



UNIVERSITY OF CENTRAL FLORIDA



# ASSESSMENT OF THE SAFETY BENEFITS OF CONNECTED VEHICLE TECHNOLOGIES

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# Overview

- **Challenges** in the transportation system
  - Increase in travel demand
  - Growth in congestion
  - Need to improve safety
  - Reality of limited resources
- **Solution:** (Pro)Active Traffic Management
  - Dynamically manage recurrent and non-recurrent (incident) congestion based on prevailing traffic conditions
- **Benefits**
  - Maximize the efficiency of the facility
  - Increase safety

# Keywords to Highlight in this Lecture

- Connected (and autonomous) Vehicles
- (Pro)Active Traffic Management (ATM)
- Big Data
- Real-Time Applications

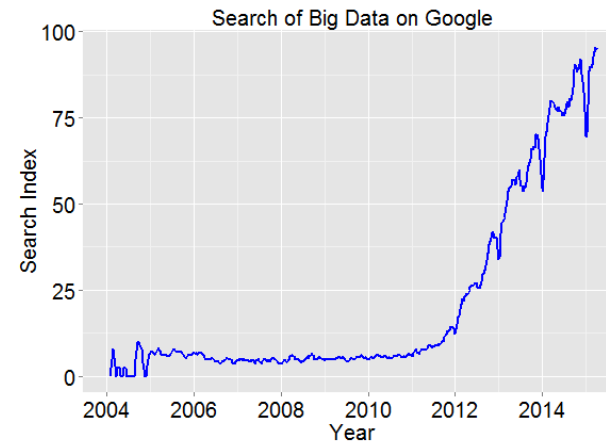
# *(Pro)Active* Perspective

- Traditional Approach
  - Where congestion/queues have formed?
  - Where a crash has occurred?
  - Where inclement weather has been detected?
- *(Pro)Active* Perspective
  - Where the congestion/queues are about to form?
  - Where a crash is more likely to occur?
  - Where inclement weather is about to begin?

❖ **Key: prediction in real-time**

# The Age of Big Data

- The advent of Big Data era
  - Since 2010
- Key words related to Big Data
  - Data
  - Big
  - Information
  - Prediction



\*Data Source from Google Trends



\*Data Source from  
Big Data: A revolution That Will  
Transform How We Live, Work,  
and Think

# What is Big Data?

- General impression: storage and analysis of unfathomable amounts of information
- The most widely cited definition: three Vs (basic)
  - **Volume**: increasing size of data
  - **Velocity**: unprecedented streaming speed of data
  - **Variety**: wide range of data formats
- Additional dimensions of Big Data (sometimes used)
  - **Veracity**: trust and uncertainty with regards to data and the outcome of analysis of that data
  - **Variability**: data flow inconsistency with periodic peaks
  - **Complexity**: link, match, cleanse and transform data across systems

# Data and Monitoring

- **Traffic Detection Systems**

- Loop detectors
- Automatic Vehicle Identification (AVI) Systems
- Microwave Vehicle Detection Systems (MVDS)
- BlueTooth detectors



# Traffic Detection Systems

- **AVI Data**

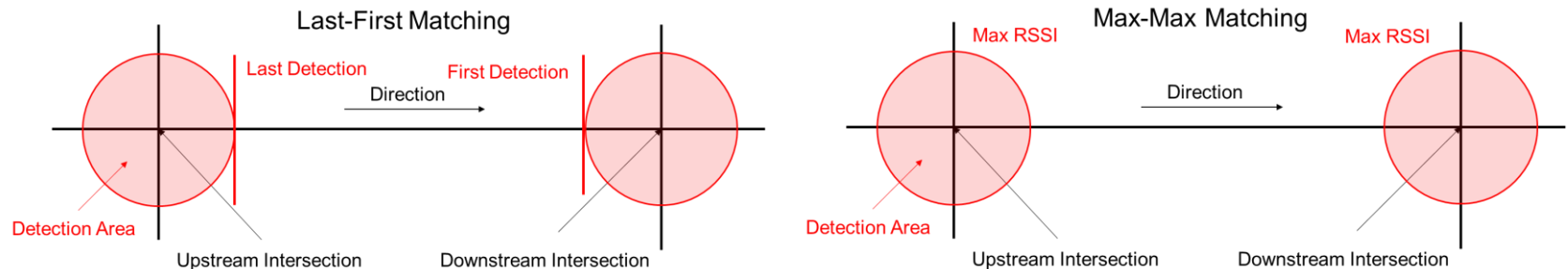
- Data collected for vehicle equipped with tags
- Uncapped AVI Data
  - Vehicle based
  - Uncapped at speed limit
  - Partial traffic volume (equipped with tag)

- **MVDS/RTMS Data**

- Usually 20-60 -seconds intervals
- Lane and Lane Type (lanes, ramps, etc)
- Speed
- Volume
- Lane Occupancy
- Vehicle Classes
- Spacing

# Bluetooth and Private data on Arterials

- HERE, INRIX, Google
  - Third-party speed data, from probe vehicles (black box)
  - 1 min aggregated **space mean speed** of a link
- Bluetooth
  - Link travel time for individual vehicles: BlueTOAD, BlueMAC
  - Travel time of BlueMAC is calculated by matching logs of the same vehicle. There are several matching methods to overcome the multiple detection.

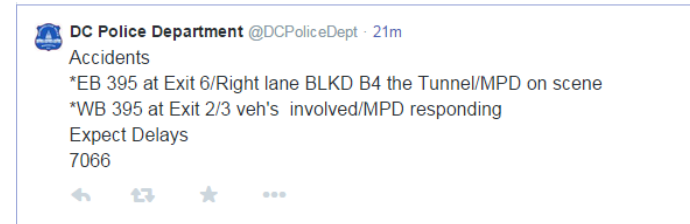


- Aggregated link space mean speed is calculated by individual link travel time

# Big Data in the Transportation Arena

- Sources of Big Data in transportation

- Web traffic, network comments
- ITS facilities (traffic sensors)
- Weather Detection Systems
  - Weather sensors (e.g. temperature, precipitation, visibility, fog, etc.)
- Roadway geometric database
- Crash database
- GIS database
- Socio-demographic database



\*Data source from Twitter

- Data type

- Structured data
  - Traffic detection data
  - Road geometric data
  - Crash data
  - Socio-demographic data
- Unstructured data
  - Video images
  - Social media text
  - Text documents



\*Data source from Facebook



\*Automatic Vehicle Identification (AVI) System (above)

\*Microwave Vehicle Detection System (MVDS) (right)



# Future Potential of Big Data in Traffic Safety Management

- Event/incident detection
  - Providing more detailed information regarding the events
- Sentiment analysis of travelers' attitudes towards traffic safety and operation
- Creative approaches to summarize, describe and analyze the information contained in the data
- New applications of the data

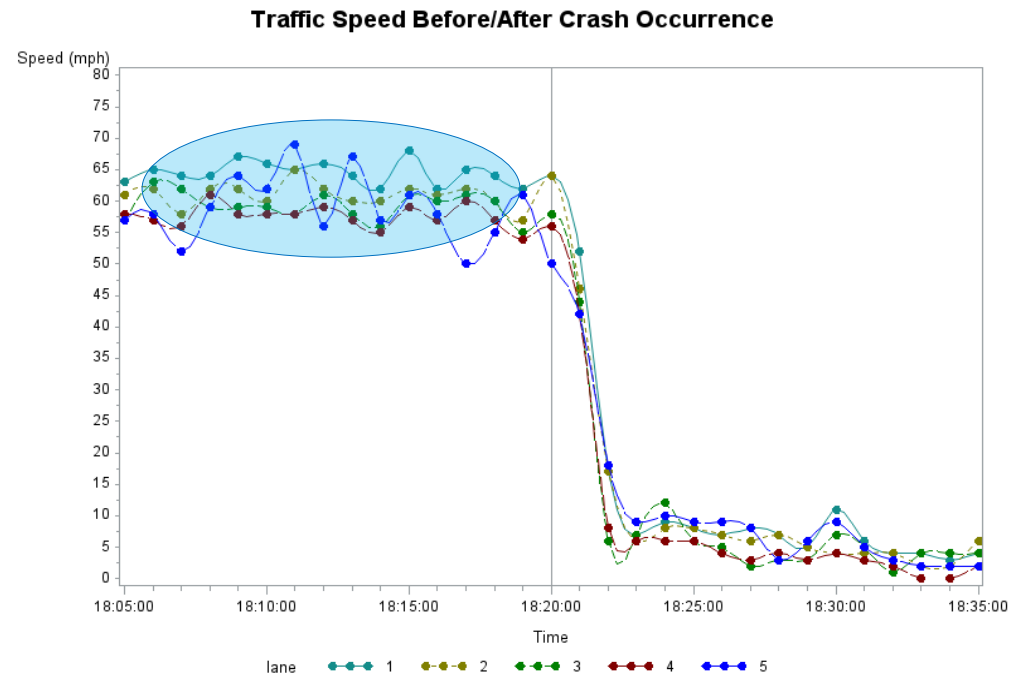
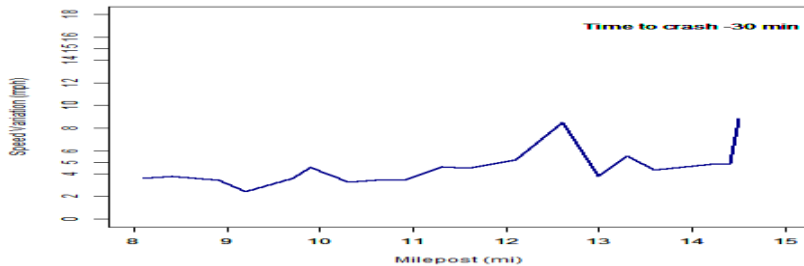


Translation of tweet:  
Chaos on Capelseplein  
in the direction of  
Rotterdam, because of  
a delivery van in the  
crash barrier

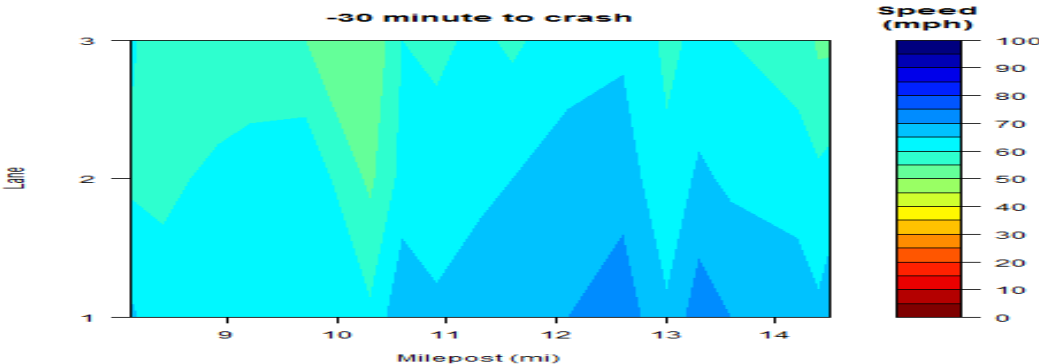
\*Data Source from  
Twitter as a spatio-temporal information source for  
traffic incident management

# Big Data Applications in Microscopic Traffic Safety Analysis

- Real-time nature of Big Data to reflect the occurrence of crash and their effects on traffic flow

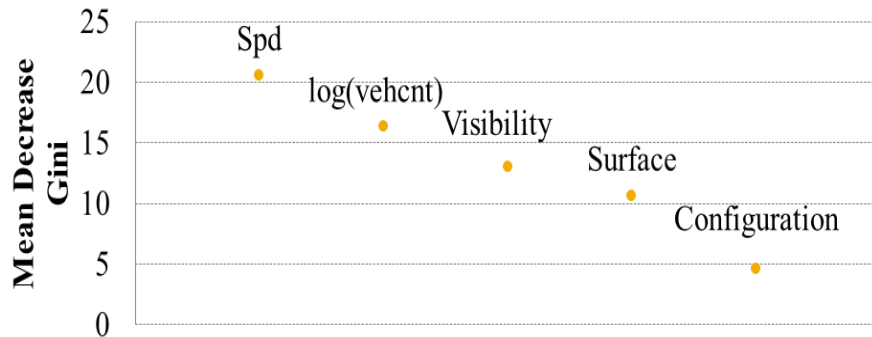


Direction: WB, @MM:12.1, Type: Rear-end, Vehicles: 4, Injuries: 3

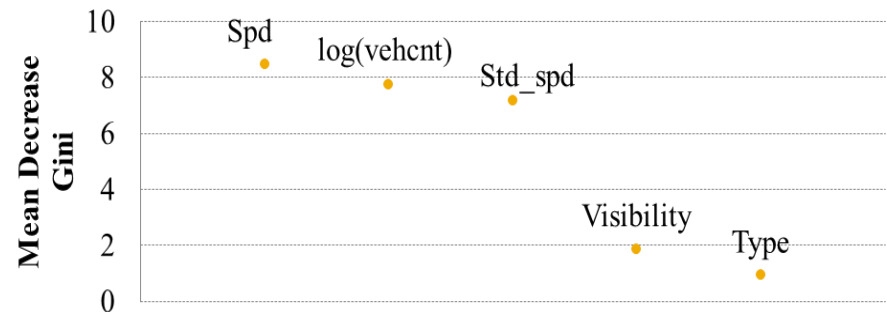


# Big Data Applications in Microscopic Traffic Safety Analysis

- Big Data analytics of real-time expressway ramp safety
  - Data mining: Random Forest
    - Importance ranking of crash contributing factors
    - Traffic > Weather > Geometry
    - Speed is the most important factor

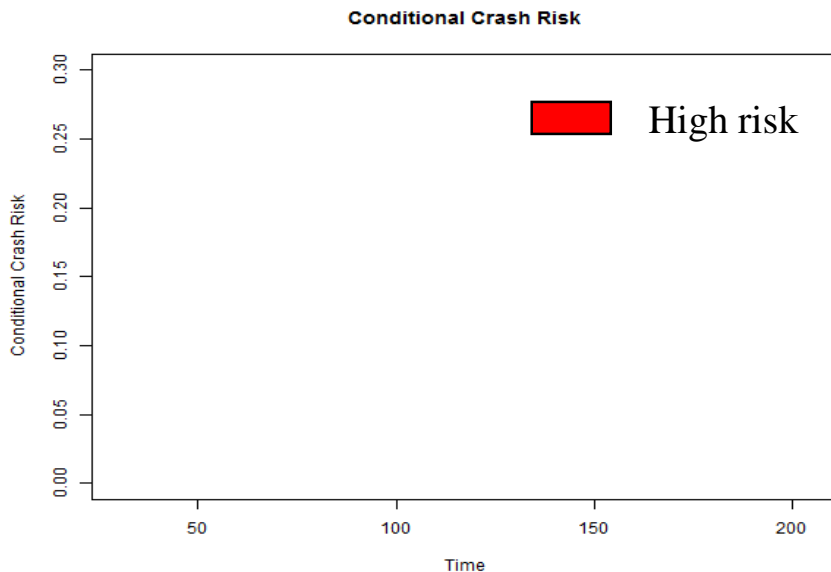
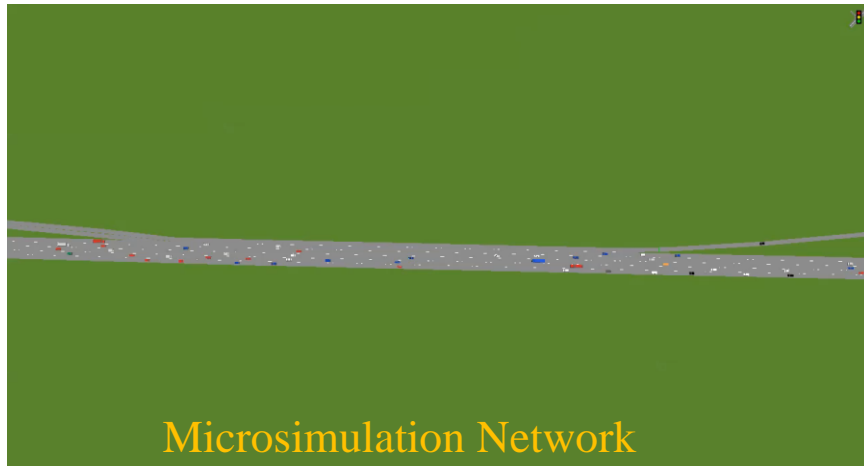


a) SV Crash Model



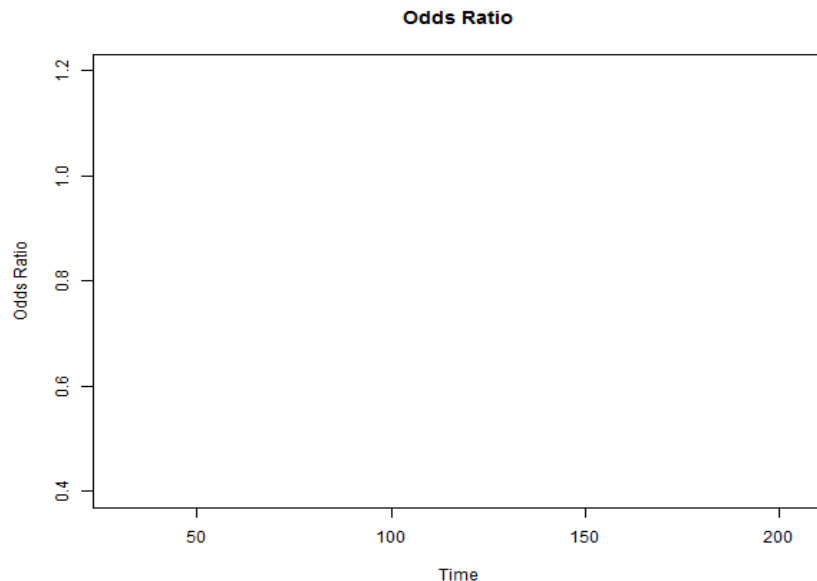
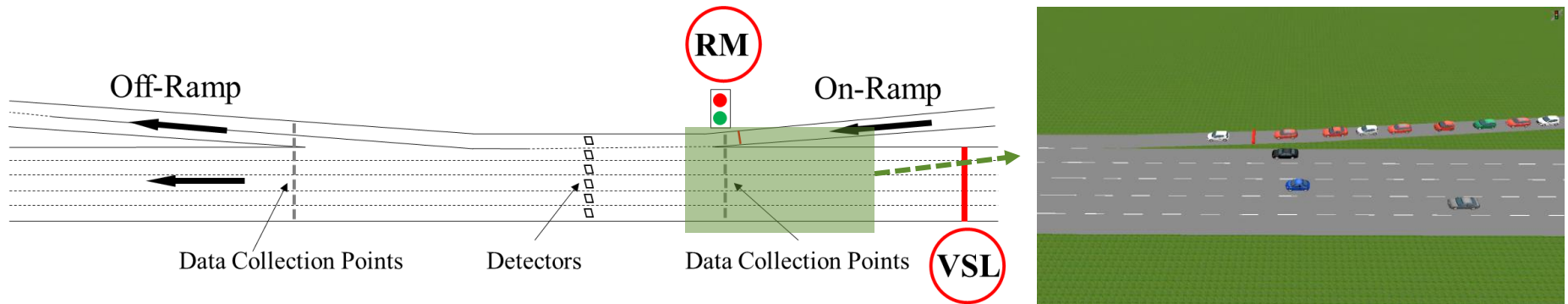
b) MV Crash Model

# ATM in Safety Improvement of a Weaving Segment



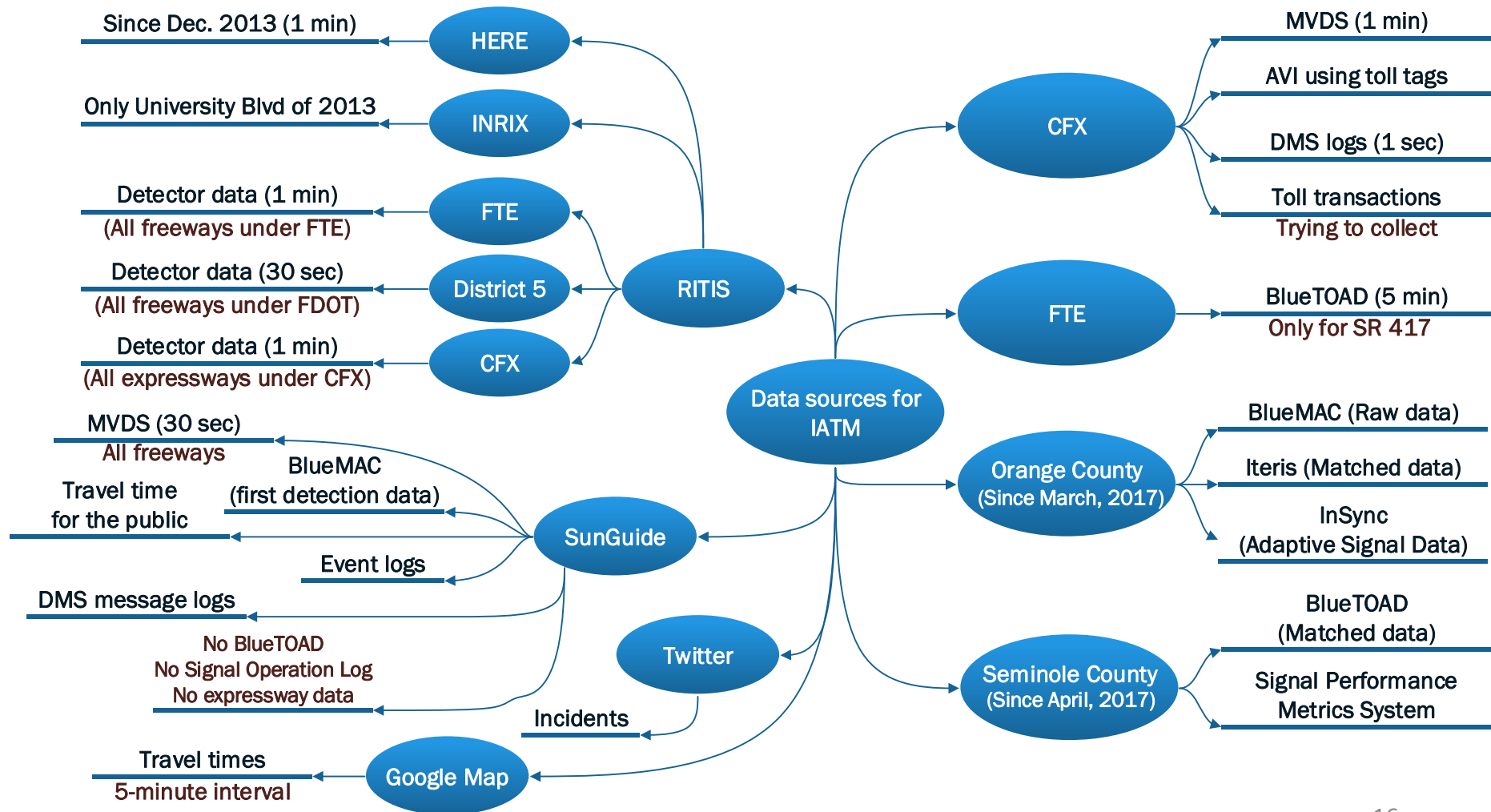
- Crash mechanism of weaving segments
  - Speed difference between the beginning and the end of weaving segment (+)
  - Volume (+)
  - Weaving configuration (+)
  - Weaving influence length (+)
  - Wet pavement (+)
- ATM Strategy
  - Apply Variable Speed Limit (VSL)
    - To reduce speed difference (-)
  - And apply Ramp Metering (RM)
    - To reduce weaving influence length by decreasing on-ramp volume (-)

# ATM in Safety Improvement of a Weaving Segment



- Integrated RM and VSL
  - Reduced crash odds by 6.0%
  - Reduced conflict number by 16.8%
  - Continuously improved safety
  - Increased average travel time by 6.9%

# Examples of Big Data for ATM



# CAV BACKGROUND



# What are Connected and Autonomous Vehicles (CAV) Technologies?

**Connected Technology**

①+②+③

Feel by Vehicle, **Control by Man**

+

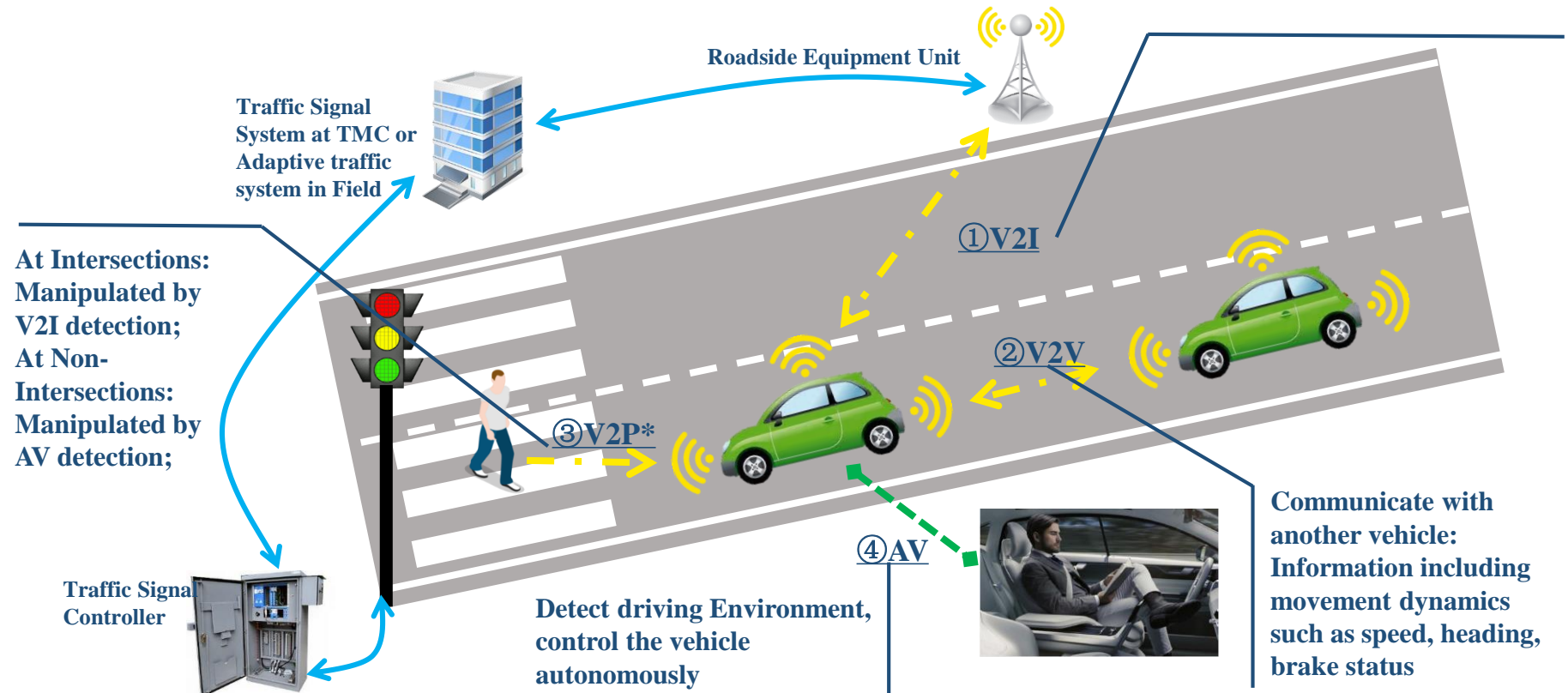
**Autonomous Technology**

④

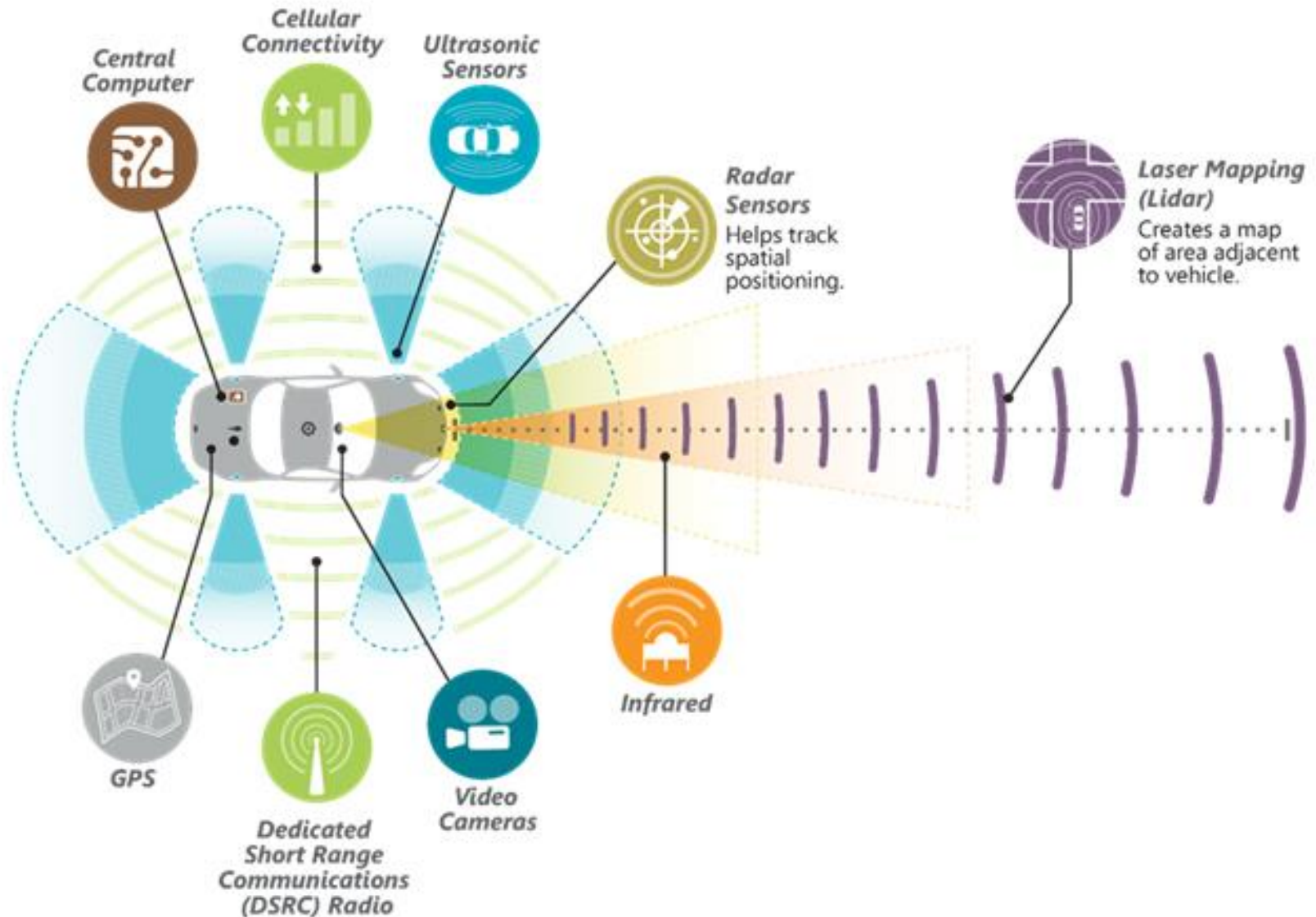
Feel by Vehicle,  
**Control by Vehicle Itself.**

=

**CAV Technologies**



# CONNECTED AUTOMATED VEHICLE (CAV) TECHNOLOGY



# Why could CV Technology be helpful?

## ① V2I Safety Benefits



Help a driver know Road Conditions like downstream congestion, speed limit on a curve, signal status, stop sign and pedestrian crosswalks, so that the driver could adjust his/her driving speed, awareness or travel route and so on to avoid a potential crash or congestion.

## Examples of V2I Technology Pre-crash Warning Scenario

Scenario and Warning Type		Scenario example
<b>Road departure collision scenarios</b>	<b>Curve speed warning</b>  Approaching a curve or ramp at an unsafe speed or decelerating at insufficient rates to safely maneuver the curve	(Source: Battelle) <p>Driver Vehicle Interface (DVI) Example</p>
<b>Crossing path collision scenarios</b>	<b>Running red light/stop sign</b>  Violation at an intersection controlled by a stop sign or by traffic signal	Source: Maile et al. <p>Driver warned if signal violation is predicted</p> <p>Messages to vehicle</p> <p>Signal about to turn red for car</p> <p>Intersection Equipment</p>

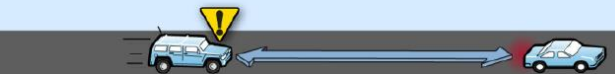




# Why could CV Technology be helpful?

## ② V2V Safety Benefits



Help a driver know an unobservable presence or an unpredictable movement of another vehicle in pre-crash scenarios, so that an evasive action by the driver could be made in advance.

### Examples of V2V Technology Pre-crash Warning Scenario

Scenario and warning type	Scenario example
<b>Rear end collision scenarios</b>  <b>Forward collision warning</b> Approaching a vehicle that is decelerating or stopped.	
<b>Emergency electronic brake light warning</b> Approaching a vehicle stopped in roadway but not visible due to obstructions.	
<b>Lane change scenarios</b>  <b>Blind spot warning</b> Beginning lane departure that could encroach on the travel lane of another vehicle traveling in the same direction; can detect vehicles not yet in blind spot.	
<b>Do not pass warning</b> Encroaching onto the travel lane of another vehicle traveling in opposite direction; can detect moving vehicles not yet in blind spot.	
<b>Intersection scenario</b>  <b>Blind intersection warning</b> Encroaching onto the travel lane of another vehicle with whom driver is crossing paths at a blind intersection or an intersection without a traffic signal.	

Source: GAO analysis of Crash Avoidance Metrics Partnership information.

# Why could CV Technology be helpful?

## ③ V2P\* Safety Benefits



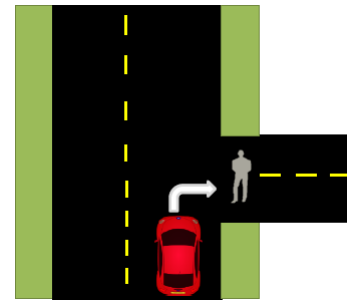
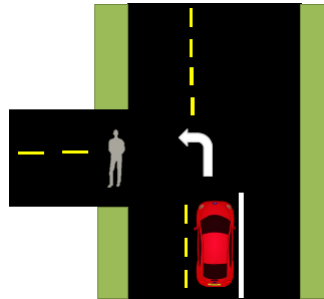
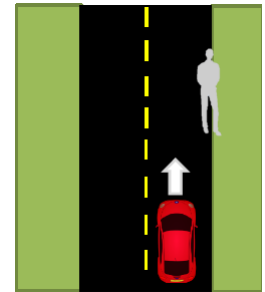
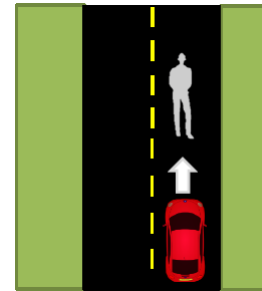
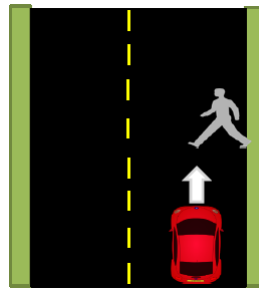
Help the driver and pedestrian be aware of the presence of each other, so that we prevent or mitigate a potential vehicle-pedestrian collision

V2P\*:

at non-intersection locations, V2P is operated by AV detectors and sensors;

At intersection locations, V2P could also be operated by V2I detectors and sensor.

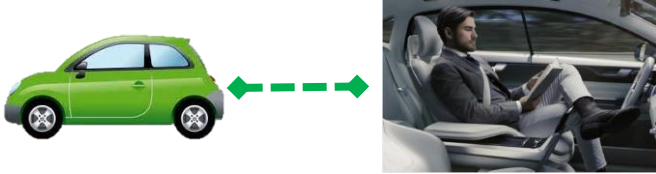
### Examples of V2P Technology Pre-crash Warning Scenarios



Source: Swanson et al. 2016

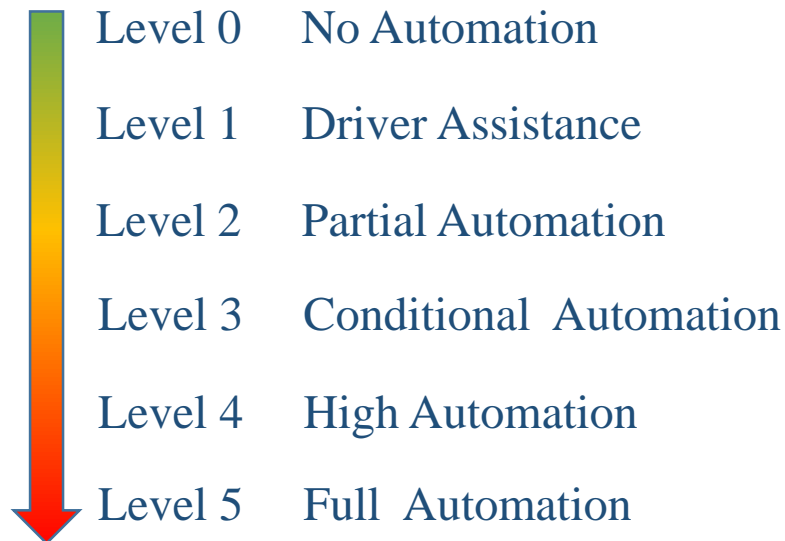
# Why could CAV Technology be helpful?

## ④ AV Safety Benefits

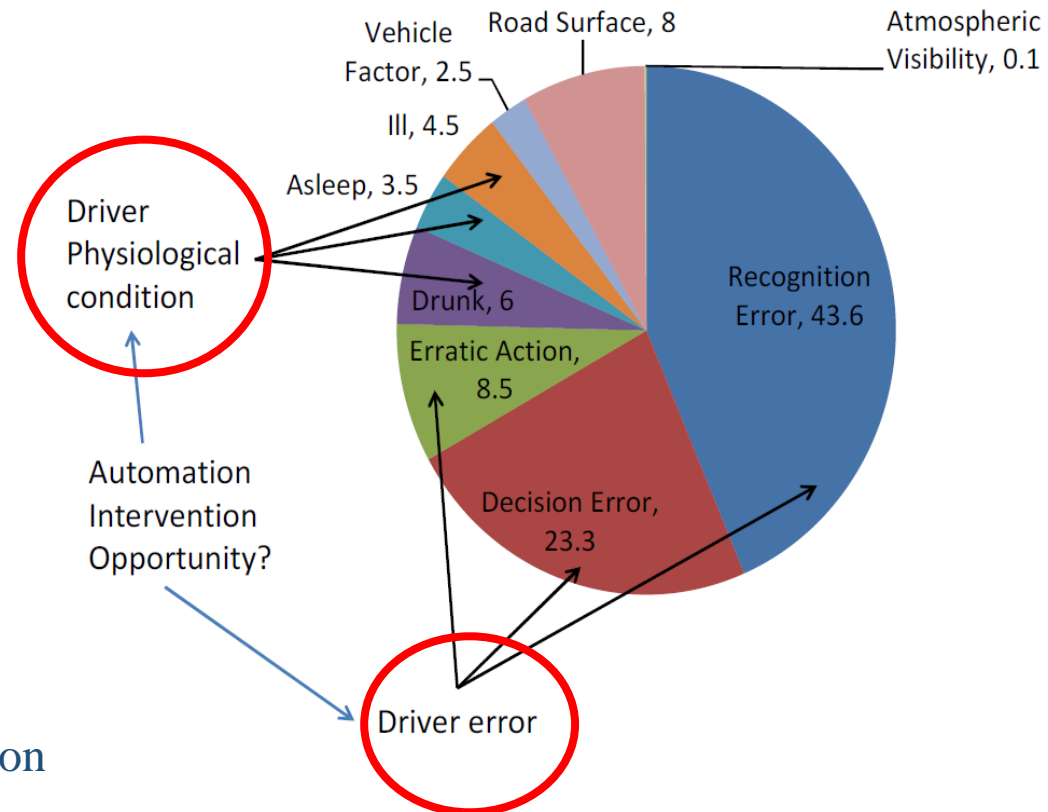


Help perform driving controls effectively without the constraint of driver inputs.

**Six levels of automation (SAE, 2014) :**

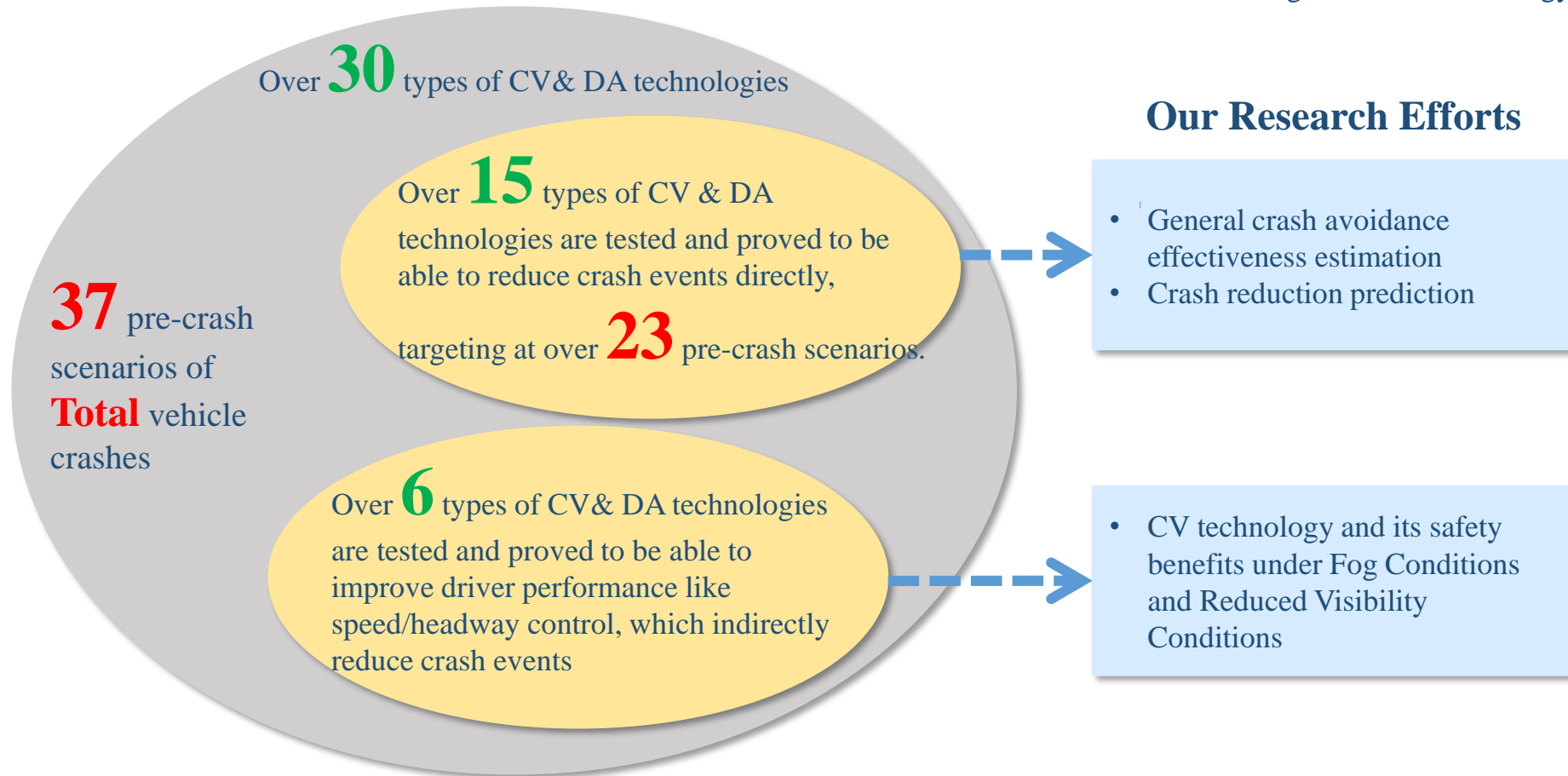


## Critical Causal Factors for Light Vehicle Crashes



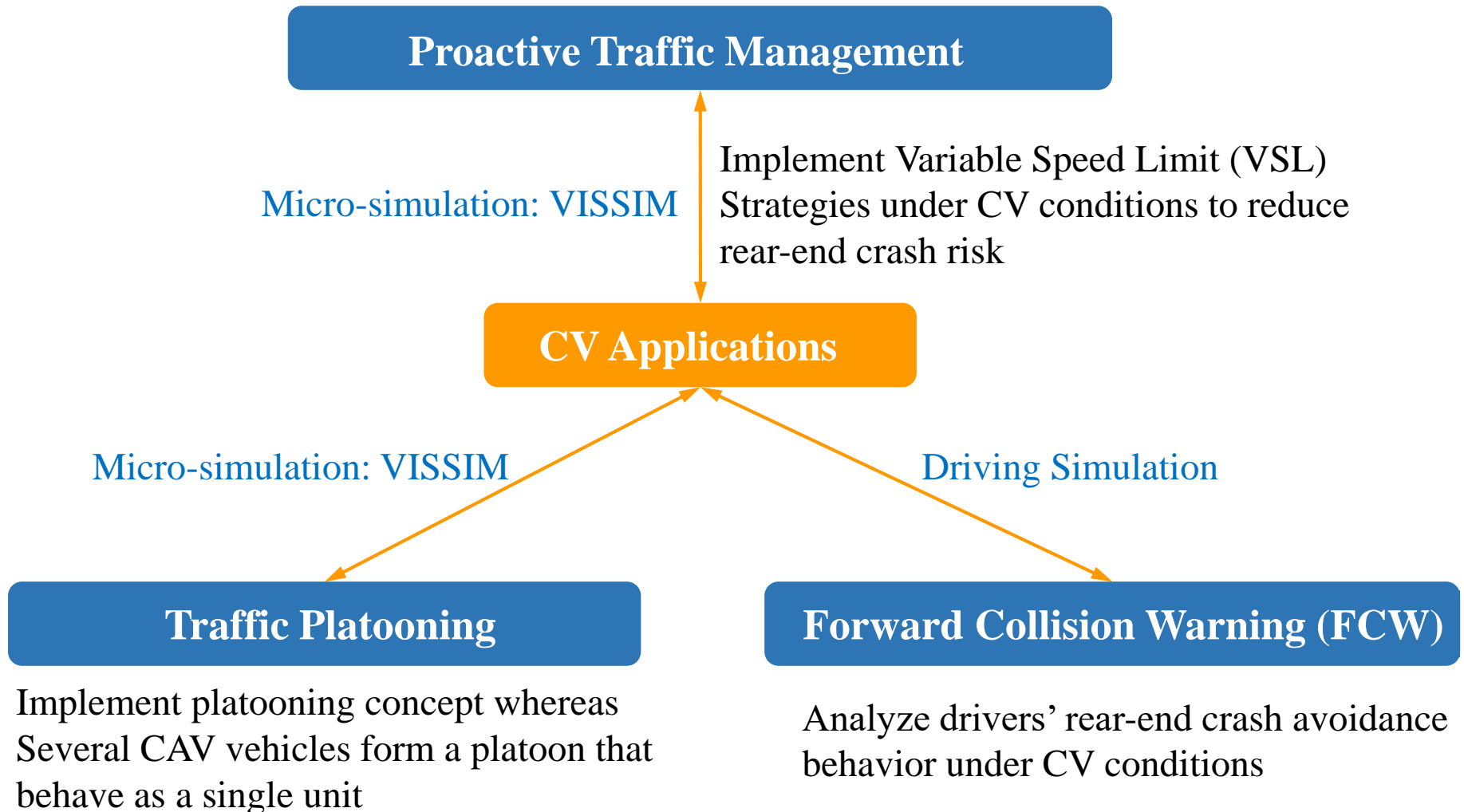
# Research work of CV&DA for Safety Benefits

CV: Connected Vehicle Technology  
DA: Driving Assistive Technology



# Connected Vehicles Applications

## CV studies at UCF



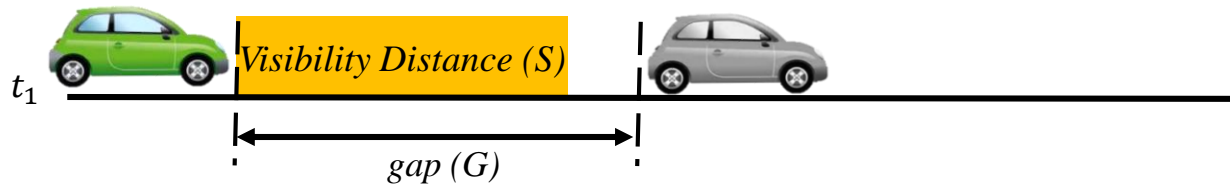
# **Analysis of Rear-end Crash Avoidance Behaviors under Fog Conditions by Driving Simulator Experiments**



# Rear-End Crash Risk in Reduced Visibility

*If visibility distance ( $S$ ) < Gap ( $G$ )*

Traffic flow Direction  
→



The front vehicle begins to **brake**



The following vehicle can **see** the front vehicle

The following vehicle begins to decelerate when the following vehicle *can see the front vehicle*.

# Driving Simulator Experiment

- ❖ Forward Collision Warning (FCW)
- ❖ The front car makes an emergency stop under fog conditions
- ❖ “Slow Vehicle Ahead” warning through Heads-up Display (HUD)



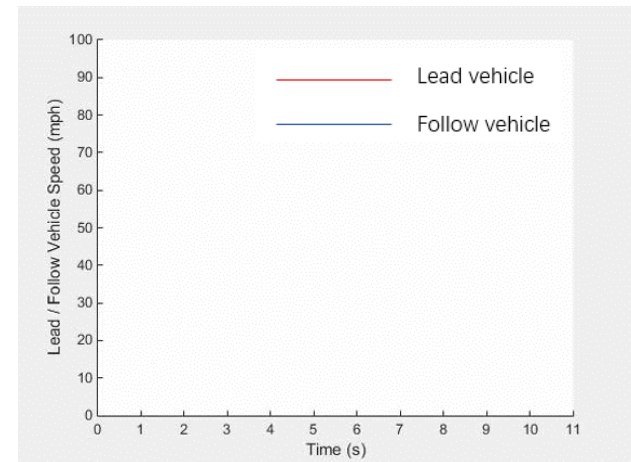
# Driving Simulator Experiment (V2V)

## *Scenario in Driving Simulator*

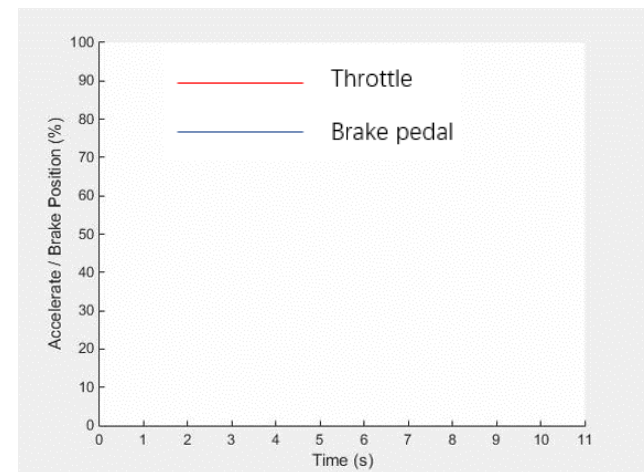
Front vehicle suddenly decreases its speed under fog conditions



## *Lead/Follow Vehicle Speed*

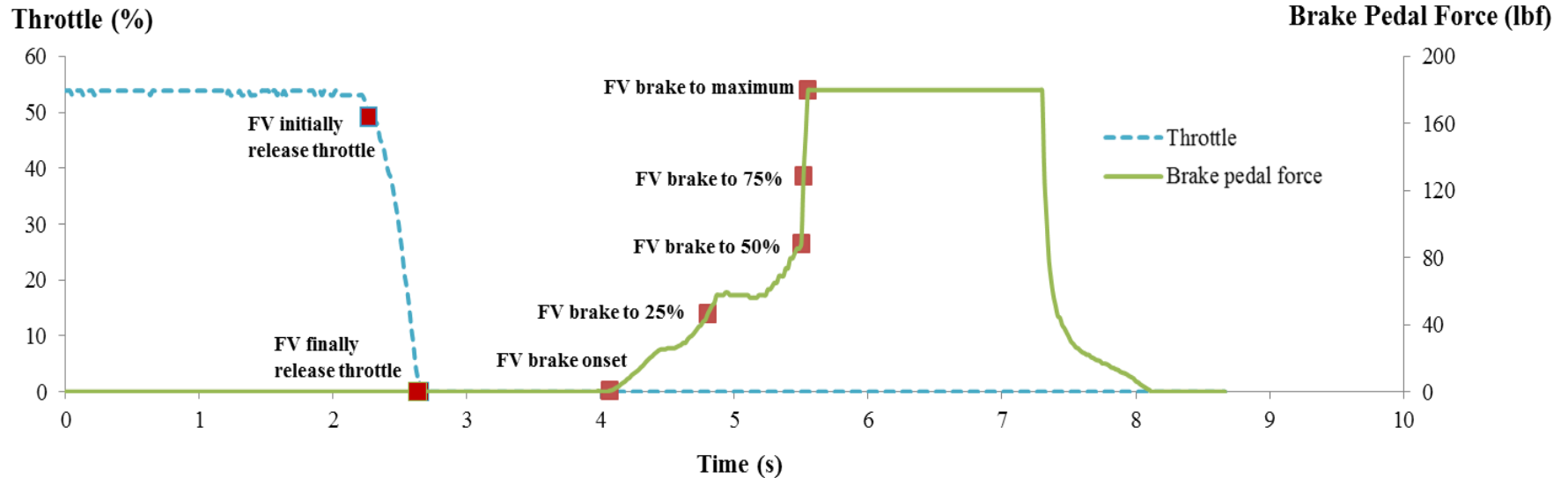


## *Accelerate/Brake*



# Dependent Variables

## A Typical Rear-End Crash Avoidance Behavior



Different times during the crash avoidance behavior were selected as dependent variables in this study.

Other dependent variables include: brake reaction time ( $BRT$ ) and Maximum brake pedal pressure ( $Brake_{max}$ ), Minimum time-to-collision ( $MTTC$ ).

# Driving Simulator Results

Factors		Warning type	Fog Level	Age
Throttle Release Time	$t_{Release}$	**		
	$t_{brake}$	**		
Brake Transition Time	$t_{75\%brake}$	*		*
	$t_{maxbrake}$	*		**
Response Time	BRT	**		**
Minimum Time to Collision	$MTTC$	**	**	
Maximum Brake Pedal Pressure	$Brake_{max}$		**	**

\*\* indicates significant at an alpha level of 0.05, \* indicates significant at an alpha level of 0.1

Warning type, fog level, and age group have significant effects on crash avoidance behaviors.

# Fog Ahead Warning (I2V)



# Curve Ahead Warning (I2V)



# **Understanding the Highway Safety Benefits of Different Approaches of Connected Vehicles**



# CV Implementation for RE Crash Risk

(1) No Connected Vehicle Condition

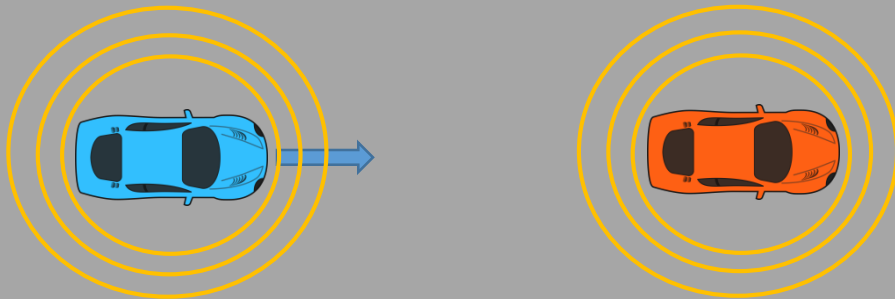
Rear-end Crash



(2) Connected Vehicle Condition (V2V)

➡ Visibility Distance

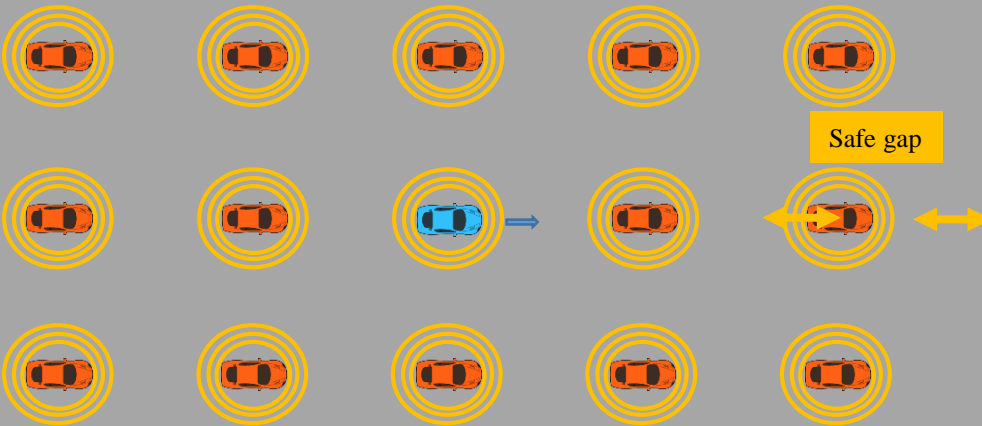
Slow Vehicle Ahead



# V2V Implementation

Microsimulation, such as VISSIM, can be used to model connected vehicle behavior between vehicle to vehicle (V2V) and vehicle to infrastructure (V2I).

## Vehicle to Vehicle (V2V)



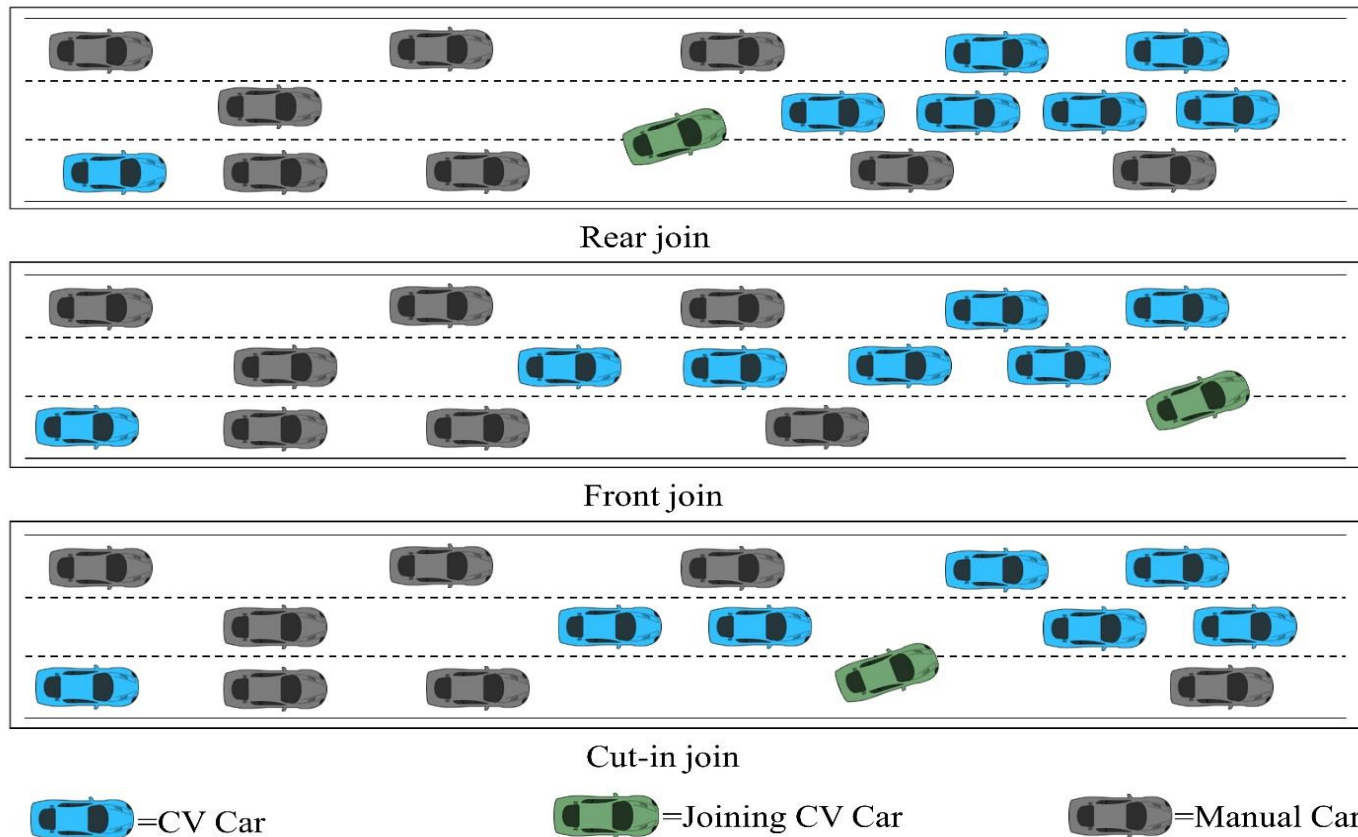
Slow vehicle ahead → Decelerate and maintain a safe gap  
Controlled by VISSIM driver model through API

# Different Approaches of CV

- ❖ Two approaches of CV were implemented. Connected vehicle without platooning (CVWPL) and connected vehicle with platooning (CVPL).
- ❖ The aforementioned two driving behavior models (i.e., CVWPL, CVPL) were implemented as Dynamic Link Library (DLL) plug-in for both approaches, which overrides the VISSIM default driving behavior.
- ❖ Intelligent Driver Model (IDM) was used for CVs car following behavior in fog conditions.
- ❖ These two DLL were written in C++ programming language which offers VISSIM an option to replace the internal driving behavior.
- ❖ During the simulation, the DLL file is called up in each time step and then controls the behavior of the vehicle for all or part of the vehicles depending on the MPRs.
- ❖ Note that the car following and the lane changing behavior of non-CVs were determined by VISSIM's default driving behavior model.

# Platooning Concept of CAV

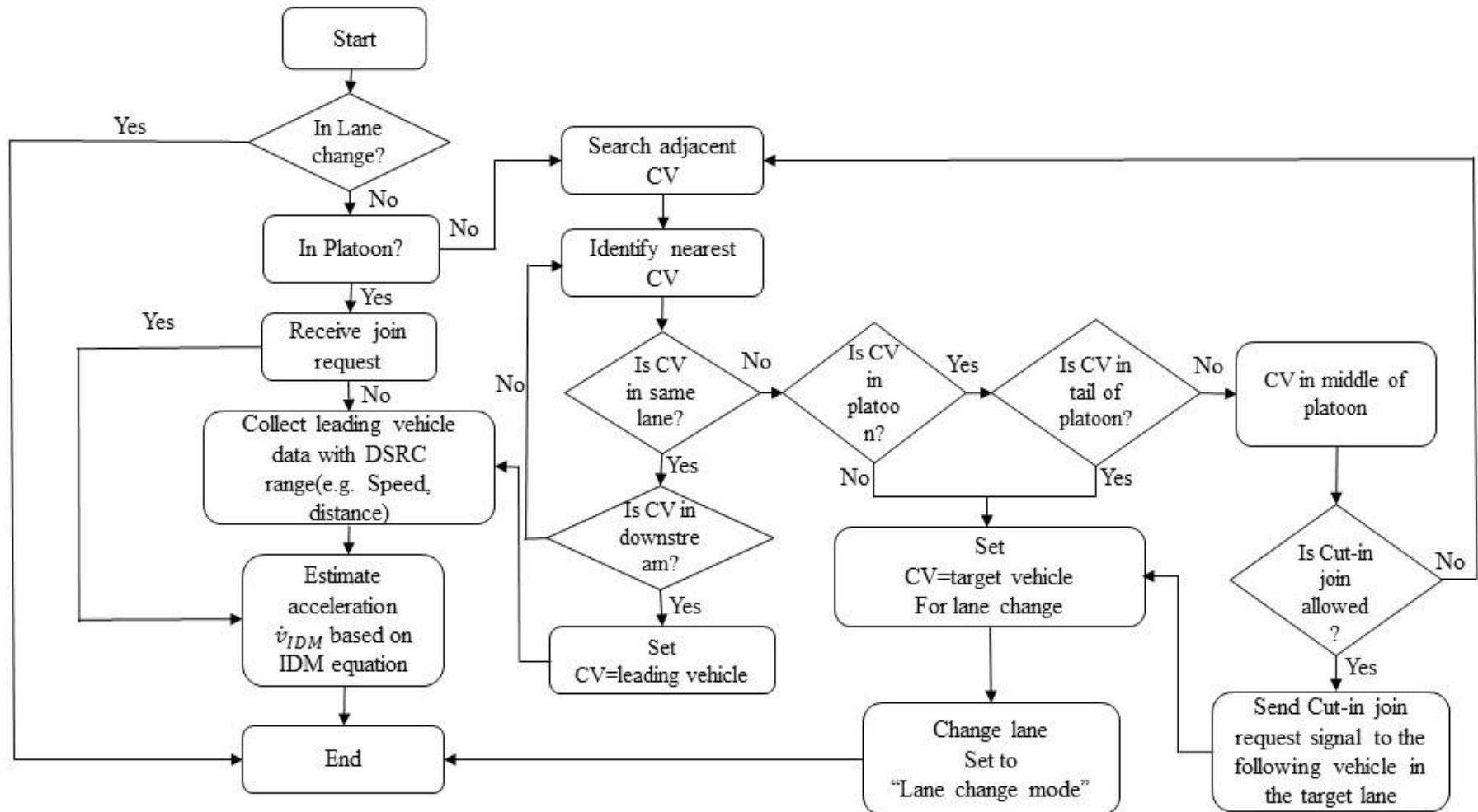
CVs were also implemented as a platooning concept (CVPL), wherein several vehicles form a “platoon” that behaves as a single unit.



**Joining of CVs to maintain a platoon.**

# Control Algorithm of CV Platooning

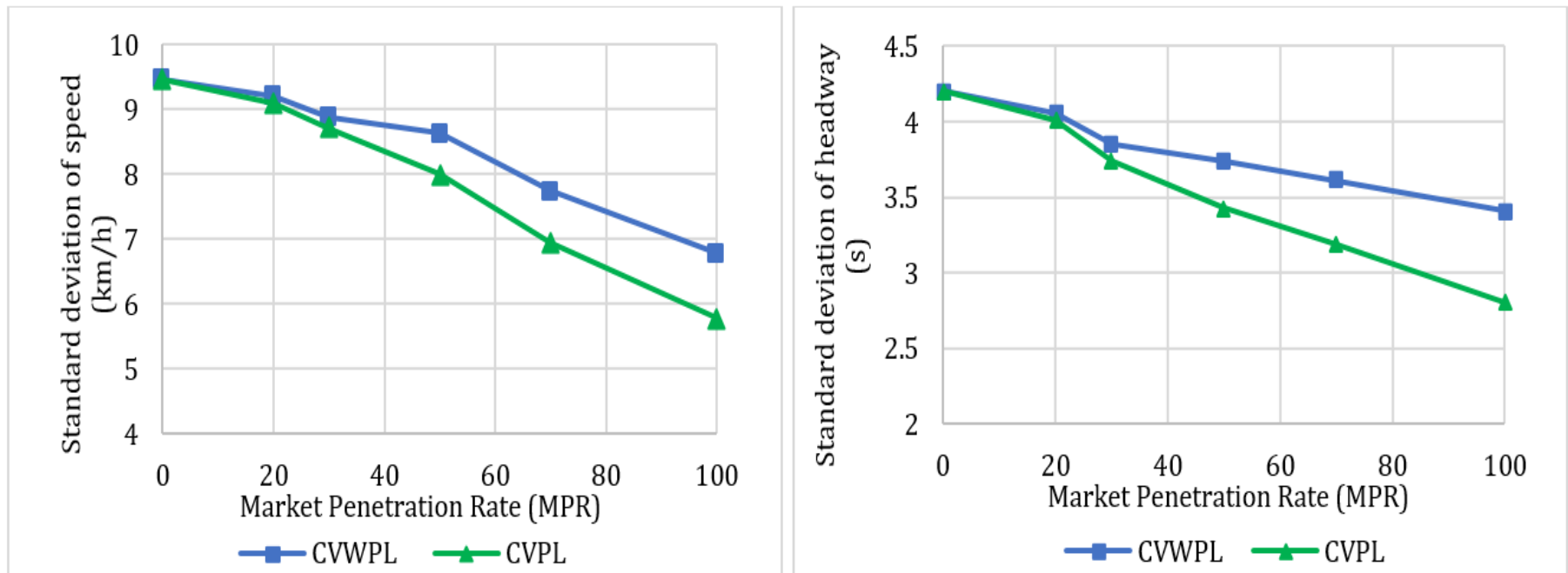
We developed a high-level control algorithm architecture for CVPL approach .



## Control algorithm of CVs to maintain a platoon.

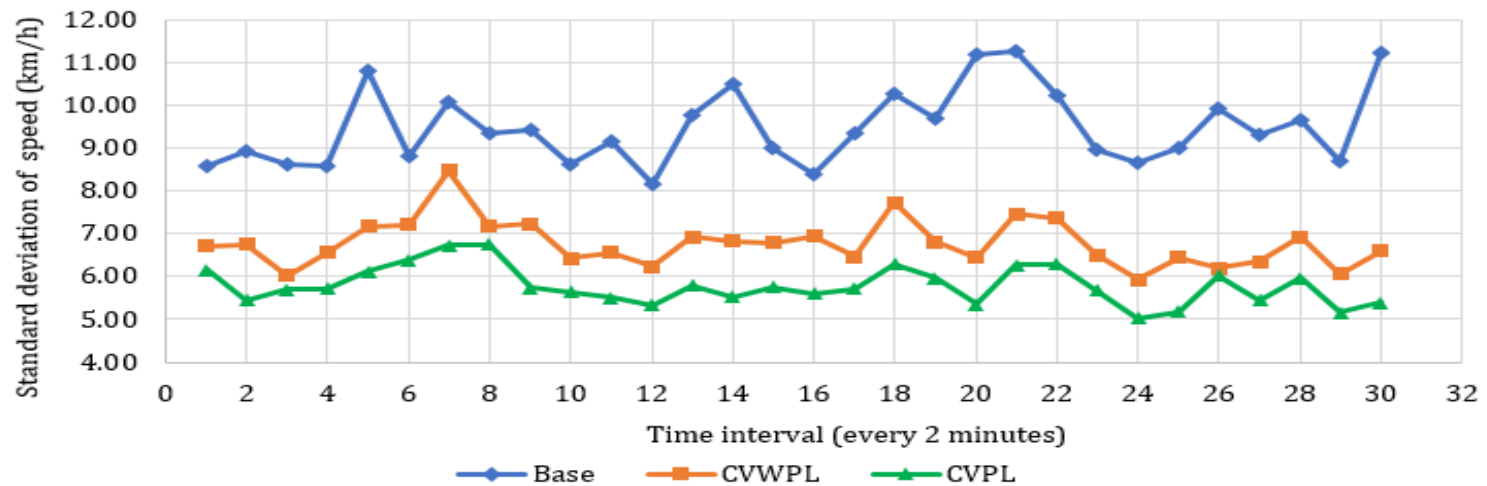
# Effect of CAV for Different MPRs

Figure shows the decreasing trend of standard deviation of speed and standard deviation of headway for CVWPL and CVPL approaches with increasing MPRs. As seen from the figure, the higher the percentage of the CVs implemented, the lower were the standard deviations of speed and headway.

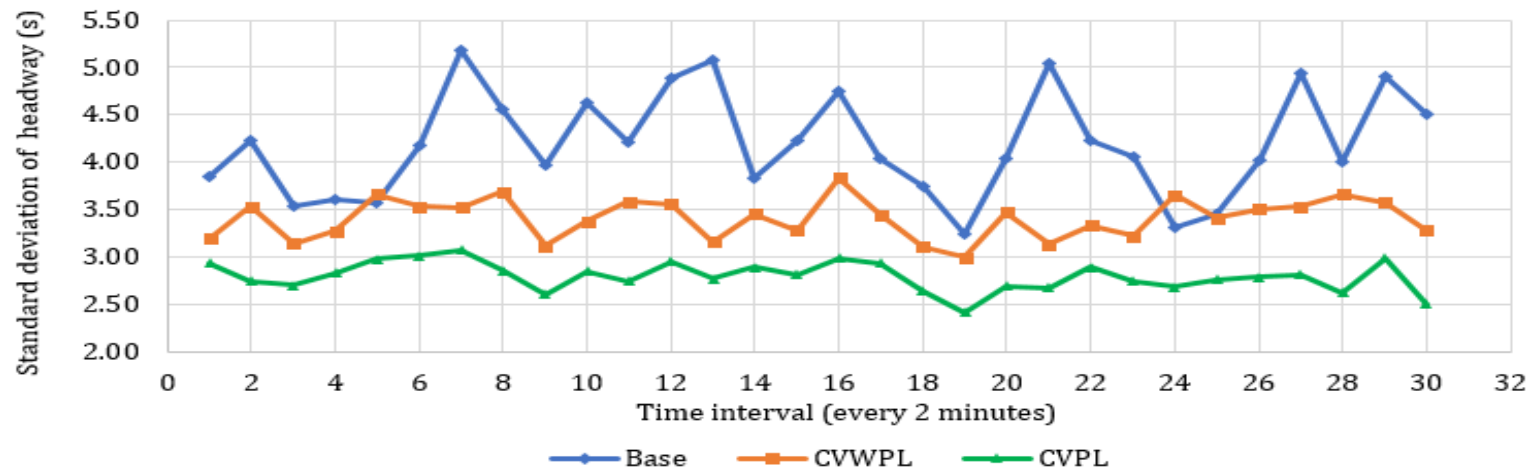


**Reduction of surrogate measures of safety with different MPRs**

# Temporal Effect of CAV



(a)

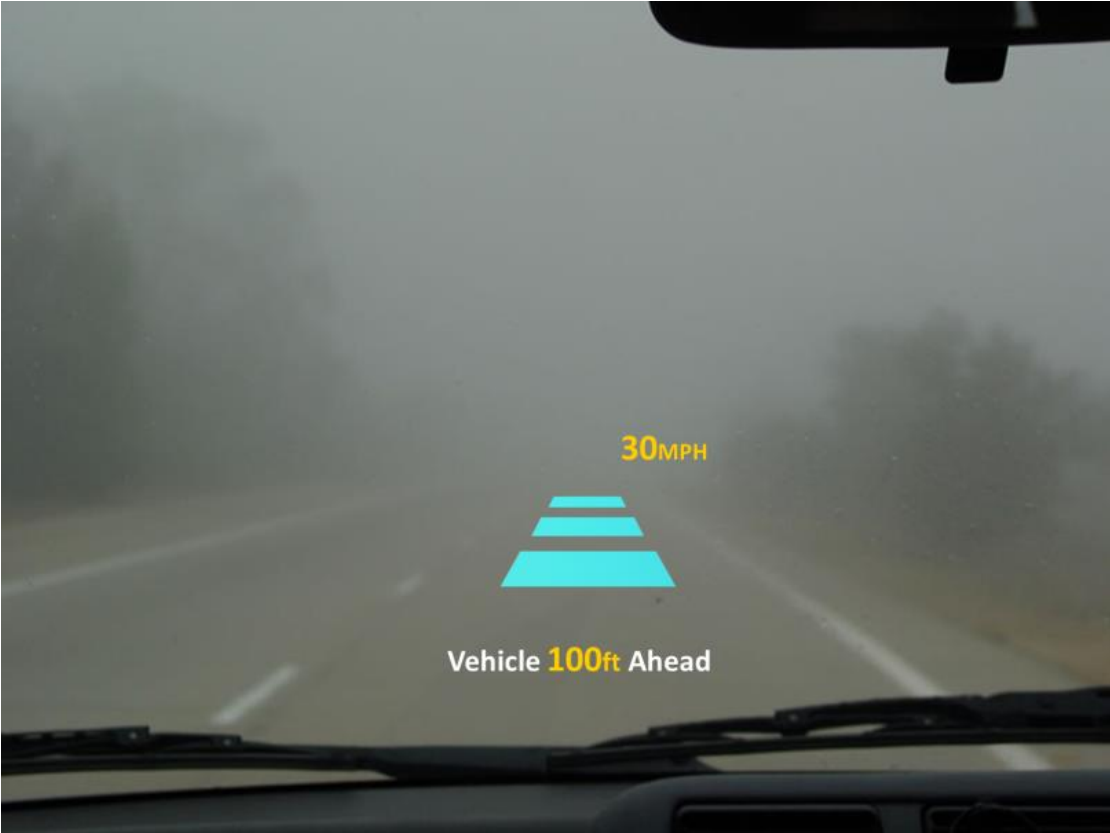


(b)

**Stabilize profile of surrogate measures of safety at 100 % MPR**

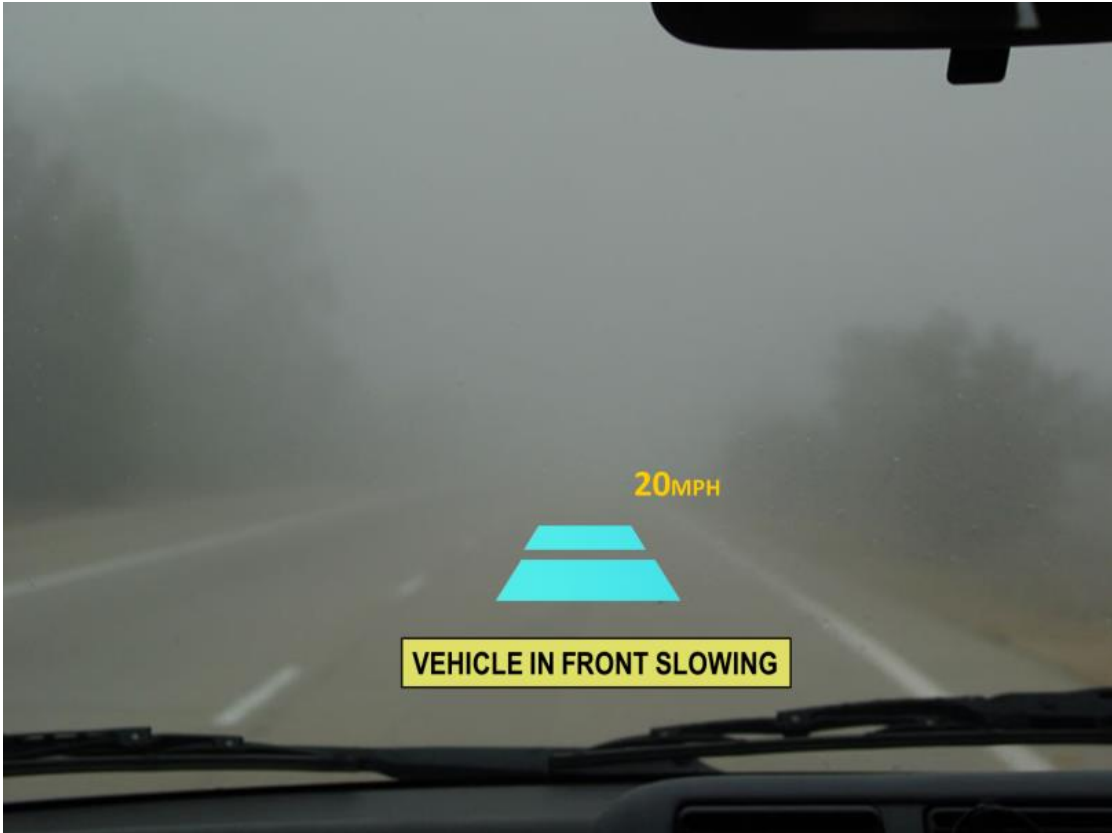
# Optimized HUD Design under CV

- Scenario: Rear-end crash risk= **Low**

Recommended HUD Design	Driving Scenarios	Design Description
	<p><b><u>Weather:</u></b></p> <ul style="list-style-type: none"> <li>• Dense fog</li> </ul> <p><b><u>Rear-end crash risk (based on real-time prediction):</u></b></p> <ul style="list-style-type: none"> <li>• Low</li> </ul> <p><b><u>Traffic condition:</u></b></p> <ul style="list-style-type: none"> <li>• Two vehicles keeping a safe distance</li> </ul>	<p><b><u>3 Information:</u></b></p> <ul style="list-style-type: none"> <li>• Distance between two vehicles in real-time= “numerical distance value in yellow text”</li> <li>• Location of front vehicle in real-time= “bar marking with narrow squared stripes in light blue color”</li> <li>• Speed of front vehicle in real-time= “numerical speed value of front vehicle in yellow text”</li> </ul>

# Optimized HUD Design under CV

- Scenario: Rear-end crash risk= **High**

Recommended HUD Design	Driving Scenarios	Design Description
	<p><b><u>Weather:</u></b></p> <ul style="list-style-type: none"> <li>Dense fog</li> </ul> <p><b><u>Rear-end crash risk (based on real-time prediction):</u></b></p> <ul style="list-style-type: none"> <li>High</li> </ul> <p><b><u>Traffic condition:</u></b></p> <ul style="list-style-type: none"> <li>Front vehicle suddenly decelerates</li> </ul>	<p><b><u>3 Information:</u></b></p> <ul style="list-style-type: none"> <li>Warning information (using real-time updates)= “warning information with black text in yellow background”</li> <li>Location of front vehicle in real-time= “bar marking with narrow squared stripes in light blue color”</li> <li>Speed of front vehicle in real-time= “numerical speed value of front vehicle in yellow text”</li> </ul>

# Crash Avoidance Effectiveness for CV&DA



# Crash Avoidance Effectiveness for CV& DA: Summary

Summary of Research reports and Papers from 2007-2017: seventeen connected vehicle technologies (CV) and driving assistive technologies (DA) targeted at pre-crash types including 23 pre-crash scenarios.

CV&DA Technology	Automation Level(SAE)	Target Pre-Crash Type and Pre-Cash Scenarios
Forward Collision Warning (FCW,CV/DA), Collision Warning System (CWS, DA)	0	<b>Rear-End:</b> 1.Lead Vehicle Stopped
Adaptive Cruise Control(ACC, DA)	1	2.Following Vehicle Making a Maneuver
Autonomous Emergency Braking (AEB, DA), Autobrake(DA), Advanced Braking System (AdvBS, DA)	1	3.Lead Vehicle Decelerating 4.Lead Vehicle Moving at Lower Constant Speed
Collision Mitigation Brake System (CMBS)	1	5.Lead Vehicle Accelerating
Electronic Stability Control (ESC,DA)	1	<b>Run-Off-Road:</b> 6.Control Loss without Prior Vehicle Action 7.Control Loss with Prior Vehicle Action
Backup Collision Intervention (BCI,DA)	1	<b>Backing:</b>
Rearview Cameras (RCA,DA)	0	8.Backing Up into Another Vehicle
Blind Spot Warning (BSW,CV)	0	<b>Lane Change:</b>
Lane Change Warning (LCW,DA)	0	9.Vehicle(s) Turning – Same Direction, 10.Vehicle(s) Changing Lanes – Same Direction ,11.Vehicle(s) Drifting – Same Direction
Left Turn Assist(LTA,CV)	0	<b>Crossing Paths:</b>
Collision Mitigation Brake System (CMBS, DA)	1	12.Left Turn Across Path from Opposite Directions at Non-Signalized Junctions 13.Left Turn Across Path from Opposite Directions at Signalized Junctions
Intersection Movement Assist (IMA,CV)	0	<b>Crossing Paths:</b> 14.Vehicle Turning Right at Signalized Junctions, 15.Vehicle Turning at Non-Signalized Junctions, 16.Straight Crossing Paths at Non-Signalized Junctions 17.Running Stop Sign, 18.Running Red Light
Pedestrian Crash Avoidance and Mitigation System(PCAM,DA)	1	<b>Pedestrian:</b> 19.Pedestrian Crash With Prior Vehicle Maneuver 20.Pedestrian Crash Without Prior Vehicle Maneuver
Lane Departure Warning(LDW,DA)	0	<b>Run-Off-Road:</b>
Curve Speed Warning(CSW,CV)	0	21.Road Edge Departure With Prior Vehicle Maneuver 22.Road Edge Departure Without Prior Vehicle Maneuver 23.Road Edge Departure While Backing Up

# Crash Avoidance Effectiveness for CV&DA : Conclusion I

The CV&DA technology performs better on heavy trucks than on light vehicles.

Two potential reasons:

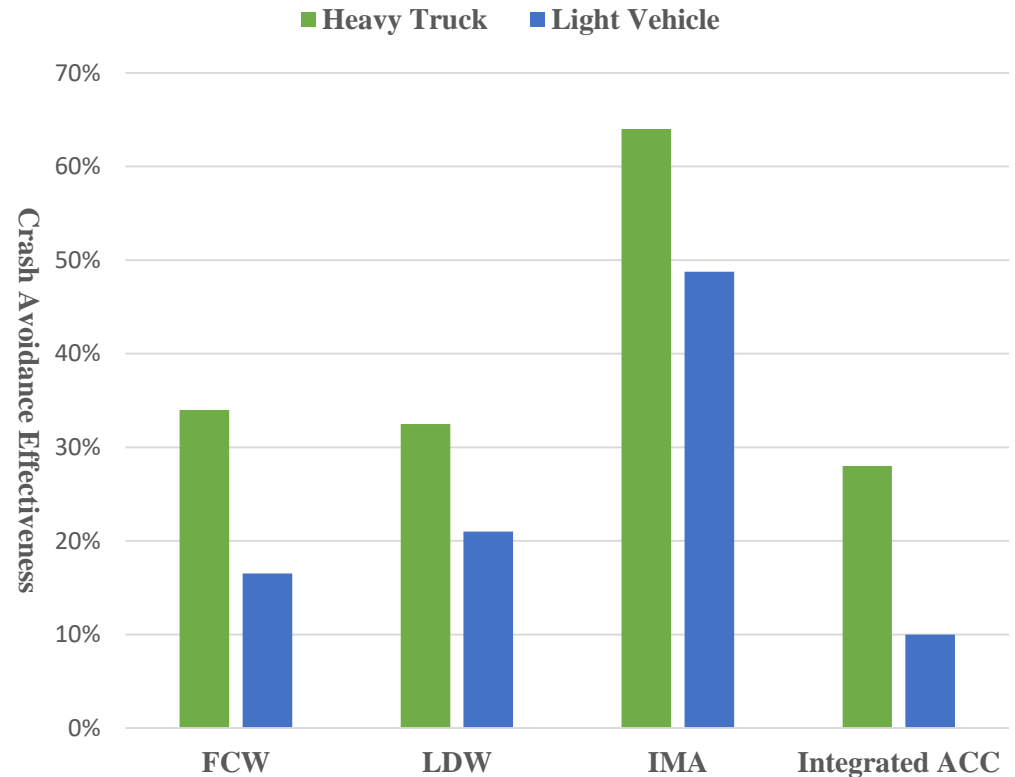
(1) Exposure rate of pre-crash scenarios:

Heavy trucks: low

Light vehicles: high

(2) Driver behavior:

Heavy truck drivers may be more cautious and more complying to CV&DA Warnings



# Crash Avoidance Effectiveness for CV&DA : Conclusion II

The crash avoidance effectiveness estimated by Statistical Analysis Methodology (SAM) , Safety Impact Methodology (SIM) or Field Operation Test (FOT) varies substantially for the same CV&DA technology.

## SAM:

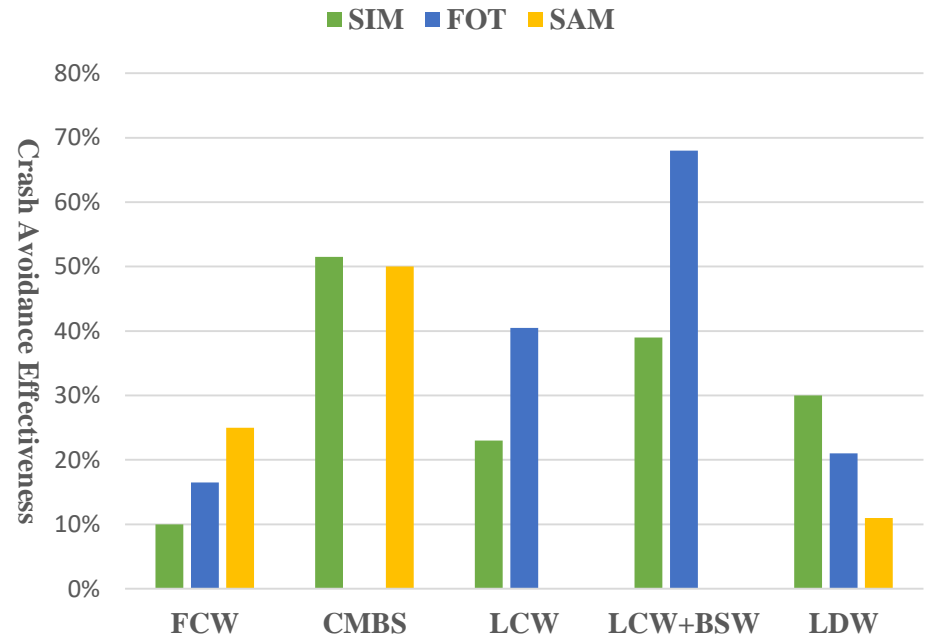
- Uses crash files for vehicles equipped /not equipped the technology.
- better “actual estimation”

## FOT:

- Crash-occurrence-based
- Sensitive to volunteers samples
- Potential low exposure rate of pre-crash scenarios

## SIM:

- Crash-probability-based
- Able to create enough exposure to all pre-crash scenarios
- Not perfect compared with real world;

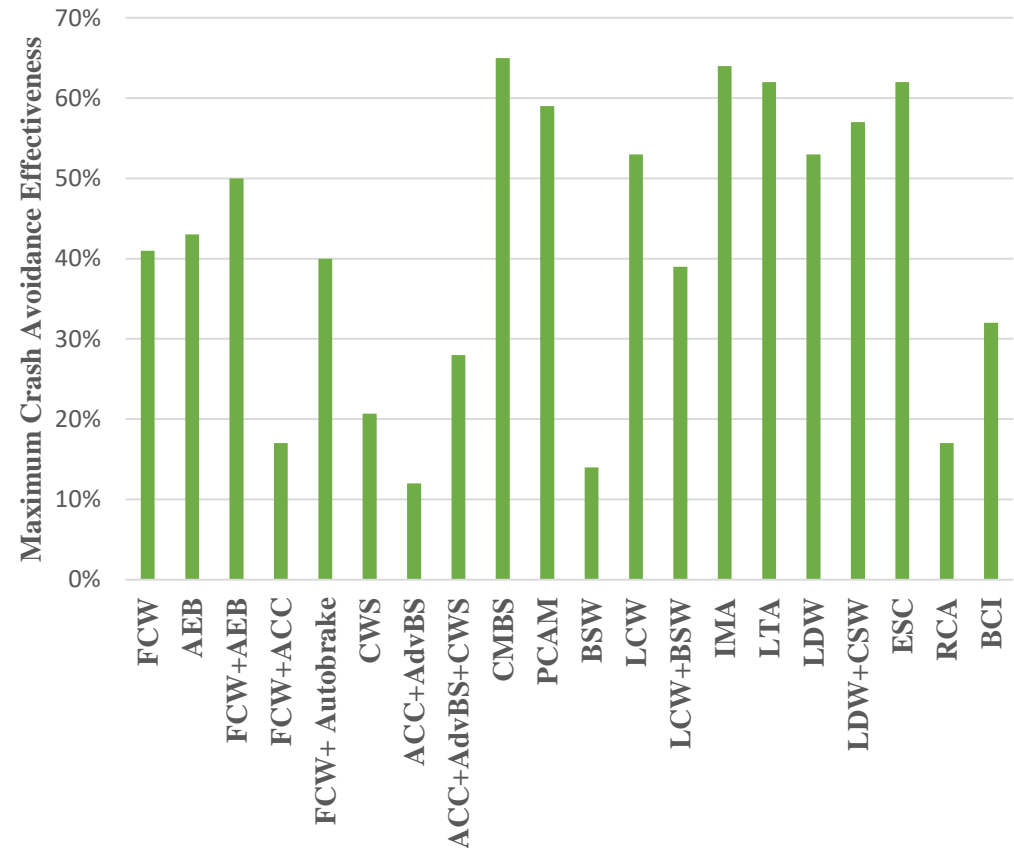


# Crash Avoidance Effectiveness for CV&DA : Conclusion III

No tested CV&DA technology whose crash avoidance effectiveness is over 70%.

Safety effectiveness could depend on five types of factors:

- technology-based factors
- vehicle-based factors
- environment-based factors
- driver-based factors
- estimation methodology based-factors



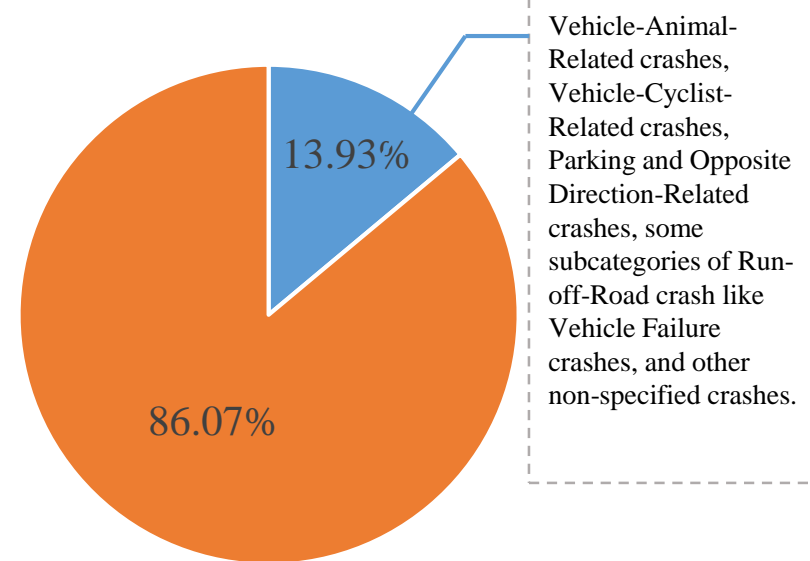
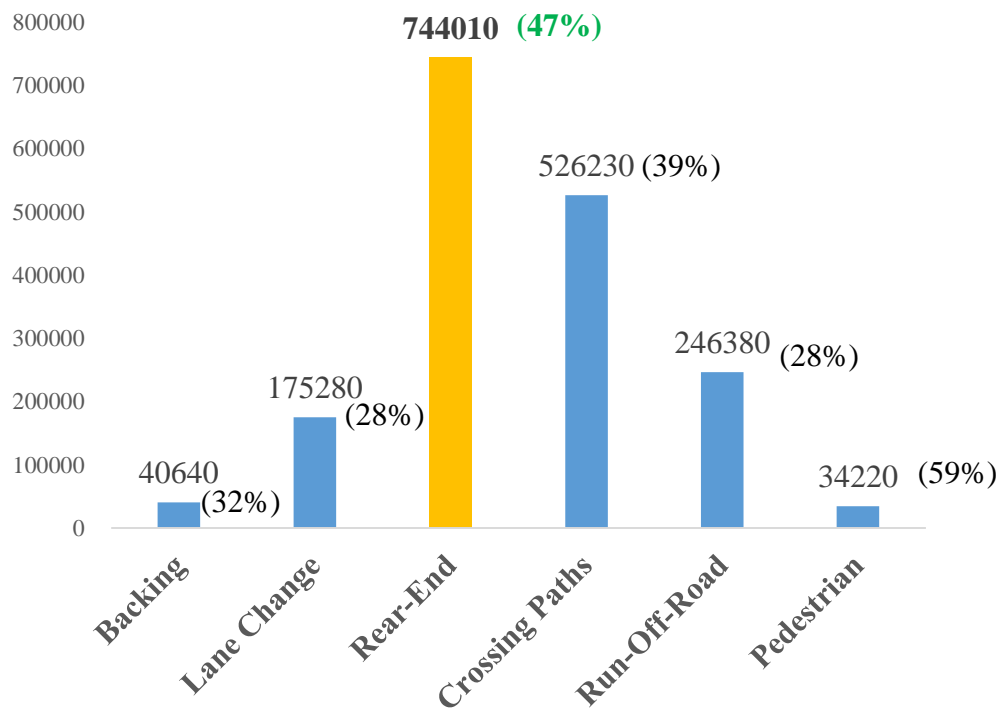
# Crash Avoidance Effectiveness for CV& DA : Estimation

Suggested Crash Avoidance Effectiveness of CV & DA technologies

Target Crash Type	CV&DA technology	Vehicle Type	Suggested Crash Avoidance Effectiveness	
			Conservative	Aggressive
Rear-End	FCW(Fog*)	LV	35%	
	FCW+AEB, CMBS, FCW+ Autobrake,	HV	70%	
		LV	47%	
Lane Change	LCW+ BSW	HV	43%	70%
		LV	28%	63%
Crossing Paths	LMA	HV	65%	70%
		LV	40%	56%
Crossing Paths	LTA	HV	60%	70%
		LV	36%	62%
Run-Off-Road	LDW+ CSW	HV	21%	65%
		LV	11%	38%
Run-Off-Road	ESC	HV	68%	70%
		LV	41%	62%
Backing	BCI	HV	53%	
		LV	32%	
Pedestrian	PCAM	HV	70%	
		LV	59%	

# Crash Avoidance Effectiveness for CV& DA : Prediction For Light Vehicles\*

Avoid **32.99%** of all light vehicle crash



■ Remained crash population  
■ CV&DA Target Crash Population

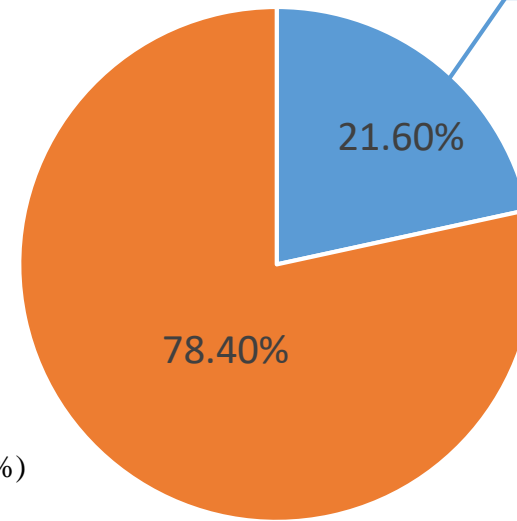
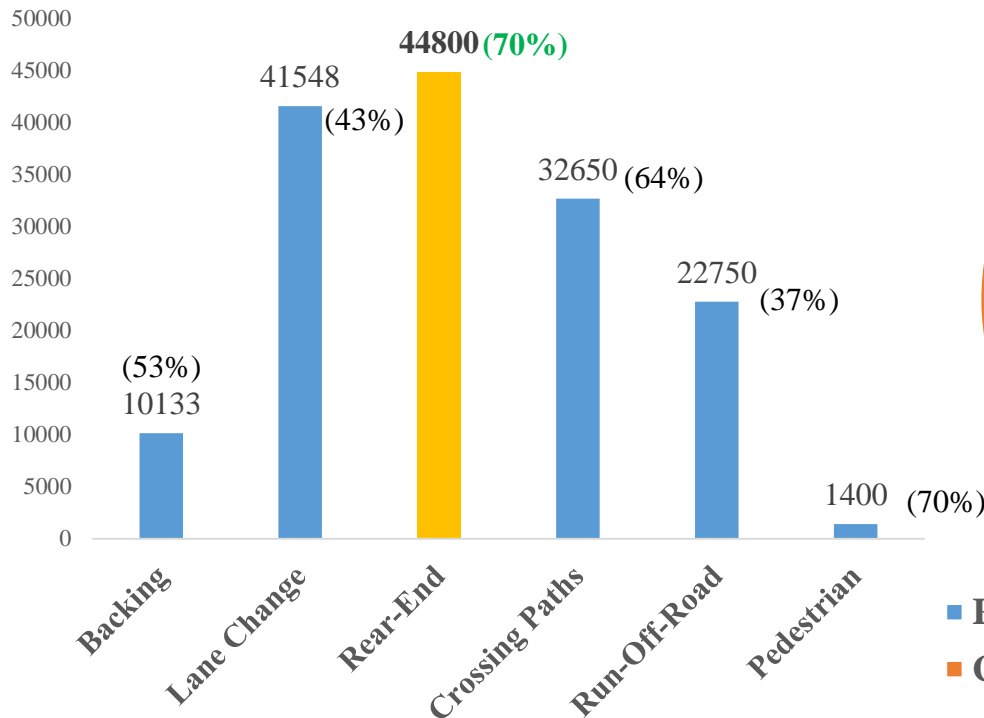
Total light vehicle crash numbers: 5,356,000

Light vehicle crash reduction of each crash type

\* For 17 CV/DA technologies; Under the conservative scenario, based on 2005-2008 GES crash records; 100% CV/DA penetration

# Crash Avoidance Effectiveness for CV& DA : Prediction For Heavy Trucks\*

Avoid **40.88%** of all heavy truck crash



Vehicle-Animal-Related crashes, Vehicle-Cyclist-Related crashes, Parking and Opposite Direction-Related crashes, some subcategories of Run-off-Road crash like Vehicle Failure crashes, and other non-specified crashes.

- Remained crash population
- CV&DA Target Crash Population

Total Heavy truck crash numbers: 375,000

Heavy truck crash reduction of each crash type

\* For 17 CV/DA technologies; Under the conservative scenario, based on 2005-2008 GES crash records; 100% CV/DA penetration

# Conclusions



# Conclusions

- The crash reduction rate of 15% - 70% is expected from most CV&DA technologies.
- The result shows a crash avoidance effectiveness of FCW under fog weather is 35%. This may be due to the reason that drivers rely more on FCW under fog weather.
- The CV technology package, e.g. FCW+AEB, FCW+ Autobrake, CMBS, which target rear end crashes could be made as the first priority of deployment, because of its largest crash reduction compared with other CV&DA technologies.
- The CV technology package, e.g. Left Turn Assist (LTA,CV) and Intersection Movement Assist (IMA,CV), which target crossing paths crashes could be made as the first priority of deployment, because of its largest crash reduction compared with other CV&DA technologies.

# Conclusions

- CV&DA technologies could improve both traffic safety and traffic efficiency, while Active Traffic Management (ATM) strategies could be deployed to further improve safety under CV&DA environment.
- In terms of surrogate measure of safety, noticeable benefit is observed at 30% market penetration.
- It was found that CV with platooning significantly outperformed CV without platooning when MPRs were equal or higher than 50%.
- Different designs for HUD under CV are needed based on the condition and driver.

# Vision for Transportation

(Era of Digital / Data Transformation)

- **Connected and Autonomous Vehicles**
- **More (Pro)Active (data intensive) approaches / Real-Time**
- **Ever richer information**
  - Smartphones, sensors, onboard vehicle hardware, provide continuous data
  - Traffic status, weather conditions in real-time
- **Better operation and safety**
  - Bottleneck detection in real-time
  - Crash risk evaluation and prediction in real-time
- **More accurate prediction**
  - Formation of congestion, queue length, congestion duration
  - Crash-prone conditions: unstable traffic flow, adverse weather
- **Timely communication**
  - Media: smartphone, webpage, DMS, radio
  - Suggested countermeasures: trip planning, route choice, travel time calculation, VSL, speed advice, etc.

# THANK YOU

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