Traffic Safety in the Era of Connected and Autonomous Vehicles

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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.

**Potential SAFETY Benefits** (based on NHTSA estimates)

- Prevent 41-55% intersection crashes
- Save 1,083 lives/year with just 2 CV apps
- Prevent 59,200 crashes/year with just 2 CV apps
- Reduce up to 80% of crashes/year with all CV apps
HOW CAN AUTOMATED AND CONNECTED VEHICLES IMPROVE ROAD SAFETY?

CONNECTED VEHICLES

Exchanging safety-critical information between vehicles and infrastructure makes it possible to drive down the number of accidents and casualties.

"Warning, I’m braking!"

Using this information it is possible to:

- IMPOSE VARIABLE SPEED LIMITS
- OPEN OR CLOSE TRAFFIC LANES
- HELP AVERT ACCIDENTS
- FLAG HAZARDS ON THE ROAD AHEAD
- SLOW DOWN

AUTOMATED VEHICLES

Today, partially automated vehicles are able to perform an increasing number of driving tasks in specific scenarios.

- AUTOMATIC PARKING
- HIGHWAY PILOT

Advanced driver assistance systems (ADAS) take over safety-critical functions in dangerous situations.

STEERING

BRAKING

https://roadsafetyfacts.eu/
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
NYC CONNECTED VEHICLE PILOT DEPLOYMENT 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.

NYC CVPD Applications

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

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
Advancing 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

NYC-CV Pilot
Mobile Accessible Pedestrian Signal System

The NYC Connected Vehicle Pilot will deploy two pedestrian oriented applications. One of them is to support visually impaired pedestrians.

The application will be implemented using a portable personal device which supports cellular operation.

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**

CONVERT BASIC SAFETY MESSAGES INTO TRAFFIC SAFETY MEASURES

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

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.

From vehicle trajectories to synthetic Basic Safety Messages to measures

Source: Federal Communications Commission (FCC)
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.

<table>
<thead>
<tr>
<th>Safety Measure</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard Braking (HB)</td>
<td>Hard braking is defined to occur when a vehicle’s longitudinal deceleration is greater than a certain pre-determined threshold.</td>
</tr>
<tr>
<td>Deceleration Rate to Avoid Collision (DRAC)</td>
<td>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.</td>
</tr>
<tr>
<td>Time-To-Collision with Disturbance (TTCD)</td>
<td>TTCD is defined as the time to collision modified by imposing a hypothetical deceleration to the leading vehicle.</td>
</tr>
</tbody>
</table>

Algorithm testing include:
- Identify the optimal threshold that achieves the highest Spearman’s ρ correlation between HB/DRAC/TTC 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.
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

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**.
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:

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

s.t. \( g(\theta, I) \leq 0 \)

where \( L(\theta) \) is the loss function of interest.

### 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.

<table>
<thead>
<tr>
<th>Time</th>
<th>Simulation (s)</th>
<th>Observation (s)</th>
<th>Abs Diff. (s)</th>
<th>Difference (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7:00 AM</td>
<td>474.51</td>
<td>426.12</td>
<td>48.39</td>
<td>48.39</td>
</tr>
<tr>
<td>7:15 AM</td>
<td>483.76</td>
<td>520.39</td>
<td>36.63</td>
<td>-</td>
</tr>
<tr>
<td>7:30 AM</td>
<td>503.48</td>
<td>448.18</td>
<td>55.30</td>
<td>55.30</td>
</tr>
<tr>
<td>7:45 AM</td>
<td>540.26</td>
<td>505.97</td>
<td>34.29</td>
<td>34.29</td>
</tr>
<tr>
<td>8:00 AM</td>
<td>486.13</td>
<td>565.84</td>
<td>79.71</td>
<td>-</td>
</tr>
<tr>
<td>8:15 AM</td>
<td>473.18</td>
<td>524.00</td>
<td>49.82</td>
<td>-</td>
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<tr>
<td>8:30 AM</td>
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<td>24.47</td>
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<tr>
<td>8:45 AM</td>
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<td>473.43</td>
<td>95.70</td>
<td>95.70</td>
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<tr>
<td>9:00 AM</td>
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<td>589.14</td>
<td>11.70</td>
<td>-11.70</td>
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<tr>
<td>9:15 AM</td>
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<td>503.61</td>
<td>10.94</td>
<td>10.94</td>
</tr>
<tr>
<td>9:30 AM</td>
<td>489.53</td>
<td>505.86</td>
<td>16.33</td>
<td>-16.33</td>
</tr>
<tr>
<td>9:45 AM</td>
<td>547.68</td>
<td>531.36</td>
<td>16.32</td>
<td>16.32</td>
</tr>
</tbody>
</table>

Average 40.05

\[ BDAE_{\text{Threshold}}: 82.15, \quad \frac{\sum_{i=0}^{N_{\text{F}}} |t_i(t) - t_i(o)|}{N_{\text{F}}} = 40.05, \quad \frac{\sum_{i=0}^{N_{\text{F}}} |t_i(t) - t_i(o)|}{N_{\text{F}}} = 7.52 \]

\[ \text{CRITERION III } \frac{\sum_{i=0}^{N_{\text{F}}} |t_i(t) - t_i(o)|}{N_{\text{F}}} \leq BDAE_{\text{Threshold}} \text{ is met.} \]

\[ \text{CRITERION IV } \frac{\sum_{i=0}^{N_{\text{F}}} |t_i(t) - t_i(o)|}{N_{\text{F}}} \leq \frac{1}{3} x BDAE_{\text{Threshold}} \text{ is met.} \]
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.

\[ D_{KL}(P \parallel Q) = \sum_{x \in \mathcal{X}} P(x) \log \left( \frac{P(x)}{Q(x)} \right) \]

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.

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.
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

Adaptive Connected Cruise Control (ACCC)

Yielding large gap to allow cut-in HOV

Red: Autonomous; Blue: Human-Operated
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