CV): System fully deployed and operational but ***with*** user notification of ASD perceived warnings. In active mode, the ASDs will record the normal driver behaviors before the issue of the ASD warning and the modified or revised behavior and actions following that warning.

These two modes were considered for inclusion of the CVPD study vehicles in two primary ways: a pure Before and After design, and a post-test Control and Treatment design. The following sections describes both methods and the advantages and disadvantages of each within the NYC environment.

6.2.1 Before and After Collection Methods

For a pure before (without) and after (with) CV data collection design, all ASDs would first be put into silent mode for the pre-test or before period, during which the ASDs would collect and document the driver reactions surrounding event that would have triggered an app warning if the ASDs were not silenced. Following this, the post-test or after period would see a systemwide conversion of all ASDs equipment to an active mode, where warnings generated by the ASDs are now actually issued to the drivers, and the new driver behavior and reactions to the warnings can be seen in the ASD data. There are advantages and disadvantages of this method:

- Advantages
    - A clear distinction between with and without periods to allow better correlation of non-CV related data measures (e.g., Crash records) to CV deployment.
    - The city's legal advisors have expressed liability concerns that once the CV system is activated, it should not be turned off for selective evaluation periods. A pure before and after collection of CV data avoids that concern.
    - A larger sample size and market penetration of active ASD units can be seen on NYC roadways in the after period versus a control and treatment plan. With all vehicles set to an active mode, the likelihood of the apps warning and preventing accidents is increased given the rare and unpredictable nature of crashes.

    - Under the presumption that the CV pilot deployment will prevent crashes or reduce crash severity, the full deployment of active ASDs in the after period may save lives.
- Disadvantages
    - Shorter duration of collection of each collection period given limited time frames for the study.
    - Increase in difficulty in assessing the impacts of confounding effects since operational conditions will not be identical for before and after periods. This is especially true for unusual non-recurring conditions such as inclement weather which may not occur similarly in both before and after periods.

6.2.2 Control and Treatment Collection Methods

Even under the proposed control and treatment methods, a before period would be provided with all CV-equipped vehicles set to silent (without) mode to allow for a pre-test collection of detailed data that is not possible without the installed CV equipment. For the deployment of a post-test control (without) and treatment (with) CV data collection, ASDs would be assigned (ideally randomly) into either the control or treatment group at the beginning of the evaluation period, and they would remain in that group for the entire evaluation period. Advantages and disadvantages of this method include:

- Advantages
    - Longer duration of collection of each collection period.
    - Decrease in difficulty in assessing impacts of confounding effects since vehicles with and without CV deployment will be recorded in the same operational conditions.
- Disadvantages
    - No clear distinction between with and without periods to allow correlation of non-CV related data measures (e.g., Crash records) to CV deployment.
    - Smaller sample size and market penetration of active ASD units on NYC roadways, meaning fewer vehicles would receive alerts that may prevent accidents or reduce accident severity.
    - Possible security concerns related to tracing vehicle identity to determine if the vehicle is in the control group of the treatment group when ASD event data is recorded. This may complicate ensuring proper maintenance and operation of the ASD devices as well if the driver cannot provide feedback to fleet managers regarding if the device is properly working or not.
    - Possible IRB and evaluation concerns related to drivers moving from an active vehicle to a silent vehicle depending on the day, since drivers do not consistently drive the same vehicle every day in the majority of the stakeholder groups. IRB and evaluation concerns related any survey feedback or assessment of driver satisfaction with the CV deployment if the driver does not know if the vehicle is in the active or control group.
    - Costs associated with re-tooling the CVPD deployed ASDs in the control group to the treatment group upon completion of Phase 3 when the CV system is expected to continue post-pilot.
    - Potential lost ability to prevent an accident due to the ASD device being part of the control group

6.3 Recommended Experimental Design

After reviewing the advantages and disadvantages for the collection of driver actions under both with and without CV deployment, the initial recommendation of a before and after design was made under the ideal that *safety trumps everything*.

The before and after experimental design is planned to maximize the likelihood of preventing or reducing the severity of accidents after the ASDs are switch into active mode since it has all ASDs warning drivers of potential hazards. The possibility of a severe or fatal accident occurring involving a CV equipped vehicle that was placed into a control group that could have possibly been prevented by the ASD being active and issuing a warning to the driver is the primary reasoning for this initial selection of a before / after experimental design rather than a control / treatment experimental design.

However, while the initial recommendation for a pure before and after experimental design was made, there is also the recognition of the need to isolate the impacts of confounding factors which may change throughout the study outside of the control of the NYC CVPD team. Considering this, an inclusion of control and treatment design was also recommended for inclusion in the experimental design.

6.3.1 Experiment Design Details - Vehicles

The nature of the fleets being deployed as part of the NYC CVPD limit the degree to which a random assignment of vehicles in the control and treatment groups can be made. Since the CVPD team has no control or influence over which particular drivers operate any particular fleet vehicle on any given day, the inclusion of control and treatment groups complicates the experimental design. Having drivers moving between control and treatment vehicles on any given day would be in itself an additional confounding factor which could influence the study evaluation. Thus, the design of the control group is aimed to minimize the probabilities of the driver migration between control and treatment vehicles during the evaluation period.

Certain city vehicles are assigned to particular staff members or more likely to be repetitively used by the same driver. By targeting these vehicles to assign to the control group, the probabilities of drivers moving between control and treatment vehicles can be reduced, although not outright prohibited. By using reports from the fleet management system installed on many of city owned vehicles, along with the agency's knowledge of typical vehicle usage and drivers, a subset of the equipped vehicles can be assigned to the control group that exhibit comparable usage patterns of the treatment vehicles but help reduce the chances of drivers migrating between the control and treatment group vehicles.

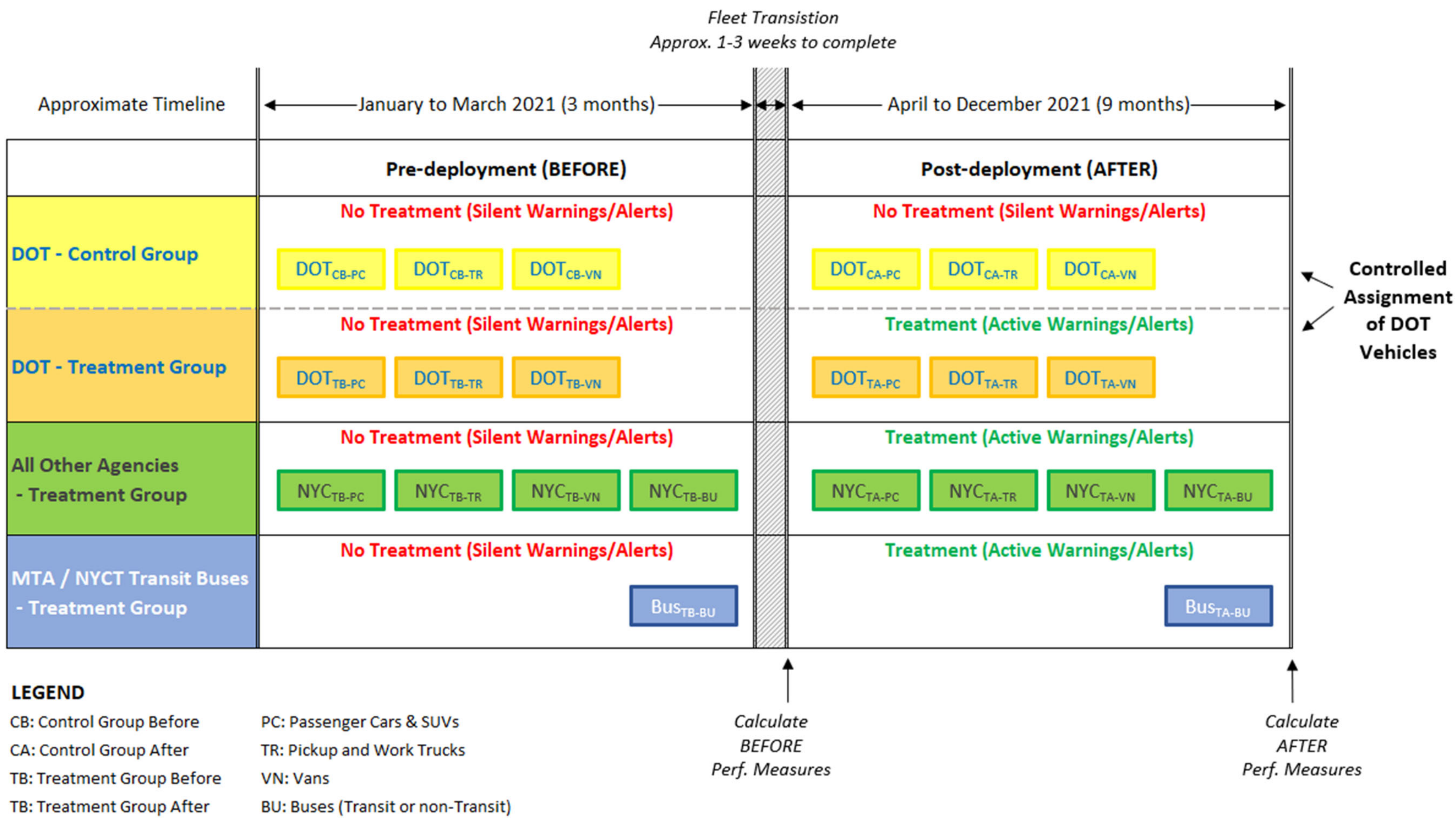
To allow for a large enough control group to yield more statistically valid comparisons between the treatment and control groups while still maximizing the size of the treatment group to maximize the potential safety benefits of the pilot, a control group size of 150 vehicles or a 5% share of the equipped vehicles is targeted. Given the large proportion of the DOT vehicles that are equipped, together with the added knowledge about the typical vehicle usage that the CVPD deployment team has for the DOT's vehicles, it is proposed that only DOT vehicles are assigned to the control group. Different vehicle types will also be assigned to the control group, ideally in the same proportions by vehicle type as the treatment group; approximately two-thirds passenger cars and SUVs, and one-third pickups, vans, and other work trucks).

Figure 2 illustrates the overall experimental design and setting of the ASD mode of operation (silent for without CV, active for with CV) for the CVPD vehicle fleets during the before (pre-test) and after (post-test) periods of Phase 3. The figure illustrates that the same set of vehicles will be equipped with ASDs, with DOT vehicles assigned to either the control or treatment group, while all other vehicles from other agencies are only assigned to treatment groups.

During the pre-deployment (before) period, warnings that would normally be generated by the ASDs will be suppressed and not audibly issued to all drivers in all groups (silent warnings/alerts). During the post-deployment (after) period, only the treatment group ASDs will be set to active mode, and all ASD generated warnings will be issued to the drivers to alert them and for them to respond to. The DOT control group vehicles will remain in the silent mode throughout both the pre- and post-deployment periods, and these vehicles will never receive audibly issued ASD warnings during the entire evaluation period.

The estimated timeline for duration of the 12-month Phase 3 evaluation period is also shown at the top of Figure 2. The approximate three month before period is set to start at the beginning of January 2021, followed by a short transition around the end of March to the after period which will conclude at the end of December 2021. During the transition, over-the-air (OTA) updates will be distributed to the fleet vehicles to switch from silent to active. It is important to note that the transition from silent to active for each individual vehicle will be completed as soon as the ASD receives and successfully applies the OTA update. The timing of that update is dependent each on equipped vehicle being in contact with an RSU broadcasting the update long enough for a successful transfer of the update package to the ASD via DSRC. Based on experiences with OTA updates of the ASD equipment during the Phase 2 testing, it is estimated that it will take approximately one to three weeks for the majority of the treatment vehicles fleet to receive the OTA update and switch to active alert mode.

Not shown in the figure but important to mention is the Phase 2 testing period, which preceded the pre-deployment period. During this time, installations of the CV equipment were ongoing and the system and CV application testing and tuning were undertaken. Data was collected from this period to support the build-out and testing of the equipment and to test the data collection, cleaning, and obfuscation method. However, since the testing and changing of parameters is an additional confounding factor in the evaluation data sets of assessing driver actions, data from the testing period will not be used as part of the evaluation process and is not considered ‘before’ data.



Source: NYCDOT, 2017

Figure 2. Proposed Experimental Design by Fleet Vehicle Type

Additionally, through the Phase 3 evaluation period, there may be the need to issue updates to the operation of the ASD firmware and application settings. While much of this was completed during Phase 2, it can be expected that additional updates to the ASDs may occur during the Phase 3 period. While these updates will be minimized to the extent possible to not add to the confounding factors to consider during the evaluation, some updates will be inevitable. Details of these updates will be documented, and details of the firmware version and settings active on the ASD at the time of any warning are recorded within each event record.

6.3.2 Experiment Design Details - Pedestrians

A much different process will be undertaken to conduct the experiments of the PID devices designed to assist visually impaired pedestrians safely navigate crosswalks at signalized intersections. Instead of the “deploy and monitor” process being undertaken with the ASDs in vehicles, the deployment and evaluation of the PIDs will be completed under more defined test conditions, albeit in the real-world operating environment of NYC city streets. Based on NYCDOT guidance from testing of the prototype PID devices in Phase 2, the following research focused experimental setup is proposed.

The study will recruit 25 participants with visual disabilities to participate in the field tests of the PID device. PIDs will not be distributed to the participants for continued use over the duration of Phase 3, but instead will be given to participants only to be used while being accompanied by an IRB-certified NYC CVPD team member to ensure their safety.

Predefined routes (three (3) to five (5) different routes expected) will be designed to test the PID and the learn the participants’ experiences through the CV-equipped intersections. The proposed test sites are near Queens Boulevard and 34th Street in Queens, 20th Street and 6th Avenue in Manhattan, and Flatbush and Myrtle Avenues in Brooklyn. Detailed routes of multi-intersection sequential routes are planned but have not yet been finalized as they are still subject to change based on discussion with the eventual PID participant needs.

The PID will be introduced to a targeted group of 25 volunteer participants with visual disabilities, with each participant using the PID device to help navigate the defined route four different times. During every field test, each participant will be accompanied by at least one IRB-certified CVPD team member, and each participant will be led along the pre-determined routes by the team members. Each run will take approximately 10 minutes, depending on the length of each route to be determined. The objective of the tests is to obtain about 100 runs (4 times x 25 participants) per route. The details of the routes and the number of runs largely depends on the upcoming recruitment of visually disabled participants.

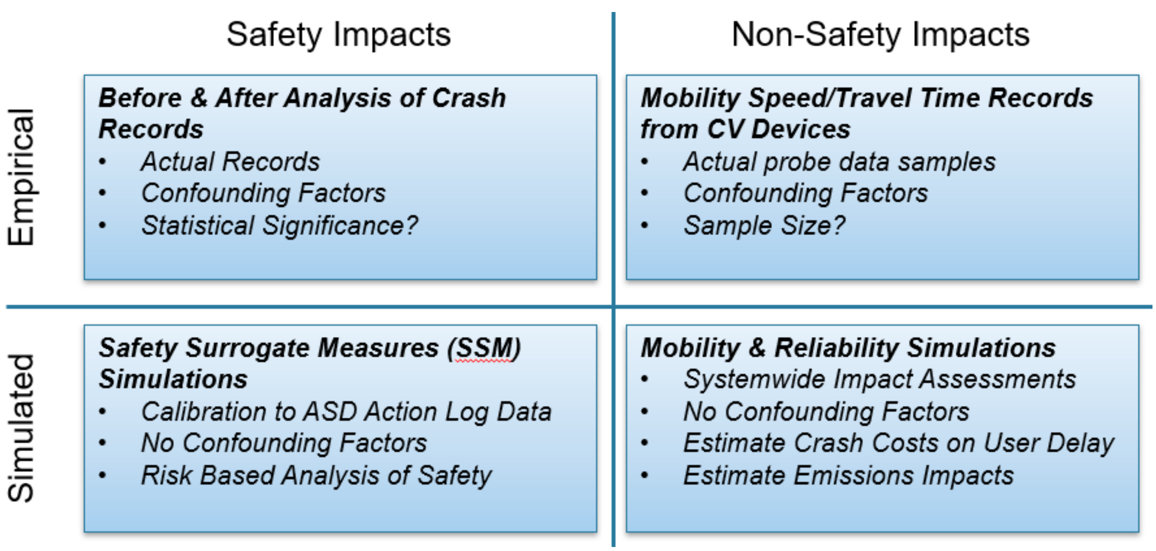
While performance metrics will be collected on the device as the tests are being completed (details in Section 7.1.4), the evaluation will be predominantly based on observations of the participants in the field test as well as through qualitative feedback surveys with the participants (detailed in Section 7.5)

It is noted that the timeline to complete the PID field tests have not yet been determined, primarily due to ongoing restrictions put in place by the IRB panel overseeing the PID deployment. While the timeline for the lifting or easing of these restrictions that would allow for the planned field testing is unknown at the time of the production of the report. Even following the removal of these restrictions, participation levels for research activity involving close contact between researchers and participants is unknown. Despite these unknowns, the working assumption is that the field tests of the PID unites with volunteer participants will be able to proceed in the Summer or Fall of 2021.

6.4 Simulation Modeling to Support Performance Evaluation

It is understood by the NYC CVPD Project team that the level of data that can be observed or field measured planned before and after CV deployment periods may be insufficient to estimate detailed conclusions about the efficacy and benefits of each CV app independently. The influences of confounding factors will be difficult to isolate from the impacts of the CV app deployment under such before and after measurement periods, and while a significant number of vehicles in the study areas will be equipped with ASDs, it will still be only a subset of the entire vehicle population and the full effect of the CV apps may be difficult to assess (especially for V2V apps). Finally, it is also expected that the observed numbers of accidents during each of the before and after periods may not be enough to prove the impacts of the CV apps in reducing the number of accidents, at least to a reasonable level of statistical significance.

Given these issues, part of the performance evaluation plan will include analysis using simulation modeling techniques instead of direct field observation. Two levels of simulation modeling are to be included; simulations related to safety and crash likelihood, and system performance assessments. Figure 3 illustrates the planned framework for the use of both simulation and empirical field data to evaluate the different types of impacts of the CV deployment, while the following sections describe that framework in more detail.



Source: NYCDOT, 2017

Figure 3. NYC CVPD Evaluation Framework

6.4.1 Crash Prediction Modeling Using Surrogate Safety Measures

Through an examination of the recorded detailed trajectory data recorded during events under both the without (silent) and with (active) ASD action logs of the CV deployment, impacts of the CV apps on changing driver performance and behaviors can be assessed and quantified for each of CV app warnings. Using those observed changes in driver reaction times or otherwise modified driver behaviors, changes to the microscopic driver behavior parameters (car following parameters, driver awareness, driver reaction time, speed limit adherence, etc.) will be estimated, calibrated, and incorporated into simulation modeling exercises for a series of scenarios for both with and without CV apps. Using existing research on surrogate safety measures and simulation modeling, the simulation results will be used to predict impacts on crash rates of the CV deployment. These simulations can also isolate the benefits from individual CV apps and eliminate the impacts of confounding factors, both items that cannot be reasonable be achieved in the direct field observations planned. These tests can also be scaled up to predict the safety impacts if all vehicles (or a higher proportion) of vehicles were equipped with similar ASDs. The existing Flatbush Avenue model (a SUMO based microsimulation model covering Flatbush Avenue in the CV pilot test area) will be used to reduce the stochastic noise in large scale models and to better isolate just the impacts the before and after effects on driver behaviors and actions from the CV deployment. The Flatbush Avenue model is calibrated in terms of both operational and safety measures to match real-world traffic conditions.

Further details on the application of SSM simulation for the performance measurement and evaluation of the NYC CVPD are presented in Section 8 of this report.

6.4.2 System Performance Simulation Modeling

In order to quantify benefits associated with changing driver behaviors on non-safety related issues (e.g., mobility), systemwide simulation modeling will be conducted. The existing Manhattan Traffic Model (MTM) (an Aimsun based microscopic model covering Midtown Manhattan) will be utilized to simulate operational conditions in the study area network both with and without CV app deployments (or more precisely with and without changes in driver behaviors and signal operation changes observed before and after the CV app deployments). By simulating network performance under a variety of recurring and non-recurring congestion scenarios, the mobility, reliability, and environmental impacts of the NYC CVPD impacts on system performance and reduction in crashes can be estimated. Monetization of all of these user and system benefits can allow for a robust assessment of the impacts and cost effectiveness of the NYC CVPD deployment.

Further details on the application of traffic simulation modeling to assess impacts on system performance resulting from the NYC CVPD are presented in Section 8 of this report.

6.5 False Alarms and Missed Alarms Assessment

The technology of connected vehicles has been tested previously in research and smaller scale demonstration projects. However, the NYC CVPD is expanding on both the scope of the CV applications being implemented and the operational conditions they are being deployed in. This includes not only the penetration rate of CV technologies that is anticipated to be achieved on the study roadways, but the dense urban building environments of Manhattan and the level of congestion that can occur on the study roadways.

The various applications running concurrently and deciding of priority for alert within the ASDs and locational accuracy required to run the applications effectively in Manhattan’s urban canyons are both concerns for the NYC deployment. Throughout Phase 2, significant efforts were undertaken by the NYC CVPD team to improve on the native GPS-based location systems of the ASDs. A combination of triangulation of location from nearby RSUs and a kinematic based dead-reckoning system using measurements of the vehicles motion have been implemented to improve on the locational accuracy of the equipped vehicles.

While improved locational accuracy should help reduce false and missed alarms, there ideally would be additional in-vehicle confirmation of the accuracy of the issued alarms. However, primarily due to privacy concerns, no in-vehicle cameras or other data acquisition devices will be installed along with the ASD units. As such, there will be no inherent way to truly evaluate if the CV applications are functioning as there were truly designed to during the deployment on a case by case basis. However, to ensure that the warnings from the ASD are indeed announced in the vehicle when they are supposed to, a microphone is being added as part of the ASD installation. The microphone will not store sound recordings, but instead listen for the audible signature of the warning sound expected to confirm that the warning was audibly issued. This procedure allows for the adherence to the in-vehicle data collection and privacy concerns, but also provides a fail-safe method to ensure that the ASD warnings are being announced in the vehicle as the ASD intends and provides a method to identify component failure or user tampering with the speakers on the ASD unit.

To help reduce the likelihood of false and missed alarms, during the later stages of Phase 2 of the NYC CVPD following the deployment of the CV technology, extensive testing and refinement of the CV applications was undertaken by the NYC CVPD deployment team. Tests completed during Phase 2 have shown significant improvement on the locational accuracy for the equipped vehicles through RSU triangulation.

Tests were conducted throughout Phase 2 to prove the efficacy of the applications themselves. As part of this process, the application's control parameters were tested and adjusted to ensure that the applications are working as designed within the NYC environment. This included testing to be comfortable that the ASDs are not missing valid warnings that should have been triggered, were not sounding false alarms when no risks existed, and were not triggering warnings for very minor events that risk the increase of driver distraction or annoyance concerns. Much of this was documented in the NYC CVPD's initial operational readiness testing conducted in August of 2019, but additional testing and refinement of applications and parameters continued throughout Phase 2 by NYC CVPD team members and the ASD device vendor. As changes to ASD firmware and parameters need to change during Phase 3, such testing by the NYC CVPD team will continue during Phase 3.

During Phase 3, vehicle operator feedback will be solicited regarding the operations and efficacy of the CV applications. This will be accomplished both informally through providing feedback from the vehicle operators to the fleet managers and then back to NYCDOT, but through more formalized anonymous driver surveys conducted through a web-based survey tool. More details on the plans for the survey tools are presented in Section 7.5.

7 Data Collection Plan

This chapter describes the data collection sources and data cleaning methods that will be employed to collect the required data to evaluate the performance of the NYC CVPD. Included in the discussion are details of the data that will be collected from the CV devices – the aftermarket safety devices (ASDs) and road-side units (RSUs) – along with non-CV related data sources. Data collection related to the pedestrian information devices (PID) for the visually impaired are included as well. Finally, the overall data processing and data fusion methods are described.

7.1 CV-Based Data

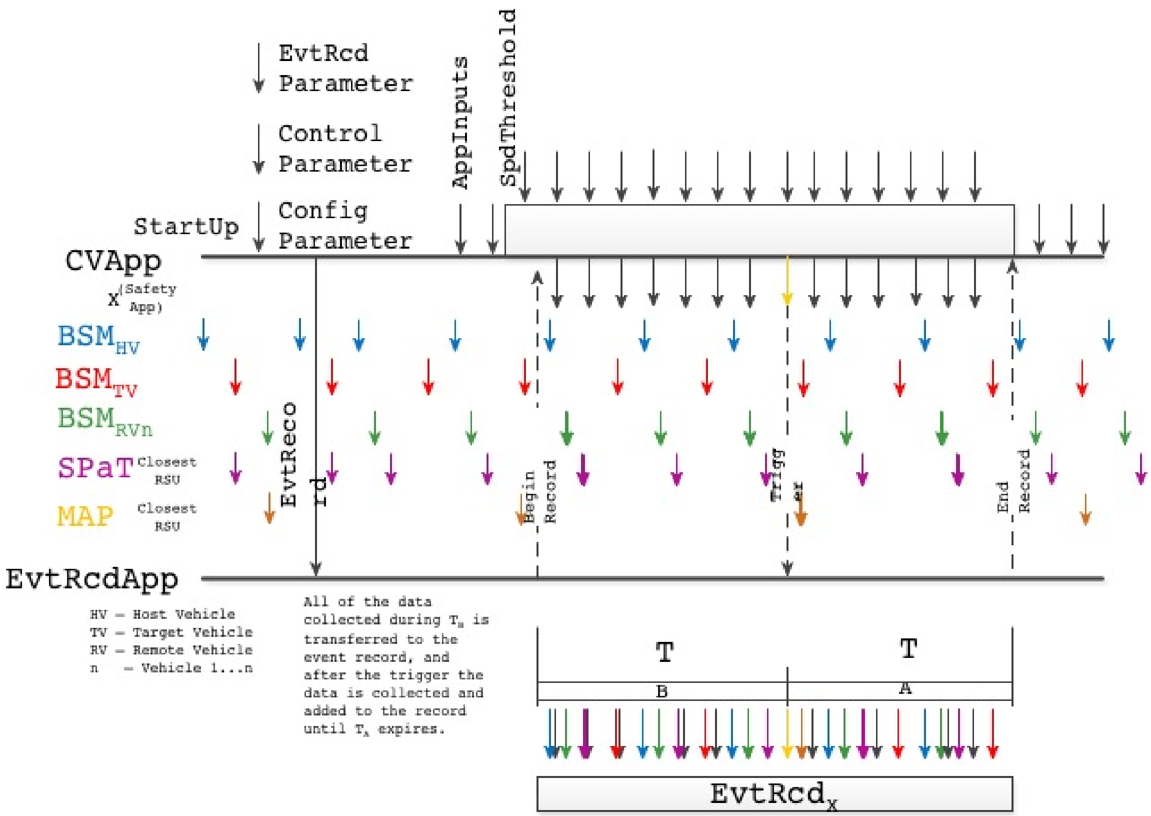
Several data items will be collected from the ASDs, RSUs, and PIDs that are being deployed to vehicles, infrastructure, and visually impaired pedestrians as part of the performance measurement and evaluation of the NYC CVPD. The following describes and details the data items that will be collected from each.

7.1.1 ASD Action Log Data

The ASDs are connected to the vehicle CAN bus (or other bus) so additional vehicle dynamics can be monitored such as directional signals, hard braking, steering wheel angle, trajectory, and speed may be collected. Details on data items from the CAN bus available are dependent on the make and model of the vehicle the ASD is installed in. The ASDs will use UTC[2] time, and will include accelerometers (X, Y, Z) that can be used to detect vehicle actions and movements. Further details of the ASD functionality and technical details are available in other NYC CVPD Phase 2 documents.

The ASD actions logs will record details of vehicle movements and the surrounding equipped vehicles (BSMs) and environment conditions (MAP, SPaT, and TIM) surrounding a CV app warning event and is an 'Action Log' of data is collected in association with a specific 'event'. An event is defined as a condition in which the ASD determines that a warning should be issued to the driver by one of the CV applications. The event data is recorded regardless of whether the warning was audibly issued to the operator by the ASD or not (e.g., when the ASD is operating in silent mode). To construct the Action Log, the ASDs records on its internal memory the information (see details below) from all CV sources available during a time window surrounding the event, including both before and after the moment of the event. Figure 4 illustrates the concept of the CV Action or Event Log data contents.

[2] Coordinated Universal Time



Source: NYCDOT, 2017

Figure 4. ASD Event Data Collection (Raindrops)

Thus, the detailed action log data will not be continuously collected, but instead will only be collected whenever an "event" occurs. The details of the data stored is limited to the data that the ASD can log give the detailed ASD installation and only what messages the vehicle hears from surrounding ASDs and RSUs, but will include:

- Details regarding the CV app which generated the warning issued, including firmware version and application parameters,
- BSM transmitted message content of the subject or host vehicle,
- BSM content received from other CV-equipped vehicles within a configurable range of the host vehicle, and
- SPaT, MAP, & TIM messages received from RSUs within a configurable range of the subject vehicle, dependent on the type of warning:
  - RLVW and PEDINXWALK will collect heard SPaT and MAP messages
  - EVACINO and OVCCLEARANCELIMIT will collect TIM messages
- Messages are all based on SAE International's J2735-201603 Dedicated Short Range Communications (DSRC) message set dictionary

The definition of the time window varies depending on the CV app that is issuing the warning, and can vary from as little as 10 seconds to as much as 360 seconds or 6 minutes. The time resolution to which the data is records can vary as well; more safety oriented applications will record at the full 10Hz resolution, while other applications which do not need as frequent data recordings could be recorded at 1Hz or even lower frequencies. The current planned recording rates by application are shown in Table 7.

Table 7. Action Log Recording Times and Frequency by CV Application

Application	Pre Warning Record Time (sec)	Post Warning Record Time (sec)	Recording Resolution (Hz)
FCW	7	10	10
EEBL	7	10	10
IMA	10	10	10
BSW	10	10	10
LCW	10	10	10
VTRW	15	10	10
SPDCOMP	20	10	1
CSPDCOMP	20	10	1
SPDCOMPWZ	20	10	1
OVCCLEARANCELIMIT	180	180	1
RLVW	7	10	10
PEDINXWALK	15	15	1
EVACINFO	180	180	1

After the event recording time window has closed, these recorded data items are compiled into a single event record file which is stored locally on the ASD and is queued for transmission back to the NYC TMC servers via an RSU.

From these recorded ASD action log datasets, a detailed vehicle trajectory and driver action log can be seen, including the latitude, longitude, elevation, 3-axis acceleration, time, speed, and heading. Since the action log data will surround the warning event, the vehicle movements and driver responses both before and after the event will be captured.

However, it is important that action logs are held only temporarily on the ASD device until they can be uploaded via the RSUs to the CVPD servers. After uploading to the CVPD servers (details follow), all locally stored action logs on the ASDs are be deleted. Additionally, the data recordings will be purged from the ASD memory after a given timeframe (currently set to 10 days) if the data record is unable to be uploaded successfully to an RSU for transmittal to the TMC.

ASD data will be stored locally on the ASD during normal operations and will periodically upload to the NYC TMC data servers via DSRC communications to RSUs set to receive the ASD data. These receiving RSUs have been strategically located throughout the study area in locations where participating vehicles will frequently visit. RSUs are being deployed at locations where many vehicles will be seen and often traveling at slow speeds (e.g., bridge and tunnel portals, fleet garages, etc.) to provide the opportunity for ASD data uploads to the RSUs. During Phase 2, a thorough review of these data collection RSU locations were undertaken to maximize the transmission of ASD data back to the TMC.

More details regarding the location of the RSU devices providing data collection services and the communication and security protocols are available in other NYC CVPD Phase 2 documents. The details of the CV data collection specifications, which includes the specifics of the ASD event records as recorded on the ASDs (see message type *MSG_NycCvpdEvent*), are included in Appendix C for further reference. Further details on the processing of the raw ASD collected to remove details including time and location data to produce the event records that will be archived and used for the performance measurement is discussed in later portions of this section of the report.

7.1.2 RSU Travel Time Data

The USDOT has expressed a need to collect ongoing vehicle situation data and infrastructure situational data that can be used by other applications through the CV data distribution system and stored into the USDOT data warehouse for analysis of network performance. For this type of data, it could be possible to log and upload a subset of the BSM data on each ASD that is sufficiently cleansed to remove potential PII details or data that could be merged with other PII datasets. Since there are a significant number of vehicles within the NYC CVPD project area, collection of this type of data without unique vehicle identifiers can then be used to monitor network performance because the logged BSMs act as breadcrumbs for the vehicle's history noting location and speed (and such speed could be averaged over several samples). However, considering the scale of the deployment, and the design for all CV data transmissions to be collected from the ASDs over DSRC, there is concern that this solution to provide travel time data would overwhelm the wireless data backhaul from the ASDs. As such, this ASD based breadcrumb data collection method to determine travel time data was rejected from consideration for widespread data collection over the life of the deployment.

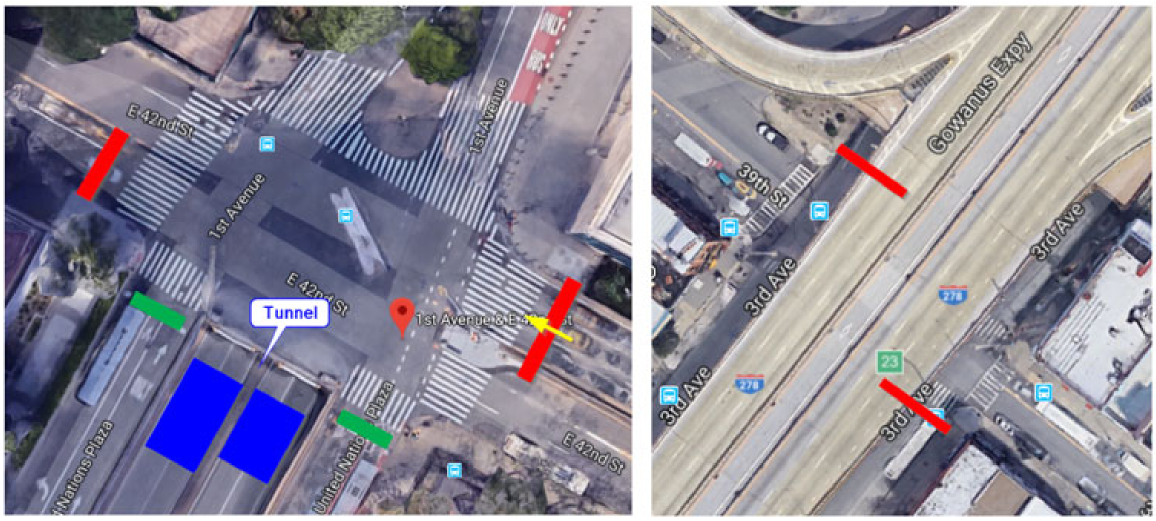
Instead of collecting travel time data via the ASDs, an alternative methodology has been developed to collect travel time data from the deployed RSUs for support the ISIGCVDATA . Each deployed RSU will record the core data from a single BSM for each equipped vehicle that passes the RSU and transmit that sighting back to the TMC. Since the BSM records the temporary ID of the vehicle, matching these RSU-ASD sighting at RSU locations can provide the RSU to RSU travel time. Details of the data to be recorded are shown for the message type *MSG_NycCvpdTravelTime* in Appendix C for further reference.

Geozones are developed for each RSU to define the geographic area or areas to decide which of the heard ASD's BSMs should be recorded. This geozone could be simply defined as the box bounded by the pedestrian crosswalks so that the first BSM recorded as the vehicle passed into the intersection would be the BSM selected. More elaborate configurations can be used instead to help select BSMs from vehicles where complex geometries or grade separated intersections exist. Two such examples of complex geozones are provide in Figure 5.

After the RSU collected BSM data is transmitted to the TMC, a matching algorithm is used to develop pairs of the BSMs from pre-defined pairs of neighboring RSUs using the temporary ID contained within the BSM. After being paired the travel time can be computed as the difference between the timestamps of the two BSMs. Schematic examples of such travel time measurements are shown in Figure 6.

A filtering algorithm is then deployed to remove travel time outliers (e.g., the equipped vehicle stopped along the block for some time producing an abnormally long travel time), and a confidence score is applied to the time interval for each RSU to RSU travel time segment. This methodology provides a confidence score that is reduced both as the number of samples becomes smaller and standard deviation of the travel time samples in that interval becomes larger.

A database of the resulting travel times has been developed and will be maintained throughout the deployment Phase 3 of the NYC CVPD. As no vehicle IDs will be retained, and only the travel time measure recorded, there is no concern of releasing the full date and time of the travel time samples. This database forms the foundation of the I-SIGCVDATA application for the NYC CVPD. While the database will be available to help assess the variations of mobility across the NYC CVPD roadways, it will also provide the basis for the comparison of similar already existing travel time measurement systems (RFID readers of electronic toll tags) to determine if a CV based travel time measurement approach can provide similar data inputs in near real time to feed the MIM adaptive signal system.



Example #1 (left): 1st Avenue & 42nd Street (Manhattan)

- Red lines approximate stop bar locations. As the yellow arrow indicates, a BSM of the vehicle crossing the stop bar would be recorded as the vehicle passes through the intersection.
- Blue squares collect NB vehicles entering the 1st Avenue Tunnel underneath the intersection versus the green lines which collect NB surface street traffic.

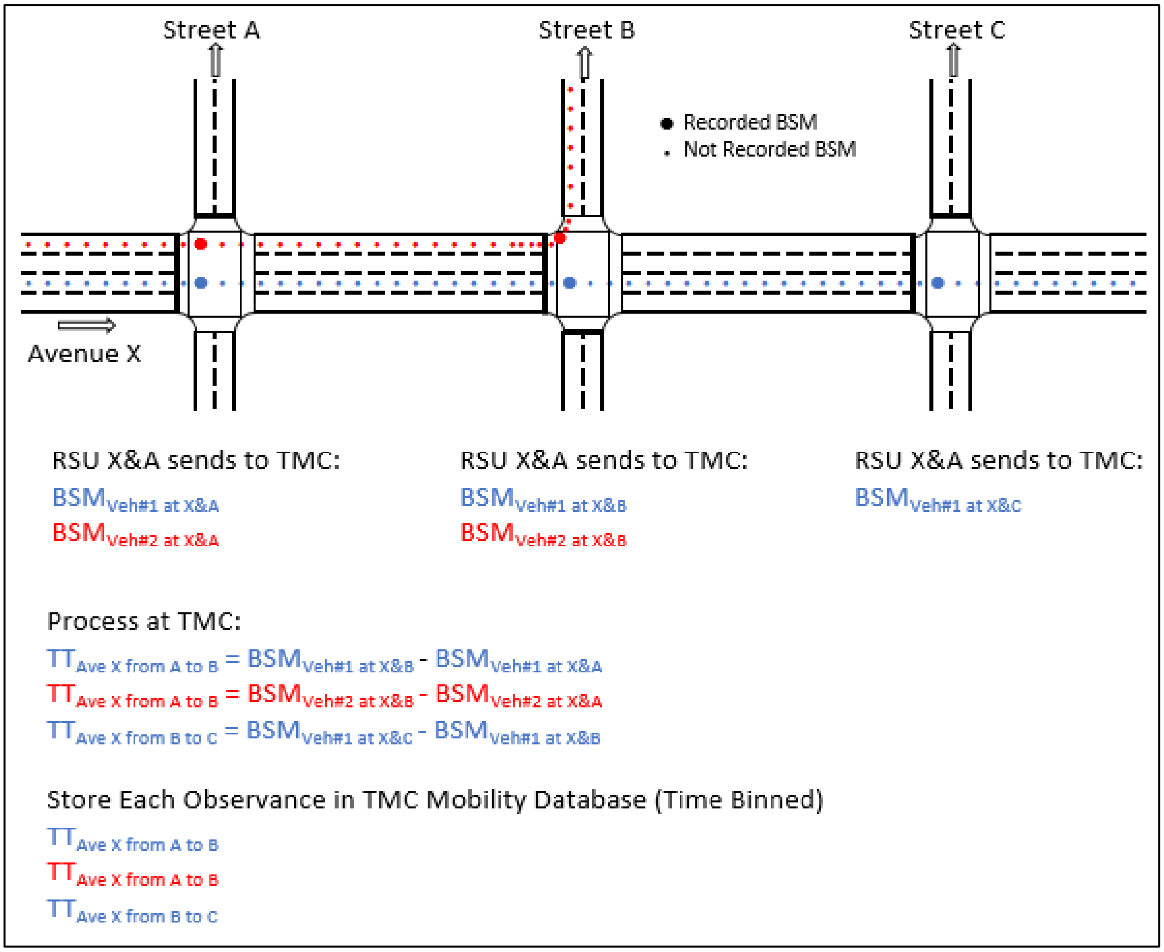
Example #2 (right): 3rd Avenue & 39th Street (Brooklyn)

- Geozones can be elevation specific as well. Red lines indicate stop bar locations for 3rd Avenue which operates under the elevated Gowanus Expressway.

Source: NYCDOT, 2017

Figure 5. Potential Geozones for RSU Travel Time Collection

While the ASD mobility measurement approach would have the advantage of providing travel times estimates away from locations where RSUs are deployed, the RSU based travel time measurements provides the advantage only needing to hear the passing ASDs, and not needing to have software or data shared by the ASDs. This is not a fundamental issue for the initial NYC CVPD where NYC DOT has access to both the RSUs and the ASDs for data collection. However, the RSU based approach allows any vehicle passing through the intersection while broadcasting BSMs via DSRC enabled vehicle to be used as potential probe vehicle, and not just those ASDs deployed by NYC DOT. As the number of non-CVPD related equipped vehicles are deployed, additional CV probe vehicles will be used for travel times measurements. This method also allows for a measurement system that is more in line with traditional DOTs operations, where the agency has control over the infrastructure elements, but not the vast majority of the vehicles using the roadways.



Source: NYCDOT, 2017

Figure 6. RSU Travel Time Collection Examples

7.1.3 System Operations Data

In addition to the ASD Action Log or Event Records, the ASD has been developed to record additional data to be used to support the maintenance and operation of the NYC CVPD.

7.1.3.1 Radio Frequency Logs

To help assess the communication range and the radio frequency (RF) patterns of the CV devices, selected messages will be recorded for each ASD and RSU in operation. As ASDs encounter other ASDs or RSUs, a sighting record of the first and last heard CV message (BSM, MAP, TIM, SPaT) from each device (or temporary ID for ASD) will be recorded to file. These records can then be analyzed to determine the range of effective DSRC communications surrounding the CV devices and help to troubleshoot DSRC communication issues during the CV Pilot.

Any PII contained in the host vehicle BSM (e.g., serial number) will be removed prior to data sharing beyond the TMC, but the time and location details of the BSM records will remain unaltered. Details of the data record contents can be found in *MSG_NycCvpdRSURF* and *MSG_NycCvpdASDRF* messages in Appendix C: CV Data Collection Specifications.

7.1.3.2 ASD Sighting Logs

Similar to the RF logs, the ASDs are configured to record a single BSM from nearby remote vehicles as they are heard by the host ASD. Of the various individual remote vehicle BSMs heard by the host ASD, the remove BSM which was closest in distance to the host ASD will be recorded, along with the corresponding host ASD's BSM from the same instant. These pairing of BSMs will allow to estimate the overall number of and proximity of the ASD interactions as the pilot progresses through the deployment phase, irrespective of the number of warning events generated.

Any PII contained in the host vehicle BSM (e.g., serial number) will be removed prior to data sharing beyond the TMC, but the time and location details of the BSM records will remain unaltered.

7.1.3.3 ASD Mobility Logs

Protocols have been developed to allow for the collection of BSMs transmitted from the ASD, to serve as breadcrumb data as the equipped vehicle operates around the roadway network. Not all BSMs will be recorded, but instead only recorded periodically. At the fastest, it would be every second and potentially at a slower rate when vehicles are operating at slower speeds. These

While the ASDs will have the ability to capture the ASD Mobility log, this data collection method will be very selectively used and only for testing and system maintenance purposes. Large scale use of this data collection could overwhelm the wireless data backhaul systems (DSRC and NYCWiN) and also could create additional privacy concerns for the pilot participants. As such, this data will remain internal to the TMC and not shared or stored long term. No performance measures or evaluation for the pilot will leverage any of the ASD mobility data that may be collected for system operations and testing.

Details of the data record contents can be found in the *MSG_NycCvpdASDMobility* message in Appendix C: CV Data Collection Specifications.

7.1.4 PID Operations Log Data

To support the evaluation of the PID units, a data log will be collected from the PID units (cell phones running the PID application) when being used by visually impaired pedestrians to cross equipped signalized intersection crosswalks. These log files will record time series based metrics of the location and movement of the pedestrian, SPaT and MAP messages from the relevant intersection, and system information about the device and its operation, including the messages delivered by and any user interactions with the PID application. All raw PID log data will be securely transmitted from the PID cell phone units to the secure IRB approved servers in NYU and can only be accessed by IRB approved researchers. All PII will be removed before data is shared outside of the IRB.

It is important to note that no before deployment or silent operations PID data will be collected, as no participants will be asked to navigate with the PID unit operating in a silent mode. PIDs will only collect log data while the application is actively being used.

From this raw log data, performance metrics regarding the use of the PID application will aggregated and be produced. This aggregated data and performance metrics can be then shared with non-IRB approved persons with the rest of the CV Pilot team, with USDOT and its independent evaluation (IE) team, and with the larger research community. The following aggregated performance measures listed in Table 8 below are planned to be produced; also shown are raw data source messages that will be used by the NYU IRB approved team to compute the aggregated metrics. It is noted that this is the current plan for the PID operations metrics and is subject to the results of ongoing testing of the operation of the PID applications, the level of involvement from the accompanying IRB approved researchers (still to be clarified due to ongoing COVID-19 concerns and precautions), and the log data collection process.

Table 8. Aggregated Performance Measures for the PID / PED-SIG Application

Measure	Description	Data Log Source Messages
Pedestrian Crossing Speed and Crossing Travel Time	These performance measures report the average crossing speed and travel time of all users.	*Required Messages* • Position.PED_IN_CROSSWALK_START • Position.PED_IN_CROSSWALK_END • Location.mLatitude • Location.mLongitude *Substitute Messages (in case of GPS errors)* • Movement.STEPS
Pedestrian Crossing Waiting Time	This performance measure reports the average crossing waiting time of all users. The crossing waiting time will be calculated using the time interval between these messages.	*Required Messages* • Position.PED_ENTERING_CROSSWALK • Position.PED_IN_CROSSWALK_START
PID Compliance Rate	This performance measure reports the ratio of all crossing volumes when the user complies with the instructions provided by the PID. The compliance rate will be calculated by using the number of crossings for which the user received feedback from the device and acted accordingly to cross the street to the user’s total number of crossing movements.	*Required Messages* • DEVICE_FEEDBACK.HAPTIC • DEVICE_FEEDBACK.VISUAL • DEVICE_FEEDBACK.AUDITORY
Inadequate Crossing Time	This performance measure indicates the portion of all crossing volumes that the pedestrian does not have enough green time to complete the crossing. The crossing decision will be defined based on if the interval between “Position.PED_IN_SAFE_ZONE” and “Position.PED_IN_CROSSWALK_START” is larger than the signal time cycle duration. Supplemental data includes the SPaT data and geometry of intersection.	*Required Messages* • Position.PED_ENTERING_CROSSWALK • Position.PED_IN_CROSSWALK_START • Position.PED_IN_CROSSWALK • Position.PED_IN_CROSSWALK_END • Position.PED_EXITING_CROSSWALK • Position.PED_IN_SAFE_ZONE • SPaT • MAP

Measure	Description	Data Log Source Messages
Pedestrian Crossing Violations	This performance measure indicates how many times users try to cross when the traffic light is red. The crossing violation time will be indicated by the alert is generated continuously during "Position.PED_IN_CROSS_WALK".	*Required Messages* • ALERT.EVENT
Time to Step into the Crosswalk When Walk Phase is On	This performance measure reports the average time for the user to step into the crosswalk when the pedestrian walk phase is on.	*Required Messages* • Position.PED_ENTERING_CROSSWALK • Position.PED_IN_CROSS_WALK_START • Position.PED_IN_CROSS_WALK • SPaT • MAP
Times Out of Crosswalk	This performance measure reports the total number of times the user steps out of the crosswalk when crossing the intersection.	*Required Messages* • Location.mLatitude • Location.mLongitude • ALERT.EVENT

7.2 Non-CV Based Data

In addition to the CV-based data collection, several data items already collected by NYC DOT or one of their partner agencies can be leveraged for use in the evaluation of the NYC CVPD. The following describes the details of those data items.

7.2.1 Accident Data

Traditional accident record geodatabases already collected are available and included in the CVPD performance evaluation process. The databases are created from existing NYPD accident reports (form MV104) which are required to be completed for any collision where someone is injured or killed, or when there is at least $1000 of damage. The NYPD database includes all crashes to which they respond and complete a report, regardless of roadway or facility type or the type of vehicles involved.

While the individual crash reports include PII data for those involved, the databases that are publicly released do not report direct PII but do include details (such as time and location) than can be tied to other records to infer PII data. Due to the privacy/liability concerns of this potential inferring of PII, police accident records will not be tied to ASD/RSU data. This was such a primary concern that it was one of the primary factors in the design of the ASD event records data obfuscation and data release process (detailed in the following sections of this chapter). Additionally, the crash reports do not identify if the vehicle is equipped with CV technology or not.

The recent implementation of the electronic crash record reporting system by the NYPD has greatly improved the timeliness that selected crash report data is available. While still lagging by a few days, summary level information of each crash is accessible via both NYPD's TrafficStat program and website and through NYC's Open Data website. It is noted that the data included in this initial public release is limited to summary level data only and is subject to be refined or corrected in subsequent reporting. While the NYPD crash database is updated daily, the crash types derived from the database are not very detailed and have missing values. The use of the NYPD crash database is subject to the sample size and data quality and may not be available for certain types of CV applications (such as IMA or EEBL).

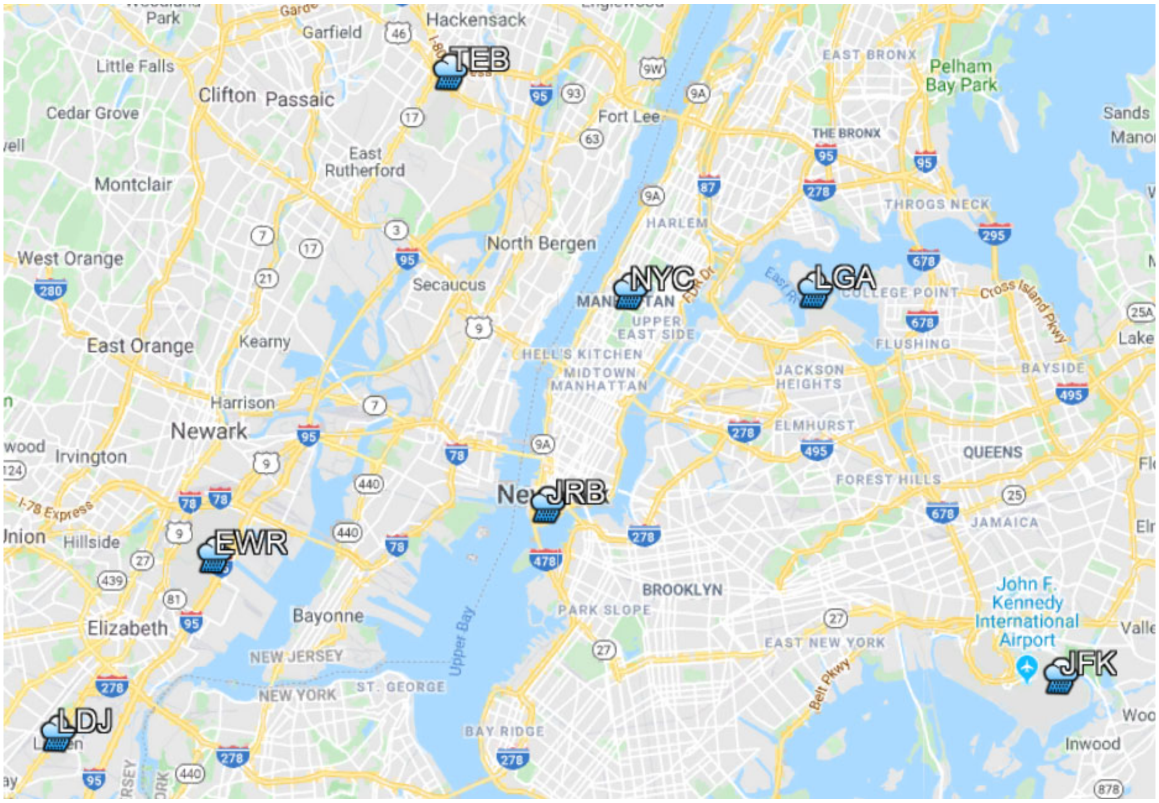
The NYS DMV regularly reconciles their records with the NYPD database, retaining crashes with either injuries or fatalities or more than $1000 amount of damage. This reconciliation process results in a more detailed crash database containing more data fields which can be useful in the evaluation of certain types of CV applications (such as work zone related crashes). Unfortunately, that reconciliation process has historically taken several months to complete and as such it is not expected to be available to the research team in time for use in the performance evaluation of the NYC CVPD. Historic records for the before deployment conditions are available and can be leveraged to assess historical conditions.

Several previous years of crash records are available. Accidents will be stratified by intersection, but will also likely be analyzed by corridor as well to increase sample sizes further. The same analysis will be completed for the active CV deployment evaluation period. Further details are presented in Section 8.3.

7.2.2 Weather Data

Data feeds of weather data need to be included in the performance evaluation plan. Weather data will come from two predominant data sources; weather station data from seven National Weather Service (NWS) and snowplow data from the PlowNYC system.

Real-time weather data is provided by the NWS in the form of Meteorological Aerodrome Reports (METAR) data from permanent weather stations in the region, usually located at airports. Within the NYC region, seven different weather stations exist and will be tracked over Phase 3. METAR data is published on an ongoing basis at rates varying from every five minutes to every hour, depending on the station. The seven stations within the NYC region that will be tracked are shown in Figure 7.



Background Image Source: Google Maps

Figure 7. National Weather Service Stations in the NYC Region

Data elements included in the METAR reports include:

- Wind
- Visibility
- Weather Conditions (e.g., Fair, Overcast, Partly Cloudy, etc.)
- Sky Condition
- Air Temperature
- Dew Point Temperature
- Relative Humidity
- Wind Chill and Heat Index Temperatures (if applicable)
- Air Pressure
- Precipitation (in prior 1-hour, 3-hour, and 6-hour increments)

Given the proximity to each station, the Central Park (KNYC) station would be best to represent the weather conditions for V2I events along the identified study corridors. However, some potential V2V interactions will occur closer to the airport locations or locations further away from the study corridors. Therefore, the nearest NWS station's weather data for the specific time and date will be merged and stored with the ASD action log data sets prior to the time and location obfuscation process. Thus, the weather details will be available for analysis with the event trajectory data even though the precise time and date have been scrubbed from the archived event data.

In addition to the obfuscation of time and location of the ASD data, some unusual weather data may allow for the identification of a particular date and time. This is likely to only include the extreme weather events, such as very high hourly precipitation amounts or extreme temperatures. Instead of listing precise precipitation amounts or temperatures, the weather data will also be slightly obfuscated to prevent matching of data to a particular time and date.

Additional weather related information will be collected via the NYC Department of Sanitation's (DSNY) PlowNYC snowplow tracking system. The system is based on automated vehicle location (AVL) systems deployed in DSNY vehicles which treat and clear snow from NYC's roadways during snow and ice events. PlowNYC has a public facing website (https://plownyc.cityofnewyork.us/plownyc/) which uses a map of all NYC maintained streets to convey the current snow clearing status, including the following details:

- The roadway link's snow removal designation (Primary, Secondary, Tertiary, Non-DSNY)
- Time since last serviced (0-1 hours, 1-3 hours, 3-6 hours, 6-12 hours or 12-24 hours)

The GPS based data which is used by this website is also available via NYC's Open Data website. The data is updated in an ongoing basis when DSNY snow removal equipment is in use, but archived data is also available.

While the PlowNYC system does not include actual road surface condition data, the system at least provides the last time that a particular roadway was visited by a DSNY vehicle during a snow event, giving some insights into the potential road surface conditions.

7.2.3 Traffic Count Data

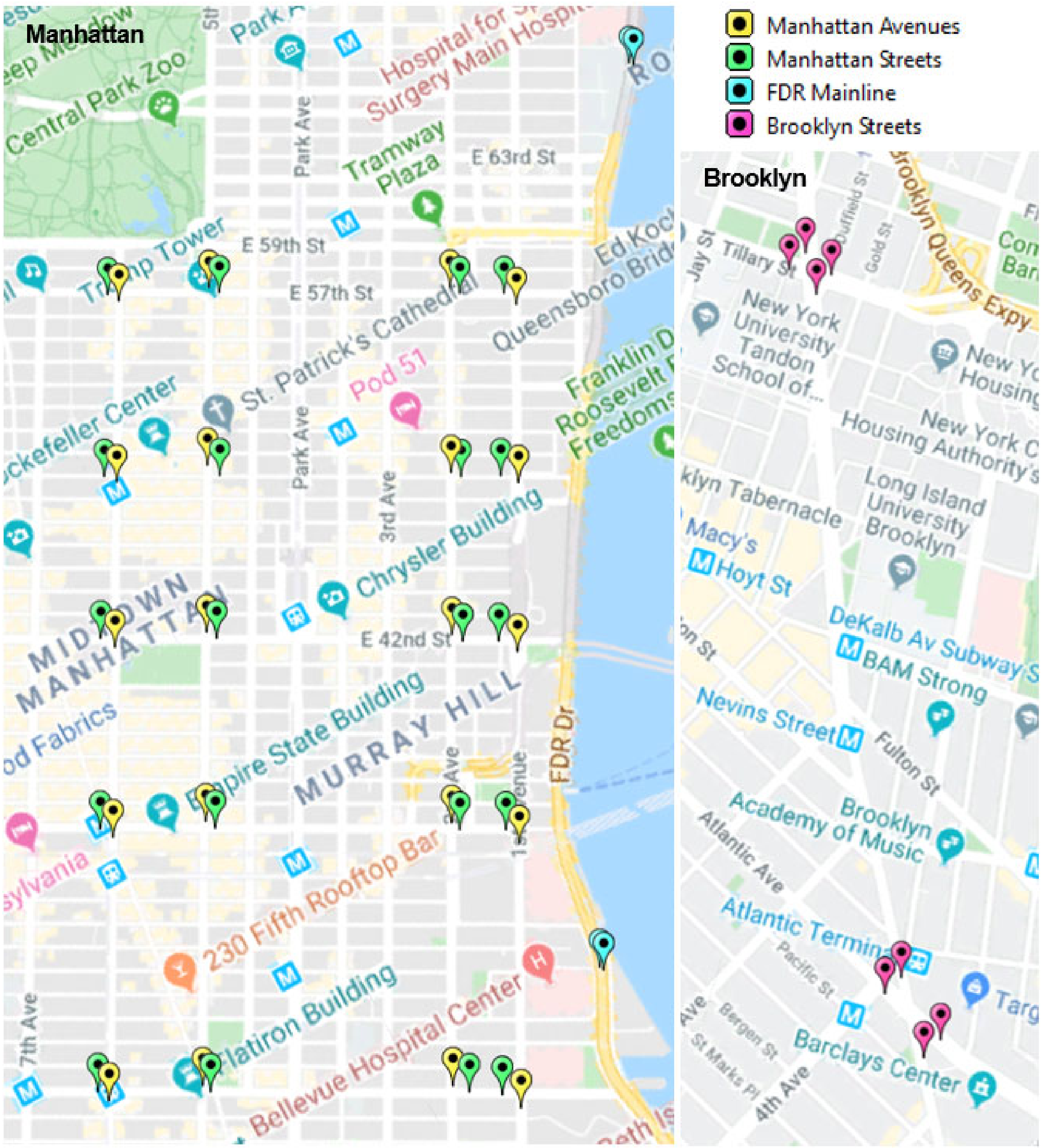
While much of the confounding factor datasets are already being collected by NYC DOT or one of its regional partners, there is a distinct lack of permanent and continuous traffic count stations in the region, and especially on the arterial systems.

To fill this hole, NYC DOT had developed an additional traffic count collection program periodically throughout the corridor to get a better estimate of the traffic count variations throughout the deployment period. The counts were to be collected are two-week continuous traffic counts at 44 different mid-block locations along the RSU equipped corridors on quarterly basis throughout Phase 3. The traffic counts are to be collected at 15-minute intervals across the two (2) week time periods via Automated Traffic Recorder (ATR) pneumatic tubes. Figure 8 illustrates the count locations.

The first set of counts were collected in October 2019. The second round of counts was scheduled for collection in the second half of March 2020, but the COVID-19 pandemic impacts required the cancelation of that collection along with all other quarterly collections in 2020.

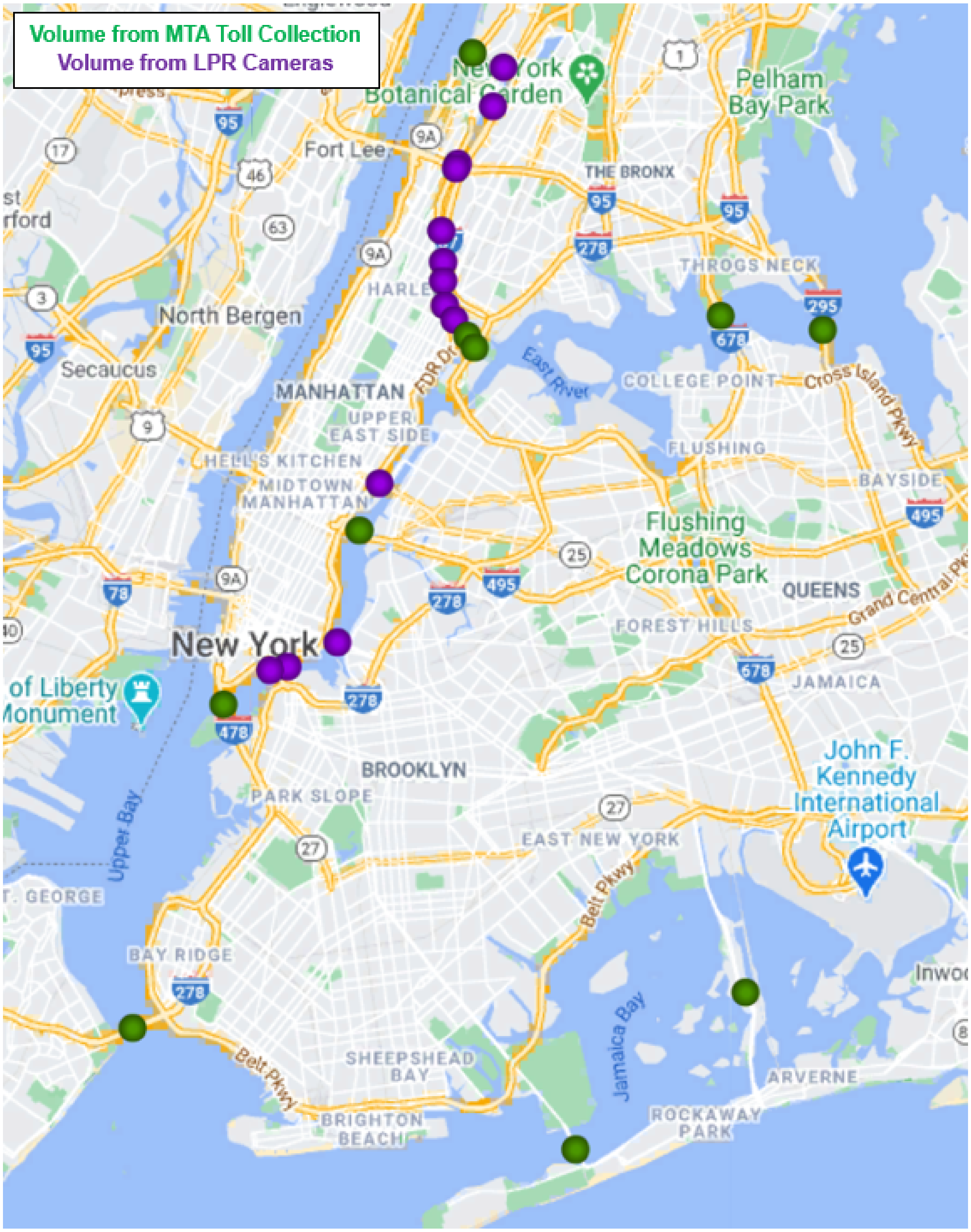
In order to better track the impacts of the COVID-19 pandemic and recovery on the region's roadways, a river crossing (bridge and tunnel) volume monitoring program was developed in March 2020. While some of this data was previously available for the tolled crossing, the recent all-electronic tolling of the MTA crossings has made this data more readily available. For the non-tolled (free) bridges between Manhattan and the other boroughs, volume data being collected via license plate recognition (LPR) cameras is now also available to NYC DOT. The combined crossing volume data from locations shown in Figure 9 below can be used to project the overall regional flows in NYC and can help assess the relative changes from hour to hour, day to day, and month to month during the Phase 3 deployment.

With the addition of the ongoing crossing volume data, the collection of the previously planned quarterly volume collection may not be needed as originally planned. NYC DOT is currently considering the need for the originally planned quarterly count collection and is considering scaling back the collection or canceling it and instead relying on the rolling crossing data and the other travel time and speed data available for the equipped roadways.



Background Image Source: Google Maps

Figure 8. Originally Planned Locations for Supplemental Quarterly Traffic Counts



Background Image Source: Google Maps

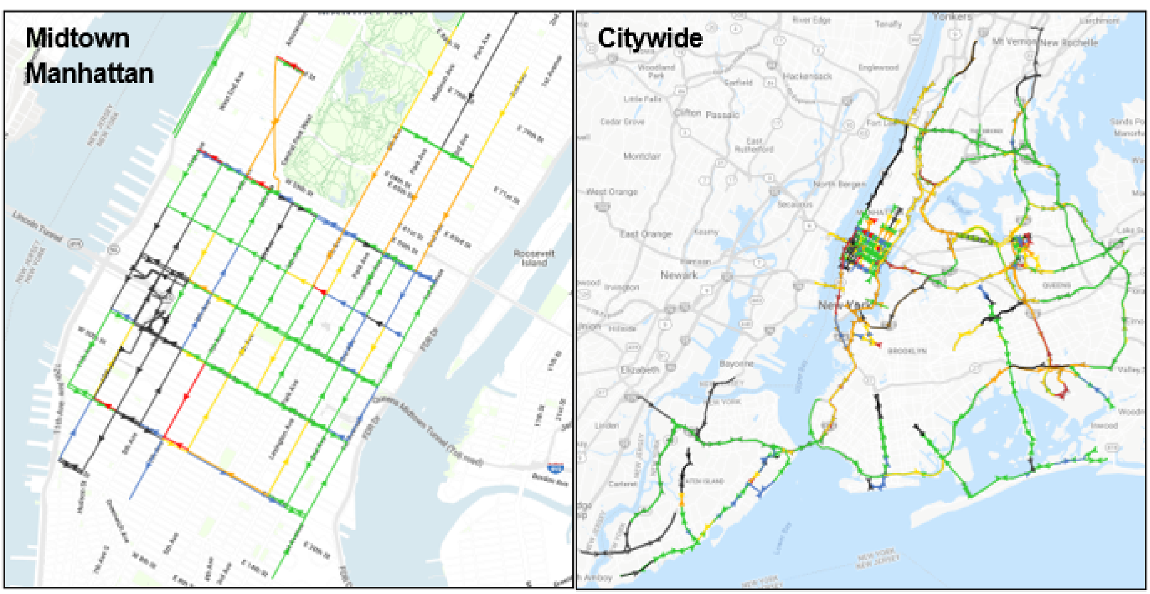
Figure 9. Crossing Volume Data Collection Locations

7.2.4 TRANSCOM Event and Link Condition Data

TRANSCOM is a coalition of regional transportation agencies in the tri-state region. One of their roles is to provide a common distribution system for transportation information from numerous TMCs across the region, including NYC DOT. Two of their data distribution feeds include the Openreach event records, and the Traffic Link Conditions data. Both the Openreach event records and the Traffic Link Conditions data feeds will be continuously logged through Phase 3. Both data feeds are provided via the internet download using with appropriately provide credentials provided by TRANSCOM.

The TRANSCOM event records are a regionwide aggregation of notices and advisory statements from TMCs across the region. The data feeds are updated and published every minute of the day, and can include information on events related to incidents or crashes, various work zone activities, or special events throughout the region that may create atypical demands (e.g., a sporting event) or affect traffic operations (e.g., lane or road closures for parade). The information is released with geographic latitude and longitude information to locate the event. It is noted that the event records do not include every event that occurs; only those that were considered significant enough to report by one of the region's TMCs are included.

The TRANSCOM Link Condition data feed Is also published on a one-minute interval basis and describes the average speed and travel time for predefined link segments. Data collection to support the travel time monitoring generally uses electronic toll tag readers to measure the experienced travel times on links (between tag readers) of vehicles with E-ZPass transponders in their vehicles. If not enough samples are collected during a specific time interval, there is no data is published for that particular link. A snapshot of the links in NYC normally included in the Link Conditions dataset are shown in Figure 10 (color coding based on average speeds). Other regional agencies have also deployed tag readers on fixed highway segments and facilities for travel time monitoring.



Source: NYCDOT, 2017

Figure 10. Transmit Links in NYC

7.2.5 Taxi and For-Hire Vehicle Data

Through the TLC, NYC DOT has access to large data sets which report the trip making characteristics of NYC's yellow taxis and green cabs, as well as high-volume for-hire vehicle operators (e.g., Uber, Lyft, Via, etc.). The Taxi Passenger Enhancements Project (TPEP) vendors supply to TLC the yellow cab revenue trip records citywide, approximately 10-13 million per month. Data fields include the medallion number, operator number, vendor, pick-up and drop-off location (coordinates only), date/time, trip distance and time, payment type, fare, tolls and tip. Similarly, the Livery Passenger Enhancements Project (LPEP) provides green "Boro" cab revenue trip records, approximately 1 million per month, and includes the same fields as TPEP trip records. More recently, the city also started receiving similar trip record data sets from high-volume for-hire vehicle operators that are licensed to operate in NYC. Versions of these data tables scrubbed to remove PII data are available via NYC's Open Data website, however, NYC DOT has internal access to the more robust data sets.

TPEP and LPEP breadcrumbs are at typically 2-minute intervals (sometimes 1-minute), and include medallion, operator number, vendor, instantaneous latitude / longitude, instantaneous date/time, and an "event" check ID, which records beginnings and ends of shifts, trips and intermittent health checks (every 1-2 minutes in the absence of any other event ID). LPEP (green cab) breadcrumbs have the same frequency and fields as TPEP. Similar data sets have also started to be collected from the high-volume for-hire vehicle operators, but the capture intervals tend to be longer in duration. These breadcrumb data sets are not publicly available in any form and cannot be shared.

The TLC trip data sets are a very good data set to track the overall activity levels and the changing for-hire marketplace within NYC. However, versions of these data sets that are not already publicly release cannot be shared outside of NYC DOT. However, NYC DOT and TLC have developed internal processes to summarize this data into travel time and average speed metrics for the TLC zone system. NYCDOT and TLC internally process the breadcrumb trip data including yellow taxi (TPEP), green taxi (LPEP) and for hire vehicle (FHV) trip records and aggregate them into TLC zone level (a 263 zone system of NYC somewhat describing neighborhoods in the city) by hour and by date. The internally processed trip record is normally lagged by no more than one month.

Similarly, processes have been developed to estimate average speed data from the breadcrumb data sets that are received monthly from TLC. While the coordinate pings in the breadcrumb data is not sufficiently accurate or frequent enough to map to individual corridors, processes have been developed to summarize the operating speed of the vehicles to the same TLC Zones.

While the data is not available frequently enough to be used to match to the CVPD event records, they can be used to help track the overall roadway network operating speeds over time and distance for Phase 3 of the CVPD.

7.2.6 NYC Street Improvement Project Information

The NYC DOT produce Street Improvement Project (SIP) summaries that contains records of ongoing and upcoming safety-oriented planned engineering improvements that use multiple treatments (signals, markings, concrete, etc.) on both corridors and at intersections across the city. Improvements are generally aimed at better organizing traffic, improving travel times, creating shorter, safer pedestrian crossings, and safer routes for bicycle travel.

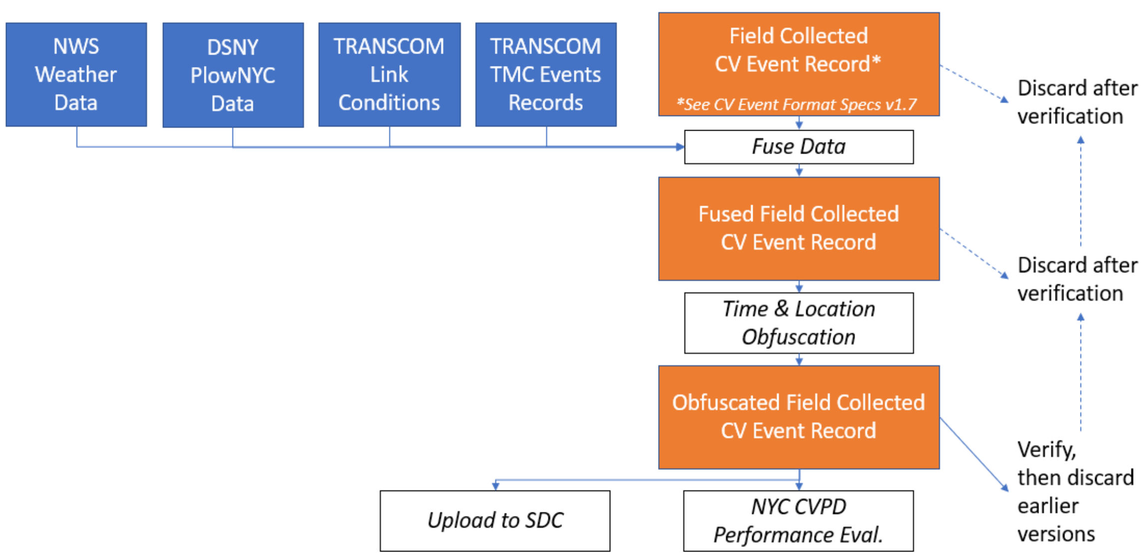
For each SIP project, detailed information including background, location, improvements, benefit, scope, classification and lead unit are available, as well as the program year to be implemented and the forecasted start and end date of implementation. Data is provided for each project in a data sheet in a PDF format, but data is also available in CSV and SHP formatted files for all projects too. It is noted that the dates listed in the SIP are forecasted dates, and actual construction dates may not completely follow those forecasts.

Due to the delays in the release of the SIP records, the project information data sets will not be able to be linked to the ASD event records, but will exist as a standalone data set to be used in helping to assess potential changes seen in the operational performance of roadways across Phase 3.

7.3 Operational Condition Data Fusion with ASD Action Logs

The process of fusing both ASD Action Log and non-CV based data is an important step in the data collection process and is needed to tie some details of the operational conditions of the surrounding roadway and environment to the detailed records of the ASD Action Log. This fused data can help provide some context of the operating conditions in which the CV App warning was issued to the driver. This will allow analysts to better account for the confounding factors on the evaluation of the ASD applications and how the driver responses may change under different conditions.

For data that is available in real-time or near real-time (daily or better), the relevant data elements from the real-time data sources will be related to the ASD Action Log data prior to obfuscation to provide additional insights for the later performance measurement processing on the obfuscated data. The data elements and the overall fusion and obfuscation process is shown in Figure 11.



Source: NYCDOT, 2017

Figure 11. Real Time Data Fusion to ASD Action Logs

Data that is not available in real-time will be compiled and stored for later use in the CVPD evaluation process and shared with the USDOT IE for their subsequent evaluations.

All real-time data will be related to the ASD Action Logs by use of the host vehicle coordinates, vehicle heading, and timestamp at the moment that the CV application issues the warning to the driver (or would issue the warning is the ASD is in silent mode). This point in time and space acts at the single warning location of the ASD Action Log.

7.3.1 NWS Weather Data Fusion

Weather data is related to the CV event data by using the most recent weather data from the closest weather station to the warning location. From the weather data, the key data items of the qualitative weather description, the air temperature, the 1-hour precipitation value, and the wind speed will be retrieved from the closest weather station. Those values will be attached to the event record using the following parameter names, data types, and units, as shown with examples in Table 9.

Table 9. NWS Data Elements Fused to ASD Action Logs

Parameter	Data Type	Units	Examples	Required / Optional
weatherCondition	String	n/a	Overcast, Clear	Required
airTemperature	Integer	°F	58	Required
precipitation1Hr	Float	Inches	0.05	Required
windSpeed	Integer	Knots	4	Required

7.3.2 PlowNYC Data Fusion

The PlowNYC database is built around a GIS system of unique roadway segments of all public roadways in NYC. Generally, each block between any intersection, ramp, merge, or diverge has a unique physical roadway ID number; there are currently over 110,000 unique segments in the GIS database. The database also includes the timestamp when a DSNY plow was seen to traverse the link. Therefore, each row of the database indicates one sighting of a plow on one segment in the GIS database.

To fuse the PlowNYC data, the ASD Action Log warning location is compared to the GIS elements, and the nearest roadway segment which flows in the same general direction (e.g., North, East, South, or West) as the vehicle heading value at the time of the warning is matched to the warning location. The timestamp of the warning location is then compared to the timestamped records for that physical roadway ID are retrieved and the latest record with a timestamp earlier than the timestamp of the event warning location is selected. The difference between the selected PlowNYC record and the warning time is then computed and rounded to the nearest five minute value and is used to report the time since the roadway was last plowed. If there is no matching timestamp record for that roadway ID which also has a timestamp before the time, it can be inferred that the street had not yet been plowed before the warning time, and a value of -1 will be used instead.

The PlowNYC data is only populated when DSNY vehicles are in use for snow removal or treating roadways. This data parameter is shown in Table 10. As such, the majority of days of the year there are no data records at all. Only ASD Action Logs which is seen within 24 hours of any PlowNYC data records will undergo this data fusion. When there are no plow records at all (anywhere in the city) in the 24 hours preceding the warning time, the fusion to PlowNYC data will be skipped and no data item will be added to the ASD Action Log.

Table 10. PlowNYC Elements Fused to ASD Action Logs

Parameter	Data Type	Units	Examples	Required / Optional
lastPlowed	Integer	Minutes	15, 65 -1 = Not plowed	Optional

7.3.3 TRANSCOM Link Condition Data Fusion

The process to fuse TRANSCOM link condition speed data with the obfuscated CV Action Log data will follow a similar process to the Fusion of the PlowNYC data. The precise location of the CV warning for the host vehicle within the Action Log data will be matched to the geography of the Link Conditions segments with data for the precise time of the CV warning, and the speed from the nearest Link Condition segment Will be recorded and included with the obfuscated records. Additional checks to assure that the heading of the vehicle is similar to the directional heading of the link segment will also be completed to ensure that the correct geographic segment is selected. Should there not be a TRANSCOM link condition segment found within the immediate vicinity of the warning location, then no link conditions speed data will be included with the obfuscated Action Log record. Similarly, if a link condition segment is found but is not populated with speed data due to sensor problems or insufficient sample sizes, then those big data will be included in the obfuscated Action Log record. The speed value will be included within the obfuscated record as listed in Table 11.

Table 11. Traffic Link Condition Elements Fused to ASD Action Logs

Parameter	Data Type	Units	Examples	Required / Optional
speedCondition	Integer	MPH	15, 5, 9	Optional

7.3.4 TRANSCOM Events Data Fusion

The disaggregate nature of the event data makes it difficult to attach various event records to a specific geographic location. the time horizon of the event records also includes a wide variety updates with can extend well beyond the time at which the event record is published. Detailed procedures are still being developed, but attempts are being made to include significant disruptions to the roadway systems, weather conditions, or other general advisories that are issued for the area that the event occurred in. This process is difficult considering the need to obfuscate the time and location of the event while still providing enough details to add context to the event record. Significant trimming of the TRANSCOM event records will be required to prevent this data from revealing a specific time or location in which the CV application warning was issued. As a result, only the very high level impact events will be included (e.g., a Gridlock Alert Day, Major Traffic Accident in region, etc.)

7.4 ASD Action Log Data Obfuscation Procedures

The ASD Action Log or warning event records data will be scrubbed of potential PII relatable data prior to storage on either the NYC DOT servers or upload to the SDC or the ITS DataHub. This is required to lessen the likelihood of using time and place specifics to marry CV Pilot performance evaluation data to other existing data sources and databases which do contain PII data, such as crash reports. Detailed data that could be construed as PII will then be deleted and not archived anywhere. Liability issues/concerns are significant when any archived data from NYC CV Pilot may be tied through location and time details to other databases/accident records.

There are three main types of data that will be obfuscated: vehicle data, time data, and location data. The following describes the specific data elements that will be removed and obfuscated in all CV data contained in the Action Log records, and in any BSM, SPaT, MAP, or TIM message included in the Action Log or Event Record.

7.4.1 Vehicle and CV Message ID Number

All data in the Action Logs that can be tied to a specific ASD device in a specific vehicle will be removed. This is predominantly limited to removing the ASD serial number that is included for the host vehicle as part of the header of the event record format. All other vehicle specific data elements in the Action Log will be retained, including:

- Temporary or Pseudo IDs periodically generated by the ASD included in the BSM messages
- Vehicle Type Information
- ASD Firmware version (for host vehicle only)
- ASD Parameter settings (for host vehicle only)

It is noted that is will prevent the measurement or longer-term assessment of individual driver learning and behavior changes resulting from the CV deployment. However, as no driver ID is ever be recorded in the event records and there are expected to be numerous drivers per vehicle, conducting this time series analysis of the performance of one ASD would still not provide the desired information. Instead, driver learning will need to be determined for the entire population of drivers, rather than by driver or by vehicle.

In addition to ASD or vehicle IDs, the specific or identifying data elements in the SPaT, MAP, and TIM messages will also be removed. This again predominantly includes only the location ID numbers included in the MAP and SPaT messages. However, in order to be able to link SPaT data to MAP messages, unique location ideas will be replaced with a unique letter code (e.g., A, B, C, etc.) for each ID included in the event record. Potentially more dead elements will be removed from TIM messages, so that locations can be confiscated as much as possible, content of the TIM messages still included to be able to evaluate the trajectory data included in the actual log record.

7.4.2 Time and Date Data

Time and date information will be obfuscated and recorded to have exact date and time scrubbed from all components of the Action Log records and all CV messages contained within it. The precise time elements will be replaced with time values relative to the moment the warning was issued in the host vehicle. Thus, in the obfuscated event records, all CV warnings will be issued at time 0.0 seconds; relative time values less than 0 will represent data points before the warning was issued while positive time values indicate data points after the warning was issued. This will allow future analysis of the event records with the same precision of actions over time that could be done with the raw records. For example, if a series of BSMs is recorded from 2:13:15.2 PM to 2:13:28.2 PM, with the CV warning in the host vehicle recorded at 2:13:20.2 PM, the exact BSM time stamps would be replaced with a series of seconds ranging from -5.0 seconds to +8.0 seconds, with the warning being issued at time 0.0 seconds. All precise time elements in any CV message will be removed and replaced with this new relative time scale in seconds.

It is also recognized that it is important to be able to identify the general time period in which the warning was issued. details such as the day of the week or the time of day can help identify or can at least help infer the surrounding operational conditions. This will also allow a time series analysis of the changes in driver responses to the CV warnings over the life of the deployment to assess if the CV devices impose a level of training to change driver behaviors over time. To retain this more general time and date information, series of bins will be established. given the exact date and time of the issue warning the appropriate time bin will be selected an attached to the obfuscated record. The month will be represented with a two-digit number (e.g., January = 01, June = 06) while the year will be retained. Additionally, the day of the week will be retained and stored as a three-letter abbreviation. The exact date will be removed from the office giving records. The precise time of the event record will also be removed and replaced with two letter code to represent the time of day when the event occurred. Five different peak periods typically seen in New York City will be recorded with the two-letter code as follows:

- Overnight period (12:00 am – 6:00 am): NT
- Morning Peak (6:00 am – 10:00 am): AM
- Midday Period (10:00 am – 3:00 pm): MD
- Afternoon Peak (3:00 pm – 8:00 pm): PM
- Evening Period (8:00 pm – 12:00 am): EV

The year, month, day of week, and time of day codes will then be concatenated and stored as a hyphen separated text string and included in the obfuscated event record. The following Table 12 presents a few examples of exact dates and the resulting text string stored with the record as a **eventTimeBin** element in the Event Record header block.

Table 12. Time Bin Coding Examples

Exact Time of CV Warning	Stored eventTimeBin Value
Thursday November 14, 2019 at 9:14:38 AM	2019-11-THU-AM
Saturday November 16, 2019 at 10:22:18 PM	2019-11-SAT-EV
Monday September 20, 2019 at 1:35:28 PM	2019-09-MON-MD

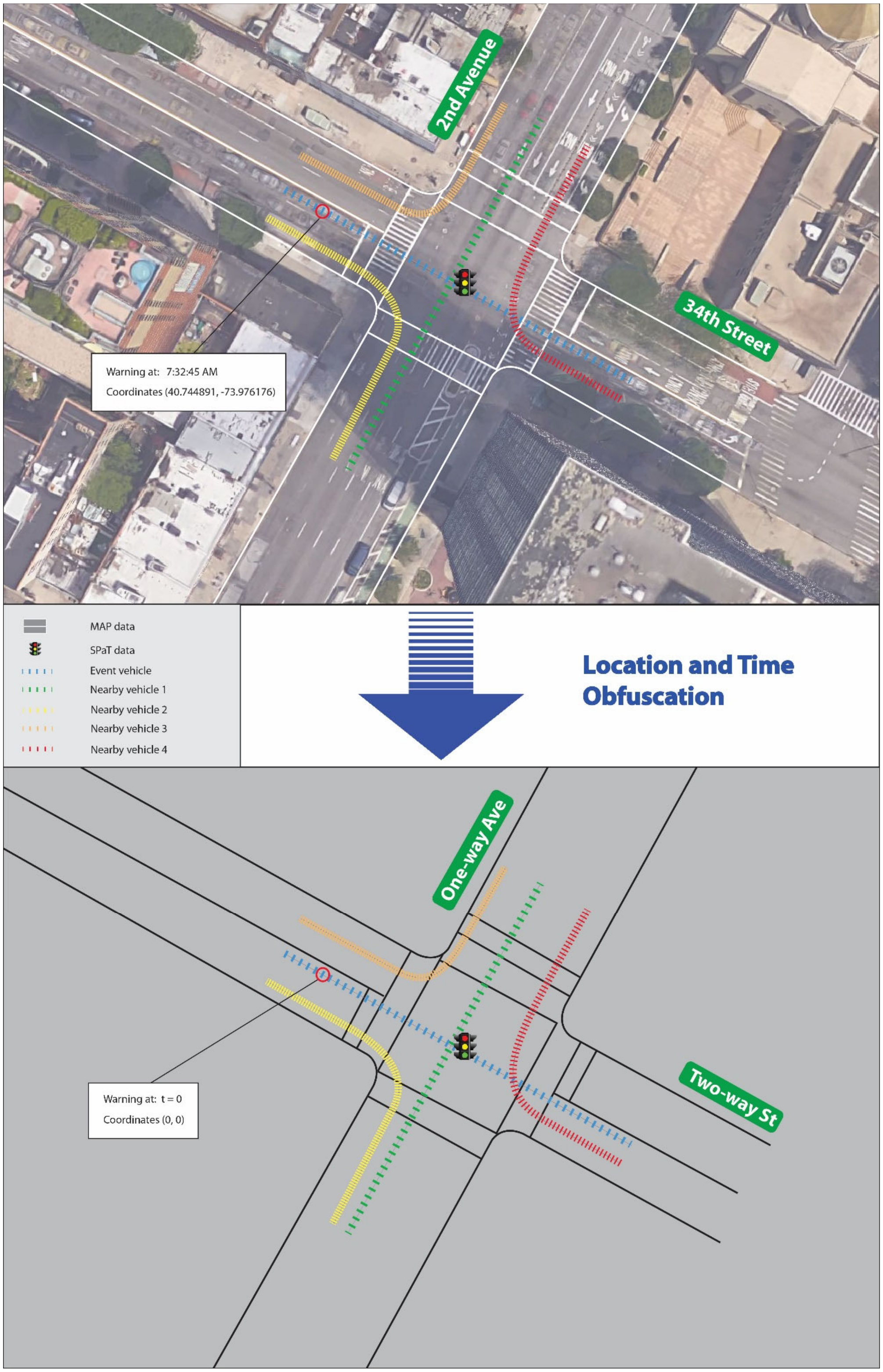
7.4.3 Location Data

Any detailed latitude, longitude, and elevation data recorded in any of the CV messages contained in the Action Logs will be removed and replaced with an undefined Cartesian coordinate system in the stored obfuscated records. Each obfuscated event data set will still retain the full recorded precision for all trajectory points relative to each other within one Action log event data set, but locations will not be recorded in any known real-world coordinate system or projection. The location obfuscation pertains to all items within the Action Log records, whether they are BSMs from the host vehicle, BSMs from nearby vehicles, or any recorded MAP or TIM messages. This removes the detailed location data that could be tied to accident records but still preserves all relative details about vehicle movements to assess driver actions taken in response to the CV app warning. All location based elements will be replaced in this manner, throughout each Action Log event record.

The obfuscation of location data will be done independently for each event Action Log data set recorded, and the new reference point for the entire data record will be the location of the host vehicle at the instant the CV warning is issued. For example, if an Action Log data set includes the warning event occurring when the vehicle was at $Latitude_0$ and $Longnitude_0$ (recorded in degrees to 7 decimals) and at $Elevation_0$, the entire data record would be scrubbed of location details and revised so that the warning would now occur at point (0,0,0) (X_0,Y_0,Z_0 all in meters, recorded to 1/100th m accuracy). This location would then serve as the 'anchor point' and all remaining exact location (Lat, Long, Elev) elements in any CV message recorded in the same event dataset will be removed and replaced with (X,Y,Z) coordinates in meters relative to the original (0,0,0) warning location. A schematic example of this process is shown in Figure 12. Within the figure, the top half is illustrative of the details that will be recorded in the unobfuscated CV messages, while the bottom half represents the same event data as stored in the obfuscated data records.

The location obfuscation process will ensure that the relative precision details of the CV messages that is available in the raw, unobfuscated data records will still be available for the future analysis in the obfuscated event records, but in an unknown coordinate system of meters rather than real-world degrees. To aid in the conversion of GPS based location measurements, the raw location coordinates will first be converted from (Lat, Long) degrees into a known Cartesian coordinate system, ESPG:6538 (NAD83-2011 FIPS 3104 New York Long Island, meters) using geoprocessing tools to develop (X,Y) coordinates in meters; the elevations will remain unchanged from the raw format (but converted to meters). After this conversion, all ESPG:6538 metric coordinates will be then simply translated to the obfuscated (0,0,0) metric coordinate system and stored in the obfuscated data record. No records of the original Latitude/Longitude coordinate system or the ESPG:6538 projected coordinate system will be retained or stored after the obfuscation process is completed.

While the redefined coordinate system used in the obfuscated Action Log records will allow analysis of the detailed trajectory and vehicle to infrastructure interactions, it is recognized that some information regarding where in the city the event occurred, and on what type of roadway the event occurred. As that type of information is not included int eh detailed trajectory data or even the obfuscated MAP records, each event record will be classified into a location bin to help provide additional context to the Action Log detailed records. Two separate types of location bins will be developed; the first for the CVPD study roadways that are equipped with RSUs (using code CV), and the other for the rest of the roadway in the city (denoted by code NY).



Source: NYCDOT, 2017

Figure 12. Schematic Example of ASD Time and Location Obfuscation Process

To help isolate warning events that occur on the equipped roadways, the directionality and nature of the roadway on which the host vehicle was located when the warning was issued will be recorded. The following bins and codes will be used for all CV equipped roadways:

- Manhattan Equipped Roadways
  - 1-way Avenues in Manhattan (code = 1wayAve)
  - 2-way Avenues in Manhattan (code = 2wayAve)
  - 1-way Cross Streets in Manhattan (code = 1waySt)
  - 2-way Cross Streets in Manhattan (code =2waySt)
  - Freeways/Parkways/Ramps
- Brooklyn Equipped Roadways
  - All Equipped Roadways (code = Art)

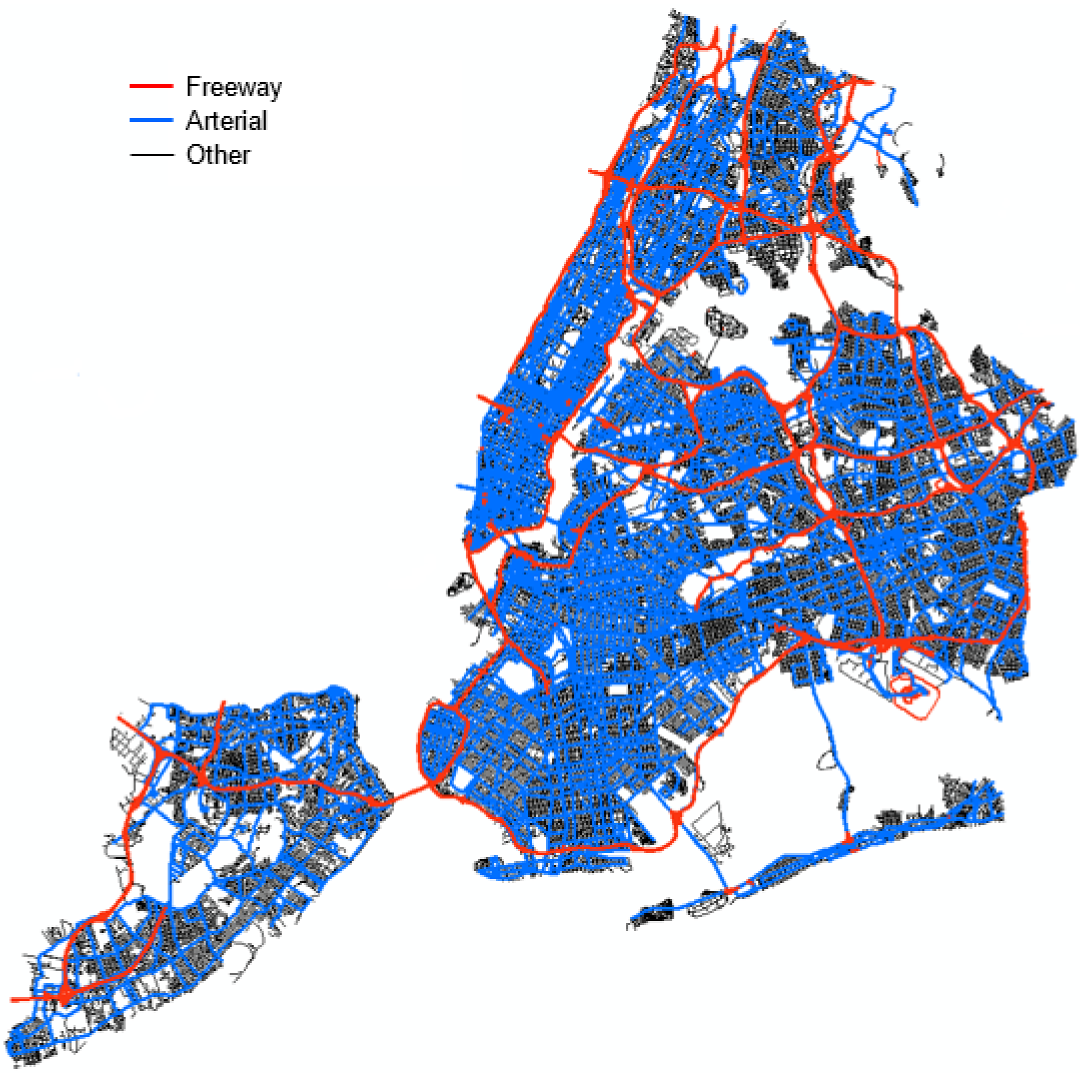
The location and heading of the host vehicle at the time of the warning will be used to identify the roadway bin that will be tagged to the Action Log data records. Prior to location obfuscation, the true coordinates of the warning will be compared to a GIS database of all equipped roadways, and all roadways which are within a given buffer distance from the warning location (e.g., 100 feet) will be identified. A comparison of the vehicles heading versus the matched roadway headings will be roughly compared to ensure that the correct roadway for the warning location is identified. For example, if the warning location was at the middle of an intersection, the vehicle heading will be used to determine if the warning should be attached to the east-west roadway or to the north-south roadway. The GIS database will include a data field identifying which of the above bins the roadway belongs, so that once the target roadway segment in the GIS database is found, the Action Log record will adopt that location bin information.

If the warning location is not tagged to an equipped roadway, a separate set of location bins for non-equipped roadways will be considered for tagging the event record to a location bin. The non-equipped roadway location bins will include an identifier of the borough in which the warning occurred (using codes MN for Manhattan, BK for Brooklyn, QN for Queens, BX for the Bronx, or SI for Staten Island) as well as a functional classification of the roadway as either FWY for Freeway (also including other controlled access roadway such as parkways and connecting ramps), ART for arterials (principal, major, and minor arterials), or OTH for other (collector and local roadways).

Figure 13 illustrates the GIS database of all public NYC roadways and the roadway classifications into the freeway, arterial, and other categories. Similar to the equipped roadways, the host vehicle location and heading at the time of the warning will be used to select which GIS roadway segment found within a set buffer distance (e.g., 100 ft) is an appropriate representation of the location bin for the event record.

If the warning location cannot be matched against any public roadway but is still located geographically within one of the NYC boroughs, the roadway classification will be recorded as other. This is expected to catch occurrences when recorded coordinates are inaccurate enough to be correctly located, or if the warning occurred off a public roadway (e.g., in a parking lot).

The final location bin code will be record in the event records as the **eventLocationBin** element and will be a concatenation of the CV or NY code for CV or non-CV roadways, the two-letter borough code, and the road type code. Examples of the stored location bin codes include “CV-MN-1waySt”, “NY-MN-ART”, “CV-BK-ART”, “NY-QN-FWY”, or “NY-MN-OTH”.



Source: NYCDOT, 2017

Figure 13. Non-Equipped Roadway Classifications Across NYC

Finally, when the warning location is identified as being outside of the NYC borough limits, the location bin will simply be recorded as “nonNYC”, with no information regarding what type of roadway the warning occurred on.

7.5 Qualitative Operator Feedback

To collect qualitative feedback from the CV pilot participant drivers and pedestrians on the effectiveness of the CV technology deployed during the Pilot, the participants will be asked to complete period surveys designed to measure more qualitative assessments that cannot be obtained from device collected data. As the primary goal of the NYC CVPD is to improve safety, and hence the goal of the user survey is to assess and measure the user population’s appreciation and perception of the technology including the overall performance of the ASD and PID devices and their CV applications, as well as their perceived impact on safety and mobility. The target audience of the survey includes numerous drivers and 25 visually impaired pedestrians that participate the CV pilot program.

It is important to note that there is likely more than one driver per CV equipped vehicles, and due to privacy concerns for participants, individual drivers cannot and will not be identifiable through the CV devices or data logs. Drivers in the CV pilot study have been exempted from Institutional Review Board (IRB) oversight. Due to the fleet nature of the majority of the NYC CVPD participants, the anonymity and privacy concerns of the vehicle operators, and the sheer number of operators expected to drive a CV equipped vehicle, the active solicitation of driver feedback via interviews is not feasible. However, the feedback from the operators as to how the ASD devices and applications are operating is an important assessment of the pilot deployment, so a web-based survey tool will be distributed for the drivers to provide feedback.

As the pedestrian users is a much smaller group of participants, individual interviews are planned to be conducted. It is noted that the visual impaired pedestrian participants are participating in the NYC CV Pilot under the oversight of NYU's IRB, and that contact with said participants must be only made by IRB approved staff, and any results of the surveys to be shared will have all participant PII removed.

7.5.1 Survey Instrument and Duration

The survey instruments are anticipated to have two major sections – user demographics, and user perception of the usability of the devices and applications. User demographics are asked to provide insights on the driver population exposed to the CV technology versus the larger driver population of NYC or beyond.

All questions are planned to be multiple choice questions that are simple to answer and hence limit the burden on the user (minutes to complete the survey). Depending on the anticipated response rate and the needed confidence bounds for the survey results – the exact number of surveys, and the planned duration of the survey will be defined in the coming months. The anonymity of all surveyed individuals will be protected.

7.5.2 Survey Technique

For participated drivers, the current plan is to conduct the survey using an electronic form that will be accessible online. For the visually impaired pedestrian participants, either in-person or phone surveys will be conducted, with the questions verbally read to the participants and spoken responses will be recorded by the surveyors.

The baseline condition survey is suggested to be administered prior to the start of training on the CV devices and applications, so as not to introduce bias. For both the pedestrian and driver participants who will receive training, this offers a good opportunity to administer the baseline survey before the training sessions.

Drivers will be notified during the training program about the planned deployment surveys. This will be augmented by notifications prior to each survey period and continuing through each survey collection window to increase awareness and participation. The pedestrian surveys will be administered before and after each field test.

Some of the considerations to increase participation from the driver participants beyond the planned online access methods have been considered. This is expected to include postcards left in the equipped vehicles during the periodic service inspections (as required by some fleets) and/or provided to the fleet owners to distribute at strategic locations (barns for the taxi cabs and buses, maintenance yards or garages for the fleet vehicles, etc.) for the drivers to take. Additionally, an incentive program may be developed to increase participation. This would administer a few small prizes (e.g., retail store gift cards) and potentially a grand prize to be randomly given to the survey participants. Details of such an incentive program are still under discussion and are still tentative.

7.5.3 Survey Timeline

For driver surveys, the current plan is to conduct three sets of surveys – (a) initial pre-deployment survey, (b) early-stage post-deployment survey, and (c) late-stage post-deployment survey.

A. Initial Pre-deployment. These interviews will aim to understand the expectations of the end user and to gather demographical data of the user population. Drivers will be notified of the baseline survey and will be encouraged to complete it via a weblink before watching the training videos, but since drivers will be trained remotely the NYC team cannot enforce this sequence.

B. Early-Stage Post-deployment. These interviews will capture early deployment experiences and initial feedback from end users

C. Late-Stage Post-deployment. These interviews will gather information as to whether or not the pilot deployment met its goals and objectives from the end users' perspective

These surveys will be tied to the project schedule as listed in Table 13 below, with tentative dates listed.

Table 13. Tentative Schedule for Driver Survey in Phase 3

Stage of Pilot	Survey Stage	Estimated Timeline
User Training	Pre-Deployment	March 2021 (Approximately 1 month before Go Live)
Post Deployment	Early Stage	June and July 2021 (First 2-3 months of Go Live)
Post Deployment	Late Stage	Late Fall 2021 (Last 2-3 months of Go Live Deployment)

Note: Go Live refers to the project stage following the silent data collection period

For visually impaired pedestrian surveys, two surveys will be administered during the deployment to understand the usefulness of the PID.

A. The pre-experiment survey is designed to establish baseline conditions for study participants. The questionnaire in the pre-experiment survey will include at least a few key demographic questions. Pedestrians will have the baseline surveys conducted in person immediately before each participant's field test.

B. The post-experiment survey aims to collect useful feedback on participants' perceptions and experiences with the CV-ped application for the whole project timeline. Ideally, it would include an additional set of questions on attitudes, institutional issues (e.g., privacy), and other relevant topics. The post-experiment survey will be administered with each participant after the field test is done.

All pedestrian surveys will be used to measure the changes in users' experiences with CV-ped application, their satisfaction with the technology, and its perceived impact on their safety and mobility. It is noted that while the user feedback is important, due to the small sample size of the survey, it may not be sufficient to conduct robust statistical analyses. The following provides preliminary survey timelines for the surveys to be collected during the deployment of the PID units under the NYC CV Pilot deployment.

The timeline for the field test, and therefore the surveys as well is still uncertain as the IRB panel is currently restricting any interactions of the IRB approved researchers with participants due to COVID-19 and social distancing precautions. However, the tests will hopefully be completed in Summer or Fall of 2021.

7.5.4 Draft Participant Surveys

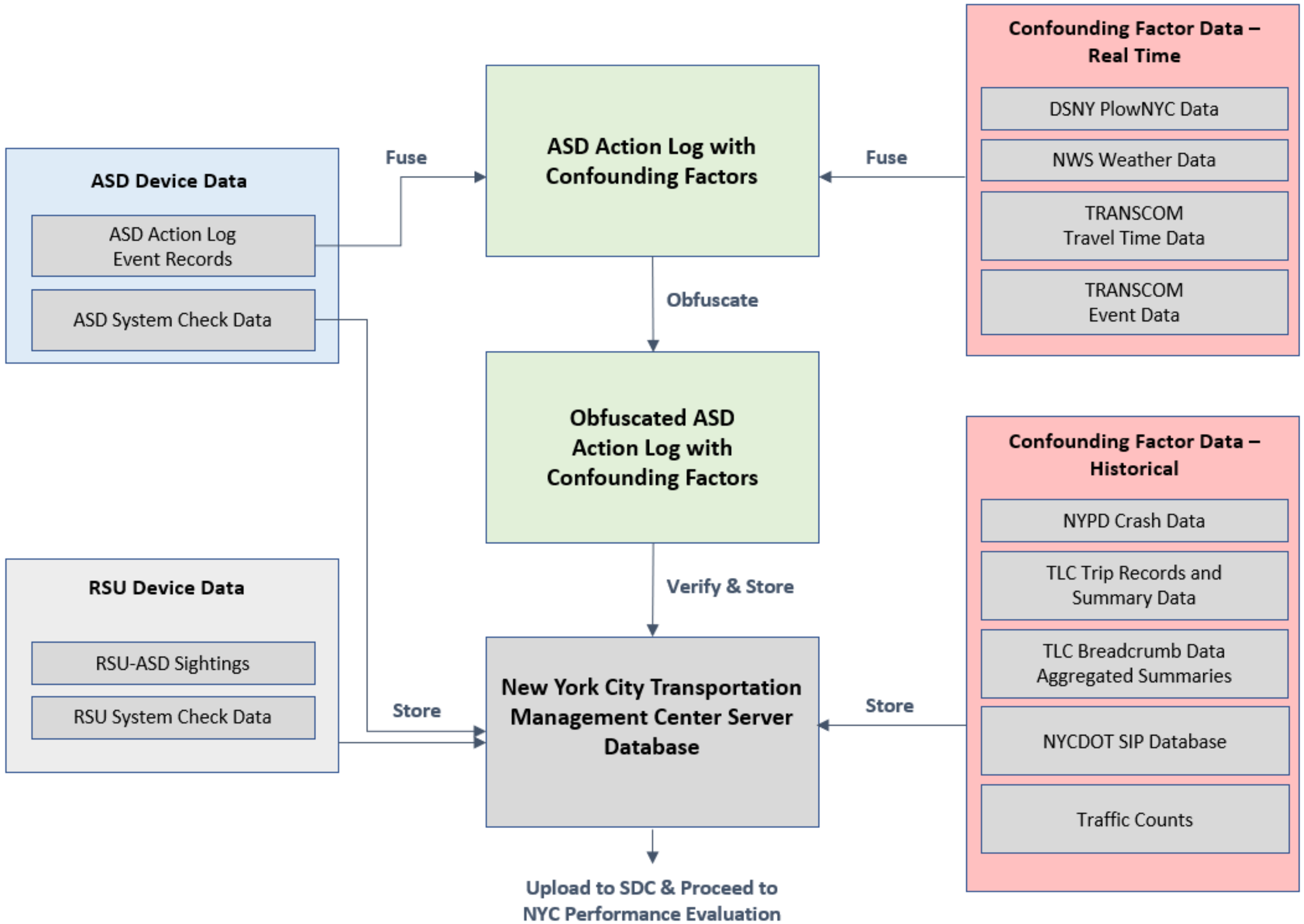
Drafts of both the driver and pedestrian participant surveys have been prepared and are included in the appendices for this report. It is noted that these surveys are still subject to minor wording changes as needed as the deployment of the CV applications are further refined and finalized to provide more targeted questions related to the specific CV application warnings and the driver experiences with them.

7.6 Data Flow and Storage

Following the procedures outlined in the previous sections, the collected, processed, scrubbed, and fused data will be stored on the CVPD team servers at the TMC. Figure 14 illustrates the overall process that will be undertake for the CVPD performance measurement and evaluation data sets other than the PID data. Within the figure, the detailed data collected from the ASD and RSU CV equipment is shown on the left while data collected via methods from anything other than CV equipment is shown on the right. The detailed ASD action log data (upper left) is fused with the real time confounding factor data sets (upper right) prior to the obfuscation process. This fusion and obfuscation process will be automated and undertaken on a daily (or less) basis. Based on the expected times to transmit the data from the ASDs via the RSEs via DSRC and then to the TMC servers via existing wireless or fiber backhaul, the full raw warning event data may take up to two days to fully make its way from the ASDs to the TMC servers. The non-obfuscated action log data will only be stored on TMC servers until the fusion and obfuscation process has been completed, after which it will be destroyed. Only obfuscated ASD action log records will be retained for long term storage.

The bottom half of Figure 14 shows the process for collecting and storing both data collected from CV equipment and from traditional methods which does not reveal potential PII issues. This data will be processed and stripped of any PII (including vehicle ASD serial numbers) and stored in the TMC servers and uploaded to the ITS DataHub without further obfuscation to be used for subsequent performance measurement and evaluation analysis. It is noted that the timeline for delivery of the non-real time data can vary significantly, but it expected to be monthly or even quarterly. Please see the Data Collection chapter for further details on the timing of the availability of these individual data sets.

Due to the IRB involvement in oversight of the PID portions of the pilot, all data collection will be completed managed by IRB-approved staff at NYU. The data will be flow directly from the PID units via cellular or wireless communications to a secure server within NYU, and only IRB-approved staff will ever have access to any unencrypted and non-sanitized data collected from the PIDs. Once the data processing and aggregation of the PID performance measures is completed by NYU staff, the sanitized and aggregated performance metrics will be uploaded to the TMC for overall inclusion in the CV pilot evaluation process.



Source: NYCDOT, 2017

Figure 14. Overall Data Collection, Processing, and Storage

8 System Impact Evaluation Plan

The following sections discusses the procedures and methods that will comprise the System Impact Evaluation Plan of the CVPD deployment. This includes both statistically viable methods for comparing with and without CV data, before and after comparisons of crash data, and simulation-based assessments of changes in safety and non-safety performance metrics.

8.1 Evaluation Plans

The classification of the data sources which will be used for the determination and evaluation of the performance metrics can be generally categorized into four categories. The following sections describe these terms as they are used in the definition of the NYC CVPD performance evaluation plan.

8.1.1 ASD Action Logs

The ASD action logs, or event records, contain both the detailed data recorded from the ASDs units surrounding an event as determined by the ASD (including the type of warning generated and the vehicle's BSMs nearby vehicle BSMs, and as appropriate the SPaT, MAP, and TIM messages from nearby RSUs), but also includes the fused confounding data which was married to the action log data prior to the obfuscation of precise time and location details from the action logs. The event triggering the action log data collection can include both triggered warnings from the ASD in either active (with CV) or silent (without CV) operations modes and non-warning generated events (e.g., hard braking above a selected threshold). These action logs can reveal the detailed driver actions taken through the observed changes in vehicle movement and projected movement both before and after the warning event as triggered by the ASD.

The primary method of evaluating the action log data for the impacts of the CV technology will be to assess the changes in the vehicle trajectory and CAN bus metrics in response to the CV issued warning. By comparing such data for the CV-equipped vehicles both with (either after or treatment group) and without (either before or control group) CV warnings audibly issued, disaggregate changes in driver reactions to the deployment of the CV technology can be estimated.

Additionally, the aggregate change in driver behavior will not only be assessed, but the different ranges of response (including no response or no change) will be tracked to arrive at a distribution of the driver responses in reaction to the deployed CV technology.

Finally, since the action logs contain details on the confounding data available in real time (weather, traffic conditions, etc.), this evaluation process will be repeated for action log records corresponding to combination of the confounding factor data sets. For example, driver behaviors can be expected to be different under varying traffic operational and weather conditions, therefore the changes in driver behaviors resulting from the deployed CV technology should be evaluated separately under those different conditions.

8.1.2 Field Data

The term Field Data is used generically to refer to any field observed or measured data which is not contained as part of the ASD action log. This includes any field measured data collected from non-CV data sources (see Section 7.2). Notably, it also includes details of any police crash or accident reports, as compiled through police accident reporting databases.

Since the field data referenced here is independent of the CV technology deployed, the collection of this field data cannot differentiate between the control and treatment groups and is representative of the entire vehicle population operating on the roadways. Given this distinction, the evaluation of this data, and in particular reported crashes, is limited to a traditional before and after evaluation method.

More details on the methods for before and after analysis methods to be used specifically related to examining to observed crashes are included in Section 8.3.

8.1.3 Simulation Modeling

Microscopic simulation engines simulate the movement, behavior, and decisions of individual drivers, based on models of car-following and lane-changing and a variety of population parameters. Typically, the analytical engine (which drives the simulation) begins by adding vehicles to the network at unconnected link entrances and at mid-block locations (representing new trips from origins along that link). These new trips are generated according to a specified distribution (e.g., Poisson, Uniform), with the shape parameters for these distributions based on user-defined values and the trip tables provided to the simulation. Similarly, driver characteristics (e.g., driver aggressiveness, following distance, acceleration or deceleration profile) are assigned for each vehicle at the time it first enters the simulation network according to statistical distributions. Each generated vehicle is also given desired destination, and its progress toward that destination is simulated in small time increments (e.g., half a second) or "simulation steps." Microscopic simulation models generally also consider roadway characteristics—including grade, lane width, and design speed—when evaluating the movement of individual vehicles on each link, with the effects of each roadway parameter being modeled according to relationships established by past research. Once a model is built, it must then be calibrated through the adjustment of driver and roadway parameters to achieve an optimal alignment between the route choices and link capacities observed in the model and measured in the field.

For the purposes of the CVPD, simulation modeling refers to the use of traffic simulation models to either collect performance metrics which are impractical to collect in the field for the entire vehicle population. This includes not only the CV-equipped vehicles, but the remaining non-CV equipped vehicles traveling the city's roadways during the evaluation period. Simulation also provides an excellent methodology to remove the influence of confounding factors from the evaluation. While the data produced is still modeled and not field observed, the use of simulation allows for a pure with and without comparison under identical circumstances that is not directly testable in the field.

Microscopic traffic simulation models will be used to assist in the performance evaluation of the NYC CVPD in these regards. Two different uses of traffic simulation modeling are planned to assist in the evaluation of the NYC CVPD project; microsimulation assessment with Safety Surrogate Measures (SSM) for accident prevention prediction modeling, and System Performance network operational modeling for the mobility and reliability impacts of reduced numbers and/or severity of crashes.

A basic tenet of simulation modeling is that the model must be calibrated to the existing conditions prior to the simulation of the changes. The NYC CVPD team acknowledges this and as such will ensure that the simulation models are calibrated to represent the existing (here without CV technology) conditions prior to the simulation of the field observed changes.

Similarly, simulating changes in behavior arising from the CV technology must also be sufficiently controlled and behavior models calibrated so the modified simulated behavior accurately represents the observed 'with CV' behavior. This calibration of driver behaviors will go beyond the typical calibration efforts of a microscopic traffic model for a 'standard' study (e.g., validation of volumes, speeds, or travel times from the model versus observed data), and especially for the SSM simulation analyses. This includes the calibration of car following or other driver characteristics that are changed as a result of the introduction of the CV technology and that can be observed through analysis of the ASD action log data from before and after or control and treatment data.

Along these lines, it is acknowledged that the detailed simulation of changes in driver behaviors as observed through analysis of the action log data pushes the limits of the capabilities of default driver behavior models contained within commercial-off-the-shelf microscopic traffic simulation software platforms. As such, specific care will need to be taken to calibrate the traffic simulation models for CV analysis and will likely dictate the development of specific driver behavior models for the simulation of the changes created by CV technology for the evaluation of the safety benefits. It is also noted that the changes in driver behavior to CV technology are not expected to be uniform, so different parameterizations must be considered to represent the ranges of driver responses observed in the analysis of the with and without ASD Action Logs.

Further details on the planned use of microscopic traffic simulation models for the NYC CVPD performance evaluation are included in sections 8.4 (SSM Simulation) and 8.5 (System Performance).

8.1.4 System Data

System Data is used to refer to any data that is produced and extracted from the CV technology but is not directly related to the detailed ASD Action Log (1/10 sec) data. Examples include general CVPD deployment statistics and health monitoring data of the ASDs and RSUs in the field, system performance report and dashboard metrics which summarize the ASD and RSU activities, as well as RSU based travel time measurements.

8.2 Evaluation Methods by Use Case

A list of the performance metrics by use case and the data collection and performance evaluation methods are presented in Table 14. This table lists the already presented use cases and performance metrics, but also includes the planned evaluation methods to assess the changes in these performance metrics resulting from the NYC CVPD project.

It is noted that some performance metrics list in this table include more than one method. In these cases, the preferred method is to use the observed data - either action log (AL) data, field data (FD), or system data (SD) - to assess the changes in the performance metrics. However, it is also recognized that microscopic simulation modeling (MS) is likely to be needed to account for impacts of confounding factors which cannot be separated from the observed data and to assist the safety evaluation for where crash data is not available or sufficient. Two distinct approaches of simulation will be used in the evaluation of the NYC CVPD; simulation to assess the safety aspects of the CVPD, and one to evaluate other mobility, reliability, and environmental aspects (non-safety).

It is noted that the use of the microscopic simulation modeling approach to assess the safety aspects of a CV application is subject to the number of the event records observed, the details of the obfuscation details released, and the real-time functionalities of the simulation software (see section 4.2.1). Selection of which CV application scenarios to simulate may be changed given the ongoing testing of the operation of the CV applications.

Table 14. Performance Measurements and Evaluation Methods per Use Case

User Need	Cat	NYCDOT Needs	CV Application	No.	Performance Measure Metrics	Question for Evaluation	Performance Evaluation Method	External (non-CV) Roadway / Operations Data Leveraged
Manage Speeds	Safety, Mobility	Discourage Spot Speeding	Speed Compliance	1	1a. Number of stops (average and distribution measures) 1b. Speeds (average and distribution measures) 1c. Emissions 1d. Reduction in speed limit violations 1e. Speed variation 1f. Vehicle throughput (average and distribution measures) 1g. Driver actions and/or impact on actions in response to issued warnings	Does speed limit adherence increase and speed variability decrease within the vehicle fleet on a given study roadway segment for a given time period (cycle length basis) from the Before period to the Pilot period, and from control group to the treatment group?	**1a. AL; MS (non-safety)** **1b. FD; SD; MS (non-safety)** **1c. MS (non-safety** **1d. AL; MS (non-safety)** **1e. FD, SD** **1f. FD; MS (non-safety)** **1g. AL**	Studied roadway section speeds from other available travel time datasets (analysis should focus on existing travel time segments, e.g. corresponding to Link Condition segments)
	Safety	Improve Truck safety	Curve Speed Compliance	2	2a. Speed related crash counts, by severity 2b. Vehicle speeds at curve entry 2c. Lateral acceleration in the curve 2d. Driver actions and/or impact on actions in response to issued warnings 2e. Number of curve speed violations at each instrumented location	Do the number of curve speed violations on each applicable studied roadway segment decrease from the Before period to the Pilot period, and from control group to the treatment group?	**2a. FD** **2b. AL** **2c. AL** **2d. AL** **2e. AL**	Roadway curve alignment data, posted speed; Weather data; Curve segment speeds from other available travel time datasets

User Need	Cat	NYCDOT Needs	CV Application	No.	Performance Measure Metrics	Question for Evaluation	Performance Evaluation Method	External (non-CV) Roadway / Operations Data Leveraged
	Safety	Improve Work Zone Safety	Speed Compliance / Work Zone	3	3a. Speed in work zone (average and distribution measures) 3b. Speed variation (distribution) at work zone 3c. Number of vehicle speed limit violations in variable speed zone areas 3d. Driver actions and/or impact on actions in response to issued warnings	Do the number of workzone speed violations on each applicable studied roadway segment decrease from the Before period to the Pilot period, and from control group to the treatment group?	**3a. FD; AL** **3b. FD; AL** **3c. FD; AL** **3d. AL**	Workzone roadway section speeds from other available travel time datasets; workzone geometry - if available (closures, tapers, lane shifts, etc.)

User Need	Cat	NYCDOT Needs	CV Application	No.	Performance Measure Metrics	Question for Evaluation	Performance Evaluation Method	External (non-CV) Roadway / Operations Data Leveraged
Reduce Vehicle to Vehicle Crashes	Safety	Reduce Vehicle to Vehicle Accidents	FCW EEBL BSW LCW IMA	4	4a. Fatality crash counts 4b. Injury crash counts 4c. Property damage only crash counts 4d. Time to Collision (vehicle to vehicle)	Do the number of reportable crashes decrease from the Before period to the Pilot period, and from control group to the treatment group?	**4a. FD** **4b. FD** **4c. FD** **4d. AL; MS (safety)**	N/A
	Safety	Reduce Accidents at High Incident Intersections	Red Light Violation Warning	5	5a. Red light violation counts 5b. Time To Collision (vehicle to cross vehicle path) at the intersection 5c. Driver actions and/or impact on actions in response to issued warnings	Do the number and severity of red-light violations at each studied intersection decrease from the Before period to the Pilot period, and from control group to the treatment group?	**5a. FD; AL** **5b. AL; MS (safety)** **5c. AL**	Intersection geometry
	Safety	Reduce Bus Incidents, Improve Safety	Vehicle Turning Right in Front of Bus Warning	6	6a. Right-turning related conflicts 6b. Time to collision (vehicle to bus) 6c. Number of warnings generated 6d. Driver actions and/or impact on actions in response to issued warnings	Do the number of bus / right turn vehicle crashes decrease from the Before period to the Pilot period, and from control group to the treatment group?	**6a. FD** **6b. AL; MS (safety)** **6c. SD** **6d. AL**	Bus route and frequency information for study roadways; presence of exclusive bus lanes (from which right turns are allowed); presence of nearside and farside stops

User Need	Cat	NYCDOT Needs	CV Application	No.	Performance Measure Metrics	Question for Evaluation	Performance Evaluation Method	External (non-CV) Roadway / Operations Data Leveraged
Reduce Vehicle to Pedestrian Crashes	Safety	Improve Pedestrian Safety on Heavily Traveled Bus Routes	Pedestrian in Signalized Crosswalk Warning	7	7a. Pedestrian related crash counts, by severity 7b. Number of warnings generated 7c. Pedestrian-related conflicts/hard braking events 7d. Time to collision (vehicle to pedestrian) 7e. Driver actions and/or impact on actions in response to issued warnings	Do the number of pedestrian related crashes decrease from the Before period to the Pilot period, and from control group to the treatment group?	**7a. FD** **7b. SD** **7c. AL** **7d. AL; MS (safety)** **7e. AL**	Intersection geometry
	Safety	Improve Safety of Visually and Audibly-impaired pedestrians	Mobile Accessible Pedestrian Signal System (PED-SIG)	8	8a. Qualitative Operator Feedback 8b. Pedestrian Crossing Speed and Crossing Travel Time 8c. Times Out of Crosswalk 8d. Waiting time at intersection for crossing	Does the mobile app improve participants' perceived safety when crossing a signalized intersection?	**8a. AL (survey)** **8b. AL** **8c. AL** **8d. AL**	Intersection geometry
Reduce Vehicle to Infrastructure Crashes	Safety	Address Bridge Low Clearance Issues/Enforce Truck Route Restriction	Oversized Vehicle Compliance	9	9a. Number of Warnings generated 9b. Number of truck route violations	Do the number of low clearance violations decrease from the Before period to the Pilot period, and from control group to the treatment group?	**9a. SD** **9b. FD**	Truck route and clearance map files
Inform Drivers of Serious Incidents	Mobility	Inform Drivers	Emergency Communications and Evacuation Information	10	Number of vehicles receiving information when generated	Do CV vehicles receive the information warnings when generated?	**SD**	N/A

User Need	Cat	NYCDOT Needs	CV Application	No.	Performance Measure Metrics	Question for Evaluation	Performance Evaluation Method	External (non-CV) Roadway / Operations Data Leveraged
Provide Mobility Information	Mobility	Replace Legacy Measurements	Intelligent Traffic Signal System Connected Vehicle Data (I-SIGCVDATA)	11	11a. Segment speed (average and distribution measures) from CV compared to legacy detection systems 11b. Travel time (average and distribution measures) from CV compared to legacy detection systems	Do the CV based mobility metrics compare favorably to legacy detection systems or provide better information?	**11a. SD; MS** **11b. SD; MS**	N/A
Manage System Operations	System Operations	Ensure Operations of the CV Deployment	NA	12	System performance statistics (system activity, down time, radio frequency monitoring range on ASD's and RSU's, number of event warnings by app)	Does the system operate reliably?	**SD**	N/A

8.3 Before and After Analysis of Crash Data Records

A before and after system safety analysis will be conducted using both before and after field data collected accident record data. The exact duration of the before period would be determined through a review of previous accident records and power analysis to determine an appropriate sample size of crashes to meet statistically significant results. Ideally, the before period from which historical crash data will be sampled will not extend prior to the implementation of the 25 mph speed limit change (November 7, 2014). The after period will be the duration of the after period where CV vehicles are in active mode during Phase 3 of the NYC CVPD project. It is important to note that both the NYPD and the NYS crash data have essential shortcomings (see section 7.2.1) and their usage in the evaluation of the safety performance metrics may be limited.

8.3.1 Crash Records Analysis Methodology

The following presents the method proposed for safety evaluation, namely the Survival Analysis Method[3].

8.3.1.1 Survival Analysis Method

Another potential way to study crash occurrence is to consider the time between each pair of consecutive crashes, which in turn can be converted into the crash frequency (Lord and Mannering 2010). Survival analysis method which models the time between each pair of consecutive crashes may be a better evaluation modeling choice in this project (Xie et al. 2018).

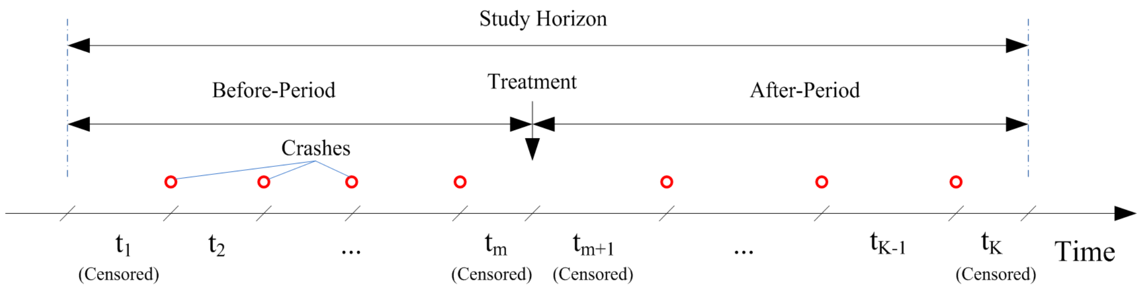
Survival analysis is used to analyze data in which the time until the event is of interest. The response is often referred to as a failure time, survival time, or event time. In traffic safety content, the response is the time until a crash occurs, which can be viewed as a transportation system failure.

However, in reality it can be the case that the exact time until the event of interest occurs is unknown. In survival analysis context, this is called censoring. Formally, censoring is present when some information about a subject's event time is known, but the exact event time is unknown. Two of the common types of censoring are right censoring and left censoring. Right censoring means that a data point is above a certain value but it is unknown by how much, while left censoring means that a data point is below a certain value but it is unknown by how much.

As in the content of the before-after analysis, some observations of intervals can be right censored naturally. As shown in Figure 15, we could not know the actual time between the first recorded crash and its predecessor. So, t_i is right censored. This is usually misinterpreted to be left censored because the start time is unknown and the missing start point is to the left of the known interval when viewed as a timeline. But because we have a lower bound on the time interval in this case, the data is still right censored. Similarly, we also could not know the actual time between the last recorded crash and its successor due to the cutoff of the study horizon. Thus, t_K are right censored too. In addition, t_m and t_{m+1} should be treated as right censored observations as well. This is because crash hazard might have been changed after the implementation of the treatment, which means that we cannot know the next crash after the last crash in the before period if no treatment has been implemented. Thus, the

[3] Xie, Kun, et al. "A New Methodology for Before–After Safety Assessment Using Survival Analysis and Longitudinal Data." Risk analysis 39.6 (2019): 1342-1357

actual values are ensured to be greater than t_m. The same logic applies to t_{m+1} as well. Because of the implement of the treatment, we cannot know the immediate predecessor before the first crash in the after period if treatment has always been implemented. So, the actual interval between the first crash in the after period and the predecessor are ensured to be greater than t_{m+1}.



Source: NYCDOT, 2017

Figure 15. Censored Observations for Before-After Study

8.3.2 Crash Data Overview

The number of crashes in both before and after periods on the studied corridors and intersections should be collected. Due to the 25 mph speed limit change on November 8th, 2014, it is preferred to sample crashes that do not extend before the implementation of speed limit change. However, sampling requirements may dictate that the before period extend prior to the citywide speed limit change. This will be determined when actual CV data becomes available since the number of crash data sampled must be sufficient to obtain statistically significant results. The after period will be the duration of the after period where CV vehicles are in active mode during Phase 3 of the NYC CVPD project.

New York City (NYC) Crash data collected by NYPD starting from July 2012 is open to public on the NYC Open Data websites[4]. Each record represents a collision by city, borough, precinct, and cross street. The number of crashes by vehicle type along all the sites between November 8th, 2014 and December 31st, 2017 are summarized in Table 15. Crashes were selected using a 65 feet buffer around polylines of each site. Because there is no indicator of the type of crashes, certain rules were defined to classify motor vehicle, pedestrian, and bicycle involved crashes. Pedestrian crashes are classified if there is pedestrian injury or fatality. Bicyclist crashes are classified if there is bicyclist injury or fatality. Crashes with no pedestrians and bicyclists injury and fatality are classified as motor vehicle crashes. Accordingly, the numbers shown in Table 15 are not unique events and it is possible that the sum of motor vehicle, pedestrian, and bicyclist crashes is not equal to the total number provided in the last column.

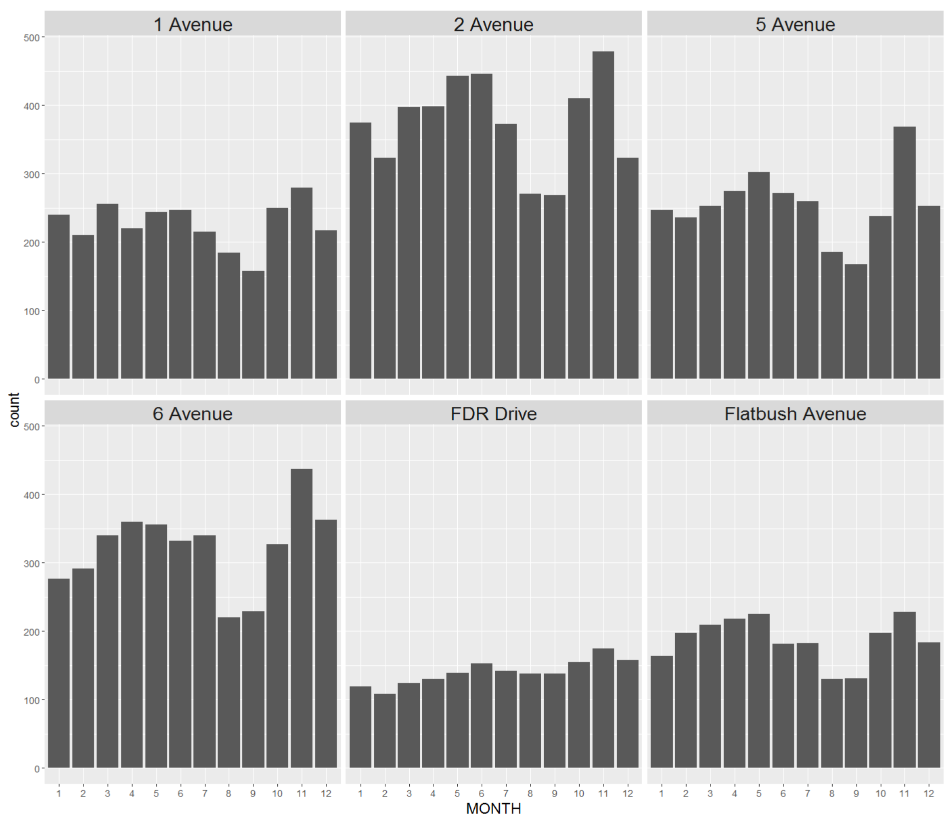
Table 15. Crash Summary of Flatbush Avenue by Vehicle Type

Corridor	Motor Vehicles	Pedestrians	Bicyclist	Total Count
Flatbush Avenue	2,127	79	39	2,245

[4] https://data.cityofnewyork.us/Public-Safety/NYPD-Motor-Vehicle-Collisions/h9gi-nx95

Corridor	Motor Vehicles	Pedestrians	Bicyclist	Total Count
FDR Drive	1,675	2	2	1,679
1st Avenue	2,408	190	124	2,720
2nd Avenue	4,138	219	149	4,506
5th Avenue	2,786	170	102	3,058
6th Avenue	3,531	195	146	3,871

Monthly crash counts for each site between January 2015 and December 2017 are shown in Figure 16. Generally, there are more crashes between March and July and between October and December. The number of crashes along FDR Drive and Flatbush Avenue are the lowest of all sites. The number of crashes of all sites by different time periods of a day is summarized in Table 16Table 15. As can be seen, most crashes occur during midday and p.m. peak hours. More detailed data from NYPD and NYS DOT will be used in the project.



Source: NYCDOT, 2017

Figure 16. Monthly Crash Counts for Each Site

Table 16. Crash Summary of Flatbush Avenue by Time Period

Corridor	AM Peak 6 AM – 9 AM	Midday 10 AM – 3 PM	PM Peak 4 PM – 7 PM	Night 7 PM – 5 AM	Total
Flatbush Avenue	333	794	395	723	2,245
FDR Drive	247	522	610	300	1,679
1st Avenue	413	895	902	510	2,720
2nd Avenue	712	1,491	1,534	769	4,506
5th Avenue	328	1,115	1,007	608	3,058
6th Avenue	415	1,413	1,295	748	3,871

8.4 Safety Surrogate Measure Simulations for Safety Benefits

The primary goal of the NYC CVPD is to further the city's Vision Zero initiative by reducing the number of accidents on urban roadways, and specifically to reduce the number of fatalities and injuries occurring in those crashes. While the number of accidents is significant, they are still relatively rare and unpredictable events on a day-to-day basis. The degree to which confounding factors change the probability of an accident occurring will vary not only day to day during the evaluation period, but minute to minute on the dynamic NYC streets.

Given this concern, additional evaluation methods beyond the analysis of crash records need to be included in the safety evaluation of the NYC CVPD. These additional methods should allow for the analysis of the change in the likelihood of accidents created from the CVPD.

In general, simulation modeling methods can be used to collect performance metrics which are impractical to collect in the field for the entire vehicle population. Simulation-based safety evaluation is crucial for the following reasons. (a) the level of data that can be observed or field-measured planned for before and after CV deployment periods may be insufficient to estimate detailed conclusions about the efficacy and benefits of each CV app independently; (b) The influences of confounding factors will be difficult to isolate from the impacts of the CV app deployment under such before and after measurement periods; (c) while a large number of vehicles in the study areas will be equipped with ASDs, it will still be only a subset of the entire vehicle population and the full effect of the CV apps may be difficult to assess (especially for V2V apps).

8.4.1 Converting Action Log Data into Driver Behavior

The CV pilot data will collect the individual vehicle traces from the ASDs (action logs) for both with and without active warnings which will capture changes in driver behavior resulting from the active warning from the ASD. This driver action data will be analyzed to modify default diver models used in the microscopic simulation. This can be as simple as modifying maximum and minimum acceleration / deceleration rates or minimum safe headway values in the car following model. However, there might also be a need for making more substantial changes to the default car following, lane change and /or gap acceptance logic. An important aspect of this task will be the possible need to incorporate these models into the microscopic simulation.

This data will also be used to help calibrate the SSM models to better reflect the driving behaviors not only to the aggregate validation metrics (which is commonly done with a traditional simulation models) but to the microscopic data available from the 1/10 second resolution action log data.

8.4.2 Scales of the SSM Simulation Models

For the safety evaluation, simple models that range from a single intersection to relatively small corridors of a few intersections will be developed. To be able to capture the impact of intersection geometry and traffic characteristics, several representative intersections will be identified and modeled. However, the number of these small simulation models has to be determined by taking into account the ultimate goals of the overall evaluation plan. For example, extremely complicated intersections that are not likely to yield significant safety benefits from the introduction of the CV applications might not be selected. Thus, a preliminary analysis of the candidate intersections will be done before starting the simulation modeling efforts. Moreover, multiple simulation models of the same intersection with a specific driver behavior model for each of the apps being evaluated might be needed. As a result, there will be a large number of combinations of scenarios and apps that will be simulated. Thus, test networks and their variations will be carefully identified as a first step in simulation model development.

It is noted that the proper simulation model of the modified CV behavior is likely to require the creation of modified driver behavior models instead of relying on one of the default behavior models from the commercial-off-the-shelf traffic simulators. While this is a significant undertaking, the NYC CVPD has prior experience and expertise required to complete this task.

8.4.3 SSM Experimental Design

Each scenario has to be tested under a range of realistic demand and environmental conditions that account for the varying confounding factors present in the field. One way to do that is to just run the simulation for certain conditions (such as a peak period), although it is preferable to also test under various different weather and incident conditions that are commonly seen in the field. In this study, it is important to consider different operational conditions and/or weather conditions such as snow, heavy rain, and ice since these can influence driver behaviors, which in turn will influence the crash risk. The impacts of these confounding factors can be incorporated into the simulation in terms of changes in driver reaction times, deceleration rates, headway following distances, and varying traffic demands.

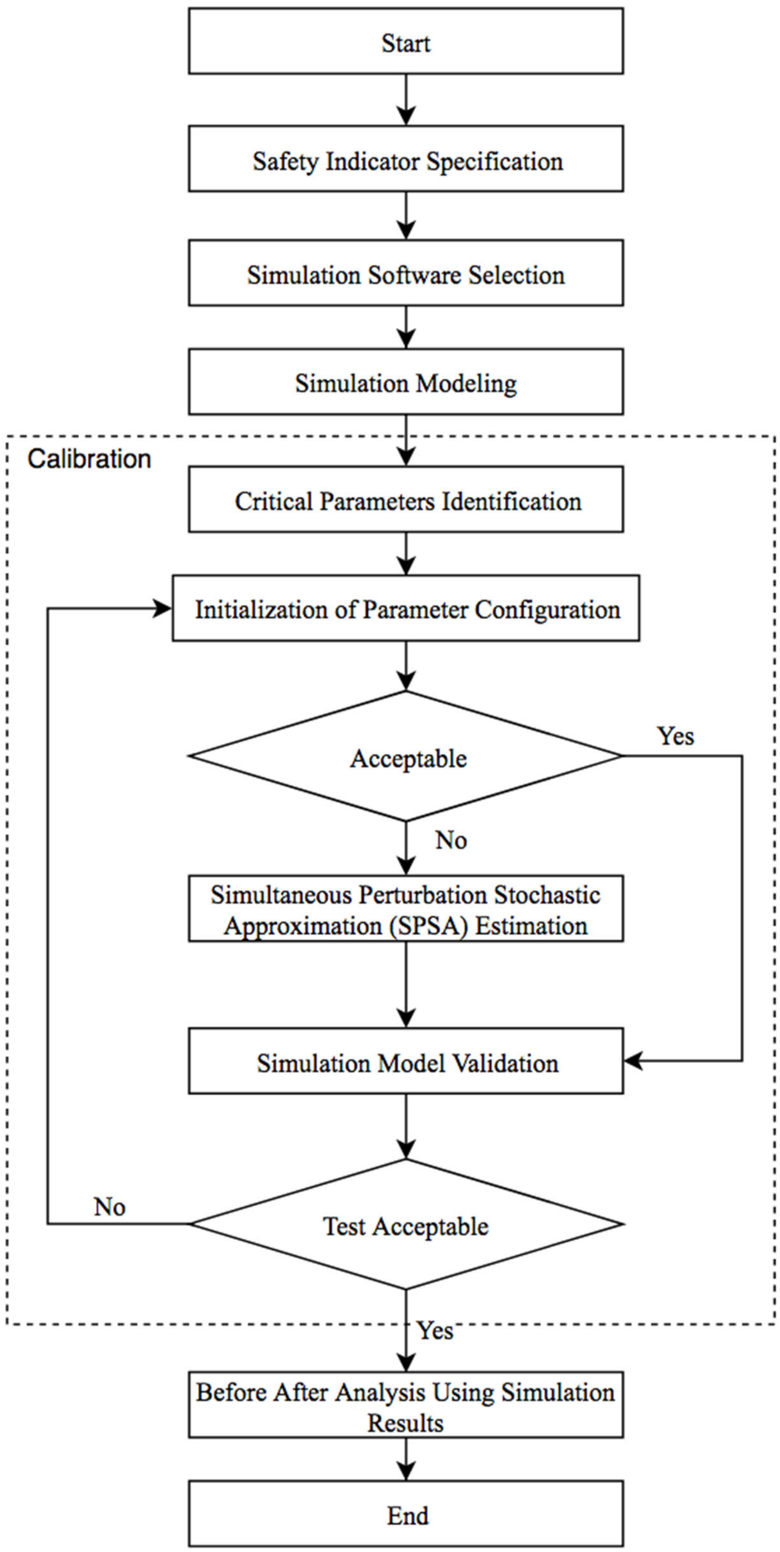
It is important to note that calibration and simulation models for different environmental scenarios will require additional data and effort since driver behavior will be highly affected by these environmental conditions. Selection of which confounding factor scenarios to simulate will be determined given the data on hand to adequately perform that calibration.

The exact groupings of variable traffic conditions, demands, weather, and other confounding factors will be based on the observed frequency of the different combination of these confounding factors from the action log data. This data will be extracted during the initial testing and before analysis periods, and a simulation analysis plan will be completed at that time. However, it is already anticipated that several dozens of combinations of geometric, operational, and weather conditions will need to be tested.

For each simulated scenario, there will be a need to conduct multiple runs with different random seeds to ensure the statistical significance (e.g. 95% confidence interval) of the simulation results given the stochastic nature of microscopic simulation and the variance of the data used to calibrate the simulation models. The number of random seed runs to be completed for each scenario will be developed to ensure statistical validity to the simulation models considering the variations in the observed traffic conditions to which the model was calibrated.

Generally speaking, micro-simulation models readily have crash avoidance mechanisms. This makes it harder to investigate various safety scenarios, such as crash occurrences. In order to quantify benefits associated with changing driver behaviors on safety-related issues, safety indicators, such as surrogate safety measures (SSMs), are frequently used and described in the literature. The whole procedure of the simulation-based safety evaluation is shown in Figure 17.

This chapter will first briefly discuss safety indicators in the sense of simulation. Secondly, different simulation tools will be discussed and one of them is selected for this project. Then, simulation modeling and calibration methods that suit safety evaluation will be introduced. Finally, simulation-based before-after safety evaluation method is proposed.



Source: NYCDOT, 2017

Figure 17. Flowchart of Simulation-Based Safety Evaluation Methods

8.4.4 Safety Indicators

Surrogate safety measures (SSMs) can be obtained from vehicle trajectories as indicators of safety performance. At its simplest, Time-To-Collision (TTC) is one of the most widely used SSMs, and it is defined as the time that remains before two road users collide unless one of them takes an avoiding manipulation such as braking or changing lanes.

To differentiate risky encounters from situations in which the driver remains safely in control, an appropriate TTC threshold (TTC*) must be defined. TTC* is related with the perception, reaction time, and driving conditions. Typical choices for TTC* may vary between 2 and 4 seconds. Vehicles pairs with TTC lower than TTC* are considered as involving conflict risk. The number of conflicts is usually used as a measure of safety performance.

There are a large number of other SSMs proposed in the literature. The NYC CVPD team will choose the most appropriate SSM(s) for the type of safety application that will be simulated. The selection of the SSM is important due to the complicated nature of this study in terms of “driver behavior” rather than merely geometric considerations that are typically studied in traditional safety evaluations.

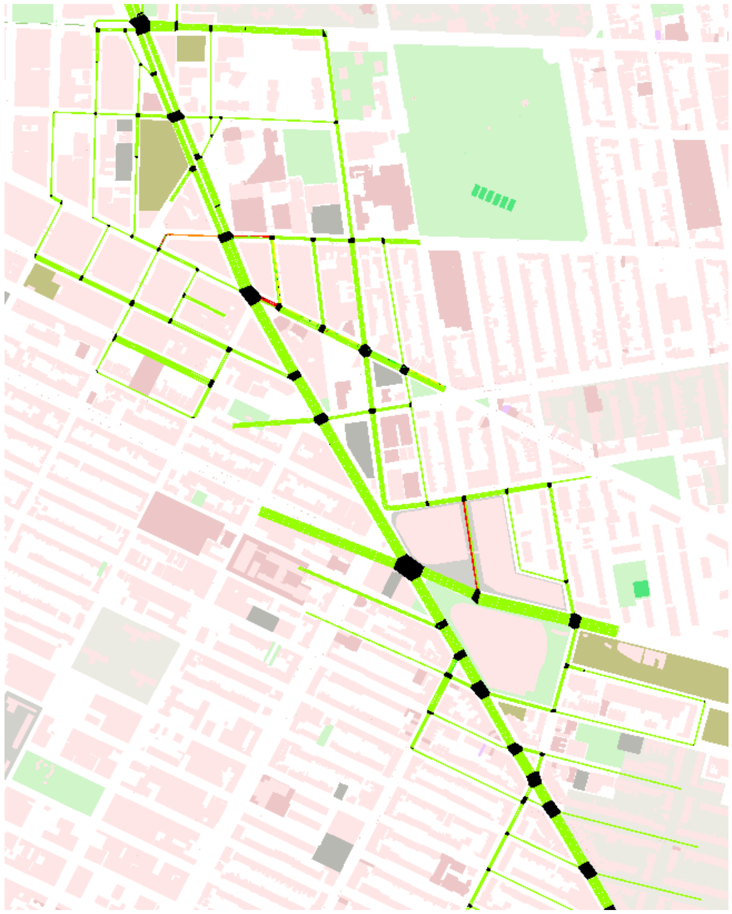
8.4.5 Simulation Software Selection

Previous studies have given some insights into the strengths and weaknesses of various simulation software used to support safety analysis. However, there are still no definitive conclusions about the selection criteria for available traffic software packages specific to safety analysis (Yang 2012). Four of the most commonly used commercial micro-simulators are Aimsun, Vissim, Paramics, and TransModeler. Recently, an open-source micro simulator named Simulation of Urban Mobility (SUMO) has attracted more attention. One of the highlights of SUMO is that it can achieve in more realistic modeling. Another advantage is that SUMO is that it is a free open-source software that its development can be benefit from multiple independent sources, generates an increasingly more diverse scope of design perspective than any one company can develop and sustain long term.

In terms of CV simulations, the parallelization of the simulation runs is critical to be able to simulate very large traffic networks. Opposite direction driving and sub-lane models enhance the capabilities of micro-simulation to a higher realistic level and provide more accurate simulation results. SUMO supports all of these approaches, while the other three software are limited in implementing these functions. Based on the above discussion, SUMO is suggested as the simulation software for the safety evaluation.

8.4.6 Simulation Models

Flatbush Avenue, which is one of the sites where RSUs will be installed, will be modeled. Simulation network built using SUMO is shown in Figure 18.



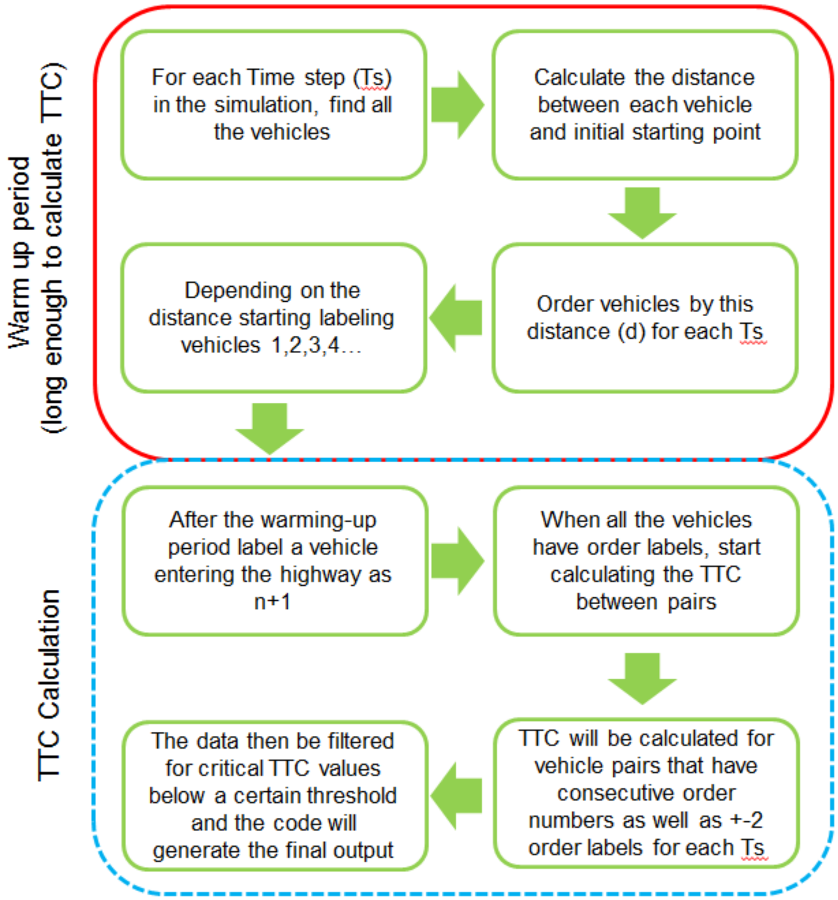
Source: NYCDOT, 2017

Figure 18. Flatbush Avenue simulation network in SUMO

Identification of conflicts from traffic simulation tools is usually conducted using Surrogate Safety Assessment Model (SSAM) (Gettman et al. 2008). It was developed to automate the process of extracting traffic conflicts using microscopic traffic simulation models. However, the input files required by the SSAM are in a *traj* file format which cannot be generated using SUMO. Therefore, a customized script for SUMO is being developed to calculate safety surrogate measures including TTC between successive vehicles. The procedure of calculating TTC is shown in Figure 19.

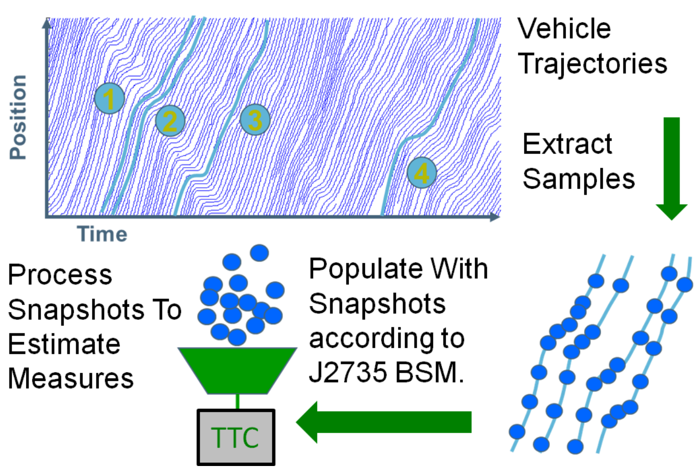
For simulation, a warm-up period is needed for the network to fill up with vehicles first before calculating TTC. This period allows the performance measures to replicate conditions that are typical of normal running conditions in the network. After the network reaches a steady state and the vehicles are labeled based on their order of arrival, TTC can be calculated for a sample of vehicle pairs. For the warm-up period, the algorithm only labels and orders vehicles by the distance traveled from a selected origin point in the network as it can be seen in Figure 19.

TTC is only calculated when the warm-up period ends. For initial models, the microscopic simulation is run for 3 hours. The warm-up period is set to be an hour to make sure the model achieves a steady state and properly reflects the observed traffic conditions (speeds, volumes, densities) at the beginning of the analysis period. Conflicts are then identified by setting a certain TTC threshold. The general procedure is shown in Figure 20.



Source: NYCDOT, 2017

Figure 19. Flowchart Depicting TTC Calculation



Source: Estimating Key Transportation Measures Using Connected Vehicle Messages, Vasudevan, et al (2016)

Figure 20. Illustration of Converting Vehicle Trajectories into Performance Measures

By using a simulation based SSM approach, the team will be able to test various scenarios and to obtain large amounts of conflict data that will enable the conduct of a statistically robust analysis of the safety benefits of the deployed CV applications.

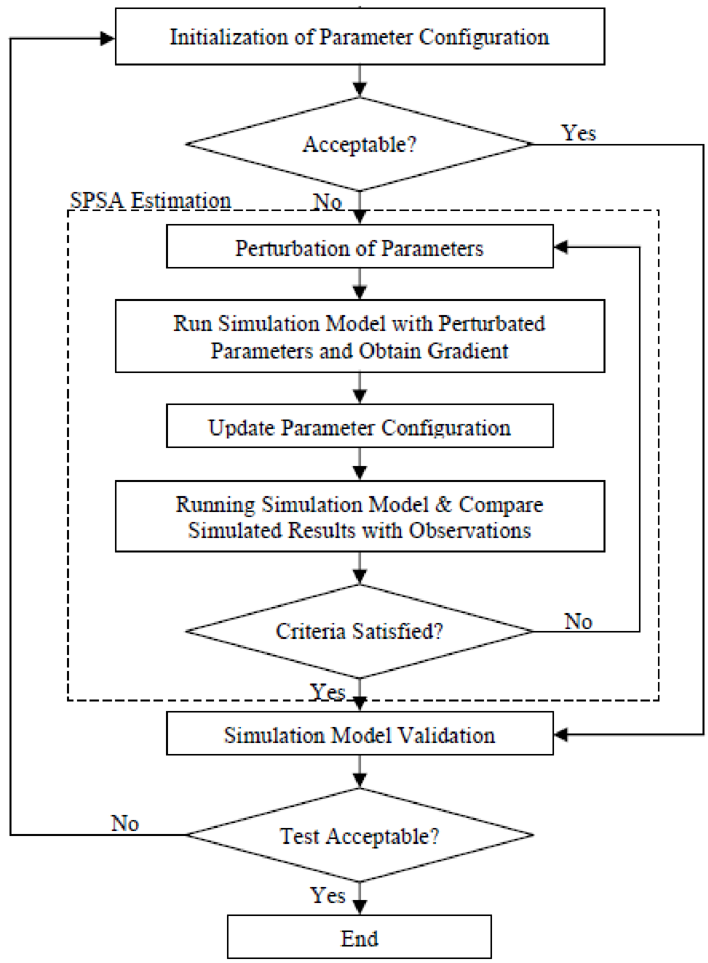
Each scenario has to be tested under a range of realistic demand and environmental conditions that account for the varying operational conditions present in the field. One way to do that is to just run the simulation for certain conditions (such as a peak period), although it is preferable to also test under various weather and incident conditions that are commonly seen in the field. In this study, it is essential to consider different operational conditions. According to the Traffic Analysis Tools Volume III 2019 Update, such operational conditions are identified by a combination of demand levels and patterns (e.g., low, medium or high demand), weather (e.g., clear, rain, snow, ice, fog, poor visibility), incident (e.g., no impact, medium impact, high impact), and other planned disruptions (e.g., work zones, special events) that impact system performance (e.g. travel times, bottleneck throughput). The impacts of these operational conditions can be incorporated into the simulation in terms of changes in driver reaction times, deceleration rates, headway following distances, and varying traffic demands. The selection of the different sets of operating conditions (combinations of demand, weather, and incident conditions) will be completed in consultation with the cluster analysis that will be undertaken on the active (after) CV event warning data sets to support the non-safety analysis. Again, the purpose of this cluster analysis is to determine which operating conditions see the highest frequency of CV application warnings being issued in an attempt to better evaluate the CV pilot as deployed in NYC.

8.4.7 Simulation Calibration

A basic tenet of simulation modeling is that the model must be calibrated to the existing conditions (here without CV technology) prior to the simulation of the field observed changes. Generally, when a driver-vehicle unit (DVU) is generated in a simulation model, a set of parameters associated with the physical and behavioral information is assigned to it. For instance, the physical parameters include length and width of the vehicle, while behavioral parameters include driver awareness, reaction time, and so on.

The first step of calibration is to identify critical parameters, of which a stable configuration has to be determined. As shown previously in Figure 17, after determining critical parameters, the next step would be to initialize these critical parameters. Typically, default values are used for the initial run. If the simulation output using the initial parameter values is acceptable, the validation process will start since there is no need for further calibration. Otherwise, critical parameters will be calibrated first before validation.

Simulation calibration can be viewed as a process of minimizing the difference between simulated and observed traffic measures. Traditionally, only operational measures, such as traffic counts, travel time are used. But to conduct safety-oriented analysis, it is essential that safety-related measures, such as safety indicators, to be included in the calibration process, i.e., to include safety-related measures when calibrating to regular traffic conditions. To achieve acceptable calibration levels, this project proposes to use simultaneous perturbation stochastic approximation (SPSA) method as the calibration process (shown in Figure 21). This method starts by generating an initial parameter configuration. If this configuration is acceptable, then it will go straight to the validation process. If it is not acceptable then a new parameter configuration will be generated. After running the simulation with this new set of parameters, the algorithm will generate another parameter configuration by minimizing the difference between simulated measures and the observed ones. If the newly generated configuration is acceptable, then it will go to the validation process. If it is not, then it will continue to iterate until pre-specified stopping criteria are satisfied.



Source: NYCDOT, 2017

Figure 21. SPSA Flowchart

The validation process will then be conducted to validate the calibration results. If the simulation model meets the criteria for the validation, then the whole calibration/validation process will stop and the calibrated values will be used in the following before-after analysis process. If the results from the validation are unacceptable, this indicates that our parameter configuration is not appropriate. In this case, a new set of initialization parameters will be generated and the whole calibration process will be conducted again until the validation test criteria is met.

In addition, the changes in behavior arising from the adoption of the CV technology must be sufficiently incorporated into simulation tools. The CV pilot event record data will collect the individual vehicle traces from the ASDs (action logs) for both with and without active warnings which will capture changes in driver behavior resulting from the active warning from the ASD. This driver action data will be analyzed to modify default driver models used in the microscopic simulation. It is important to note that calibration and simulation models for different operational conditions will require additional data and effort since driver behavior will be highly affected by these operational conditions. Selection of which operational conditions to simulate will be determined given the data on hand to perform calibration adequately.

For each simulated scenario, there will be a need to conduct multiple runs with different random seeds to ensure the statistical significance (e.g., 95% confidence interval) of the simulation results given the stochastic nature of microscopic simulation and the variance of the data used to calibrate the simulation models. The number of random seed runs to be completed for each scenario will be developed to ensure statistical validity to the simulation models considering the variations in the observed traffic conditions to which the model was calibrated.

8.4.8 Simulation Based Before-After Safety Evaluation

As discussed above, the simulation-based method provides a controlled experiment environment. Traffic and geometric design features can be kept the same in the before and after periods. So, there is no need to include for complex confounding factors into the analysis. Thus, two methods can be used to conduct before-after safety evaluation under simulation test bed, namely naïve method, and hypothesis testing.

Naïve method is simply comparing the raw data of safety indicators collected in the before and after simulation models. Hypothesis testing is to go further in terms of the naïve method to test whether there are statistically significant changes in safety indicators. Metrics previously listed in Table 14 can now be calculated and can be evaluated using the above two methods.

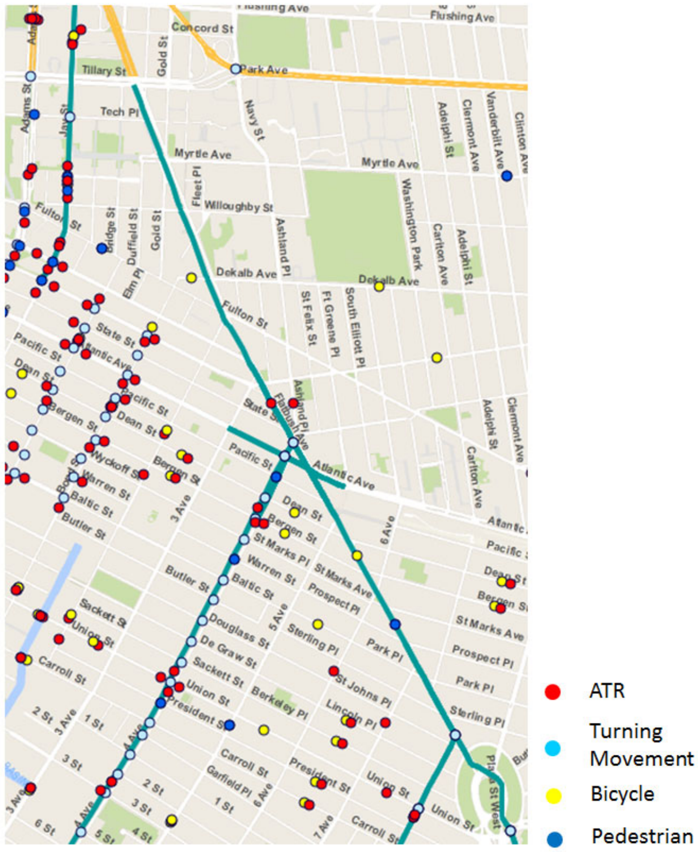
8.4.9 Transportation Data for SSM Model

8.4.9.1 Basic Road Network

Basic road network information, such as road network layout (lane count, channeling), signal timing, bus stops, parking facilities and so on, will be needed for simulation purposes. Detailed signal timings for the 28 signalized intersections located on Flatbush Avenue will be needed.

8.4.9.2 Traffic Volume and Speed

Traffic Information Management System (TIMS) is a data storage and a management system developed by NYCDOT. TIMS contains traffic volume data at various locations and various times along Flatbush Avenue. There are mainly four datasets that can be used for the simulation-based safety evaluation purpose, namely ATR data, vehicle turning movement counts, pedestrian counts, GPS travel speed runs. The locations of historical data points along Flatbush Avenue are shown in Figure 22. As for safety evaluation, more traffic volume data needs to be collected at various locations along Flatbush Avenue.



Source: NYCDOT, 2017

Figure 22. ATR Counts and Turning Movement Counts Locations

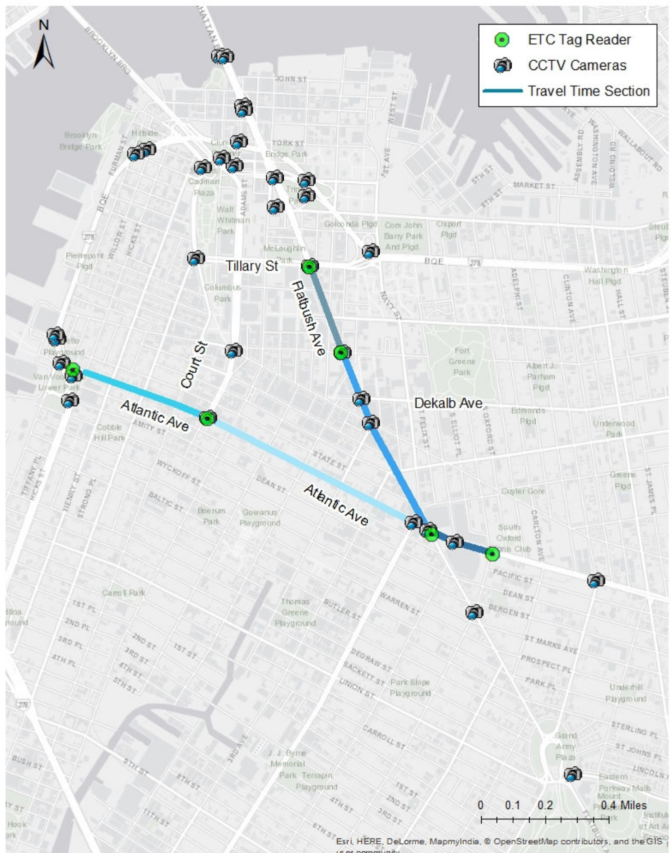
The input of simulation models include detailed turning movement counts for different vehicle types. Turning movement counts (TMCs) at each intersection level will also be needed. Camera feeds from NYC DOT may also be required to double check typical traffic conditions. Travel speed runs data (from GPS runs or from NYC TLC TLAP probe breadcrumb datasets) will be used for simulation calibration since speed is one of the key parameters of traffic simulation.

As for observational before-after analysis, if EB method is used, annual traffic counts and varies other traffic data are needed for all the reference sites and selected sites in order to estimate the expected number of crashes for selected sites in the after period if no CV warnings were deployed. If survival analysis method is used, longitudinal traffic data, such as monthly ADT, is needed. Additional data from the CV volume monitoring program may be needed to fulfill these requirements.

8.4.9.3 Travel Time

NYCDOT currently operates the Midtown In Motion (MIM) Active Traffic Management (ATM) system. Initially, this project targeted only a 110 square block are in Midtown, Manhattan. It then expanded to install more sensors at other parts of NYC, including Flatbush Avenue. Three types of sensors, including microwave sensors, ETC readers, and video cameras, were deployed to monitor traffic conditions. Microwave sensors are used to obtain flow and occupancy throughout the area and at critical locations. ETC readers are used for measuring per trip travel times in segments. Video cameras are used for verification and monitoring.

As mentioned above, segment travel times are collected using ETC tag readers deployed along the roadside. Individual per trip travel time is identified by matching the tag ID at the two ends of the trip. Four ETC Tag readers are installed along Flatbush Avenue area, which are shown in Figure 23. They are located at four intersections, namely Flatbush Avenue and Tillary Street, Flatbush Avenue and Willoughby Street, Flatbush Avenue and Atlantic Avenue, and Atlantic Avenue and S Portland Avenue. Different colors represent different travel time segments.



Source: NYCDOT, 2017

Figure 23. Locations of ETC Tag Readers and Cameras along Flatbush Avenue Area

8.4.9.4 Other Supplemental Data

Besides the data explained above, other supplemental data may be needed to comprehensively evaluate CV applications, such as taxi GPS data, MTA bus time data, weather data, incident logs, construction activity, event logs, and curbside activity. Please refer to previous sections of this report for descriptions of these datasets.

8.5 System Performance Simulation for Non-Safety Benefits

It is understood by the NYC CVPD project team that the level of data that can be observed or field measured for evaluating mobility benefits may be insufficient. The influence of the confounding factors will be difficult to isolate from the impacts of the CV application deployment under the before and after CV deployment periods. The deployment of a control group will help to assess these impacts, but it is still envisioned that a more robust way of isolating the CVPD benefits from those created by confounding factors. Therefore, to evaluate the performance evaluation plan for mobility improvement will include analysis using simulation modeling techniques instead of direct field observation.

In order to quantify benefits associated with changing driver behaviors on mobility related issues, system wide simulation modeling will be conducted. The Manhattan Traffic Model (MTM), an Aimsun based microscopic model covering Midtown Manhattan, will be utilized to simulate the operational conditions in the study area network both with and without CV app deployments, or more precisely, with and without changes in driver behaviors and signal operation changes observed before and after the CV mobility app deployments.

8.5.1 Microscopic Simulation of Large Networks

The microscopic simulation engine to be used for the non-safety impacts analysis of the CV Pilot is Aimsun. At each step in the simulation, individual vehicles may be rerouted to different paths based on network conditions (e.g., congestion) and driver characteristics (e.g., driver willingness to divert, availability of traffic information to the driver). These routing decisions are based on the evaluated generalized costs (e.g., travel time) of each potential path to the traveler's destination. Some drivers, designated as "informed," will be assumed to have perfect knowledge of real-time travel information (by means of a smartphone, global positioning system (GPS) device, etc.), and will dynamically route themselves through the network based on the currently evaluated shortest time paths to their destinations. Other drivers who are not considered to have access to real-time travel information in the simulation will evaluate whether to divert to alternate routes in the face of heavy congestion based on historical travel time information, which these drivers would have learned through experience.

The traffic assignment method within Aimsun allows the use of static and dynamic assignment methods based on requirements of different study types. Traffic assignment models are used to estimate the flow of traffic on a network. These models take as input a matrix of flows that indicate the volume of traffic between origin and destination (O-D) pairs. The flows for each O-D pair are loaded onto the network based on the travel time or impedance of the alternative paths that could carry this traffic. For traffic simulation models, the flow on a network is modeled by representing individual vehicle movements, and subsequently the link-based performance measures are evaluated based on movements of these individual vehicles as they rest in queues, travel in free flow, or maneuver through congestion. Whether all vehicles traveling a given path reach all links on the path within a given analysis period is dependent on time-variant travel conditions in the network.[5]

The key behavioral assumptions underlying the User Equilibrium (UE) assignment model are that every traveler has perfect information concerning the attributes of network alternatives, all travelers

[5] Aimsun Microsimulator and Mesosimulator User's Manual.

choose a route that minimizes their travel time or travel costs, and all travelers have the same valuations of network attributes. At UE, no individual travelers can unilaterally reduce their travel time by changing paths. A consequence of the UE principle is that all used paths for an O-D pair have the same minimum cost. An alternative and more realistic equilibrium model is known as Stochastic User Equilibrium or SUE. This model is premised on the assumption that travelers have imperfect information about network paths and/or vary in their perceptions of network attributes. At SUE, no travelers believe that they can increase their expected utility by choosing a different path. Because of variations in traveler perceptions and also in the level of service experienced, utilized paths do not necessarily have identical generalized costs. The SUE model is consistent with the concept of applying discrete choice models for the choice of route, but with the necessary aggregation and equilibrium solution.

8.5.2 Non-Safety Simulation Modeling Approach

The current MTM microscopic model covers the complete street network in Manhattan between 14th and 66th Streets from the Hudson River to the East River, as shown in Figure 24. As the original MTM model was originally developed to represent 2011 conditions and later updated for 2013 conditions, work was undertaken in Phase 2 CVPD efforts to update the MTM model to reflect observed 2018 conditions for typical weekday AM (6 AM to 9 AM) and PM (4 PM to 7 PM) peak periods. Through this effort the simulation network geometry was updated to reflect 2018 conditions and included updating all traffic signal timings and bus transit routes and schedules throughout the model. Demands were also revised to reflect recently collected traffic count data, and an overhaul of the for-hire vehicles simulated in the model was completed to reflect the changing for-hire market. This included leveraging new data sets available from the TLC for not only yellow and green cabs, but the private high volume for-hire operators as well. The model was then recalibrated to reflect the updated operational conditions of 2018. The recalibration of the MTM to 2018 conditions should well represent the before CV deployment conditions. Further details on the model update and calibration are presented in separate documents.

The MTM can be used to simulate network performance under a variety of recurring and non-recurring congestion scenarios. The NYC CVPD impacts on system performance as they relate to speed compliance can be estimated from ASD action log data and changes in speeding characteristics build into the MTM to model the CV impacts on mobility. The monetization of all of these user and system benefits can allow for a robust assessment of the impacts and cost effectiveness of the NYC CVPD deployment. Simulation outputs for performance measures such as delays, vehicle stops, travel times, roadway throughput, can be used to assess a wide variety of projects and conditions to evaluate mobility benefit attributed to CV deployment.

Source: NYCDOT, 2017

Figure 24. MTM Microscopic Model Geographic Extents

It is noted that additional ‘before CV’ models representing time periods for off-peak time periods may need to be developed beyond the typical weekday peak conditions, as well as other operational conditions such as crash conditions, or adverse weather impacts. The expectation is that the CV applications will provide the most benefits outside of the peak periods. Since the peak periods in NYC see significant congestion and slow travel speeds, the effectiveness of the CV applications being deployed are expected to provide more relevant warnings in the peak period shoulder hours, when travel volumes are still at relatively higher levels, but speeds are higher and more variable, or in the overnight hours when vehicles travel a much higher speeds and when crashes do occur they are generally more severe in nature. After an analysis of the CV application data in Phase 3 is completed to determine what set of operating conditions need to be analyzed (see discussion below), those additional time periods to represent the ‘before CV’ conditions will be developed.

To analyze the post deployment conditions, the updated MTM will also need to be further modified to reflect the changes as observed through analysis of potential changes in driver behaviors between the silent and active CV data sets. Since this data will contain a level of detail that is not available through traditional data collection means, the changes in behaviors observed in the CV data set will be used to further refine the driver characteristics of the before CV conditions (silent data) and the model will be revisited and fine-tune refinements of the calibration will be completed as needed. Following this step, after CV conditions (active data) will then be compared to the before CV datasets, changes in key parameters (headways, reaction times under emergency braking conditions, acceleration/deceleration rates, and other trajectory level information will be determined, and a new CV vehicle type will be defined within the MTM model framework. This will allow a subset of the simulated driver population (a percentage that matches the equipped vehicle market penetration rate) to be simulated using the modified CV vehicle type parameters. By conducting the same simulations with and without this subset of vehicles assigned to either the 'normal' or the CV vehicle types, the systemwide impacts of the CV deployment can be estimated.

Simulation outputs for performance measures such as delays, vehicle stops, travel times, roadway throughput, can be used to assess a wide variety of projects and conditions to evaluate mobility benefit attributed to CV deployment. The model outputs can also be used to feed as inputs into an emissions modeling process as well. The monetization of all of these user and system benefits can allow for a robust assessment of the impacts and cost effectiveness of the NYC CV Pilot deployment.

The updated MTM can be used to simulate network performance under a variety of both recurring and non-recurring congestion scenarios. Additionally, these scenarios can be further adjusted to simulate the forecasted changes in crash severity (and thus a decrease in clearance times) or even outright prevented crashes. These changes, when run over multiple crash conditions and annualized impacts are estimated using the observed changes in crash rates and/or the forecasted change in crash probabilities as developed from the safety surrogate measure simulations, the overall reliability impacts of the CV deployment on the systemwide vehicle population can be estimated.

In addition to mobility and reliability impacts, emissions impacts can be estimated for a variety of simulated conditions for both with and without CV deployment using mobile emission estimations engines (e.g., MOVES) with the simulated conditions and output of the MTM. This will be the primary source for estimating the emission impacts of the CV Pilot, as field measurements of emissions will not be undertaken.

To summarized, the following model parameters and processes envisioned to be modified in this approach include:

- Use the field data to determine the impact of CV apps on "driver behavior" from silent and active warning period data.
- Generalized driver reaction times (e.g., aggressiveness on signal clearance or reaction to yellow signals).
- Learned driver behavior (reduced speeding occurrences, revised speed limit adherence distribution).
- Update and calibrate CV sub-vehicle types in the model to reflect observed changes within the collected data.
- Retain non-CV vehicle types calibrated to either silent data or non-CV field measurements.

Worksteps in the proposed non-safety simulation analysis methodology to be completed in Phase 3 include:

1. Extend the updated weekday peak period MTM Aimsun micro-simulation model into other time periods or operating conditions to complete a set of models to represent the before CV deployment conditions. Note that the 'Before CV' conditions refer to anything that is fully absent of any influence of the deployment of the CV devices. For data collected explicitly from CV devices, this equates to data collected only the during the silent period. For data not collected via deployed CV devices, this may include Phase 2 (or even earlier) and the Phase 3 silent period.
2. Collect and analyze event records comparing the without CV conditions (both before period silent ASDs, and after period control group ASDs) and the with CV conditions (active ASDs) to determine behavior impacts or responses to the CV app warnings.
3. Collect and analyze field-observed mobility data (both CV and non-CV based).
4. Modify vehicle/driver behavior parameters in the simulation to reflect changes in aggregate behavior seen after CV deployment (reaction times, speeding distributions by road type, etc.).
5. Validate the changes to driver behavior settings by comparing the changes in mobility metrics (travel times and speeds) from the field measured before and after CV deployment to the simulated before and after CV deployment.
6. Based on SSM simulations and crash data analysis, determine likelihood of prevented crashes, or reduced severity crashes.
7. Develop list of crash events to test in the non-safety simulation model under "without CV" and "with CV" conditions; to include a cluster analysis of crash records and examination of the frequency of different CV application warnings and the anticipated crash prevention impacts.
8. Compare "with CV" and "without CV" to determine changes in systemwide metrics of reduced crash events created by CV Pilot deployment.
9. Compute non-safety impacts by comparing with and without CV simulations:
   a. Estimate mobility impacts (delays, travel times).
   b. Estimate reliability impacts (travel time distributions).
   c. Estimate emissions impacts (MOVES).
10. Monetize and annualize benefits and compare to costs.

It is noted that the above methodology will only produce a model covering the Manhattan portions of the CV deployment area. The NYC CV pilot team is attempting to focus simulation resources to look at those conditions (and locations) which receive the most CV warnings. Instead, the performance measures that will not be collected via simulation will still be computed and used to evaluate the CV deployment.

If the number of received CV warnings indicate the Brooklyn corridors as one of the more active CV locations, then a model of the Brooklyn CV corridors may be created in addition to the Manhattan model. Another ongoing NYC DOT effort has recently developed an Aimsun model for Brooklyn, and some portions which are microsimulation based could be leveraged for the CV pilot evaluation. Alternatively, the Flatbush Avenue model that are planned to be developed for the safety evaluations could also be leveraged to extract non-safety performance measures as well.

8.5.3 Impact Assessment of Confounding Factors and Identification of Operational Conditions for AMS

As discussed in Section 5, the NYC team has evaluated the relative impact and expected frequency of expected confounding factors on the overall system performance of the city and the study area roadways. The High/medium-impact and high/medium-frequency confounding factors potentially for inclusion as components of the operational conditions in the non-safety analysis of impacts resulting from the CV Pilot, in order of most importance:

- Traffic Demand Variations
- Accidents and Incidents
- Weather Events
- Work Zones (Short Term or Unplanned)

The intent is not to simulation the impacts of these confounding factors in isolation, but instead allow specific combinations of these to define the operational conditions under which the CV deployment will be evaluated. Other important factors in the design and selection of the analysis scenarios relate to changes in the driver performance data coming from the ASD Action Logs as well as which types of alerts are being issued the most. The intersection of these would be targeted to determine which scenarios to include in the analysis. It is likely that most alerts occur in the shoulders and off-peak conditions when speeds are higher but roads are still heavily traveled.

The goal of the simulation analysis will be to target those conditions where the CV technology provides the most warnings or benefits to better estimate the overall system impacts of the CV deployment. As many combinations of scenarios that can be analyzed will be simulated, but the overall resources available for analysis of the evaluation will be a limiting factor. As a result, the actual number of operational conditions and scenarios to be analyzed will be determined at a later date when the full set of CV data is available and a cluster analysis on the after CV data can be conducted.

8.5.4 Cluster Simulation Approach

Due to the uncertainties regarding the conditions under which the CV application warnings will be triggered most frequently, the specific operating conditions that will need to be modeled for evaluation purposes is unknown. Cluster analysis of the after CV period data will be employed to characterize different operational conditions in the study area and the frequency of CV applications warnings produced in those conditions, as well as the frequency of occurrence of these conditions across a typical year in NYC. The most impactful (those with most frequent CV warnings issued) clusters of operational conditions will be analyzed and then compared to the without CV simulated alternatives. These comparisons will facilitate the evaluation of impacts of the CV Pilot system on the study area. For each one of the most impactful and frequent clusters, a representative ‘after CV’ day will be selected as a representative for that cluster and the available mobility data for that day will be used to help refine the model to represent that particular day’s conditions. This will provide simulated basis for performance metrics for the ‘after CV’ conditions.

As a point of comparison, we must also have a simulated ‘before CV’ condition to track changes in metrics that we can associate as the impacts of the deployed CV technologies. However, we must also be comfortable that the variations between these two simulated data sets are indeed the result of the CV technology and not due to variations in performance from confounding factors that cannot be properly measured or from the inherent stochastic noise of the simulation analysis process itself. To address these uncertainties, the following set of contingency analysis plans have been developed. The team will assess the applicability of these plans in a stepwise fashion after data is available to ensure that the simulation analysis remains statistically sound and a defensible method to assess the non-safety impacts of the CV deployment.

8.5.4.1 Plan A: Unique 'Before CV' Representative Dataset

The preferred approach to produce the 'before CV' performance metrics for each cluster would be to use a separate observed dataset from the same cluster of operational conditions from the 'before CV' period as a point of comparison. Under this plan, the simulation model would be updated and refined to reflect the conditions of the 'before CV' period, and the simulated performance metrics from the before and after conditions can be compared and inferred as the impacts of the CV deployment.

However, in an environment as dynamic as New York City the numerous confounding factors listed above are changing rapidly and the recording specifics of such confounding factors are either very difficult (such as detailed volume data or unrecorded short term incidents like double parking, taxi / for hire pick-ups & drop-offs, or utility construction) or are not able to be recorded for privacy concerns (such as alignment of recorded incidents or crash details against the CV trajectory action logs). These factors will produce a very wide range of conditions. Combined with the anticipated low impacts on general mobility associated with the mostly safety-focused CV applications being deployed, the NYC CV Team has concerns over the noisy day to day variations in NYC operations versus the observable CV impacts. These concerns will need to be overcome before this method for CV impact is utilized.

8.5.4.2 Plan B: Remove CV Behaviors from the 'After CV' Model

While less preferred, an alternative for comparison is to simulate the identical set of operational conditions, including volume demands, weather, incidents, crashes, etc. but without the 'after CV' behaviors included in the driver behaviors. While more theoretical in design, this allows for a direct assessment of the CV impacts to non-safety network performance based on the observed changes in driver behaviors through direct comparison of the field recorded before and after CV action logs datasets.

This method assumes that the changes in the driver behaviors (e.g., reaction times, vehicle headways, speed limit adherence, acceleration or deceleration rates) can be observed in the action log datasets and can be properly represented via modifications to the simulation model's underlying driver behavior models. This method also assumes that the stochastic noise of the simulation model itself is less than the measurable signal of the changes in the non-safety CV impacts. Both of these assumptions need to be verified before this method can be considered a viable alternative to assess the non-safety CV impacts of the NYC deployment.

8.5.4.3 Plan C: Derive Non-Safety CV Impacts from Crash Prevention

Should both the above plans be determined infeasible, a fallback plan for analysis will be undertaken. Under this plan, the non-safety impacts of the CV deployment will be assessed not as a result of the changing driver behaviors from the CV deployment, but instead via the secondary, non-safety impacts from the reduction in crash frequency or crash severity that the CV deployment can achieve. The level of anticipated improvements would be based on the safety impacts assessment of an empirical crash data before and after comparison, or from the safety surrogate measures simulation analyses that will be completed.

Those anticipated improvements in crash conditions can then be assessed from a comparison of the performance metrics from the before CV crash simulation to the after CV crash simulation to derive the non-safety benefits. The after CV crash simulation would then be an alteration of the before CV crash simulation by either outright removing the crash from the simulation or through the simulating same crash but with a reduced clearance time associated with a reduced severity crash. Under this plan, the net changes on mobility, reliability, and emissions associated across the NYC network from the CV deployment can still be assessed over the duration of the CV deployment.

This section provides an overview of the non-safety performance measures that will be computed and compared between simulation model outputs. These metrics are intended to compliment the real-world field measured metrics from the CV deployment and to assist in the overall evaluation of the NYC CV Pilot Deployment.

8.5.5 Overview of Performance Measures

Overall, the non-safety performance measures computed from the simulation models will focus on the following key areas:

8.5.5.1 Mobility

Mobility describes how well the Pilot areas move people and freight. The mobility performance measures are readily forecast. Three primary types of measures are typically used to quantify mobility, including:

- **Travel time –** This is defined as the average travel time for the study area by facility type (e.g., avenue, cross street, freeway) and by direction of travel. Travel times are computed for the analysis period.
- **Delay –** This is defined as the total observed travel time less the travel time under uncongested conditions and is reported both in terms of vehicle-hours and person-hours of delay. Delays are calculated for freeway mainline and HOV facilities, transit, and surface streets.
- **Throughput –** Throughput is measured by comparing the total number of vehicles entering the network and reaching their destination within the simulation time period. The measure ensures that the throughput of the entire system can be utilized as a performance measure for all the scenarios. The corresponding VMT, Person Miles of Travel (PMT), Vehicle Hours Traveled (VHT), and Person Hours Traveled (PHT) are reported as a macroscopic measure of the general mobility of the corridor.

8.5.5.2 Reliability and Variability of Travel Time

Reliability and variability capture the relative predictability of the public's travel time. Unlike mobility, which measures how many people are moving at what rate, the reliability/variability measures focus on how much mobility varies from day to day.

8.5.5.3 Emissions and Fuel Consumption

The analysis will also produce model outputs to estimate emissions and fuel consumption, associated with the deployment of CV strategies. The emissions analysis methodology will incorporate reference values to identify the emissions and fuel consumption rates based on variables, such as facility type, vehicle mix, and travel speed. Emissions will be computed by pollutant, mode, and facility type. Fuel consumption will be computed by fuel type, mode, and facility type.

8.5.5.4 Cost Estimation

For the identified CV strategies, costs will be expressed in terms of the net present values the NYC CV Pilot team will develop planning-level cost estimates for life-cycle costs and are defined as follows:

- **Capital costs –** Include up-front costs necessary to procure and install CV equipment. These costs are shown as a total (one-time) expenditure that includes the capital equipment costs, as well as the soft costs required for design and installation of the equipment.
- **Operations and Maintenance (O&M) costs –** Include those continuing costs necessary to operate and maintain the deployed equipment, including labor costs. While these costs do contain provisions for upkeep and replacement of minor components of the system, they do not contain provisions for wholesale replacement of the equipment when it reaches the end of its useful life. These O&M costs are presented as annual estimates.
- **Annualized costs –** Represent the average annual expenditure that would be expected in order to deploy, operate, and maintain the CV improvement; and replace (or redeploy) the equipment as they reach the end of their useful life. Within this cost figure, the capital cost of the equipment is amortized over the anticipated life of each individual piece of equipment. This annualized figure is added with the reoccurring annual O&M cost to produce the annualized cost figure. This figure is particularly useful in estimating the long-term budgetary impacts of CV deployments.

Within each of the capital, O&M, and annualized cost estimates, the costs are further disaggregated to show the infrastructure and incremental costs. These are defined as follows:

- **Infrastructure costs –** Include the basic "backbone" infrastructure equipment necessary to enable the system.
- **Incremental costs –** Include the costs necessary to add additional elements/components to the deployment.

Structuring the cost data in this framework provides the ability to readily scale the cost estimates to the size of potential deployments. Infrastructure costs would be incurred for any new technology deployment. Incremental costs would be multiplied with the appropriate unit (e.g., number of intersections equipped, etc.); and added to the infrastructure costs to determine the total estimated cost of the deployment. The costs will be estimated for each scenario and a benefit/cost ratio will be assigned to all the individual performance measures.

8.5.6 Benefit Monetization

Following the computation of the above metrics, the resulting benefits from the CV deployment will be converted from their individual units into a monetary value to allow for a comparison between each other and to compare to the overall system costs of the deployment. Values of time (by vehicle type), crash costs, fuel costs, and emissions costs as listed in Table 17 below will be used to convert the various systemwide benefits into a dollar value, allowing for a more direction comparison to the anticipated costs of the deployment.

Table 17. Benefit Monetization Metrics from NYC CV Pilot Deployment

Benefit Quantity	Monetization Parameter(s)
Time Savings[6]	\$16.23 per hour for persons in buses and private autos. \$32.46 per hour for freight operators.
Crash Savings[7]	\$70,500 per crash.
Emissions Savings[8]	CO: \$75 per ton. CO_2: \$23 per ton. NO_X: \$17,300 per ton. PM_{10}: \$139,900 per ton. SO_X: \$69,800 per ton. VOC: \$1,210 per ton. $PM_{2.5}$: \$277,359 per ton.
Fuel Savings[9]	\$2.63 per gallon.

These values were used in a recently completed ICM Concept of Operations study for the I-495 Corridor in New York City, except for fuel costs which were recently obtained. The values are taken from different local, other state, and national averages based on a preliminary review of such data; should more localized values or more recently computed estimates become available, they will be considered for use in place of these values.

[6] TOPS-BC Version 1.2, default values of time.
[7] Cal-B/C Version 5, composite value of a crash across all crash categories and area types, http://www.dot.ca.gov/hq/tpp/offices/eab/LCBC_Analysis_Model.html (accessed 12-20-2016)
[8] Non PM2.5 values: Cal-B/C Version 5, http://www.dot.ca.gov/hq/tpp/offices/eab/LCBC_Analysis_Model.html (accessed 12-20-2016);
PM2.5 value: *Transportation Cost and Benefit Analysis II – Air Pollution Costs*. Victoria Transport Policy Institute. Table 5.10.4-1, http://healthpolicy.ucla.edu/Documents/Newsroom%20PDF/tca0510.pdf (accessed 2-8-2017)
[9] https://www.nyserda.ny.gov/Researchers-and-Policymakers/Energy-Prices/Motor-Gasoline/Monthly-Average-Motor-Gasoline-Prices (Jan - Oct 2019 NYC average price for regular grade motor gasoline)

9 Performance Reporting

The system performance will be observed through the use of reports that reflect data aggregated at different time horizons – both for short term (for e.g., daily) and longer term (for e.g., monthly or longer). These reports will be integrated into different dashboards designed to serve various hierarchical user groups to serve daily operations by the internal NYCDOT CV Pilot team (TMC operators, CV Pilot management team) and longer-term reporting of the operations and performance of the CV pilot for both internal (NYCDOT engineers, NYCDOT decision makers and upper management) and external (stakeholders, USDOT and its Independent Evaluator, external researchers). These dashboards will be viewable by the respective parties (pending credential checks) as desired via a web-based portal and updated daily.

Some of the performance metrics in dashboards and the system performance reports will include system operations data and the CV application performance data. System operations data will include such information as the number of ASD and RSU devices deployed in the field, the reliability of the operations of the RSUs, and the number of ASDs which communicate with the TMC. CV application performance metrics would include tallies of the number of ASD application warnings generated by application, and the number of interactions (sightings only, not warnings) between ASDs and RSUs across the city. Additionally, depending on the level of credentials used to access the site, different levels of information would be presented. For example, details of the operations of specific RSUs would likely only be presented to the TMC operators and the CV Pilot management team within NYCDOT, while more aggregated metrics of the same data (not RSU specific) could be provided to external stakeholder users.

The full design of the dashboards and system performance report is still pending completion, and further updates will be made in Phase 3.

In addition to the system monitoring and dashboard reporting, the final results of the simulation-based assessments of impacts of the CV pilot deployment will be summarized and shared at the end of the evaluation period in an overall evaluation report. These results will be presented in a multitude of ways for consumption by different interested parties, including a high-level summary of the deployment impacts for consumption by non-technical persons, while a more in-depth analysis report will be generated for traffic professionals. Given the nature of the simulation efforts and the more robust and involved overall evaluation of the pilot deployment, this will take the form of a project evaluation report which would be completed at the end of Phase 3.

10 Support to Independent Evaluation (IE) Effort

The NYC CVPD team will work with the USDOT and its selected Independent Evaluation (ID) contractor to provide the data from the NYC CVPD site and evaluation. All obfuscated CV data sets used by the NYC CVPD team for the evaluation of the pilot will be shared with the IE team via the Secure Data Commons (SDC). It is expected that daily batch uploads of the obfuscated data records will be uploaded to the SDC for use by the independent evaluators.

All historic (non real-time) data sets collected for the CV Pilot evaluation will also be shared with the IE via the SDC. The data will only be modified to remove any PII elements, and will not be obfuscated further; however, the data will also not be able to be fused or joined to the obfuscated CV data records. Depending on the nature of the data sets, this data could be shared daily at the fastest, or more periodically (e.g., monthly) via manual uploads.

Finally, other work completed during either Phase 2 or 3 of the pilot, including developed simulation models, analysis algorithms and scripts, and other field measured data sources that are used in the performance evaluation of the NYC CVPD will also be provided for review and by the IE.

The NYC CVPD team has been committed to working with the IE to determine what addition data elements that are not currently outlined to be collected could be collected, providing that the underlying need to exclude any PII data is satisfied. Appendix F lists the identified data needs by the USDOT CV team during Phase 1 of the pilot for both safety and non-safety focus area and includes the anticipated level of support for the IE team that the NYC CVPD team can provide. The team has also worked with the IE to allow access to the study corridor and the installed systems to review the deployed system as it has been installed and tested over Phase 2.

11 Data Sharing Framework

A data sharing framework has been developed and delivered as part of the Performance Measurement of the NYC CVPD, using both the USDOT's Secure Data Commons (SDC) and the ITS DataHub. The recipients of the data shared via this framework includes the USDOT and its independent evaluators working on the connected vehicle initiative (via the SDC) and the larger connected vehicle research community via the ITS DataHub . This section describes the plans for sharing performance and evaluation data from the NYC CVPD.

11.1 The Data

As part of the NYC CV Pilot, the data being collected can be grouped into two categories based on the data source – intrinsic and extrinsic. The former is data collected by the CV components (the ASDs, RSUs, and PIDs) and the latter is data from external sources (such as traffic control system data, incidents, crash statistics, weather data, traffic counts, travel times and speeds, etc.). Each of these data sets are described in Section 7 of this report.

As discussed earlier in this report, the raw data collected from the ASDs, RSUs, and PIDs will not be shared outside of the NYCDOT TMC and the NYC CVPD team. Instead, the data will be processed at the NYCDOT TMC and scrubbed to remove any PII (personally identifiable information) using the data obfuscation techniques outlined in Section 7.4. Following the obfuscation process, the raw data will be destroyed, leaving only the obfuscated data records (for ASD action log data) or the aggregated performance metric data (the PID data). RSU sightings of ASDs will be processed and used to compute travel time data which will be shared without obfuscation.

Both the disaggregated obfuscated data and aggregated processed performance metrics data will be shared with the USDOT and the independent evaluator for their evaluation of the CVPD. The disaggregated data will be uploaded on a regular basis, which is currently expected to occur daily to weekly. The aggregated data with the various measures will be uploaded on a monthly or quarterly basis.

The same data will also be shared with the larger research community, but before that data share is permitted, additional screening may be done to remove access to certain time and location bins with very few data samples. Additionally, some confounding data sets shared with USDOT that are not currently publicly released by NYC DOT or its partners cannot be shared with the larger research community. This step is required to maintain the privacy requirements of the stakeholder data that the obfuscation process was created to ensure occurs.

11.2 Data and Privacy

The data being collected by the NYC CV Pilot is owned by the individual stakeholders. The use and sharing of the data will be governed by the agreements (MOUs) between NYCDOT and the stakeholders. The guiding principles of these agreements are that the data will be obfuscated to remove any PII, and that the data is being collected to evaluate the system performance related to safety, consistent with NYCDOT's Vision Zero initiatives. The use of the data by the USDOT and the research community via the ITS DataHub should also respect the principles of privacy contained within those signed agreements.

11.3 Data Transmission

Details of the data transmission process are current under discussion with the ITS DataHub team and the NYC CVPD team. While details are yet to be finalized, the data exchange is expected to be completed using compressed files in batch uploads so that the data package transmittal is manageable and reduces the upload costs. It is anticipated that there will be two levels of upload frequencies for the data – more frequent (daily uploads), and less frequent (monthly or longer term).

The disaggregated cleansed data from both the CV and non-CV based sources, will be uploaded in daily batches, as the data processing, cleaning, fusion to confounding factor data, and obfuscation processing (as needed) is completed. The processed aggregated data will be uploaded on either a monthly or as-needed time frame, depending on the nature of the data that is to be uploaded.

12 Conclusions

This document describes the Performance Measurement and Evaluation Support Plan for the New York City Department of Transportation New York City (NYC) Connected Vehicle Pilot Deployment (CVPD) Project during Phase 2 of the pilot. The report documents the performance metrics that will be used to assess the success of the NYC CVPD project, the targets for improvement in those performance metrics, the data collection process, and the experimental design and analytical processes that will be undertaken to evaluate the impacts of the NYC CVPD project in meeting its objectives of preventing and reducing the severity of crashes on NYC's roadways. It also documents the data elements that will be provided to support the United States Department of Transportation (USDOT) independent evaluator and the data elements that will be provided to the research community via the ITS DataHub.

While the report documents the Performance Measurement and Evaluation Support Plan, it should be taken in context as one of several planning documents being prepared for the NYC CVPD project. Other planning, design, and deployment documents developed at the same time as this report are also available to provide further details on the NYC CVPD.

Appendix A: Glossary

Table 18 below defines the selected project-specific terms used throughout this Performance Measurement Evaluation Support Plan (PMESP).

Table 18. Glossary

Acronym/Abbreviation	Definition
ACDSS	Adaptive Control Decision Support System
ADT	Average Daily Traffic
API	Application Programming Interface
ASD	Aftermarket Safety Device
ASN.1	Abstract Syntax Notation.1
ASTC	Advanced Solid-state Traffic Controller (NYC standard traffic signal controller device)
ATC	Advance Traffic Controller (see ASTC)
ATM	Active Traffic Management
ATR	Automated Traffic Recorder
AVL	Automated Vehicle Location
BSM	Basic Safety Message
CAN	Controller Area Network
ConOps	Concept of Operations
CV	Connected Vehicle
CVPD	Connected Vehicle Pilot Deployment
DCAS	Department of Citywide Administrative Services
DSNY	New York City Department of Sanitation
DOT	Department of Transportation
DSRC	Dedicated Short Range Communications
EB	Empirical Bayes
ETC	Electronic Toll Collection
FHV	For-Hire Vehicle
FOIA	Freedom of Information Act
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HOV	High Occupancy Vehicle
I2V	Infrastructure to Vehicle
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
IRB	Independent Review Board
ITS	Intelligent Transportation System

Acronym/Abbreviation	Definition
JPO	Joint Program Office
KSI	Killed or Severally Injured
LPEP	Livery Passenger Enhancements Project
LTA	Left Turn Assist
MAP	Map Data Message (a DSRC message)
METAR	Meteorological Aerodrome Reports
MIM	Midtown-in-Motion
MOU	Memorandum of Understanding
MOVES	Motor Vehicle Emission Simulator
MPT	Maintenance and Protection of Traffic
MTA	Metropolitan Transportation Authority
MTM	Manhattan Traffic Model
NHTSA	National Highway Traffic Safety Administration
NWS	National Weather Service
NYC	New York City
NYCDOT	New York City Department of Transportation
NYCWiN	New York City Wireless Network
NYMTC	New York Metropolitan Transportation Council
NYPD	New York City Police Department
NYS	New York State
NYU	New York University
O&M	Operations & Maintenance
OBE	On-Board Equipment
OCMC	Office of Construction Mitigation and Coordination
OEM	Office of Emergency Management
OER	Office of Emergency Response
PANYNJ	Port Authority of New York and New Jersey
PHT	Person Hours Traveled
PID	Personal Information Device (e.g., SmartPhone)
PII	Personally Identifiable Information
PKI	Public Key Infrastructure
PMESP	Performance Measurement and Evaluation Support Plan
PMT	Person Miles of Travel
RF	Radio Frequency
RFID	Radio Frequency Identification
RSE	Roadside Equipment
RSU	Roadside Unit
SAE	Society of Automotive Engineers International
SAPO	Street Activity Permit Office
SBS	Select Bus Service
SDC	Secure Data Commons

Acronym/Abbreviation	Definition
SIP	Street Improvement Project
SPaT	Signal Phase and Timing (a DSRC message)
SPSA	Simultaneous Perturbation Stochastic Approximation
SSAM	Safety Surrogate Assessment Model
SSM	Safety Surrogate Measures
SUE	Stochastic User Equilibrium
SUMO	Simulation of Urban Mobility
TBD	To Be Determined
TIM	Traveler Information Message
TIMS	Traffic Information Management System
TLAP	Time Lapse Aerial Photography
TLC	New York City Taxi & Limousine Commission
TMC	Traffic Management Center
TPEP	Taxi Passenger Enhancements Project
TTC	Time to Collision
UE	User Equilibrium
UPS	United Parcel Service
USDOT	United States Department of Transportation
V2I (I2V)	Vehicle-to-Infrastructure (Infrastructure-to-Vehicle)
V2V	Vehicle-to-Vehicle
VHT	Vehicle Hours Traveled
VMT	Vehicle Miles Traveled
VZ	Vision Zero
VRU	Vulnerable Road User
WAVE	Wireless Access in Vehicular Environments
Wi-Fi	Wireless Fidelity (short to mid-range wireless network)
WSA	WAVE Service Advertisement
XML	eXtensible Markup Language

Appendix B: CV Vehicle Fleet Activity

Estimated Average Daily CV Vehicle Penetration Rates (2017 Data)

Table 19. Daily (AADT) VMT Estimates for NYC

Borough (County)	Vehicle Miles Traveled (VMT)
Bronx (Bronx)	9,211,000
Brooklyn (Kings)	13,393,000
Manhattan (New York)	8,860,000
Queens (Queens)	20,289,000
Staten Island (Richmond)	5,856,000
NYC Total	57,609,000

*Source: NYSDOT Highway Data Services, Vehicle Miles Traveled Report
https://www.dot.ny.gov/divisions/engineering/technical-services/hds-respository/Tab/Vehicle_Miles_of_Travel_2017_revised_2018-07-24.zip

Table 20. New York City Daily Vehicle Fleet Miles Traveled

	Light Vehicles	Medium Vehicles	Total Vehicles
Number of Vehicles*	3,844	1,296	5,140
Annual Miles Traveled	1,203,799	791,337	1,995,137
Annual Miles / Vehicle	7,518	6,193	7,184
Avg. Daily Miles / Vehicle	20.6	17.0	19.7

*Includes vehicles samples (total count) from the following agencies:
DCAS (2,386), DEP (917), DHMH (272), DOC (9), DOT (1,190), Parks (358), and DSNY (8)
*Source: NYC DOT DCAS, Local Law 75 Reports
https://www1.nyc.gov/assets/dcas/downloads/pdf/fleet/Local-Law-75-Report-on-Use-Based-Fuel-Economy-1-29-2019.pdf

Table 21. Estimated CV Pilot Market Penetration (City-wide average)

Performance Measure	#
Avg. Daily VMT per City Vehicle:	19.7
CV Fleet Size (vehicles):	3,000
Avg Daily VMT for All CV Vehicles:	59,044
Avg. Daily VMT in NYC (All Vehicles):	57,609,000
Avg. Daily CV Fleet Penetration Rate:	0.10%

Notes:

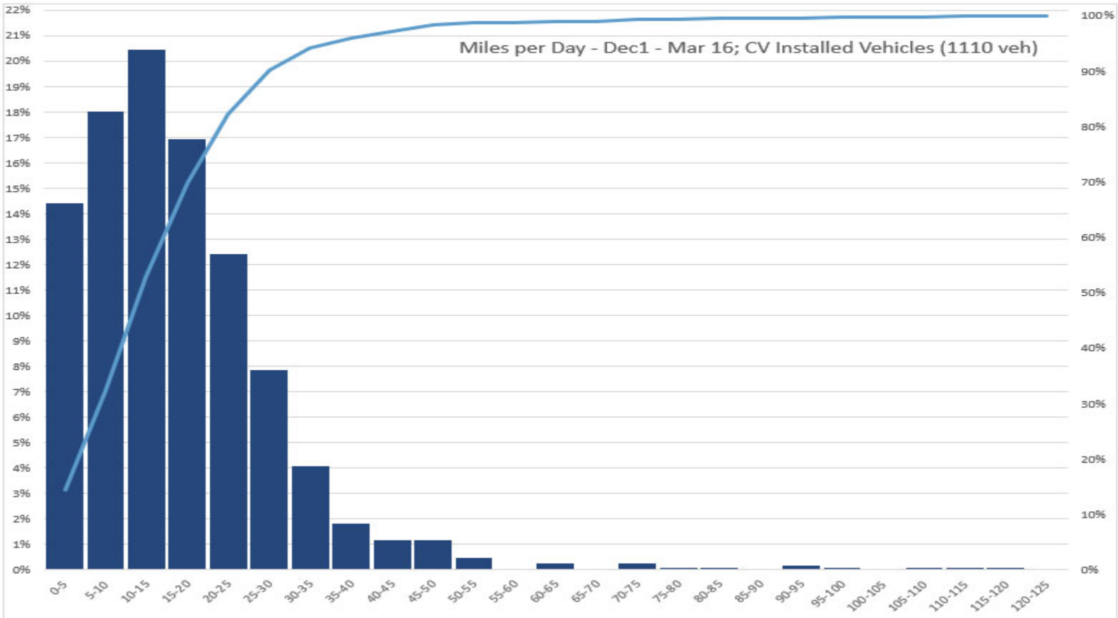
- Source data used is from 2017, the latest year for which all data sources are available. Noted that these values are all before the COVID-19 pandemic,
- Estimates for the Phase 3 evaluation period (2021) may see different penetration rates from both reduced general traffic flow changes and NYC fleet vehicle usage.

Many of the city owned vehicles are tracked as part of the city's fleet management system Geotab. The Geotab system allows general reporting of vehicle usage on a daily basis. GPS tracking is not fully possible, but the system does report locations for Exceptions. An exception can include periods of excessing idling, speeding, hard braking or accelerating, as well as events such as seatbelt alerts, indicators of needed vehicle service, unapproved after hours vehicle usage, or other such events.

The system is completely passive to the driver, and no driver alerts, warnings, or feedback are provided to the driver by the system. It is noted that in cases of repeated and excessive offenses of speeding or otherwise aggressive driving behaviors or abuses, a driver could be warned by their manager to improve, but such warnings are not common and are for the most abusive conditions only.

The majority of the city's CV equipped fleet is equipped with the Geotab system, but there are some that are not. The system can also be set to record events using basic some geofencing abilities, and all pilot RSUs have been added as geofenced locations to trigger alerts. The CVPD team has worked to be able to filter the Geotab data and reports to only include those vehicles which are equipped with ASDs.

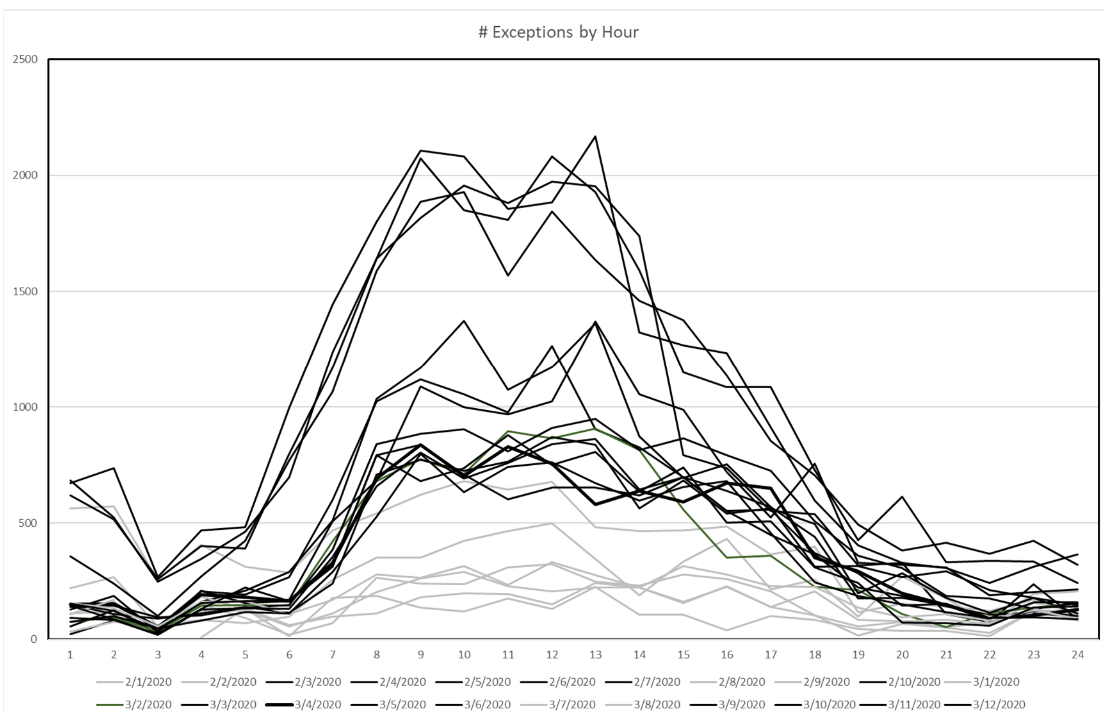
The following information is based on the Geotab data and reports, and it provides additional insights regarding the typical operations of the CV-equipped fleet vehicles for 2020 conditions. Data is presented for both under pre- and post-COVID impacted timeframes.



Note: Median = 14.3 miles traveled per day

Source: NYCDOT, 2017

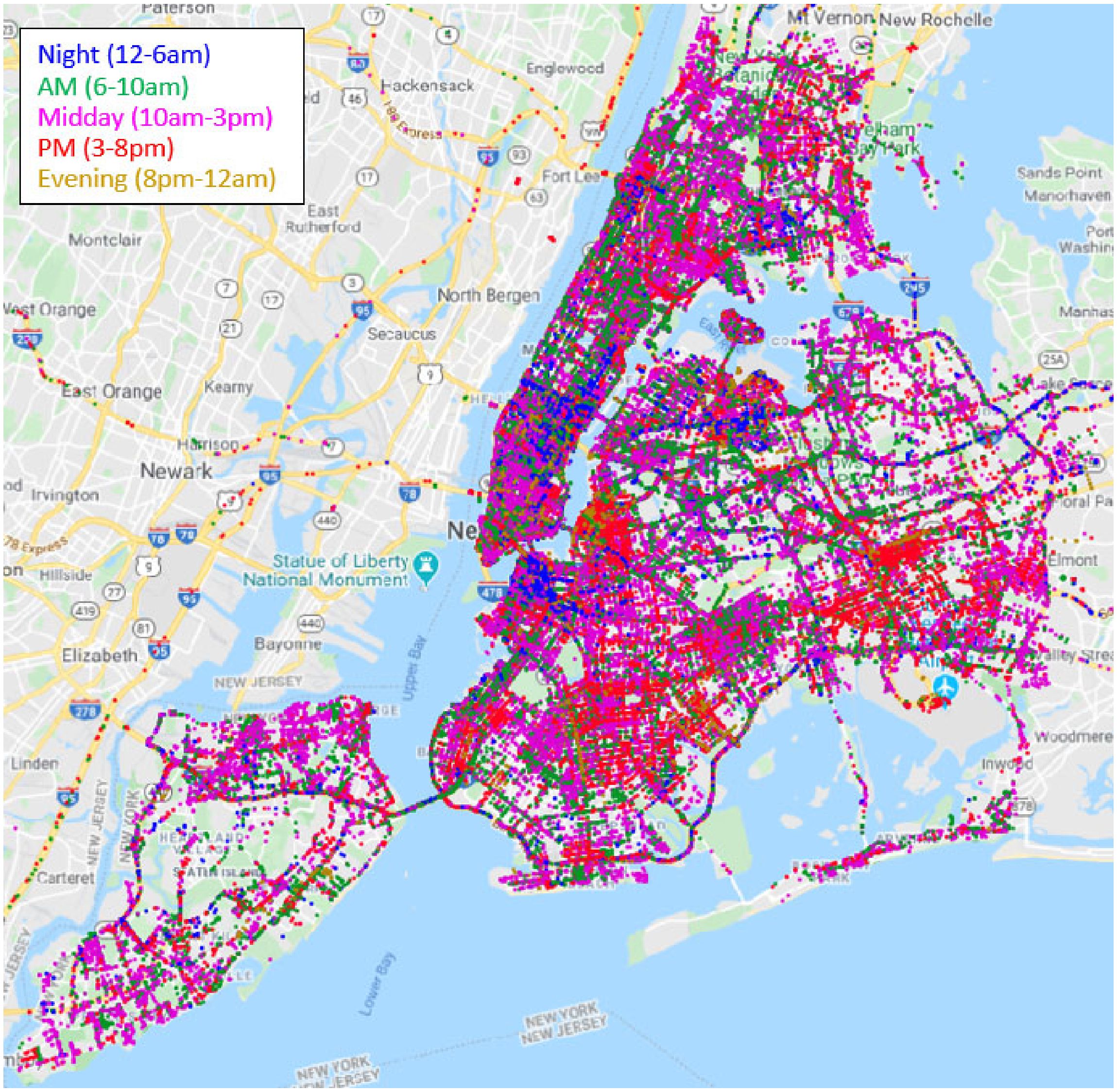
Figure 25. Distribution of Daily CV Fleet Vehicle Use during Pre-COVID Conditions: Dec 1, 2019 – March 16, 2020



Note: Black = Weekdays, Grey = Weekends

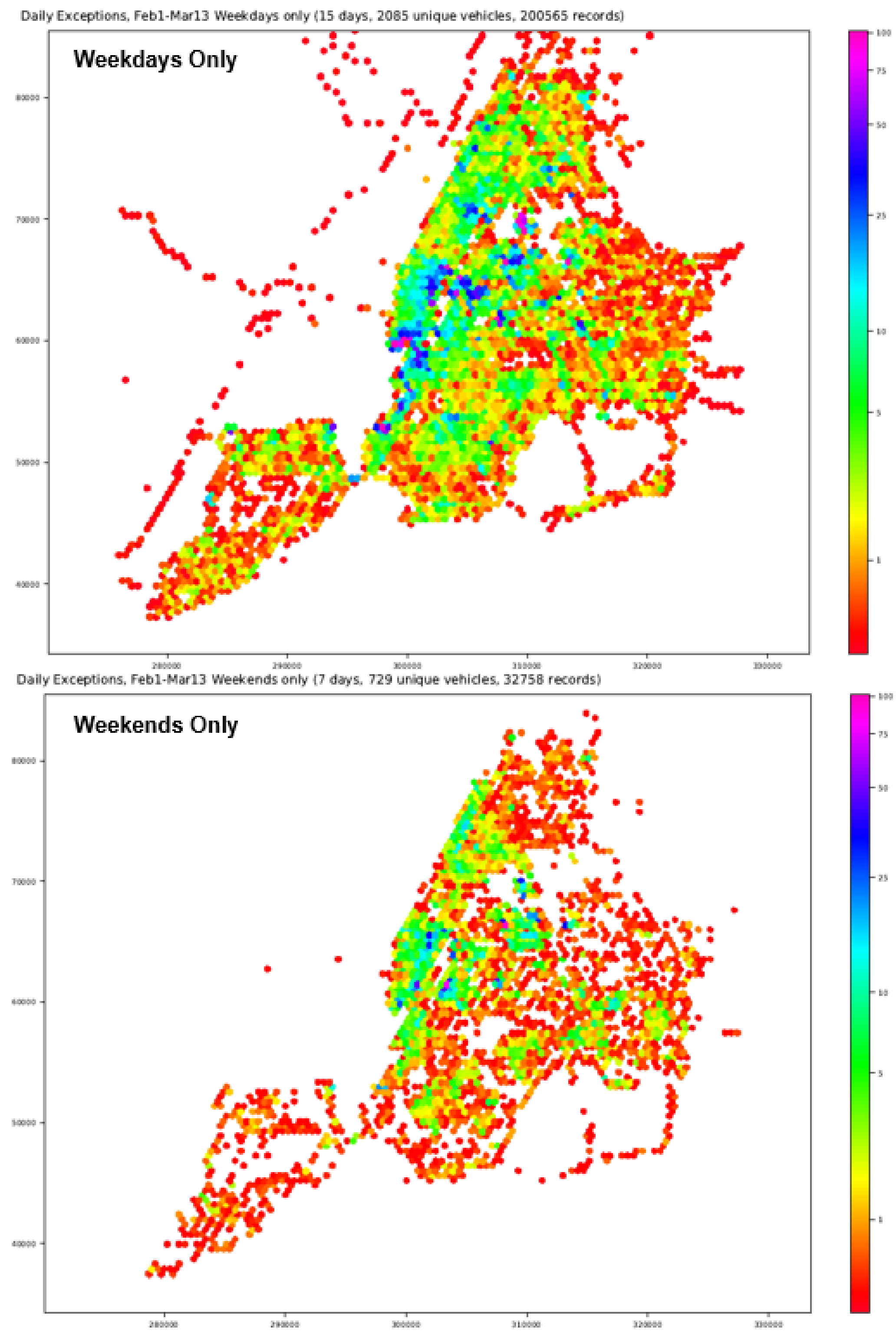
Source: NYCDOT, 2017

Figure 26. Temporal Profile of Daily Exceptions Per Hour during Pre-COVID Conditions: Data from February 1 - 10 and March 1 - 12, 2020



Source: NYCDOT, 2017

Figure 27. Locations of Exception Reports by Time of Day during Pre-COVID Conditions: Data from February 1 - 10 and March 1 - 12, 2020

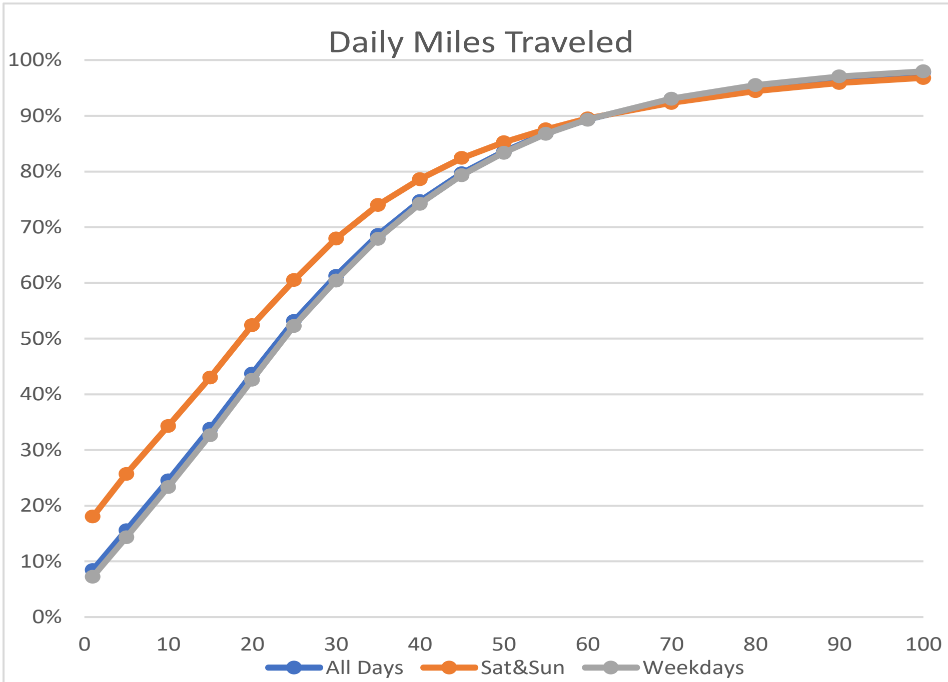


Source: NYCDOT, 2017

Figure 28. Locations of Daily Exception Reports by Day of Week during Pre-COVID Conditions: Data from February 1 - 10 and March 1 - 12, 2020

Table 22. Weekly Summary of CV Fleet Vehicle Operations during Post-COVID Conditions: Data from June 28 to October 10, 2020

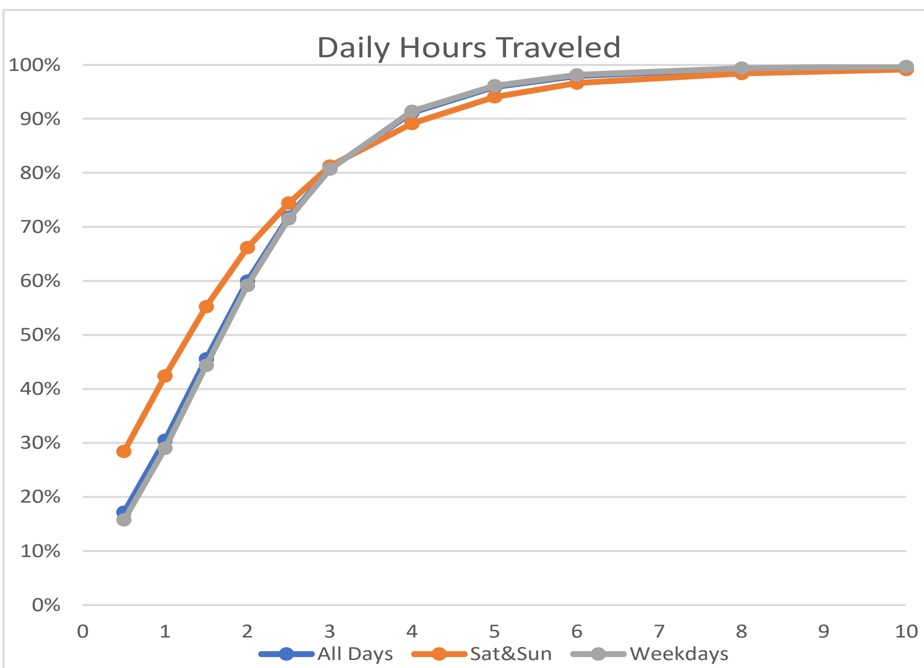
Week of Report (All 2020)	Vehicles Reporting	Weekly Hours Traveled	Avg Weekly Hours / Vehicle	Total Weekly Miles	Avg. Weekly Miles / Vehicle
June 28- July 4	1,090	7,529	6.9	115,051	105.6
July 5-11	1,100	8,313	7.6	127,418	115.8
July 12-18	1,109	8,591	7.7	127,350	114.8
July 19-25	1,131	8,512	7.5	130,903	115.7
July 26 -Aug. 1	1,110	8,487	7.6	130,540	117.6
Aug. 2-8	1,139	8,925	7.8	133,243	117.0
Aug. 9-15	1,116	9,146	8.2	140,821	126.2
Aug. 16-22	1,125	8,915	7.9	134,687	119.7
Aug. 23-29	1,126	8,720	7.7	130,876	116.2
Aug. 30-Sept. 5	1,153	8,878	7.7	132,304	114.7
Sept. 6-12	1,117	7,713	6.9	114,057	102.1
Sept. 13-19	1,168	9,152	7.8	138,198	118.3
Sept. 20-26	1,348	10,749	8.0	162,564	120.6
Sept. 27-Oct. 3	1,340	10,778	8.0	160,821	120.0
Oct. 4-10	1,442	11,421	7.9	171,236	118.7
Total		**135,829**		**2,050,069**	



Note: *Report includes only data from days where a vehicle was used.

Source: NYCDOT, 2017

Figure 29. Daily CV Fleet Vehicle Miles Traveled (VMT) during Post-COVID Conditions from July to September, 2020



Note: *Report includes only data from days where a vehicle was used.

Source: NYCDOT, 2017

Figure 30. Daily CV Fleet Vehicle Hours Traveled (VHT) during Post-COVID Conditions from July to September, 2020

Appendix C: CV Data Collection Specifications

The following presents the detailed specifications for the collection of CV based data from the ASD and RSU devices, current as of the date of this report.

NYC CVPD Event Format Specification

NYC CVPD Event Format Specification

Version 2.0 DRAFT

Oct 30, 2019

Updated: October 05, 2020

Document Number

TRANSCORE

Trusted Transportation Solutions

The following data dictionary specification is provided for the transmittal of Event Data from the ASD to the TMC. Data elements and frames not defined in this document can be referenced from the SAE International's J2735-201603 Dedicated Short Range Communications (DSRC) Message Set Dictionary.

1 Messages

1.1 MSG_NycCvpdEvent

This message collects the information for each event and puts it in a single structure. Sizes are not specified for the various lists as the maximum number of messages for an event cannot be reliability calculated.

ASN.1 Representation:

```
NycCvpdEvent ::= SEQUENCE {
        eventHeader     ,
        bsmList         SEQUENCE OF BSMEvent,
        mapList         SEQUENCE OF MAPEvent OPTIONAL,
        spatList        SEQUENCE OF SPaTEvent OPTIONAL,
        timList         SEQUENCE OF TIMEvent OPTIONAL,
        …
}
```

1.2 MSG_NycCvpdRSURF

This message collects the BSM messages used to evaluate the RF distribution around an RSU. The TMC
will pull this message back on a frequent basis to keep the effective size

small. NycCvpdRSURF ::= SEQUENCE OF BSMRecordRSURF

1.3 MSG_NycCvpdASDRF

This message collects the BSM, MAP, SPaT and TIM messages to evaluate the RF distribution around an
ASD.

```
NycCvpdASDRF::= SEQUENCE {
        asdSerialNumber     VisibleString,
        bsmRFList           SEQUENCE OF BSMRecordASDRF OPTIONAL,
        mapRFList           SEQUENCE OF MAPRecordRF OPTIONAL,
        spatRFList          SEQUENCE OF SPaTRecordRF OPTIONAL,
        timRFList           SEQUENCE OF TIMRecordRF OPTIONAL
        }
```

1.4 MSG_NycCvpdTravelTime

This message reports the BSMs for calculating travel time at the TMC. These will be the BSMs recorded when the vehicle is in the center of the intersection. This data is collected by the RSU.

```
NycCvpdTravelTime ::= SEQUENCE {
        bsmList                 SEQUENCE OF BSMRecordTravelTime,
        …
}
```

1.5 MSG_NycCvpdASDMobility

This message reports the BSMs collected by the ASD to track the overall movement of a vehicle through the system to evaluate overall mobility. This message contains information to identify the vehicle and therefore must be encrypted on the ASD for transmittal to the RSU for upload to the TMC.

```
NycCvpdASDMobility ::= SEQUENCE {
        vehID           VINstring, -- As specified in J2735 paragraph 7.225
        asdSerialNumber         VisibleString,
        locList         SEQUENCE OF VehLocRecord,
        timeRecordResolution    TimeRecordResolution,
        …
}
```

2 DataFrames

2.1 DF_BSMRecord

The BSMRecord data frame adds a message header to each BSM message recorded by either the ASD or RSU.

```
BSMRecord ::=SEQUENCE {
        msgHeader               MsgHeader, bsmMsg
                                BasicSafetyMessage
}
```

2.2 DF_BSMEvent

The BSMEvent data frame adds the EventMsgSeqNum data element to all of the BSMRecord data frames that are part of the event.

```
BSMEvent ::= SEQUENCE  {
        seqNum          EventMsgSeqNum,
        bsmRecord               BSMRecord
}
```

2.3 DF_BSMRecordRSURF

This data frame collects the RF data for remote vehicles as seen from an RSU. A change in the tempID of the remote vehicle will trigger the previous BSM recording as the last vehicle sighting and the current BSM as the first sighting of the new vehicle.

```
BSMRecordRSURF::= SEQUENCE {
    firstBSMTime        DDateTime,
    firstBSM            BSMRecord,
    lastBSMTime         DDateTime,
    lastBSM             BSMRecord
    }
```

2.4 DF_BSMRecordASDRF

This data frame collects the RF data for remote vehicles as seen from an ASD. The host vehicle BSM must also be recorded to gather information about the location of the host vehicle with respect to the remote vehicle. A change in the tempID of the remote vehicle will trigger the previous BSM recording as the last vehicle sighting and the current BSM as the first sighting of the new vehicle.

```
BSMRecordASDRF::= SEQUENCE {
        firstBSMTime        DDateTime,
        firstHVBSM          BSMRecord,
        firstRVBSM          BSMRecord,
        lastBSMTime         DDateTime,
        lastHVBSM           BSMRecord,
        lastRVBSM           BSMRecord
}
```

2.5 DF_BSMRecordTravelTime

The BSMRecordTravelTime is used to collect the BSM that will be used for the travel time calculations at central. Each record will contain the standard message header along with the detection geo zone and the BSM itself.

```
BSMRecordTravelTime ::= SEQUENCE {
        msgHeader           MsgHeader,
        geoZone             GeoZone,
        bsmMsg              BasicSafetyMessage
}
```

2.6 DF_EventHeader

This data frame captures the meta information about the event. If the event is an internal event (ex. red light violation warning or a speed warning) the hostVehId and the targetVehId will be the same. The triggerHvSeqNum and triggerTvSeqNum will also be the same.

```
EventHeader ::= SEQUENCE {
     eventTimeStamp          DDateTime,
     locationSource          LocationSource,
     asdSerialNumber         VisibleString,
     asdFirmwareVersion      VisibleString,
     eventAlertActive        EventAlertActive,
     eventAlertSent          EventAlertSent,
     eventAlertHeard         EventAlertHeard,
     hostVehID               TemporaryID,
     targetVehID             TemporaryID,
     triggerHVSeqNum         EventMsgSeqNum,
     --The sequence number of the HV BSM that triggered the event
     triggerTVSeqNum         EventMsgSeqNum,
     --The sequence number of the TV BSM that triggered the event
     eventType               EventType,
     parameters              ParameterSet,
```

```
        grpId                       GroupId,
        …
}
```

2.7 DF_MAPRecord

This data frame contains a list of Map messages for the event

```
MAPRecord::=SEQUENCE {
        msgHeader       MsgHeader,
        mapMsg          MapData
}
```

2.8 DF_MAPEvent

This data frame contains a list of Map messages for the event

```
MAPEvent::=SEQUENCE {
        seqNum          EventMsgSeqNum,
        mapRecAct       MAPRecord
}
```

2.9 DF_MAPRecordRF

This data frame collects the information on the received MAP messages to evaluate the RF effectiveness.

```
MAPRecordRF::= SEQUENCE {
            firstMAPTime            DDateTime,
            firstMAPRecord          MAPRecord,
            lastMAPTime             DDateTime,
            lastMAPRecord           MAPRecord,
            firstMAPLocation        BasicSafetyMessage,
            lastMAPLocation         BasicSafetyMessage
}
```

2.10 DF_MsgHeader

This data frame is attached to each message (BSM, SPaT, TIM, MAP) by the receiving device (ASD or RSU).

```
MsgHeader ::= SEQUENCE { myRFLevel
                        RFLevel,
        authenticated   MsgAuthenticated
}
```

2.11 DF_ParameterSet

This data frame captures the parameters in force in the ASD at the time of the event.

```
ParameterSet ::=SEQUENCE {
            recordingROI            NumericString OPTIONAL,
            -- the number of seconds before the event
            timeRecordBefore        NumericString,
```

```
        -- the number of seconds after the event
        timeRecordFollow          NumericString,
        timeRecordResolution      TimeRecordResolution,
        -- for this specific type of event minSpdThreshold
                                  NumericString,
        timeToCrash               NumericString OPTIONAL,
        excessiveCurveSpd         NumericString OPTIONAL,
        excessiveSpd              NumericString OPTIONAL,
        excessiveSpdTime          NumericString OPTIONAL,
        excessiveCurveSpdTime     NumericString OPTIONAL,
        excessiveZoneSpd          NumericString OPTIONAL,
        excessiveZoneSpdTime      NumericString OPTIONAL,
        minCurveSpd               NumericString OPTIONAL,
        minZoneSpd                NumericString OPTIONAL,
        stopBarTolerance          NumericString OPTIONAL,
        yellowDurationTolerance NumericString OPTIONAL,
        hardBrakingThreshold      NumericString OPTIONAL,
        assumedDriverBraking      NumericString OPTIONAL,
        postedHeightLimit         NumericString OPTIONAL,
        postedSizeLimit           NumericString OPTIONAL,
        postedZoneSpeed           NumericString OPTIONAL,
        regulatorySpeed           NumericString OPTIONAL,
        …
}
```

2.12 DF_SPaTRecord

This data frame assembles the additional information required to record SPaT messages.

```
SPaTRecord::= SEQUENCE {
        msgHeader       MsgHeader,
        spatMsg         SPAT
}
```

2.13 DF_SPaTRecordRF

This data frame collects the SPaT data for evaluation of RF effectiveness.

```
SPaTRecordRF ::= SEQUENCE {
        firstSPaTTime             DDateTime,
        firstSPaTRecord           SPaTRecord,
        lastSPaTTime              DDateTime,
        lastSPaTRecord            SPaTRecord,
        firstSPaTLocation         BasicSafetyMessage,
        lastSPaTLocation          BasicSafetyMessage
}
```

2.14 DF_SPaTEvent

This data frame adds the message sequence number for the SPaT message within an event.

```
SPaTEvent::= SEQUENCE {
```

```
        seqNum          EventMsgSeqNum,
        spatRecord      SPaTRecord
}
```

2.15 DF_TIMRecord

This data Frame adds the additional information to a TIM for recording and evaluation.

```
TIMRecord::= SEQUENCE {
        msgHeader       MsgHeader,
        timMsg          TravelerInformation
}
```

2.16 DF_TIMRecordRF

This data frame collects the information on the received TIM messages to evaluate the RF effectiveness.

```
TIMRecordRF::= SEQUENCE {
        firstTIMTime            DDateTime,
        firstTIMRecord          TIMRecord,
        lastTIMTime             DDateTime,
        lastTIMRecord           TIMRecord,
        firstTIMLocation        BasicSafetyMessage,
        lastTIMLocation         BasicSafetyMessage
}
```

2.17 DF_TIMEvent

This data frame captures additional information for TIM messages received during an event.

```
TIMEvent::=SEQUENCE {
        seqNum          EventMsgSeqNum,
        timRecord       TIMRecord
}
```

2.18 DF_ VehLocRecord

This data frame captures the vehicle location at a specific time. Since this is providing data to evaluate overall mobility, time resolution greater than 1 second is not required.

```
VehLocRecord::= SEQUENCE {
        timeStamp               DDateTime,
        longitude               Longitude,
        latitude                Latitude,
        elevation               Elevation
}
```

3 Data Elements

3.1 DE_EventAlertActive

This data element records the control state of audible notifications – they are either Silent (FALSE) or Active (TRUE) mode, with the default being the Active mode. If this data element is TRUE, then audible notifications are active in the ASD.

EventAlertActive::=BOOLEAN

3.2 DE_EventAlertHeard

This data element flags if the alert generated by this event was heard/detected. If this event did not send an alert, indicated when EventAlertSent is FALSE, then this data element must be FALSE. However, the EventHeard data element has not been coming back turned on as intended. As a result, there is no way to determine if the alert was heard at the present time.

EventAlertHeard::=BOOLEAN

3.3 DE_EventAlertSent

This data element flags the event as an event generating an alert. In the case of multiple events occurring simultaneously the performance analysis needs to know which event generated an alert. If this event sent an alert the value will be TRUE. A higher priority event may occur and result in this event's alert being suppressed in which case this event's value will be FALSE.

EventAlertSent::=BOOLEAN

3.4 DE_EventMsgSeqNum

This data element captures the order in which messages are received or stored for the event the oldest message (BSM, SPaT, TIM or MAP) will be 1. The first message in each event will start at 1.

EventMsgSeqNum ::=INTEGER (1..16384)

3.5 DE_EventType

This data element reports the event type.

```
EventType::=ENUMERATED {
        unknown (0),
        fcw (1),
        eebl (2),
        bsw (3),
        lcw (4),
        ima (5),
        vtrw (6),
        spdcomp (7),
        cspdcomp (8),
        spdcompwz (9),
        rlvw (10),
        ovcturnprohibit (11),
        ovcclearancelimit (12),
        evacinfo (13),
        pedinxwalk (14),
        pedSig (15)
}
```

3.6 DE_GeoZone

This data element is part of the BsmRecord and records the geozone for BSMs recorded to support the central travel time calculations. A value of 0 for GeoZone indicates that the BSM was not in a defined detection geo zone.

NOTE: The range is set at 0 to 128. We do not expect more than 16 zones

per RSU.

GeoZone::= INTEGER(0..128)

3.7 DE_RFLevel

This data element captures the RF level of the received message. The measurement shall be in increments of 0.5 dBm. Internal messages will have a reading of 301.

RFLevel:: = INTEGER (-300..301)

3.8 DE_TimeRecordResolution

This is a data element that specifies the rate at which event data is logged.

```
TimeRecordResolution:: = ENUMERATED {
                resOneTenthOfSec, -- every 1/10 second
                resTwoTenthOfSec, -- every 2/10 second
                resFiveTenthsOfSec, -- every 5/10 second
                resEverySec, -- every 1 second
                resEveryTwoSec, -- every 2 seconds
                resEveryFiveSec, -- every 5 seconds
                resEveryTenSec  -- every 10 seconds
}
```

3.9 DE_MsgAuthenticated

This data element is a Boolean value to indicate if the message was authenticated by ASD.

MsgAuthenticated:: = BOOLEAN

3.10 DE_LocationSource

This data element defines the data fusion process used to enhance location accuracy.

```
LocationSource ::= ENUMERATED {
        unknown (0),
        directgps (1),
        gps (2),
        gpsrsu (3)
}
```

3.11 DE_GroupId

This data element contains the assigned group identification number for managing the OTA updates. See the list of OTA Groups.

GroupId ::= INTEGER (0..255)

Appendix D: Draft Driver Surveys

The following presents the draft surveys to solicit feedback on the operation and effectiveness of the ASD based CV applications.

Part 1 – Vehicle Usage (Included in all driver surveys)

Table 23 below is part one (1) of the driver survey on vehicle usage. Note that the list of vehicle models will be updated prior to the survey deployment based on vehicle installation records.

Table 23. Driver Survey: Part 1 – Vehicle Usage

No	Question	Responses	Multiple Choices
1.1	Where do you primarily operate the vehicle during a typical work week?	Select all that apply	Manhattan a) Lower Manhattan (South of 14th St) b) Midtown Manhattan c) Upper East Side d) Upper West Side e) Upper Manhattan (North of 96th St) Brooklyn a) Downtown Brooklyn b) Outer Brooklyn Staten Island a) Staten Island Queens a) Long Island City b) LaGuardia Airport c) John F. Kennedy Airport Bronx a) Southern Bronx b) Northern Bronx

No	Question	Responses	Multiple Choices
1.2	At what times of day do you typically operate?	Select all that apply	Weekdays a) AM Rush (6AM-9AM) b) Mid-day (9AM-3PM) c) PM Rush (3PM-7PM) d) Evening (7PM-12AM) e) Other (12AM-6AM) Weekends a) Daytime (7AM-7PM) b) Nighttime (7PM-7AM)
1.3	Which agency owns the vehicle you drive for work?	Select One	a) NYC Department of Transportation (DOT) b) NYC Department of Corrections (DOC) c) NYC Department of Environmental Protection (DEP) d) NYC Department of Homeless Services (DHS) e) NYC Department of Parks and Recreation (Parks) f) NYC Taxi and Limousine Commission (TLC) g) NYC Human Resources Administration (HRA) h) NYC Department of Citywide Administrative Services (DCAS) i) NYC Department of Design and Construction (DDC) j) NYC Department of Buildings (DOB) k) NYC Administration for Children's Services (ACS) l) Metropolitan Transit Authority – Bridges and Tunnels (MTA B&T) m) Metropolitan Transit Authority – Bus (MTA Bus) n) New York City Transit (NYCT) o) Other: ______________________________

No	Question	Responses	Multiple Choices
1.4	What is the make/model* of the fleet vehicle you typically drive?	Check all that apply *(Note: possible answers provided will be filtered on response to Q1.3)*	*If Q1.2 is MTA Bus or NYCT* a) New Flyer b) Nova Bus c) Orion d) Other___ *Otherwise:* a) Chevrolet Bolt b) Chevrolet Express c) Chevrolet Silverado d) Ford E350 e) Ford Explorer f) Ford F150 g) Ford F250 h) Ford F350 i) Ford F550 j) Ford Fusion k) Nissan Leaf l) Ram 2500 m) Toyota Camry n) Toyota Prius o) Toyota Rav4 p) Other: ____________________
1.5	Do you typically drive the same vehicle, or do you drive different vehicles within common fleet?	Select One	a) Typically same assigned vehicle b) Different vehicles within common fleet

No	Question	Responses	Multiple Choices
1.6	What is the typical range in the number of miles you drive your fleet vehicle *per workday?*	Enter Range	Minimum: ______ Miles Maximum: ______ Miles
1.7	What is the typical range in the number of hours you drive your fleet vehicle *per workday?*	Enter Range	Minimum: ______ Hours Maximum: ______ Hours
1.8	What is the typical range in the number of days you drive your fleet vehicle *per work week?*	Enter Range	Minimum: _______ Days Maximum: ______Days

Part 2 – User Perception/Attitude (Included in all driver surveys)

Table 24 below is part two (2) of the driver survey on user perception and attitude.

Preface message: Vehicles equipped with connected vehicle technology are able to "talk" wirelessly to other vehicles, traffic signals, and roadside equipment. Safety applications of the technology provide warnings to drivers when there is a danger. Other applications are designed to improve traffic flow.

Table 24. Driver Survey: Part 2 – User Perception/Attitude

No	Question	Responses	Multiple Choices
2.1	Please indicate your level of familiarity with Connected Vehicles and Connected Vehicle applications	Select One	a) Very familiar (I've heard about many of the applications and understand how they work) b) Somewhat familiar (I've heard about some of the applications and understand how they work) c) Not too familiar (I've heard about some of the applications but don't know how they work) d) Not at all familiar (I had not heard of Connected Vehicles before this study and have no information about the applications)
2.2	Do you anticipate that drivers will benefit from the use of Connected Vehicle technologies?	Select One	a) Yes b) No c) Don't know enough about the technology

No	Question	Responses	Multiple Choices
2.3	Do you have any of the following concerns about the Connected Vehicle technology system?	Select all that apply	a) Cost (i.e., it will be too expensive for you to purchase for your own personal vehicle) b) Safety c) Privacy d) Distraction (i.e., the system will be distracting) e) Trust in the technology f) Too many alerts or warning g) False alerts or warning (i.e., when there is no real danger h) Other (please specify: ____) i) Don't know enough about the technology
2.4	Based on your perceptions when you are driving in the City for work, what is your likelihood of each of the following?	Please select one response for each item	A crash or near-crash with a pedestrian or bicyclist a) Extremely Likely b) Very Likely c) Moderately Likely d) Slightly Likely e) Not at all likely f) Not applicable A crash or near-crash with another vehicle a) Extremely Likely b) Very Likely c) Moderately Likely d) Slightly Likely e) Not at all likely f) Not applicable A crash or near-crash by yourself (e.g. hit roadway barrier or off-road crash): a) Extremely Likely b) Very Likely c) Moderately Likely d) Slightly Likely

No	Question	Responses	Multiple Choices
			e) Not at all likely f) Not applicable
2.5	In general, how safe do you feel when driving in the City for work (i.e., that you won't be involved in a crash)?	Select one	a) Extremely safe b) Very safe c) Moderately safe d) Slightly safe e) Not at all safe f) Not applicable (Do not drive in the City for work)

Part 3 – User Experience (Not include in the pre-deployment driver survey, but included in both post-deployment surveys)

Table 25 below is part three (3) of the driver survey on user experience.

Table 25. Driver Survey: Part 3 – User Experience

No	Question	Responses	Multiple Choices
3.1	How often do you hear the alerts?	Select One	a) Many times per day b) Few times per day c) Few times per week d) Less than weekly e) Never *If Q3.1 response is 'Never', skip remaining Part 3 Questions and proceed to*

No	Question	Responses	Multiple Choices
			Part 4.
3.2	How would you rate the sound volume of the alerts?	Select One	a) Much Too Loud b) Somewhat too Loud c) About right d) Somewhat too Quiet e) Much Too Quiet
3.3	Are the audible alerts distracting or not?	Select one	a) Extremely distracting b) Very distracting c) Moderately distracting d) Slightly distracting e) Not at all distracting
3.4	Do you find the audible alerts helpful or not?	Select one	a) Extremely helpful b) Very helpful c) Moderately helpful d) Slightly helpful e) Not at all helpful
3.5	Have the audible alerts affected how you drive in the City or not?	Select one	a) The alerts have affected my driving b) The alerts have not affected my driving
3.6	*If Yes to Q 3.5:* How would you define the effect on your driving	Select one	a) Very Positive b) Somewhat Positive c) Somewhat Negative d) Very negative Please indicate the reason for your response:

No	Question	Responses	Multiple Choices
3.7	Which of these warnings do you recall hearing? *(Note: Responses will be modified at a later date to better align with the specifics of text/warnings heard by the driver for each application)*	Check all that apply:	☐ Emergency Electronic Brake Lights ☐ Forward Crash Warning ☐ Intersection Movement Assist ☐ Blind Spot Warning ☐ Lane Change Warning ☐ Vehicle Turning Right in Front of Bus Warning ☐ Red Light Violation Warning ☐ Speed Compliance ☐ Curve speed compliance ☐ Speed Compliance in Work Zone ☐ Oversize Vehicle Compliance ☐ Emergency Communications and Evacuation Information ☐ Pedestrian in Signalized Crosswalk Warning ☐ I have received warnings, but I cannot tell them apart *[if selected, skip to Q3.9]* ☐ I can't recall if I received warnings-SKIP TO 3.9 *[if selected, skip to Q3.9]* ☐ I have not received any warnings – END SURVEY *[if selected, skip to Part 4]*

No	Question	Responses	Multiple Choices
3.8	Which three warnings do you recall hearing most often? *(Note: Responses will be modified at a later date to better align with the specific audio/warnings heard by the driver for each application)*	Check all that apply: (Will be filtered to show only those selected in Q3.7)	☐ Emergency Electronic Brake Lights ☐ Forward Crash Warning ☐ Intersection Movement Assist ☐ Blind Spot Warning ☐ Lane Change Warning ☐ Vehicle Turning Right in Front of Bus Warning ☐ Red Light Violation Warning ☐ Speed Compliance ☐ Curve speed compliance ☐ Speed Compliance in Work Zone ☐ Oversize Vehicle Compliance ☐ Emergency Communications and Evacuation Information ☐ Pedestrian in Signalized Crosswalk Warning ☐ Can't recall
3.9a	Do you think any of the warnings have helped you drive more safely?	Select One If Q3.9a is no, skip to Part 4	☐ Yes ☐ No

No	Question	Responses	Multiple Choices
3.9b	Check all that have helped you drive more safely: *(Note: Responses will be modified at a later date to better align with the specific audio/warnings heard by the driver for each application)*	Check all that apply: (Will be filtered to show only those selected in Q3.7)	☐ Emergency Electronic Brake Lights ☐ Forward Crash Warning ☐ Intersection Movement Assist ☐ Blind Spot Warning ☐ Lane Change Warning ☐ Vehicle Turning Right in Front of Bus Warning ☐ Red Light Violation Warning ☐ Speed Compliance ☐ Curve speed compliance ☐ Speed Compliance in Work Zone ☐ Oversize Vehicle Compliance ☐ Emergency Communications and Evacuation Information ☐ Pedestrian in Signalized Crosswalk Warning
3.10	Overall, how satisfied or dissatisfied are you with the warning system?	Select one	a) Very dissatisfied b) Dissatisfied c) Somewhat dissatisfied d) Indifferent e) Somewhat satisfied f) Satisfied g) Very satisfied

Part 4 – Demographics

Table 26 below is part four (4) of the driver survey on demographics.

Table 26. Driver Survey: Part 4 – Demographics

No	Question	Responses	Multiple Choices
4.1	How many years have you been driving for work in New York City?	Select one	a) 0-2 years b) 3-5 years c) 6-10 years d) More than 10 years
4.2	What is your age?	Select one	a) 18-24 b) 25-44 c) 45-64 d) Older than 65
4.3	What is your proficiency with English?	Select one	a) Fluent b) Good c) Limited d) None

Appendix E: Draft Visually Impaired Pedestrian Surveys

The following presents the draft surveys to solicit feedback on the operation and effectiveness of the cell phone based CV PID application.

Suggested Survey Questions for the Visually Impaired Pedestrian Assistant Device Evaluation

Two surveys will be administered for the Visually Impaired Pedestrian Assistant Device Evaluation:

- Pre-Experiment Interview
- Post-Experiment Interview

Note that the survey headings included below are for survey organization purposes only; they will not be mentioned to the respondents. Other notes in italics are also internal notes only and will not be conveyed to the respondents.

As the surveys are IRB certified, unique identifiers will be generated for the study participants. The questions will be read to the participants. All surveys will be used to measure the changes in users' experiences with the Ped App, their satisfaction with the technology, and its perceived impact on their safety and mobility.

I. Pre-Experiment Interview Protocol

The pre-experiment interview will be administered at the start of each field test. It is designed to establish baseline conditions for study participants.

Demographic Information

1. Name: ____________________________________

2. What is your age:
   - 18-24
   - 25-44
   - 45-64
   - Older than 65

3. Which borough do you reside in?
   - Manhattan
   - Bronx
   - Brooklyn
   - Queens
   - Staten Island

4. Which of the following best describes your visual disability?
   - Partially-sighted or low vision
   - Legally-blind
   - Totally blind

5. At what age did you become visually impaired?
   - _______ years old
   - __ visually impaired since birth

6. On average, how often do you cross a signalized intersection?
   - 6 or more intersections a day
   - 4 or 5 intersections a day
   - 2 or 3 intersections a day

- Less than 2 intersections a day

Self-ratings: Technology

7. Have you participated in any orientation and mobility training?
   - Yes
   - No

8. Do you currently use a mobile phone?
   - Yes: IOS or Android
   - No

9. Do you currently use a mobile navigation assistant / Global Positioning System (GPS)?
   - Yes
   - No

10. Have you experienced an Accessible Pedestrian Signal before? These signals give you audio or tactile information about the state of the light at the intersection or the location of the crosswalks in addition to a light signal.
    - Yes
    - No

Navigation & Mobility

11. What is your preferred method of assistance while navigating to a destination (select only one)?
    - Long or white cane
    - Guide dog
    - Electronic travel aid (e.g., laser cane)
    - Personal navigation device / GPS on the phone
    - Asking other pedestrians I pass
    - Other (please specify____________)

12. How often do you use each of the following methods of assistance while navigating to a destination?
    A. Many times per day B. Few times per day C. Few times per week D. Less weekly E. Never

    - Long or white cane: _______
    - Guide dog: _______
    - Electronic travel aid (e.g., laser cane): _______
    - Personal navigation device / GPS on phone: _______
    - Asking other pedestrians I pass: _______
    - Other (please specify: ___________): _______

13. In general, how safe do you feel when you cross a signalized intersection?

    - Extremely Safe ________
    - Very safe ________
    - Moderately safe ________
    - Slightly safe ________
    - Not at all safe ________

14. How would you rate your proficiency in each of these travel skills? Are you well below average, below average, average, above average, or well above average? *[INTERVIEWER: REPEAT RESPONSE CATEGORIES AS NEEDED]*

Table 27. Pedestrian Survey: Proficiency in Travel Skills

	Well below average	Below average	Average	Above average	Well above average
General sense of direction					
Independent travel					
Signalized street crossings					

II. Post-Experiment Interview Protocol

The post-experiment interview aims to collect useful feedback on participants' perceptions and experiences with the Ped App after the field test is done. It includes an additional set of questions on attitudes, safety, and other relevant topics.

User Experience:

1. How do you rate the Ped App overall?
   - Poor
   - Fair
   - Good
   - Very good
   - Excellent

2. Did you experience any of the following problems in using the Ped App? Select all that apply.
   - Slow response
   - Insufficient battery life
   - Information provided not useful
   - Other. Please specify. ____

3. When using the Ped App, do you feel you have sufficient time to cross the intersection or not?
   - Yes
   - No
   - Don't know

4. When using the Ped App, do you feel you stay oriented within the crosswalk?
   - Yes
   - No
   - Do not know

5. For each of the following statements, please tell me whether you strongly disagree, somewhat disagree, neither agree nor disagree, somewhat agree, or strongly agree. *[INTERVIEWER SHOULD REPEAT RESPONSE CATEGORIES AS NEEDED]*

   a. I am familiar with the operation of the Ped App.

Strongly Disagree	Somewhat Disagree	Neither agree nor disagree	Somewhat Agree	Strongly Agree

   b. The operation of the Ped App is easy to use.

Strongly Disagree	Somewhat Disagree	Neither agree nor disagree	Somewhat Agree	Strongly Agree

   c. I am more confident in my ability to cross a signalized intersection with the pedestrian application compared to other assistive technologies I have used before.

Strongly Disagree	Somewhat Disagree	Neither agree nor disagree	Somewhat Agree	Strongly Agree

Application Performance Measures

6. Does the Ped App provide sufficient information through AUDIO to assist your intersection crossing?
   - No
   - Yes
   - Do not know

7. Does the Ped App provide sufficient information through VIBRATION to assist your intersection crossing?
   - No
   - Yes
   - Don’t know

8. For each of the following statements, please tell me whether you strongly disagree, somewhat disagree, neither agree nor disagree, somewhat agree, or strongly agree. *[INTERVIEWER SHOULD REPEAT RESPONSE CATEGORIES AS NEEDED]*
   a. Alerts given by the Ped App are timely.

Strongly Disagree	Somewhat Disagree	Neither agree nor disagree	Somewhat Agree	Strongly Agree

   b. Alerts given by the Ped App are accurate.

Strongly Disagree	Somewhat Disagree	Neither agree nor disagree	Somewhat Agree	Strongly Agree

   c. Alerts given by the Ped App are helpful.

Strongly Disagree	Somewhat Disagree	Neither agree nor disagree	Somewhat Agree	Strongly Agree

Safety Related:

[Placeholder] Safety related questions will be modified/added once more information becomes available.

9. In general, how safe do you feel when using the Ped App?
   - Extremely Safe
   - Very safe
   - Moderately safe
   - Slightly safe
   - Not at all safe

10. How would you rate your ability to easily navigate the pedestrian crosswalk?
    - Excellent
    - Very Good
    - Good
    - Fair
    - Poor
    - Very Poor

11. Do you anticipate that pedestrians will benefit from the use of Ped App technologies?
    - Yes
    - No

12. Do you have any of the following concerns about the Ped App technologies? Check all that apply.
    - Safety
    - Privacy
    - Trust in the technology
    - Too many alerts or warnings
    - False alerts or warnings (i.e., when there is no real danger)
    - Distraction (i.e., the system will be distracting)
    - Other (please specify: ______________________________)
    - No concerns
    - Don't know enough about the technology

Additional Questions:

13. Do you have any suggestions for improving the Ped App?

    ____

14. Would you recommend the Ped App to other prospective users? Please specify why or why not.
    - Yes
    - No

    ____

References

[1] Liao, C.-F. Using a smartphone app to assist the visually impaired at signalized intersections. 2012.

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[4] Golledge, R., R. Klatzky, J. Loomis, and J. Marston. Stated preferences for components of a personal guidance system for nonvisual navigation. *Journal of Visual Impairment & Blindness,* Vol. 98, No. 03, 2004

Appendix F: NYCDOT Response to IE Evaluation Needs

The following outlines the responses of the NYC CVPD team to the list of data needs presented by the USDOT CV team in support of the Independent Evaluator during Phase 1 of the pilot.

CV Pilots Preliminary Non-Safety Evaluation Needs: New York City

Table 28 below list the NYC mobility, environment, and public agency efficient (MEP) evaluation needs for NYC CV Pilot deployment.

Table 28. Mobility, Environment, and Public Agency Efficiency (MEP) Evaluation Needs for New York City

ID	Area	Type	Evaluation Need	When Applicable	Priority	NYC To Provide
NMEP.1	Mobility, Environmental	System Data	Need non-real time access to raw BSMs heard by RSEs, within the Site boundaries at specific pre-defined locations and times to support IE efforts	With[1]	High	Partially. As outlined in ASD action logs and in breadcrumb data collection discussions
NMEP.2	Mobility, Environmental	System Data	Need non-real time access to warnings and alerts generated by Aftermarket Safety Devices (ASDs) by type (e.g., signal violation, pedestrian warning, over-speed warning, over-height warnings, V2V warnings, in-vehicle evacuation warnings, etc.), date, time, and location (i.e., where generated), within the Site boundaries, and supporting meta data	With[1]	High	Yes, with PII obfuscation provisions
NMEP.3	Mobility, Environmental	System Data	Need non-real time access to warnings and information sent to pedestrians' smartphones by ID of device/equipment sending warning/information, type, date, time, and location (area where warnings/information received), within the Site boundaries, and supporting meta data	With[1]	High	Yes, as final design of Ped devices permit and as privacy concerns allow

[1] With: After system is active and operational

ID	Area	Type	Evaluation Need	When Applicable	Priority	NYC To Provide
NMEP.4	Mobility, Environmental	System Data	Need non-real time access to a sample of warnings and information received by pedestrians' smartphones by type, date, time, location (where received) and ID of device/equipment sending warning/information, within the Site boundaries at specific pre-defined locations and times to support IE efforts, and supporting meta data	With[1]	Low	Yes, as final design of Ped devices permit and as privacy concerns allow
NMEP.5	Mobility, Environmental	System Data	Need non-real time access to pedestrian/bicyclist warnings and messages (sent by smartphones or Vulnerable Road User (VRU) detectors) heard by RSEs and traffic signal controllers, within the Site boundaries, and supporting meta data	With[1]	High	Yes, as final design of Ped devices permit and as privacy concerns allow
NMEP.6	Mobility, Environmental	System Data	Need non-real time access to sample of messages sent by visually-impaired pedestrians' smartphones to traffic signal controllers by date, time, location (where sent), and receiving signal controller ID, within the Site boundaries at specific pre-defined locations and times to support IE, and supporting meta data	With[1]	Low	Yes, as final design of Ped devices permit and as privacy concerns allow
NMEP.7	Mobility, Environmental	System Data	Need non-real time access to sample of pedestrian warnings transmitted by Vulnerable Road User (VRU) detectors by date, time, VRU ID transmitting the warning, and IDs of RSE and traffic signal controllers receiving the warning, within the Site boundaries, and supporting meta data	With[1]	Low	Yes, as final design of Ped devices permit and as privacy concerns allow
NMEP.8	Mobility, Environmental	System Data	Need non-real time access to warnings generated by buses by type (e.g., pedestrian, bicyclist, right-turning vehicle), date, time, and location (where generated), within the Site boundaries, and supporting meta data	With[1]	High	Yes, privacy concerns allow

ID	Area	Type	Evaluation Need	When Applicable	Priority	NYC To Provide
NMEP.9	Mobility, Environmental	System Data	Need non-real time access to warnings and alerts generated by commercial vehicle applications by type (e.g., speed reduction, over-height warning, curve speed warning, etc.), date, time, and location (where generated), within the Site boundaries, and supporting meta data	With[1]	High	Yes, privacy concerns allow
NMEP.10	Mobility, Environmental	Performance Measure	Need generated/calculated mobility and environmental performance measures for trips, facilities and frequencies, as identified in the Performance Measurement Plan, and supporting meta data	Without[2], With[1]	High	Yes, as predicted through simulation
NMEP.11	Mobility, Environmental	Performance Measure	Need access to crashes and injuries by date, time, and location, within the Site boundaries, and supporting meta data	Without[2], With[1]	High	Yes
NMEP.12	Mobility, Environmental, Public Agency Efficiency	Performance Measure	Need cost of operations data to assist the IE in identifying costs in the “with” and “without” cases, and supporting meta data	Without[2], With[1]	High	Yes
NMEP.13	Public Agency Efficiency	Performance Measure	Need site-relevant public agency efficiency measures as identified in the Performance Measurement Plan, and supporting meta data	Without[2], With[1]	High	Yes
NMEP.14	Mobility, Environmental	Performance Measure	Need algorithm or technical approach used for calculating key performance measures identified in the Performance Measurement Plan	Without[2], With[1]	Medium	Yes
NMEP.15	Mobility, Environmental	Performance Measure	Need code, and supporting software documentation, if developed for the Pilot Deployment effort, for calculating key performance measures identified in the Performance Measurement Plan	Without[2], With[1]	Medium	Yes

[2] Without: Prior to system becoming operational

ID	Area	Type	Evaluation Need	When Applicable	Priority	NYC To Provide
NMEP.16	Mobility, Environmental	Performance Measure	Need procedures for data QA/QC, including site's acceptable levels of accuracy by data element	Without[2], With[1]	Low	Yes
NMEP.17	Mobility, Environmental	Network Data	Need IDs and locations of RSEs, within the Site boundaries.	With[1]	High	Yes
NMEP.18	Mobility, Environmental	Network Data	Need IDs and locations of upgraded traffic signal controllers, within the Site boundaries.	With[1]	High	Yes
NMEP.19	Mobility, Environmental	Network Data	Need IDs and location of Vulnerable Road User (VRU) pedestrian detectors, within the Site boundaries	With[1]	High	Yes
NMEP.20	All	Staff Access	Need to facilitate IE access to all Site staff and subcontractors, across all functions, as requested by the IE for interview, survey, or technical clarification	Without[2], With[1]	High	Yes, as MOUs permit
NMEP.21	Mobility, Environmental	Staff Access	Need to facilitate IE access to relevant stakeholders as requested by the IE for data (e.g., City-provided traveler information content by date, time, and location, within the Site boundaries), interviews, surveys, or technical clarification	Without[2], With[1]	High	Yes, as MOUs permit
NMEP.22	Public Agency Efficiency	Staff Access	Need to facilitate IE access to Site efficiency management staff and support their participation in interviews, surveys, or other follow-up information gathering sessions	Without[2], With[1]	High	Yes, as MOUs permit
NMEP.23	Mobility, Environmental	Management Data	Need logs of actions taken by system managers by date, time, and location, within the Site boundaries	Without[2], With[1]	Medium	Yes, via TMC logs
NMEP.24	Mobility, Environmental	Management Data	Need action plans available for system managers by type of event, within the Site boundaries	Without[2], With[1]	Low	Yes, via TMC logs
NMEP.25	Mobility, Environmental	Management Data	Need to facilitate IE access to logs of system and power outages by date, time, and affected devices/equipment, within the Site boundaries	With[1]	Low	Yes, via TMC logs

ID	Area	Type	Evaluation Need	When Applicable	Priority	NYC To Provide
NMEP.26	Mobility, Environmental	Contextual Data	Need to facilitate IE access to non-crash related incidents and lane closure data by date, time, and location, within the Site boundaries	Without[2], With[1]	Low	Yes, via TMC logs
NMEP.27	Mobility, Environmental	Contextual Data	Need to facilitate IE access to road work information (e.g., lane closures, active work zones) by date, time, and location, within the Site boundaries	Without[2], With[1]	Low	Yes, via TMC logs
NMEP.28	Mobility, Environmental	Contextual Data	Need to facilitate IE access to special events information (e.g., lane closures, change in lane restrictions, facility use, etc.) by date, time, and location, within the Site boundaries	Without[2], With[1]	Low	Yes, via TMC logs
NMEP.29	Mobility, Environmental	Signal Data	Need default traffic signal phasing and timing plans for all intersections within the Site boundaries (239 signals)	Without[2], With[1]	Low	Yes
NMEP.30	Mobility, Environmental	Models	Need simulation and analytical models, if developed or enhanced for the Pilot Deployment effort, for Site performance measurement and monitoring	Without[2], With[1]	Medium	Yes
NMEP.31	Mobility, Environmental	Models	Need to facilitate IE access to simulation models developed for the Site, even if developed using resources outside of the Pilot Deployment effort	Without[2], With[1]	Low	Yes (models only – no licenses)

Table 29 lists the security and privacy evaluation needs for NYC CV Pilot deployment.

Table 29. Security and Privacy Evaluation Needs for New York City

ID	Area	Type	Evaluation Need	When Applicable	Priority	NYC to Provide
NSP.1	Security	Management Data	Need security incident logs that include description (i.e., to the extent possible, the nature of the incident, and a description of the individuals and technologies relevant to or impacted by the incident), resulting impacts, actions taken, and lessons learned. (NOTE: Procedures need to be included as part of the Security Management Operating Concept and ConOps.)	Without[3], With[4]	Medium	Yes, as logged
NSP.2	Security	Staff Access	Need to facilitate IE access to staff associated with the Site Security Planning and Management staff and support their participation in interviews, surveys, or other follow-up information gathering sessions. (NOTE: Support should be documented in the Evaluation Support Plan.)	Without[3], With[4]	Medium	Yes, as IRB permits
NSP.3	Privacy	Management Data	Need privacy violation logs that include description (i.e., to the extent possible, the nature of the incident, and a description of the individuals and data relevant to or impacted by the incident), resulting impacts, actions taken, and lessons learned. (NOTE: Procedures need to be included as part of the Privacy Management Operating Concept.)	Without[3], With[4]	Medium	Yes, as logged
NSP.4	Privacy	Staff Access	Need to facilitate IE access to staff associated with the Site Privacy Planning and Management staff and support their participation in interviews, surveys, or other follow-up information gathering sessions. (NOTE: Support should be documented in the Evaluation Support Plan.)	Without[3], With[4]	Medium	Yes, as IRB permits

[3] Without: Prior to system becoming operational
[4] With: After system is active and operational

ID	Area	Type	Evaluation Need	When Applicable	Priority	NYC to Provide
NSP.5	Privacy	System Data	Need types of PII that had to be collected for operational use. (NOTE: Should be included in the Data Sharing Framework and the Privacy Management Operating Concept.)	With[4]	Medium	Yes

Table 30 lists the financial and institutional evaluation needs for NYC CV Pilot deployment.

Table 30. Financial and Institutional Evaluation Needs for New York City

ID	Area	Type	Evaluation Need	When Applicable	Priority	NYC to Provide
NFI.1	Financial, Institutional	Management Data	Need to define and describe the "without" system management (business) processes, including diagrams and maps. (NOTE: Should be documented in the ConOps.)	Without[5], With[6]	Medium	Yes
NFI.2	Financial, Institutional	Management Data	Need to define and describe the "with" system management (business) processes, including diagrams and maps. (NOTE: Should be documented in the ConOps and the CDP.)	Without[5], With[6]	Medium	Yes

[5] Without: Prior to system becoming operational

[6] With: After system is active and operational

CV Pilots Preliminary Safety Evaluation Needs: New York City

Table 31 lists the Red Light Violation Warning (RLVW) application data needs for NYC CV Pilot deployment.

Table 31. Red Light Violation Warning (RLVW) Application Data Needs

	Metric/Data Need	Description	Comments	Priority	NYC to Provide
1	Red Light Violation Rate	Frequency with which vehicles violate the red light at designated intersections, with and without the RLVW application	Could be in terms of percentage of vehicles or intersection crossings, or temporal frequency (e.g., number per day/week/month). Should include time-after-red data (i.e., violation elapsed time since the onset of the red light).	High	Yes, via ASD Action Logs and via existing Red Light Running Camera Violation System
2	Red Light Violation-Related Crash Rates	Red light violation-related crash rates at designated intersections, with and without RLVW application	Broken down by crossing-path crash type (i.e., straight-crossing versus left-turn crash types)	High	Only as captured in crash database (generally not available)
3	Secondary intersection-related crash rates	Intersection crashes not directly related to red light violations (e.g., rear-end crashes)	Broken down by crash type	Medium	Yes, as captured in crash database

	Metric/Data Need	Description	Comments	Priority	NYC to Provide
4	Application performance statistics	A measure of how accurately the application works in the pilot deployment (i.e., true, false, and miss alert rates, and alert timeliness)	E.g., In-vehicle data collection with cameras in a sample of vehicles, or infrastructure-based data collection	High	Partial –Yes via application testing/turning and ASD action logs; but no in-vehicle cameras will be deployed.
5	Red light violation statistics/relationship to crashes	Data that describe how signal violation rates, including time-after-red statistics, are related to intersection crashes	To be able to interpret how changes in signal violation rates would impact crash rates.	Medium	Yes, via ASD action logs
6	SPAT data	Signal Phase and Timing data	For validation of application alerts and health monitoring of the system. Especially critical if in-vehicle data/video is not provided.	Medium	Yes, via ASD action logs
7	Driver response to valid warnings	A way to determine if, and how drivers respond to valid warnings	Most likely via in-vehicle data	Tentative	Yes, via ASD action logs

Notes:
Unless crash rates in the designated intersections are relatively significant and consistent from year to year, signal violation rates along with other data elements in the above table will be integrated to create surrogate measure for crashes to assess the impact of the application.

Table 32 below lists the Curve Speed Compliance (CSPD-COMP) application data needs for NYC CV Pilot deployment.

Table 32. Curve Speed Compliance (CSPD-COMP) Application Data Needs

	Metric/Data Need	Description	Comments	Priority	NYC to Provide
1	Lane-departure/control loss related crash rates	Unintended lane departure and control loss crash rates at designated curves, with and without the CSW application	Broken down by crash type (i.e., lane-change, opposite-direction, run-off-road crashes)	High	Yes, as recorded in crash database
2	Vehicle speeds at curve entry	Traffic speed at the entry to the designated curve, with and without the CSW application	Either in-vehicle or infrastructure-based sensing	High	Yes, via ASD action logs
3	Application performance statistics	A measure of how accurately the application works in the pilot deployment (i.e., true, false, and miss alert rates and alert timeliness)	E.g. In-vehicle data collection with cameras in a sample of vehicles, for external validation	High	Partial –Yes via application testing/turning and ASD action logs; but no in-vehicle cameras will be deployed.
4	Driver response to valid warnings	A way to determine if, and how drivers respond to valid warnings	Most likely via in-vehicle data	Low	Yes, via ASD action logs
5	GIS roadway data	Detailed information about the roadway on the designated curves	E.g., road curvature radius, speed limits, etc.	Medium	Yes
6	Weather data	Information to infer whether or not the		Medium	Yes, via NWS and NYC snowplow databases

	Metric/Data Need	Description	Comments	Priority	NYC to Provide
		designated curve was slippery at a given data/time			
7	Lane-departure and control-loss driving conflicts	A way to determine "close call" scenarios for hazardous driving events	Exposure and response to conflicts provide a surrogate measure for crashes, which are only necessary if the impact on actual crash rates is not measurable, or of enough magnitude to be statistically significant.	Tentative	Yes, via ASD action logs

Notes:
Unless crash rates in the designated curves are relatively significant and consistent from year to year, exposure and response to lane-departure and control-loss driving conflicts will be integrated to create a surrogate measure for crashes to assess the impact of the application.

Table 33 below lists the Speed Compliance in Work Zone (SPDCOMPWZ) for Reduced Speed application data needs for NYC CV Pilot deployment.

Table 33. Reduced Speed/Work Zone Warning Application Data Needs

	Metric/Data Need	Description	Comments	Priority	NYC to Provide
1	Vehicle speed in variable speed zone areas	A method to determine the speed of vehicles in reduced speed zone areas, with and without application warnings	Needs to be normalized by time of day, day of week, and time of year	High	Yes, via ASD action logs and ASD Breadcrumb data
2	Work zone related crash rates	Work zone-related crash rates in reduced speed zones, with and without application	Broken down by crash type	High	Only as captured in crash database (generally not available)
3	Application performance statistics	A measure of how accurately the application works in the pilot deployment	E.g., In-vehicle data collection with cameras in a sample of vehicles, and/or infrastructure-based sensing	High	Partial –Yes via application testing/turning and ASD action logs; but no in-vehicle cameras will be deployed.
4	Recommended speeds	The speeds recommended to drivers in work zone warning areas		High	Yes
5	Driver response to valid warnings	A way to determine if, and how drivers respond to valid warnings	Most likely via in-vehicle data	Tentative	Yes, via ASD action logs

Notes:

Unless work-zone related crash rates are relatively significant and consistent from year to year, driver response to warnings, speed adaptation, lane keeping, or other surrogate measures for safety will be used as a surrogate measure for crashes to assess the impact of the application.

Table 34 below lists the Pedestrian in Signalized Crosswalk (PEDINXWALK) application data needs for NYC CV Pilot deployment.

Table 34. Pedestrian in Signalized Crosswalk Warning Application Data Needs

	Metric/Data Need	Description	Comments	Priority	NYC to Provide
1	Pedestrian related crash rates	Transit bus/pedestrian crash rates at designated intersections, with and without application warnings		Low	Only as captured in crash database (generally not available)
2	Application performance statistics	A measure of how accurately the application works in the pilot deployment	E.g., In-vehicle data collection with cameras in a sample of vehicles and/or infrastructure-based sensing	High	Partial –Yes via application testing/turning and ASD action logs; but no in-vehicle cameras will be deployed.
3	Driver response to valid	A way to determine if, and how drivers respond to valid warnings	Most likely via in-vehicle data	High	Yes, via ASD action logs
4	SPAT data	Signal Phase and Timing/pedestrian sensor data	For validation of application alerts and health monitoring of the system, especially critical if in-vehicle data/video is not provided.	Medium	Yes, via ASD action logs
5	Pedestrian-related conflicts/hard braking events	A way to determine "close call" scenarios for transit bus/pedestrian crashes	Conflicts are a surrogate measure for crashes, so this metric is only	Tentative	Yes, via ASD action logs

	Metric/Data Need	Description	Comments	Priority	NYC to Provide
			necessary if the impact on actual crash rates is not measurable, or of enough magnitude to be statistically significant		

Notes:
Crash rates of this type are likely to be very low, making them an unsuitable measure of performance. Therefore, driver response to warnings or pedestrian related conflicts will likely be used as a surrogate measure of performance.

Table 35 below lists the Speed Compliance (SPDCOMP) application data needs for NYC CV Pilot deployment.

Table 35. Speed Compliance Application Data Needs

	Metric/Data Need	Description	Comments	Priority	NYC to Provide
1	Vehicle speed in speed violation warning (SVW) areas	A method to determine the speed of vehicles traveling in the SVW equipped areas, with and without application warnings	Needs to be normalized by time of day, day of week, and time of year	High	Yes, via ASD action logs and ASD Breadcrumb data
2	Posted speed limits in SVW areas	Posted speed limits for each road segment in SVW equipped areas	To determine speed overages	High	Yes
3	Closing speed between vehicles in SVW areas	A method to determine closing speeds, or speed variation between vehicles in the SVW areas	This metrics would address potential unintended consequences of the application, i.e., disruption in traffic flow.	Low	Yes, via ASD action logs and ASD Breadcrumb (speed variation only)
4	Application performance statistics	A measure of how accurately the application works in the pilot deployment, or measures that will allow the accuracy to be determined	E.g., In-vehicle data collection with cameras in a sample of vehicles, for external validation	High	Partial –Yes via application testing/turning and ASD action logs; but no in-vehicle cameras will be deployed.

Table 36 below lists the Mobile Accessible Pedestrian Signal System (PED-SIG) application data needs for NYC CV Pilot deployment. Note that this application involves the visually-impaired pedestrians and is separate from the PEDINXWALK application which involves the ASDs and the vehicle drivers/operators.

Table 36. Mobile Accessible Pedestrian Signal System (Ped-Sig) Application Data Needs

	Metric/Data Need	Description	Comments	Priority	NYC to Provide
1	Visually-Impaired pedestrian-related crash-rates	Crash statistics of relevant crash rates at designated intersections, with and without the application		Low	Only as captured in crash database (generally not available)
2	Application performance statistics	A measure of how the application is working in the pilot deployment	E.g., wait times for crossing	High	Yes, via action logs as PED-SIG final design and IRB permits
3	Conflicts with visually impaired pedestrians	A way to determine "close call" scenarios with visually impaired pedestrians during the "don't cross" signal phase.	Includes straight-crossing and left/right turning vehicles.	Tentative	Only qualitatively as captured through observations of the IRB approved researchers accompanying the participants

Notes:
Crash rates of this type are likely to be very low, making them an unsuitable measure of performance. Therefore, they are rated as low priority.

Table 37 below lists the Vehicle Turning Right in front of Bus Warning (VTRW) application data needs for NYC CV Pilot deployment.

Table 37. Vehicle Turning Right in Front of Bus Warning Application Data Needs

	Metric/Data Need	Description	Comments	Priority	NYC to Provide
1	Bus/right turn related crash statistics	Crash statistics of relevant crash rates at equipped bus stops, with and without the application		High	Only as captured in crash database (generally not available)
2	Application performance statistics	A measure of how accurately the application works in the pilot deployment, or measures that will allow the accuracy to be determined	E.g. In-vehicle data collection with cameras in a sample of vehicles, for external validation	High	Partial –Yes via application testing/turning and ASD action logs; but no in-vehicle cameras will be deployed.
3	Driver response to valid warnings	A way to determine if, and how drivers responded to valid warnings	Most likely via in-vehicle data	Tentative	Yes, via ASD action logs
4	Right-turning vehicle related conflicts	A way to determine “close call” scenarios for crashes with right-turning vehicles at bus stops.	Can be used as a surrogate measure for crashes.	Tentative	Yes, via ASD action logs

U.S. Department of Transportation
ITS Joint Program Office-HOIT
1200 New Jersey Avenue, SE
Washington, DC 20590

Toll-Free "Help Line" 866-367-7487
www.its.dot.gov

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