UNIVERSITY OF CENTRAL FLORIDA

Connected-Autonomous Vehicles (CAV): Background and Opportunities

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What are Connected and Autonomous Vehicles (CAV) Technologies?

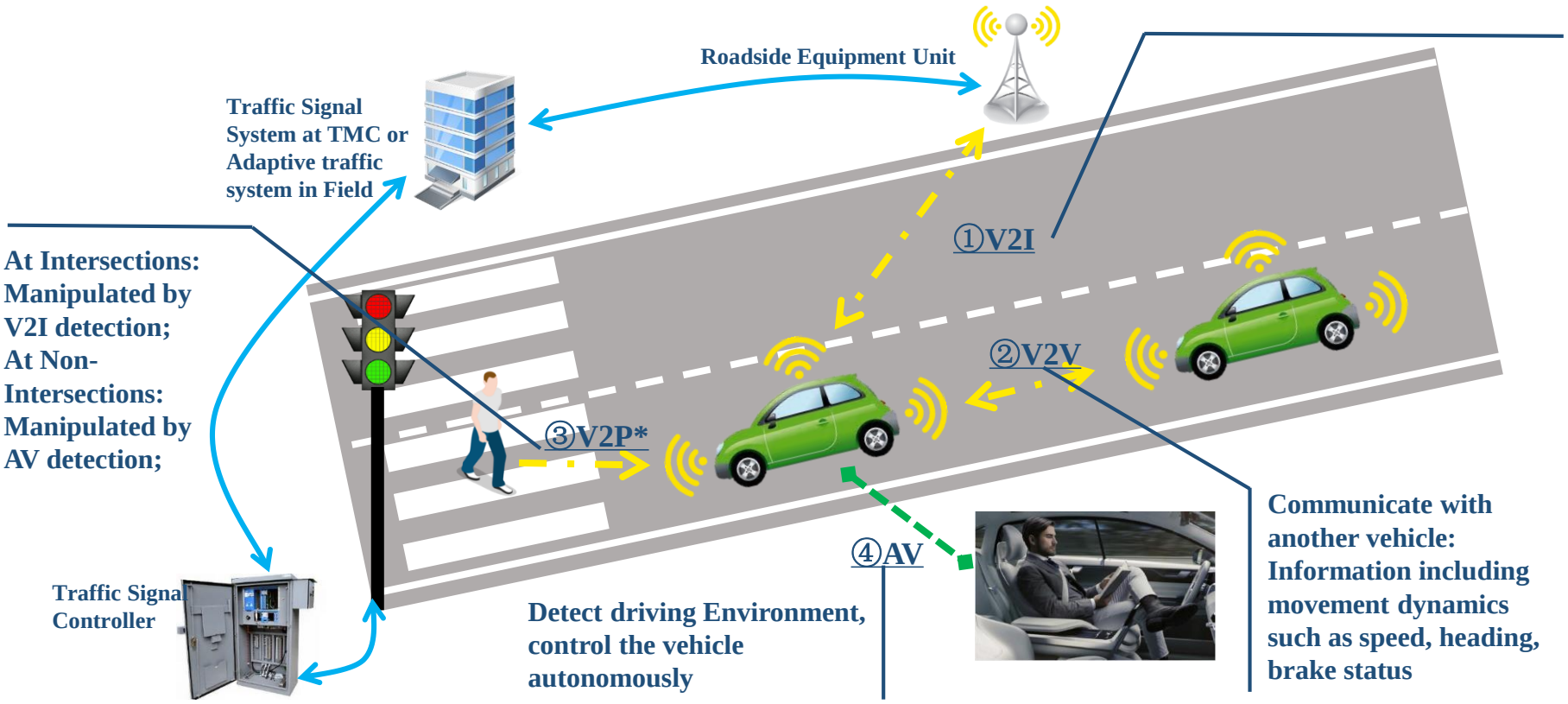
Connected Technology
①+②+③
Feel by Vehicle, Control by Man

+

Autonomous Technology
④
Feel by Vehicle, Control by Vehicle Itself.

=

CAV Technologies

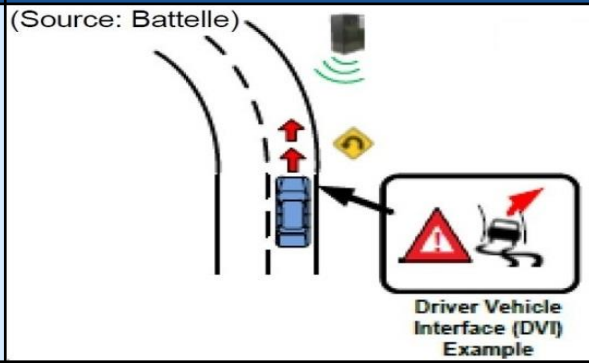
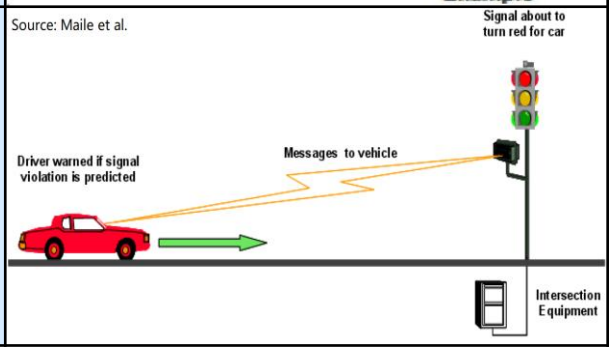


Why CV Technology could be helpful?

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 Warning Pre-crash Scenario

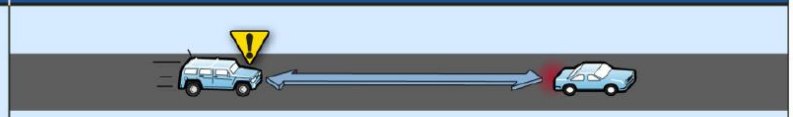
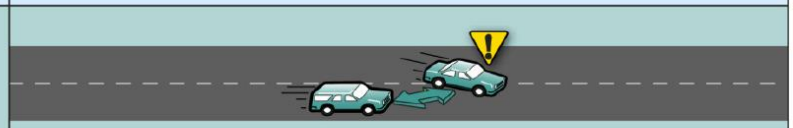
Scenario and Warning Type		Scenario example
Road departure collision scenarios	**Curve speed warning** Approaching a curve or ramp at an unsafe speed or decelerating at insufficient rates to safely maneuver the curve	
Crossing path collision scenarios	**Running red light/stop sign** Violation at an intersection controlled by a stop sign or by traffic signal	

Why CV Technology could 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 Warning Pre-crash Scenario

Scenario and warning type		Scenario example
Rear end collision scenarios	**Forward collision warning** Approaching a vehicle that is decelerating or stopped.	
	Emergency electronic brake light warning Approaching a vehicle stopped in roadway but not visible due to obstructions.	
Lane change scenarios	**Blind spot warning** 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.	
	Do not pass warning Encroaching onto the travel lane of another vehicle traveling in opposite direction; can detect moving vehicles not yet in blind spot.	
Intersection scenario	**Blind intersection warning** 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?

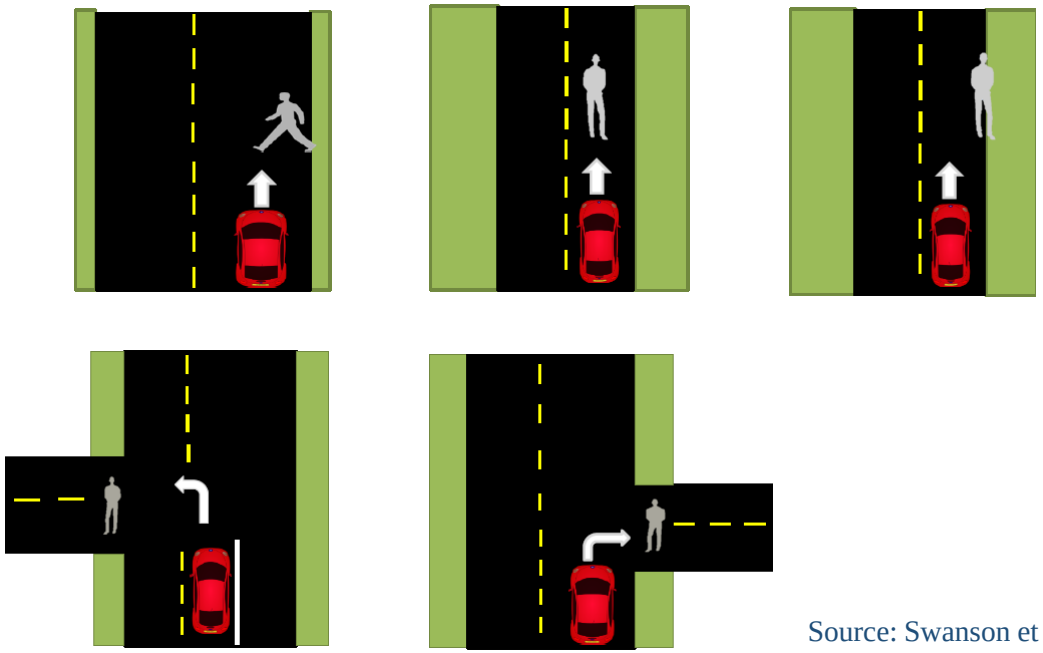
③ V2P* Safety Benefits

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.

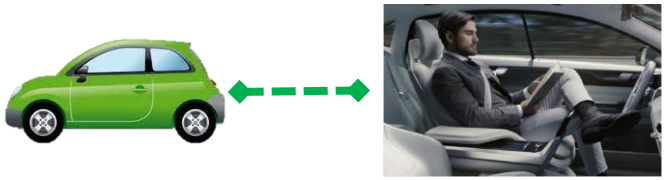
Examples of V2P Technology Warning Pre-crash Scenario



Source: Swanson et al. 2016

Why could CAV Technology be helpful?

④ AV Safety Benefits

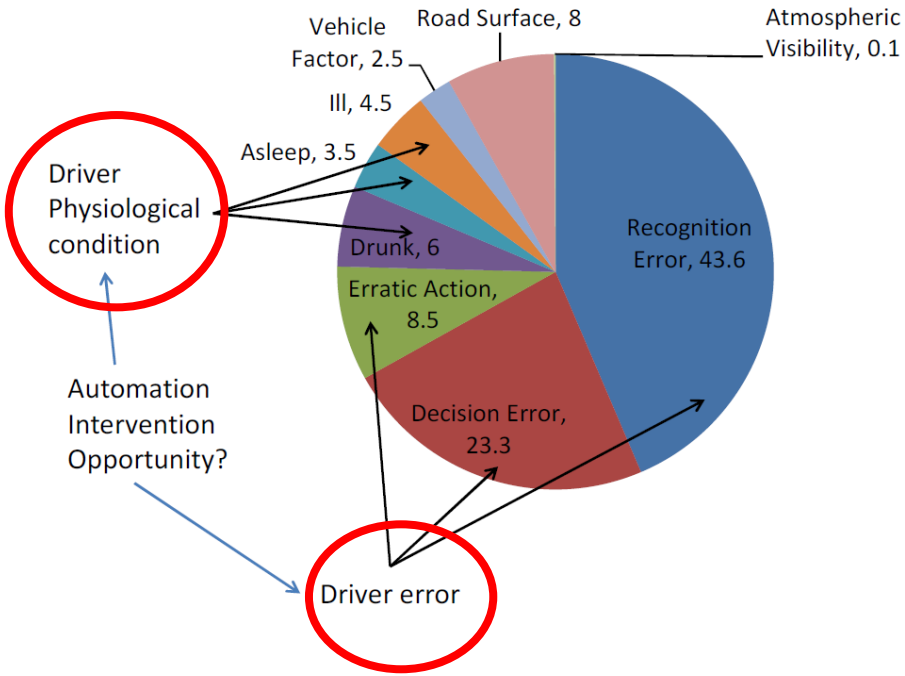


Help perform driving controls effectively without the constraint of driver inputs.

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

- Level 0 No Automation
- Level 1 Driver Assistance
- Level 2 Partial Automation
- Level 3 Conditional Automation
- Level 4 High Automation
- Level 5 Full Automation

Critical Causal Factors for Light Vehicle Crashes



Source: Rau et al. 2015

Research work of CV&DA for Safety Benefits

CV: Connected Vehicle Technology
DA: Driving Assistive Technology

Over **30** types of CV& DA technologies

37 pre-crash scenarios of **Total** vehicle crashes

Over **15** types of CV & DA technologies are tested and proved to be able to reduce crash events directly, targeting at over **23** pre-crash scenarios.

Over **6** types of CV& DA technologies are tested and proved to be able to improve driver performance like speed/headway control, which indirectly reduce crash events

Our Research Efforts

- General crash avoidance effectiveness estimation
- Crash reduction prediction

- CV technology and its safety benefits under Fog Conditions and Reduced Visibility Conditions

Driving Simulator Experiment

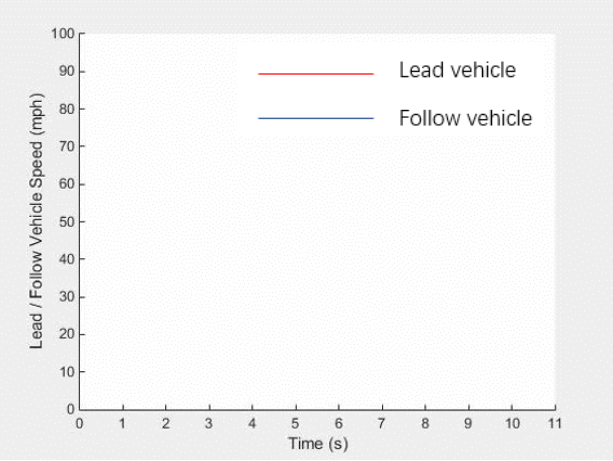
- Forward Collision Warning (FCW)
- The front car makes an emergency stop under fog conditions
- “Slow Vehicle Ahead” warning through Heads-up Display (HUD)

Driving Simulator Experiment (V2V)

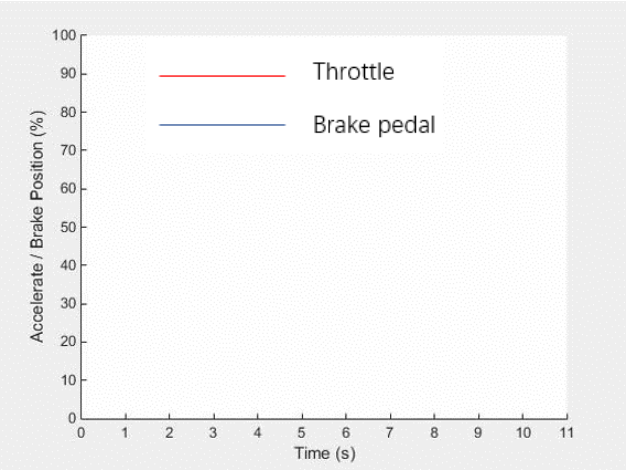
Scenario in Driving Simulator

Front vehicle suddenly decreases its speed under fog conditions

Lead/Follow Vehicle Speed



Accelerate/Brake



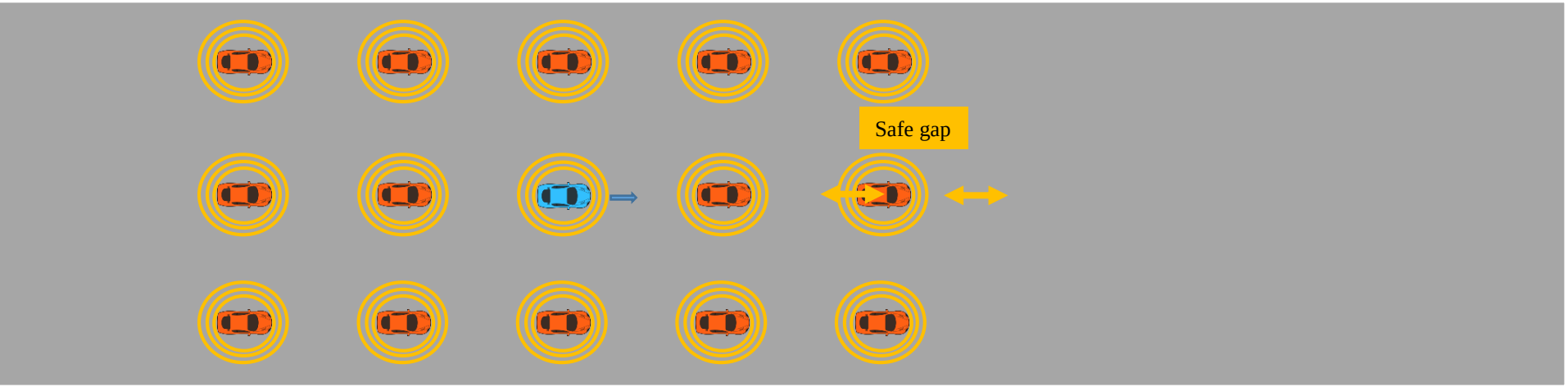
Fog Ahead Warning (I2V)

Curve Ahead Warning (I2V)

V2V Implementation

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

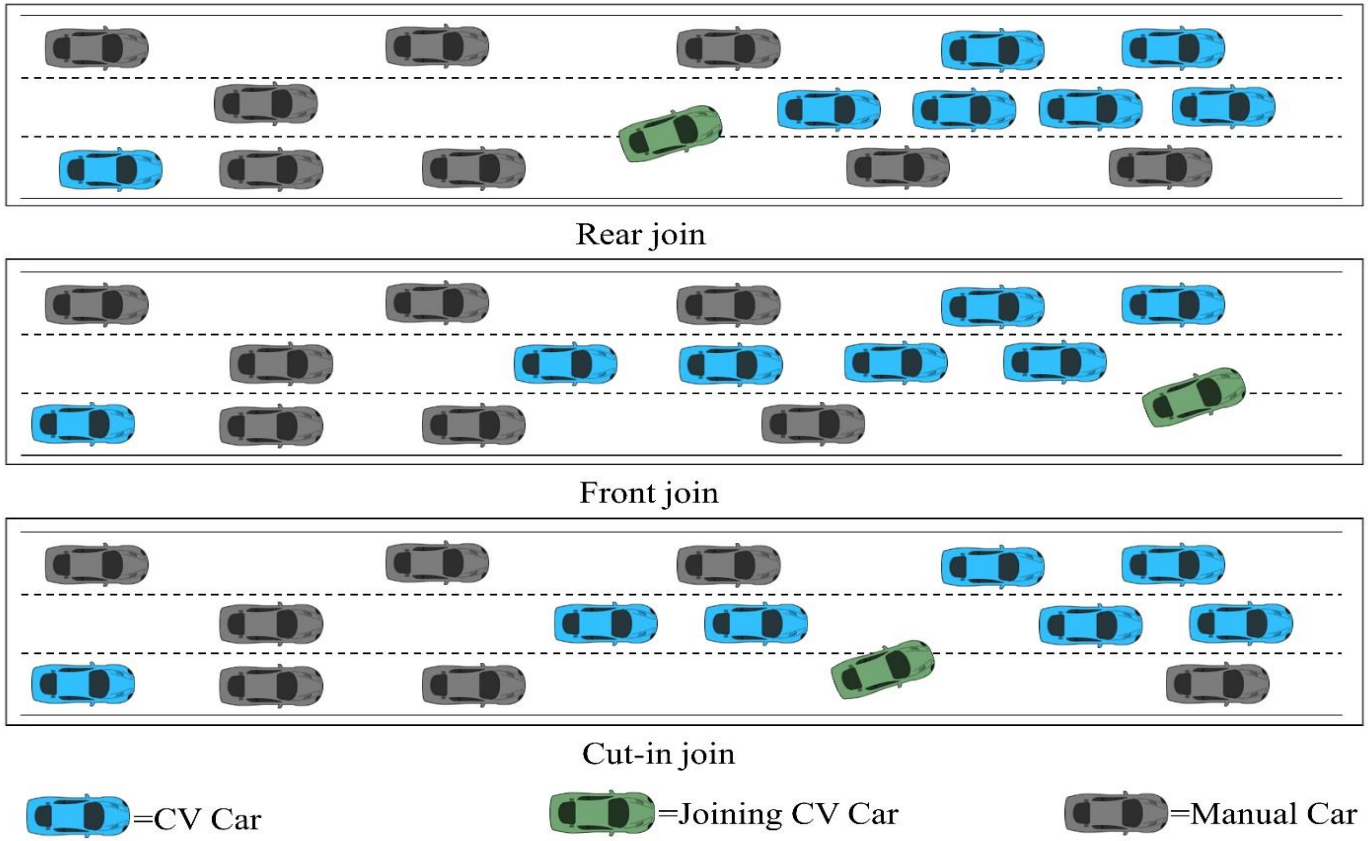
Vehicle to Vehicle (V2V)



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

Platooning Concept of CAV

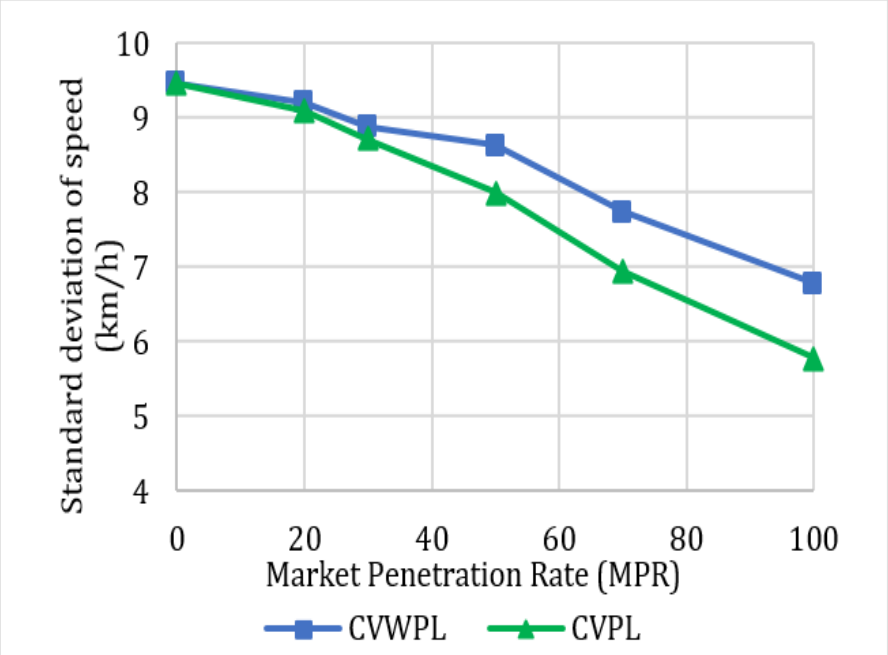
CVs were also implemented as a platooning concept (CVPL), wherein several vehicles form a “platoon” that behaves as a single unit.

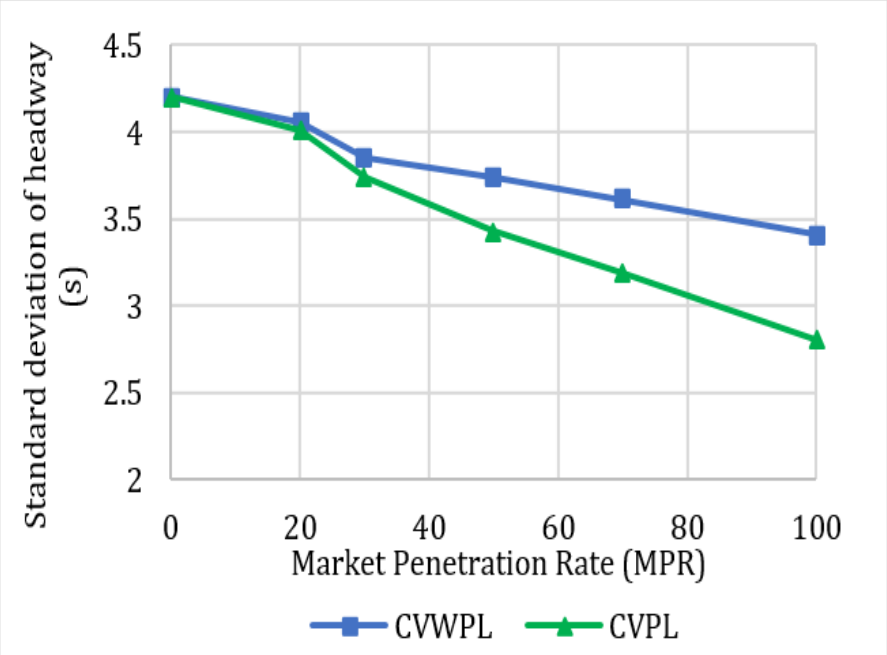


Joining of CVs to maintain a platoon.

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.

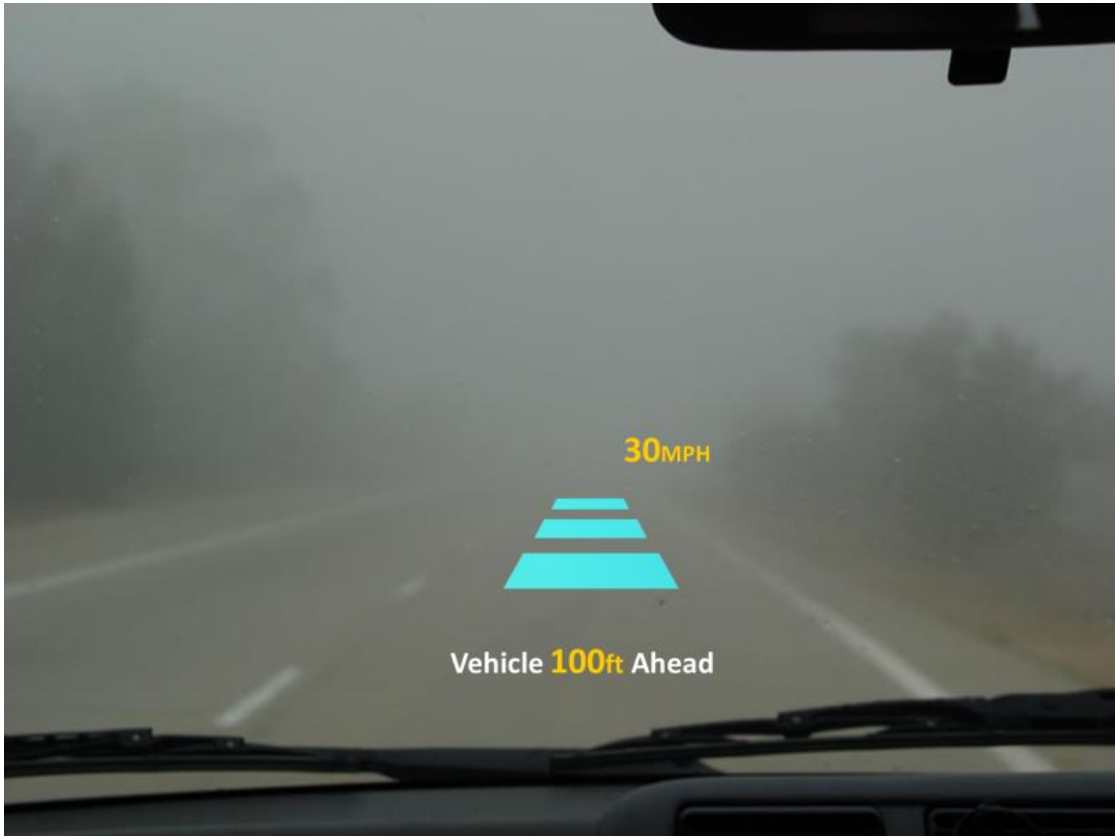




Reduction of surrogate measures of safety with different MPRs

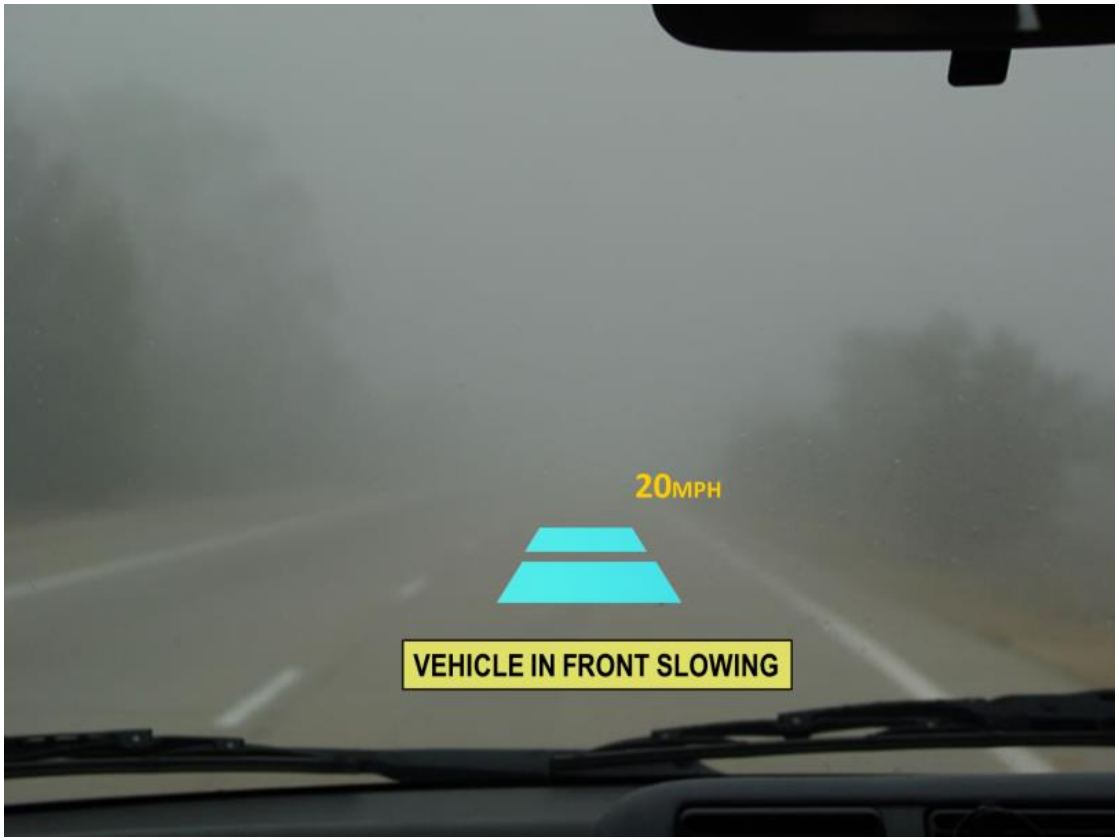
Optimized HUD Design under CV

- Scenario: Rear-end crash risk= Low

Recommended HUD Design	Driving Scenarios	Design Description
	**Weather:** • Dense fog **Rear-end crash risk (based on real-time prediction):** • Low **Traffic condition:** • Two vehicles keeping a safe distance	**3 Information:** • Distance between two vehicles in real-time= "numerical distance value in yellow text" • Location of front vehicle in real-time= "bar marking with narrow squared stripes in light blue color" • Speed of front vehicle in real-time= "numerical speed value of front vehicle in yellow text"

Optimized HUD Design under CV

- Scenario: Rear-end crash risk= High

Recommended HUD Design	Driving Scenarios	Design Description
	**Weather:** • Dense fog **Rear-end crash risk (based on real-time prediction):** • High **Traffic condition:** • Front vehicle suddenly decelerates	**3 Information:** • Warning information (using real-time updates)= "warning information with black text in yellow background" • Location of front vehicle in real-time= "bar marking with narrow squared stripes in light blue color" • Speed of front vehicle in real-time= "numerical speed value of front vehicle in yellow text"

Crash Avoidance Effectiveness for CV&DA

Crash Avoidance Effectiveness for CV& DA: Summary

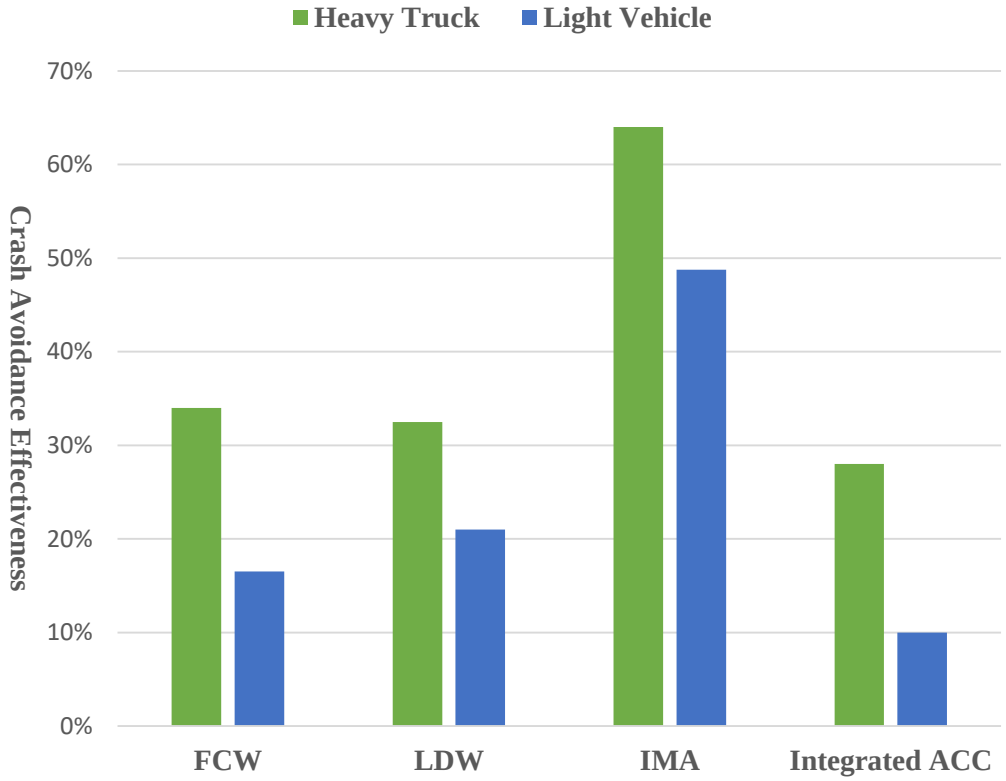
Summary of Research reports and Papers From 2007-2017: seventeen connected vehicle technologies (CV) and driving assistive technologies (DA) targeted at six pre-crash types including 23 pre-crash scenarios.

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	**Rear-End:** 1.Lead Vehicle Stopped 2.Following Vehicle Making a Maneuver 3.Lead Vehicle Decelerating 4.Lead Vehicle Moving at Lower Constant Speed 5.Lead Vehicle Accelerating
Adaptive Cruise Control(ACC, DA)	1	
Autonomous Emergency Braking (AEB, DA), Autobrake(DA), Advanced Braking System (AdvBS, DA)	1	
Collision Mitigation Brake System (CMBS)	1	
Electronic Stability Control (ESC,DA)	1	**Run-Off-Road:** 6.Control Loss without Prior Vehicle Action 7.Control Loss with Prior Vehicle Action
Backup Collision Intervention (BCI,DA)	1	**Backing:** 8.Backing Up into Another Vehicle
Rearview Cameras (RCA,DA)	0	
Blind Spot Warning (BSW,CV)	0	**Lane Change:** 9.Vehicle(s) Turning – Same Direction, 10.Vehicle(s) Changing Lanes – Same Direction ,11.Vehicle(s) Drifting – Same Direction
Lane Change Warning (LCW,DA)	0	
Left Turn Assist(LTA,CV)	0	**Crossing Paths:** 12.Left Turn Across Path from Opposite Directions at Non-Signalized Junctions 13.Left Turn Across Path from Opposite Directions at Signalized Junctions
Collision Mitigation Brake System (CMBS, DA)	1	
Intersection Movement Assist (IMA,CV)	0	**Crossing Paths:** 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	**Pedestrian:** 19.Pedestrian Crash With Prior Vehicle Maneuver 20.Pedestrian Crash Without Prior Vehicle Maneuver
Lane Departure Warning(LDW,DA)	0	**Run-Off-Road:** 21.Road Edge Departure With Prior Vehicle Maneuver 22.Road Edge Departure Without Prior Vehicle Maneuver 23.Road Edge Departure While Backing Up
Curve Speed Warning(CSW,CV)	0	

Crash Avoidance Effectiveness for CV&DA : Conclusion I

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

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

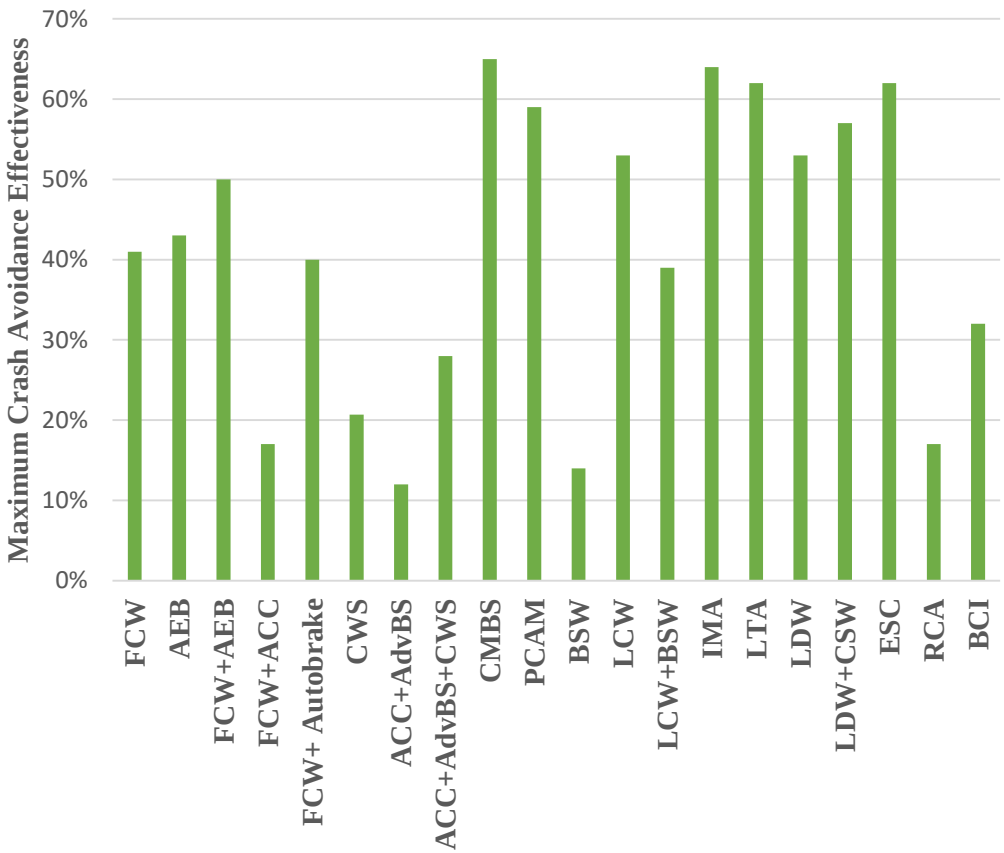


Crash Avoidance Effectiveness for CV&DA : Conclusion II

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

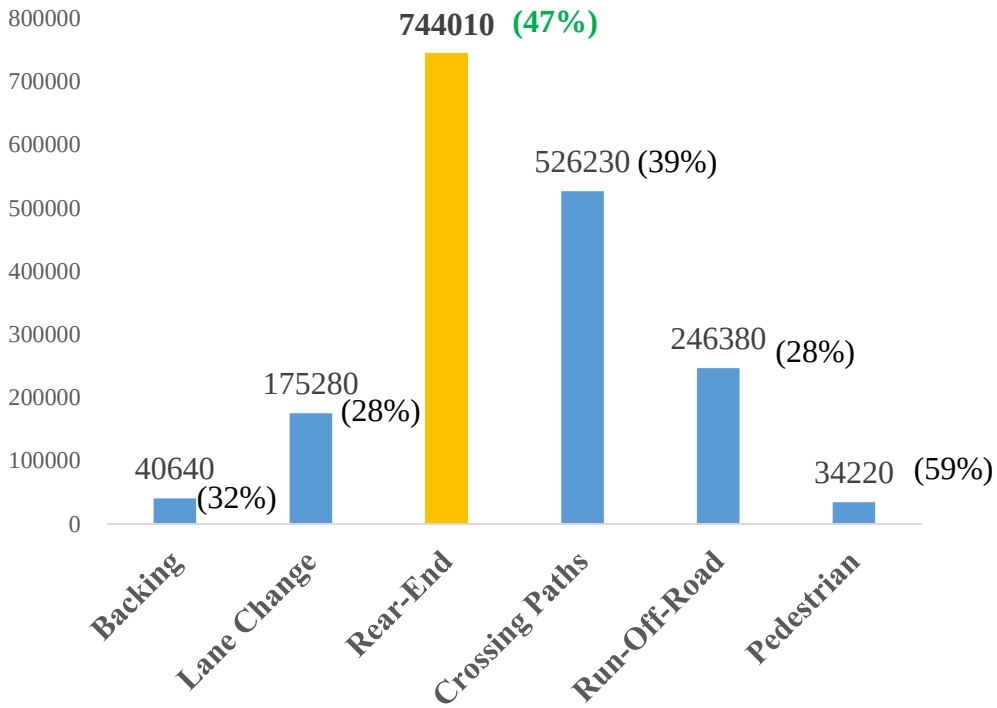
Safety effectiveness could depend on five types of factors:

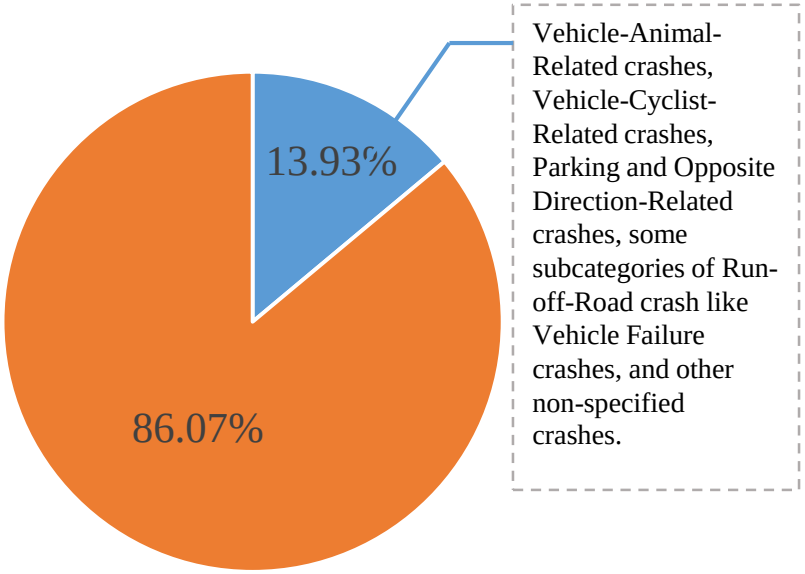
- technology-based factors
- vehicle-based factors
- environment-based factors
- driver-based factors
- estimation methodology based-factors



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

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





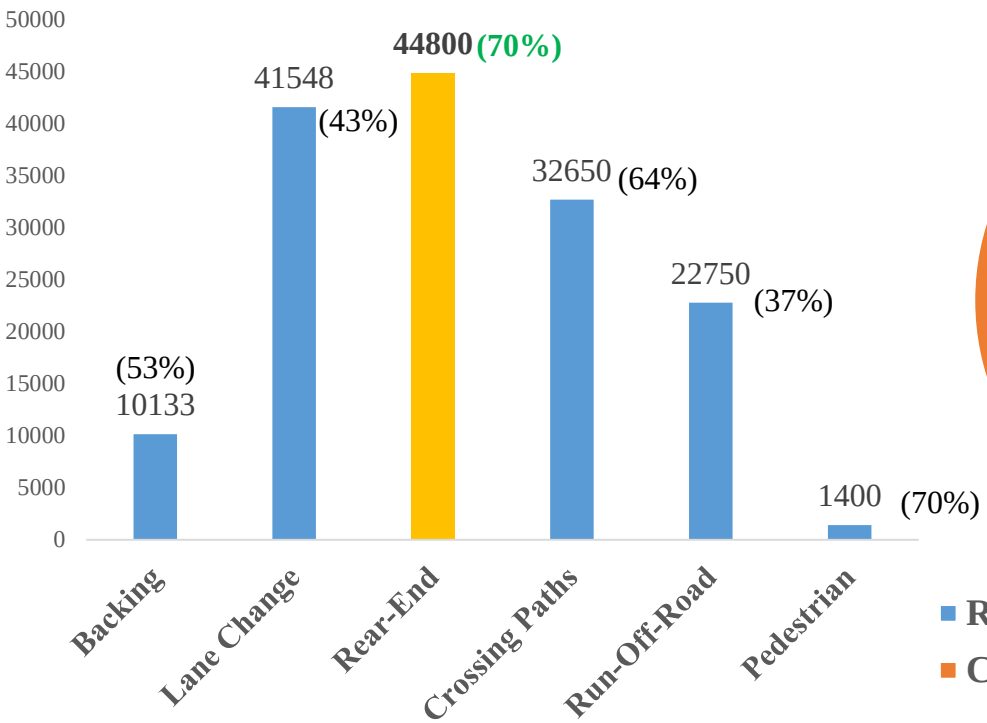
Total light vehicle crash numbers: 5,356,000

Light vehicle crash reduction of each crash type

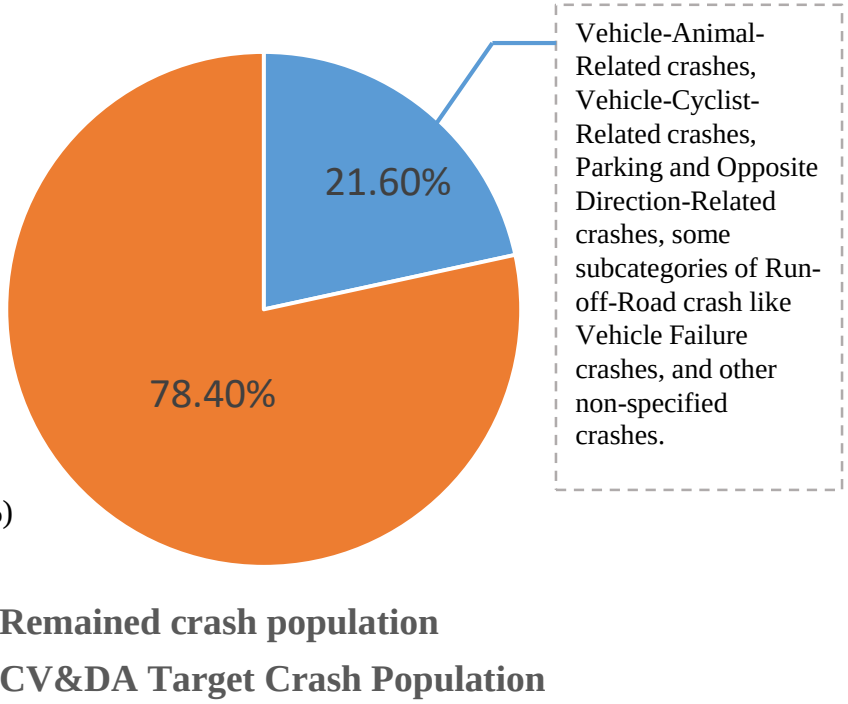
*** For 17 CV/DA technologies; Under the conservative scenario, based on 2005-2008 GES crash records; 100% CV/DA penetration**

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

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



Heavy truck crash reduction of each crash type



Total Heavy truck crash numbers: 375,000

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

Conclusions

Conclusions

- 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.
- FCW under fog weather results show a crash avoidance effectiveness of 35%
- The crash reduction rate of 15% - 70% is expected from most CV&DA technologies.
- 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.
- Different designs for HUD under CV are needed based on the condition.

THANK YOU

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UCF

March 2018