Research on the Road, Part 4

Traffic Safety in the Era of Connected and Autonomous Vehicles

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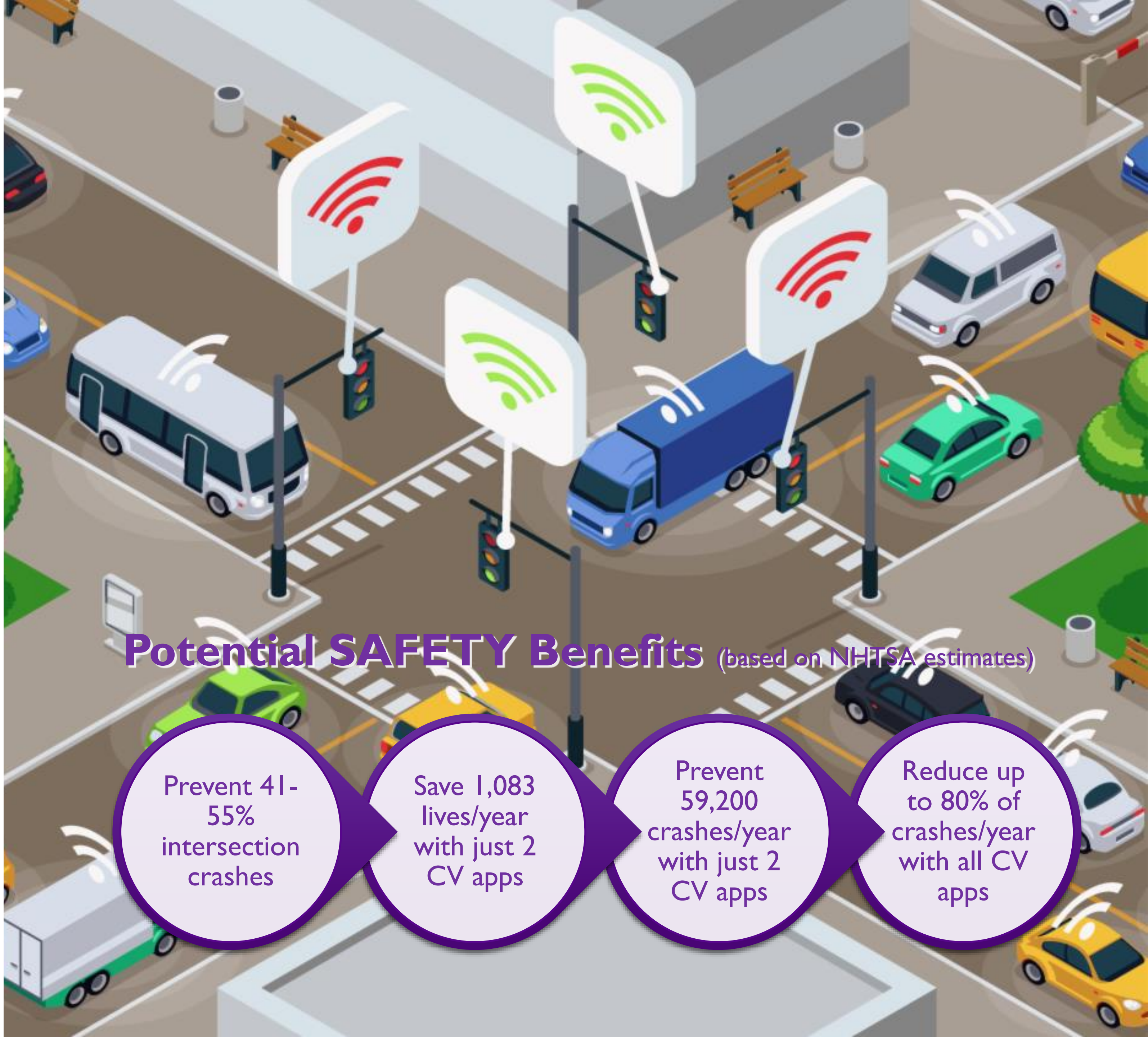
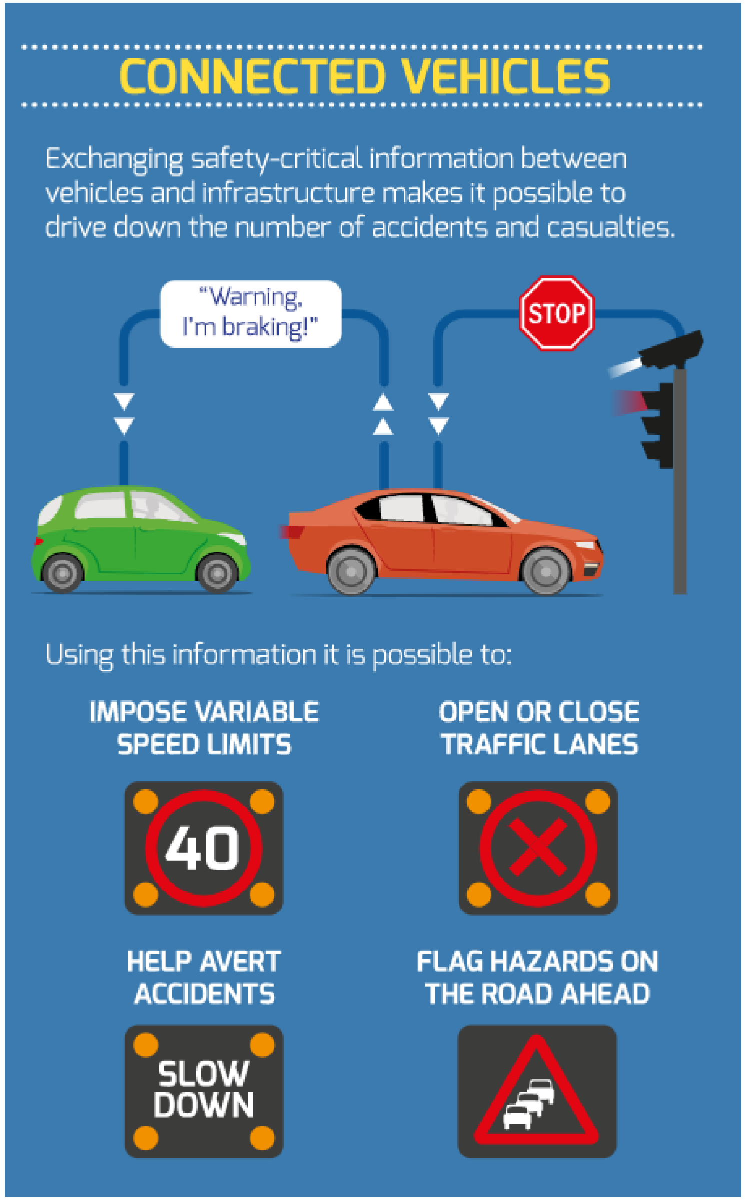
OVERVIEW

The adoption of connected and autonomous vehicle (CAV) technologies present a systematic approach in alerting vehicles of unsafe roadway conditions and has the potential to provide numerous safety benefits, such as minimizing distracted driving, that facilitate Vision Zero's goals and initiatives.

Image credit: Texas Instruments & OHM Advisors



HOW CAN AUTOMATED AND CONNECTED VEHICLES IMPROVE ROAD SAFETY?



https://roadsafetyfacts.eu/

USDOT NYC CONNECTED VEHICLE PILOT DEPLOYMENT

New York City is one of three ***Connected Vehicle (CV) pilot deployment*** sites selected by USDOT to demonstrate the benefits of this new Connected Vehicle technology.

The CV technology is a new tool to help NYC reach its ***Vision Zero*** goals to eliminate traffic related deaths and reduce crash related injuries and damage to both the vehicles and infrastructure.

3000+ vehicles

450+ Roadside Units

14 Mobility and Safety Applications
(include one that supports people with visual disabilities)

NYC Connected Vehicle pilot deployment Website: [*https://cvp.nyc*](https://cvp.nyc)

NYC CONNECTED VEHICLE PILOT DEPLOYMENT APPLICATIONS

NYC CVPD Applications

The NYC deployment is primarily focused on ***safety applications*** – which rely on vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and infrastructure-to-pedestrian (IVP) communications. These applications provide drivers with alerts so that the driver can take action to avoid a crash or reduce the severity of injuries or damage to vehicles and infrastructure.

Vehicle to Vehicle (V2V)

- Emergency Electronic Brake Lights
- Forward Crash Warning
- Intersection Movement Assist
- Blind Spot Warning
- Lane Change Warning
- Vehicle Turning Right in Front of Bus Warning

Vehicle to Infrastructure (V2I)

- Red Light Violation Warning
- Speed Compliance
- Curve speed compliance
- Speed Compliance in Work Zone
- Oversize Vehicle Compliance
- Emergency Communications and Evacuation Information

Mobility

- Pedestrian in Signalized Crosswalk Warning
- Mobile Accessible Pedestrian Signal System

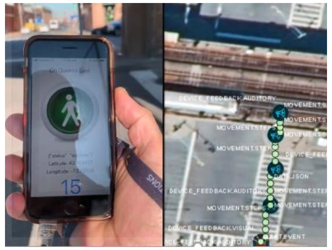
For more details, please contact: **Mohamad Talas**, Director of System Engineering , Intelligent Transportation System & Management Lead, NYC Connected Vehicle Pilot Deployment, NYC Department of Transportation | Mtalas@dot.nyc.gov

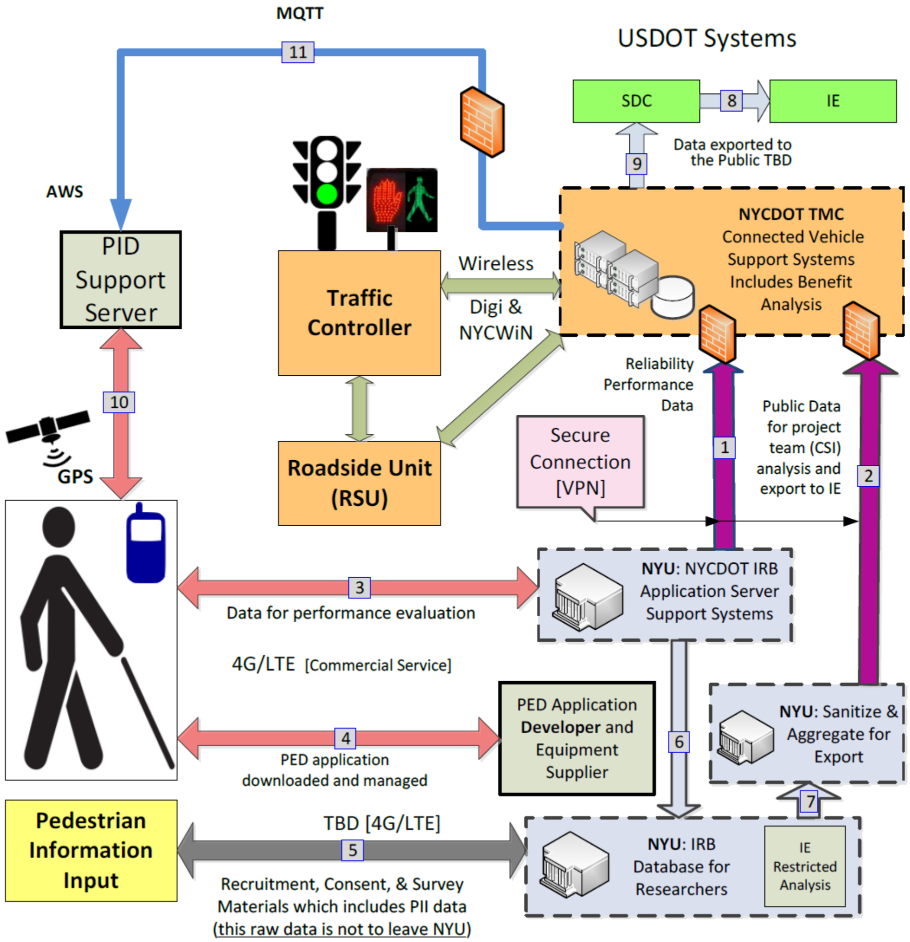
NYC Connected Vehicle pilot deployment Website: https://cvp.nyc

ADVANCE SOCIAL EQUITY WITH CAVS

Assist visually impaired pedestrians in safely crossing the streets at instrumented intersections:

- Equip 25+ pedestrians with a Personal Information Devices (PID)
- Obfuscate, encrypt, and transmit operational data to secure servers to protect privacy
- Learn the participants' experiences through the CV-equipped intersections





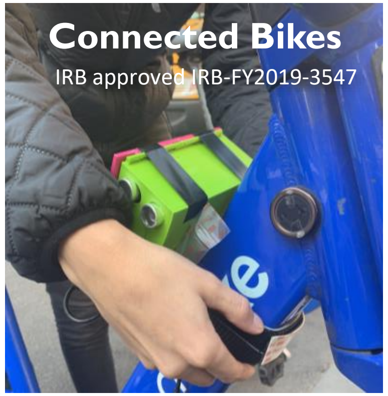
Visually Challenged Pedestrian Application Context Diagram

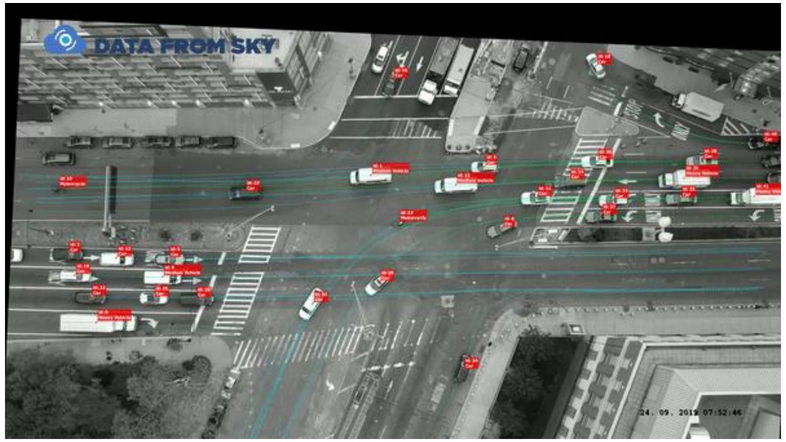
https://www.cvp.nyc/
https://c2smart.engineering.nyu.edu/nyc-cv-pilot/

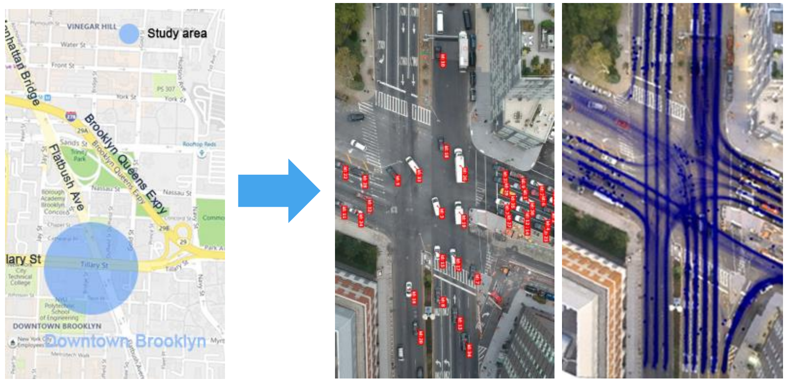
EMERGING CV TECHNOLOGIES AND APPROACHES FOR SAFETY

Most of the innovation in predictive and operational approaches to improve traffic safety in urban areas and deployment efforts are fueled by the availability of big data generated by connected & autonomous vehicles (CAV) as well as ubiquitous mobile devices, sensors, and fixed and drone-based cameras.

- Emerging data collection method
- Leveraging CAV data such as Basic Safety Messages (BSMs)
- Develop cyber-physical test-bed
- Surrogate safety measure-based simulation assessment





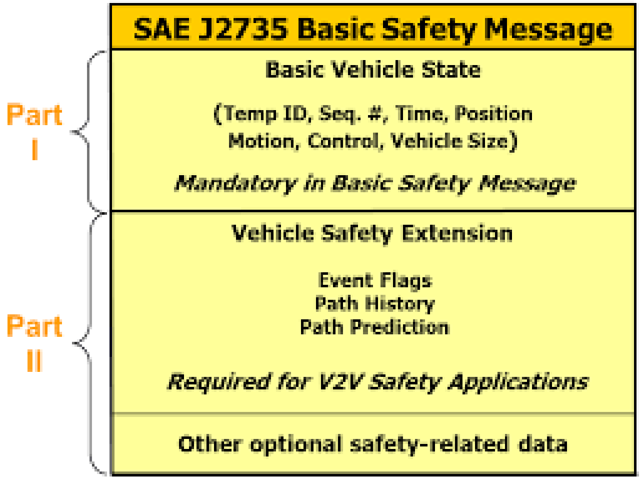


Bernardes, Suzana Duran, Abdullah Kurkcu, and Kaan Ozbay. "Design, Implementation and Testing of a New Mobile Multi-Function Sensing Device for Identifying High-Risk Areas for Bicyclists in Highly Congested Urban Streets." Procedia Computer Science 155 (2019): 218-225.
New York University C2smart Center, 2019. "Vehicle trajectory data extracted from drone-recorded videos in new york city".
http://c2smart.engineering.nyu.edu/wp-content/uploads/Vehicle-Trajectory-Data-Extracted-from-Drone-Recorded-Videos-in-New-York-City.pdf

CONVERT BASIC SAFETY MESSAGES INTO TRAFFIC SAFETY MEASURES

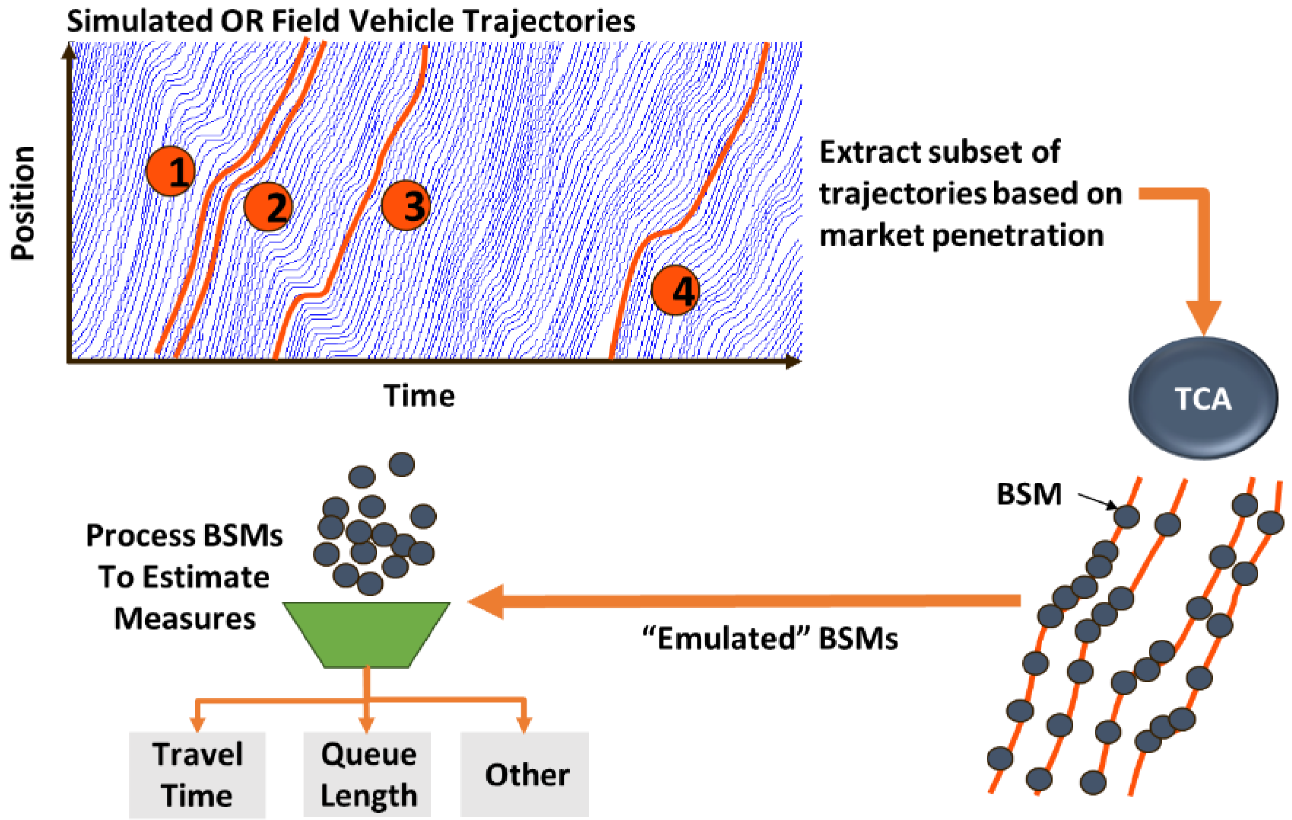
Connected vehicles (CV), travelers using connected mobile devices, and Intelligent Transportation (ITS) devices and traffic management systems sharing and using Basic Safety Messages (BSM) has the potential to transform transportation systems management, traveler safety and mobility, and system productivity.

The BSM includes attributes (e.g., vehicle size, brake system status, event trigger flags) that cannot be measured using traditional surveillance technology.



Source: Federal Communications Commission (FCC)

From vehicle trajectories to synthetic Basic Safety Messages to measures



Noblis & NYU C2SMART center, NCHRP 03-127 Algorithms to Convert Basic Safety Messages into Traffic Measures (Working in progress).

CONVERT BASIC SAFETY MESSAGES INTO TRAFFIC SAFETY MEASURES

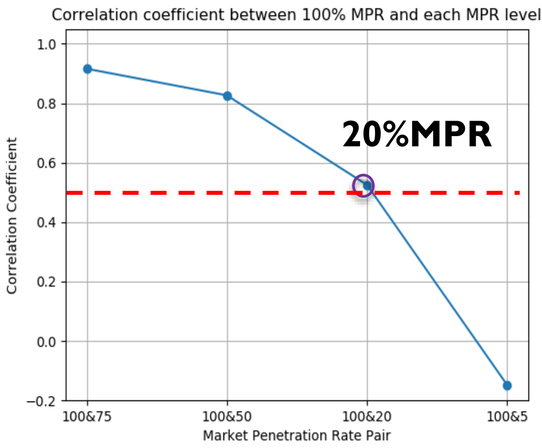
Novel algorithms are developed to convert BSM into three high-priority safety measures for safety performance evaluation, hotspots identification, and safety countermeasure development.

Safety Measure	Definition
Hard Braking (HB)	Hard braking is defined to occur when a vehicle's longitudinal deceleration is greater than a certain pre-determined threshold.
Deceleration Rate to Avoid Collision (DRAC)	DRAC is defined as the minimum deceleration rate required by the following vehicle to come to a timely stop (or match the leading vehicle's speed) and hence to avoid a crash.
Time-To-Collision with Disturbance (TTCD)	TTCD is defined as the time to collision modified by imposing a hypothetical deceleration to the leading vehicle.

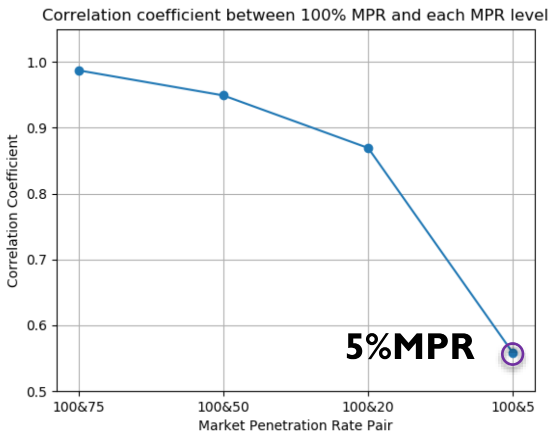
Algorithm testing include:

- Identify the optimal threshold that achieves the highest Spearman's ρ correlation between HB/ DRAC/TTCD events and crashes.
- Identify the minimum market penetration rate (MPR) level that will not greatly affect the similarity/spatial hotspots distribution if 100% MPR cannot be reached.

Urban Arterial



Urban Freeway



Noblis & NYU C2SMART center, NCHRP 03-127 Algorithms to Convert Basic Safety Messages into Traffic Measures (Working in progress).

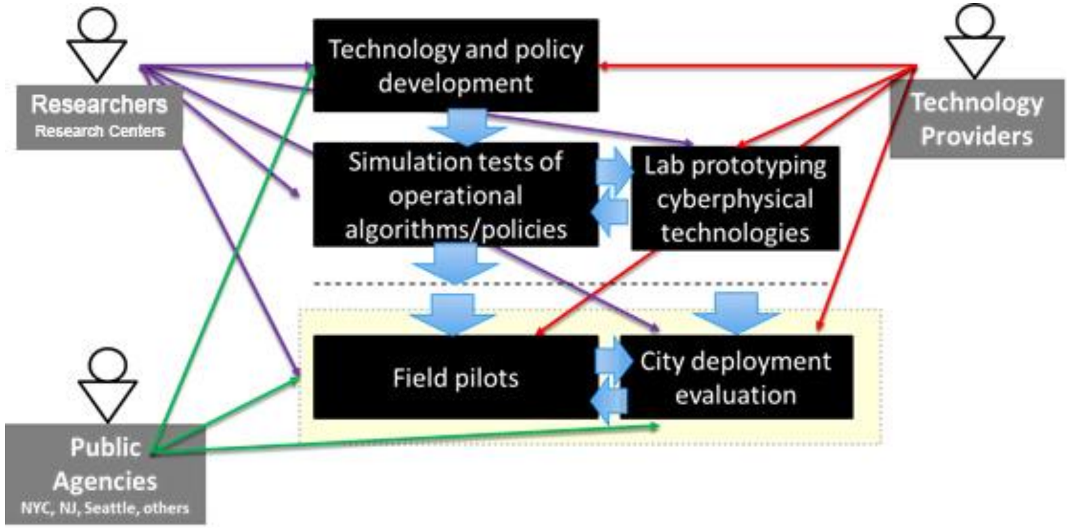
DEVELOPING CYBER-PHYSICAL TESTBED
FOR MODELING, SIMULATION, AND FIELD TESTING OF NEW IDEAS

Developing virtual and physical testbeds

- Innovators (academia and industry) can test and demo new technologies
- Decision-makers can learn about upcoming ideas and advances

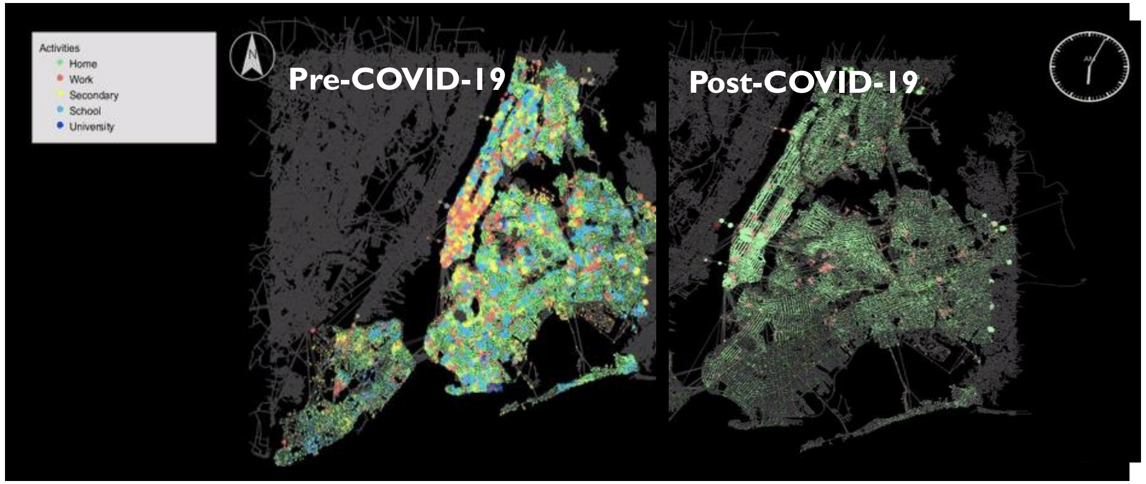
Testbeds are key drivers of future success

- Integration of all available datasets
- Taken initial investment to grow into large operations with decision-making platform



How can the testbed be used to meet State and City needs?

- Modeling the effect of CAVs on city streets
- Modeling the effect of ridesharing and EVs on traffic congestion
- Investigate new mobility providers' impacts on transit usage
- Sketch-planning tool for various demand and supply changes
- Evaluate pandemic impacts and potential new policies



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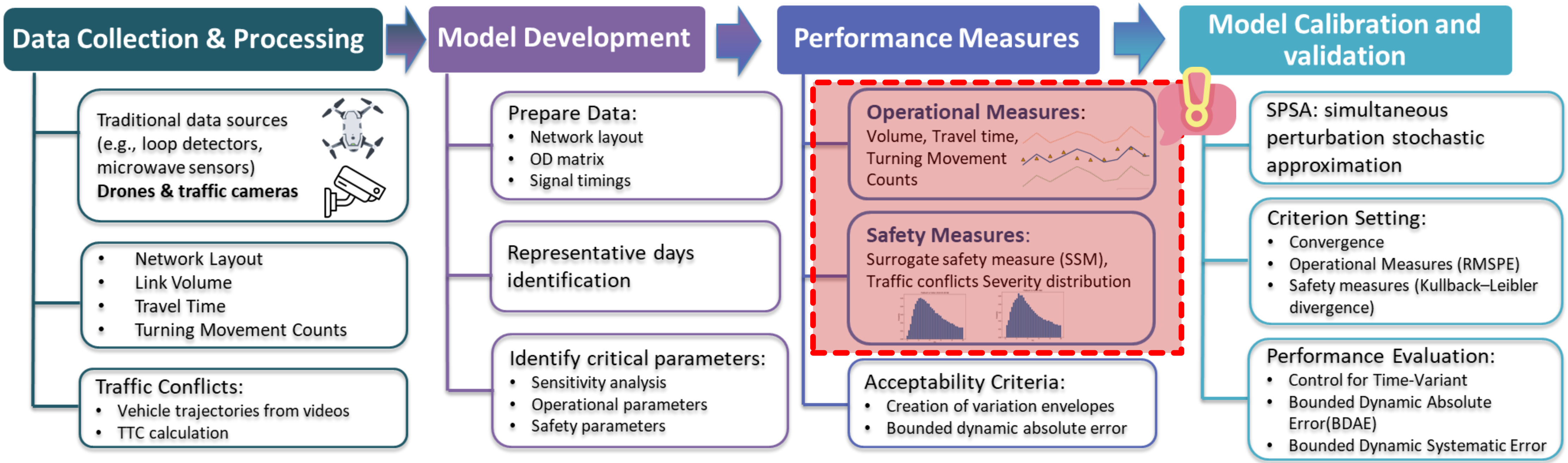
NYU C2SMART, Development of an Open Source Multi-Agent Virtual Simulation Test Bed for Evaluating Emerging Transportation Technologies and Policies, https://c2smart.engineering.nyu.edu/open-source-multi-agent-virtual-simulation-test-bed

SURROGATE SAFETY MEASURE-BASED SIMULATION ASSESSMENT

Using the **microscopic traffic simulation models** allows for confounding factors to be controlled in the simulation environment.

The **unique challenge** is that data for **operational measures**, such as traffic counts and travel times, must be calibrated along with **safety measures**.



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New York University C2SMART Center, 2020. "[Pre-cv deployment Flatbush Avenue model development and calibration]".

STOCHASTIC TRAFFIC SIMULATION MODELS

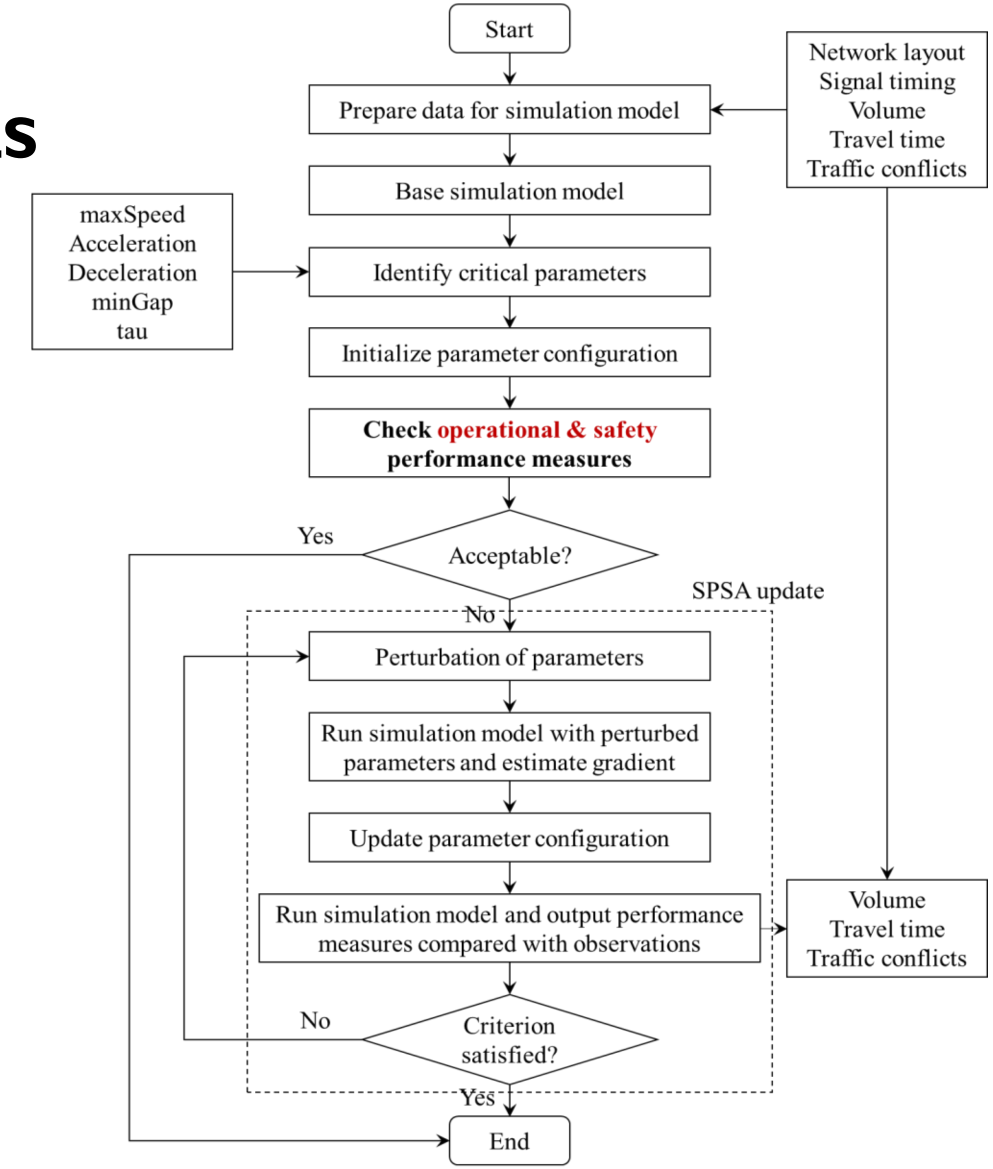
- Real-world conflicts are extracted using vehicle trajectories from a total of 14 hours' drone and traffic camera videos.
- Multiple key parameters, such as acceleration and minimum gap, are considered as random variables and are calibrated as probability distributions based on the real-world trajectory data.
- The **conflict distribution** of different severity levels categorized by **time to collision (TTC)** is applied as the safety performance measure.
- **Simultaneous perturbation stochastic approximation (SPSA)** is used to find the optimal simulation model parameters that minimize the total simulation error of both operational and safety performance measures.

Optimizing simulation parameters:

$$\min \quad L(\theta, I) = \left| O_{sim}(\theta, I) - O_{obs} \right|$$

$$\text{s.t.} \quad g(\theta, I) \le 0$$

where L(θ) is the loss function of interest.

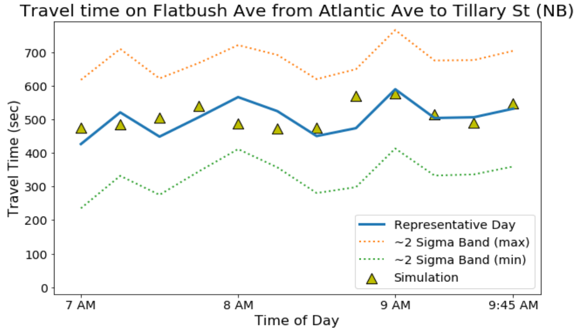


Sha, D., K. Ozbay, and Y. Ding, 2020. Applying Bayesian Optimization for Calibration of Transportation Simulation Models. Transportation Research Record, 2674(10), pp.215-228.
Sha, D., K. Ozbay, Z. Bian, et al., 2019. A stochastic collocation method for uncertainty quantification and calibration of microscopic traffic simulation models. 98th Annual Meeting of Transportation Research Board, Washington, D.C., 2019.

CALIBRATION RESULTS – OPERATIONAL MEASURES

Link volumes:
The root mean square percentage error (RMSPE) for the observed and simulated link volumes ranges from 0.23% to 16.61%, with an average RMSPE value of 11.01%.

Travel Times:
The calibrated simulation model satisfies all of the four acceptability criteria with respect to travel time.



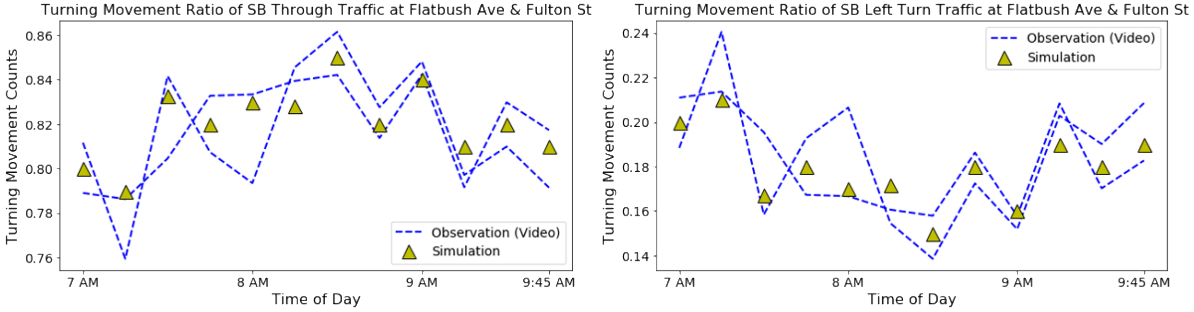
Time	Simulation (s)	Observation (s)	Abs Diff. (s)	Difference (s)
7:00 AM	474.51	426.12	48.39	48.39
7:15 AM	483.76	520.39	36.63	-36.63
7:30 AM	503.48	448.18	55.30	55.30
7:45 AM	540.26	505.97	34.29	34.29
8:00 AM	486.13	565.84	79.71	-79.71
8:15 AM	473.18	524.00	50.82	-50.82
8:30 AM	474.33	449.86	24.47	24.47
8:45 AM	569.13	473.43	95.70	95.70
9:00 AM	577.44	589.14	11.70	-11.70
9:15 AM	514.55	503.61	10.94	10.94
9:30 AM	489.53	505.86	16.33	-16.33
9:45 AM	547.68	531.36	16.32	16.32
		Average	40.05	7.52

BDAE Threshold: 82.15, $\frac{\sum_t |c_r(t)-\tilde{c}_r(t)|}{N_T} = 40.05$, $\left|\frac{\sum_t c_r(t)-\tilde{c}_r(t)}{N_T}\right| = 7.52$

CRITERION III ($\frac{\sum_t |c_r(t)-\tilde{c}_r(t)|}{N_T} \leq BDAE\ Threshold$) is met.

CRITERION IV ($\left|\frac{\sum_t c_r(t)-\tilde{c}_r(t)}{N_T}\right| \leq \frac{1}{3} \times BDAE\ Threshold$) is met.

Turning Movement Ratios:
the simulation results demonstrate good accuracy for each turning movement.



Example of turning movement ratios calibration and validation results

Meeting FHWA new guideline on Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software 2019 Update to the 2004 Version

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CALIBRATION RESULTS – SAFETY MEASURES

Traffic Conflict Distribution Comparison

To measure the goodness-of-fit of the simulated conflict distribution compared to the ground truth distribution, the Kullback–Leibler divergence (also called relative entropy), a metric that can quantify the "distance" between two distributions, is used.

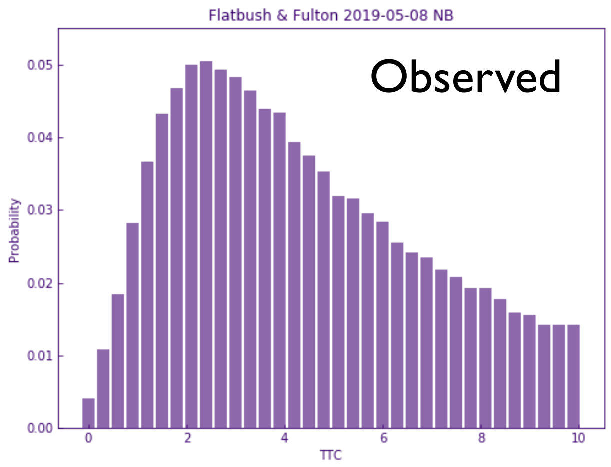
$$D_{\mathrm{KL}}(P \,||\, Q) = \sum_{x \in \mathcal{X}} P(x) \log\left(\frac{P(x)}{Q(x)}\right)$$

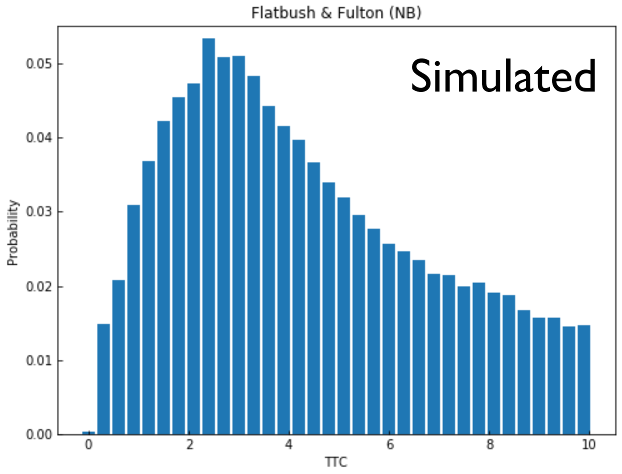
where P and Q are discrete, simulated, and observed conflict severity distributions respectively defined on the same probability space, $\mathcal{X}$.

The different levels of severity of traffic conflicts are categorized using an indicator called time to collision (TTC).

TTC: the time required for two vehicles to collide if they continue on the same path at their present speeds.

Conflict distributions after calibration (D_{KL}=0.0047)





Low KL divergence values (with an average value of 0. 0223) were observed for all studied locations. The results also show that the calibrated parameters can significantly improve the performance of the simulation model to represent real-world traffic conflicts as well as operational conditions.

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FUTURE OF TRAFFIC SAFETY RESEARCH

Opportunities and challenges

- Shared perception and adoption of connected and cooperative technologies
- New The Society of Automotive Engineers (SAE) cooperation classes
- Pedestrian Applications
- Development in highly congested and complex urban environments, such as NYC

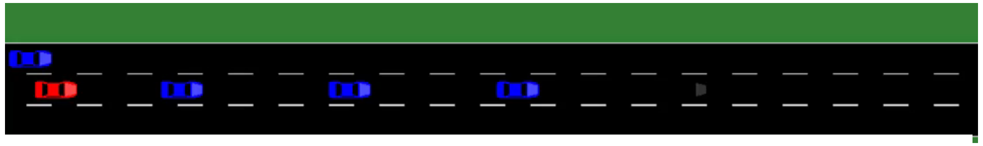
SAE levels and cooperation classes (source: SAE international)

No Automation		Partial Automation of DDT			Complete Automation of DDT		
		SAE Level 0: No Driving Automation (Human Does All Driving)	SAE Level 1: Driver Assistance (Longitudinal or Lateral Vehicle Motion Control)	SAE Level 2: Partial Driving Automation (Longitudinal and Lateral Vehicle Motion Control)	SAE Level 3: Conditional Driving Automation	SAE Level 4: High Driving Automation	SAE Level 5: Full Driving Automation
No Cooperative Automation		E.g., signage, TCD	Relies on driver to complete the DDT and to supervise feature performance in real time		Relies on ADS to perform complete DDT under defined conditions (fallback condition performance varies between levels)		
SAE Class A: Status Sharing	Here I am and what I see	E.g., brake lights, traffic signal	Potential for improved object and event detection*		Potential for improved object and event detection**		
SAE Class B: Intent Sharing	This is what I plan to do	E.g., turn signal, merge	Potential for improved object and event prediction*		Potential for improved object and event prediction**		
SAE Class C: Agreement Seeking	Let's do this together	E.g., hand signals, merge	N/A		C-ADS designed to attain mutual goals through coordinated actions		
SAE Class D: Prescriptive	I will do as directed	E.g., hand signals, lane assignment by officials			C-ADS designed to accept and adhere to a command		

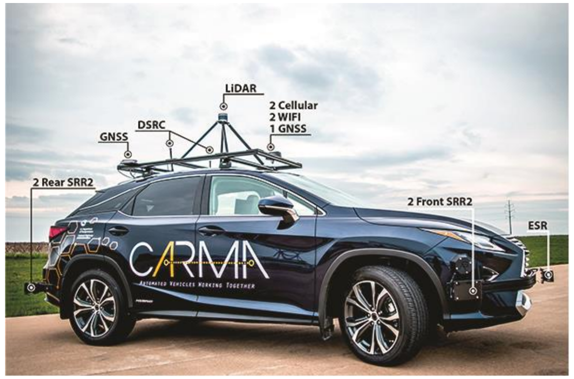
Adaptive Connected Cruise Control (ACCC)

Yielding large gap to allow cut-in HOV

Red: Autonomous; Blue: Human-Operated



M. Huang, Z. -P. Jiang and K. Ozbay, "Learning-Based Adaptive Optimal Control for Connected Vehicles in Mixed Traffic: Robustness to Driver Reaction Time," in IEEE Transactions on Cybernetics



Source: FHWA.

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