Alternative Intersection Designs with Connected and Automated Vehicle

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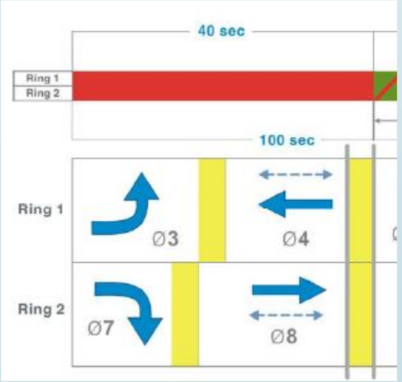
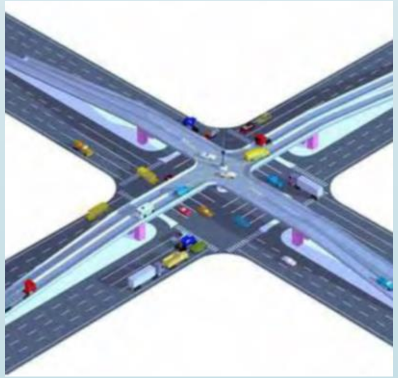
Background

- Safety
  - 1.35 million people die each year as a result of traffic accidents since 2016
  - intersection related crashes account for 36% and 43% in the U.S and EU27 countries, respectively
- Mobility
  - 6.9 billion hours of travel delay
  - $160 billion congestion cost
- Environment
  - 3.1 billion gallons of fuel wasted
  - 60 billion pounds of additional CO_2

Tackling Intersection Congestion

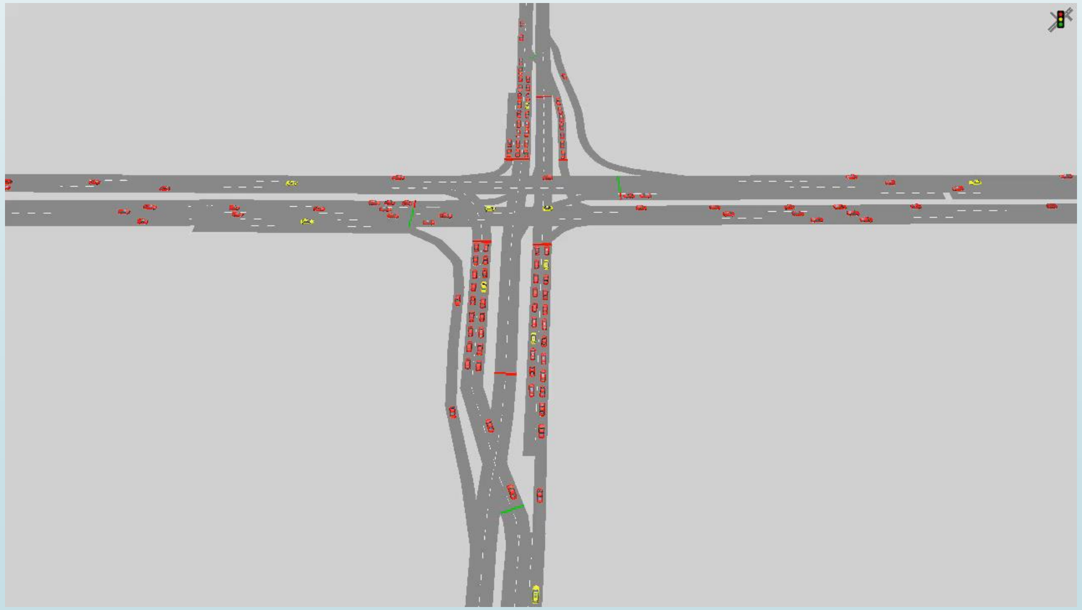
- Optimize signal timing and phase (SPaT) plans
- Geometric reconfiguration
  - grade-separated interchange
  - **alternative intersection design (AID)**
- Adopt CAV technology (V2I intersection advisory, eco-driving, autonomous intersection management, etc.)

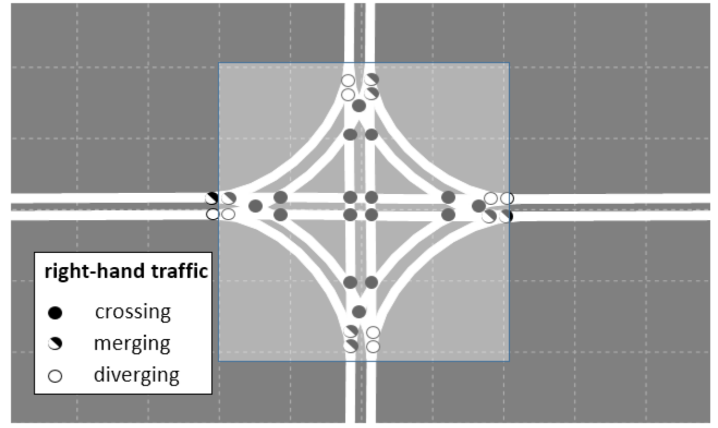




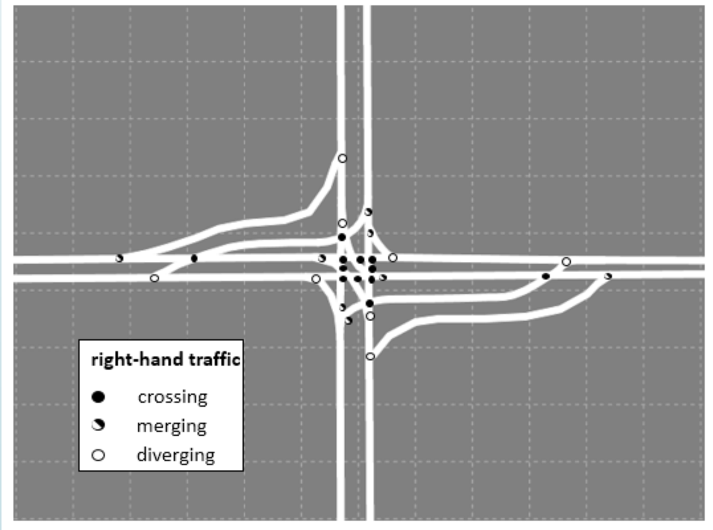
Alternative Intersection Designs

- Alternative geometric configuration
  - Change conflict point composition
  - Streamline traffic movements
  - Reduce signal phases





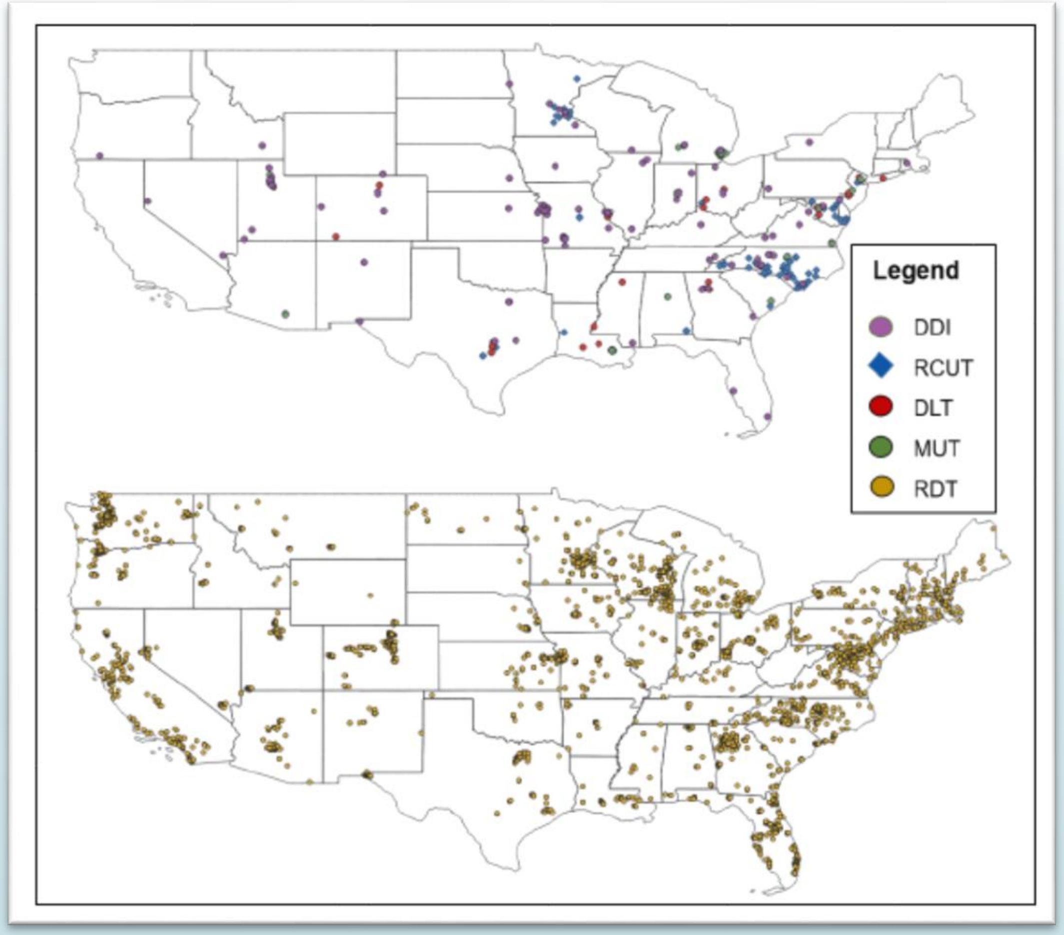
Conventional 4-leg intersection



Displaced left-turn intersection

CAV-AID Deployment in the Near Term

- 25-30 yrs. for CAVs to reach 95% penetration (Volpe National Transportation Center)
- AIDs have been growing steadily and gained recognition
- The driver's confusion could be remedied even with early-stage CAV technology
- A hybrid solution (CAV + AID) is one of the logical steps in the near term under mixed traffic conditions



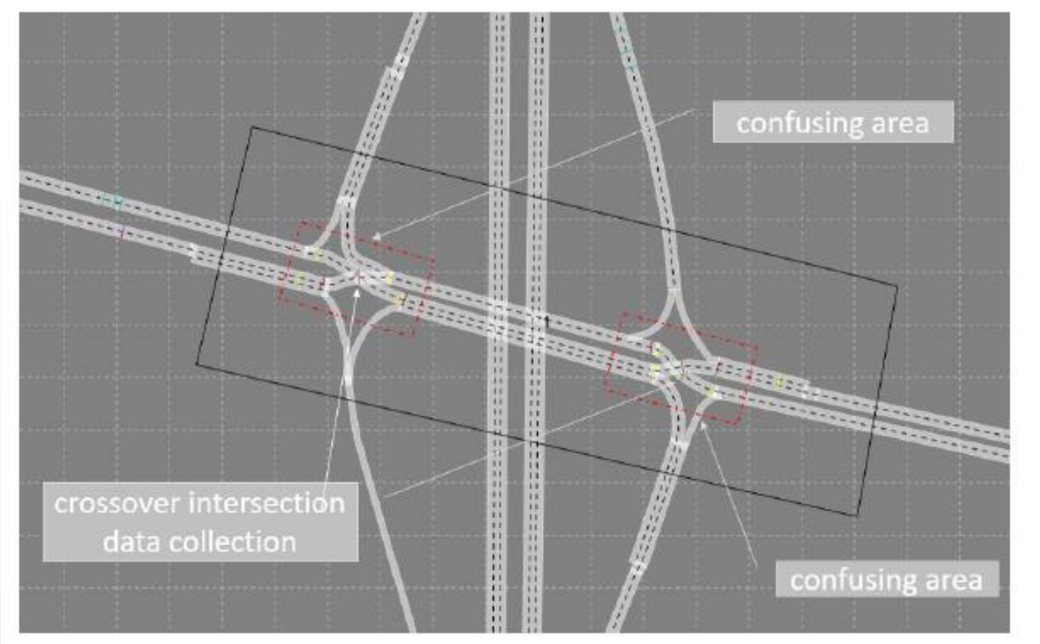
DDI-Diverging diamond interchange
RCUT-restricted crossover U-turn
DLT-displaced left-turn, **MUT**-median U-turn, **RDT**-roundabout

Benefits of CAV and AID

Benefit	AID	CAV
Intersection conflict pt. reduction	Y	
Signal phase reduction	Y	
Streamline traffic movement	Y	
Short following headway		Y
No start-up lost time		Y
Synchronously discharge		Y
Driver’s confusion prevention		Y

Simulation Study for DDI

- Two improvements for mobility
  - Conversion to DDI from CDI
  - Introduction of CAV
- DDI interchange at State Highway 72 (DE-72) and US Highway 13 (US-13)
- Simulation conducted in PTV Vissim with its Driver Model API



Simulation network

	CDI	DDI	CAV	MPR
Base-CDI	✓			0%
Base-DDI		✓		0%
CAV-CDI	✓		✓	10%-100%
CAV-DDI		✓	✓	10%-100%

Simulation scenarios

	Longitudinal Control	Lateral Control
Human Driver	Calibrated Wiedemann 99	Vissim default
CAV	Intelligent Driver Model (IDM)	Vissim default

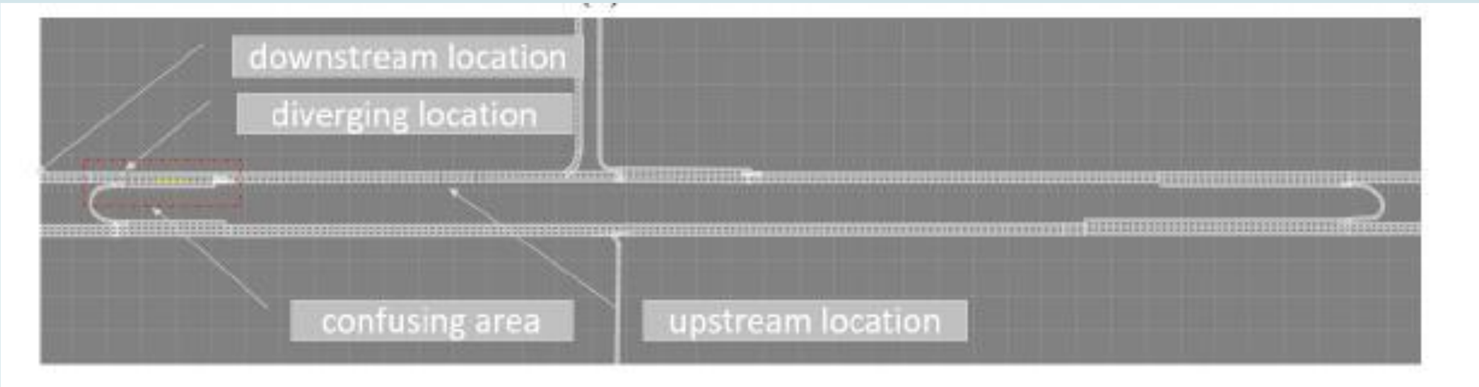
Vehicle behavior

Simulation Study for R-CUT

- Assess the Impact of driver's confusion
- Traffic sensors placed at three locations: upstream, diverging, and downstream location
- Behavior caused by driver's confusion
  - Sudden slow-down at the ramp pocket lane (diverging area)
  - Abrupt lane change as approaching the end of the pocket lane

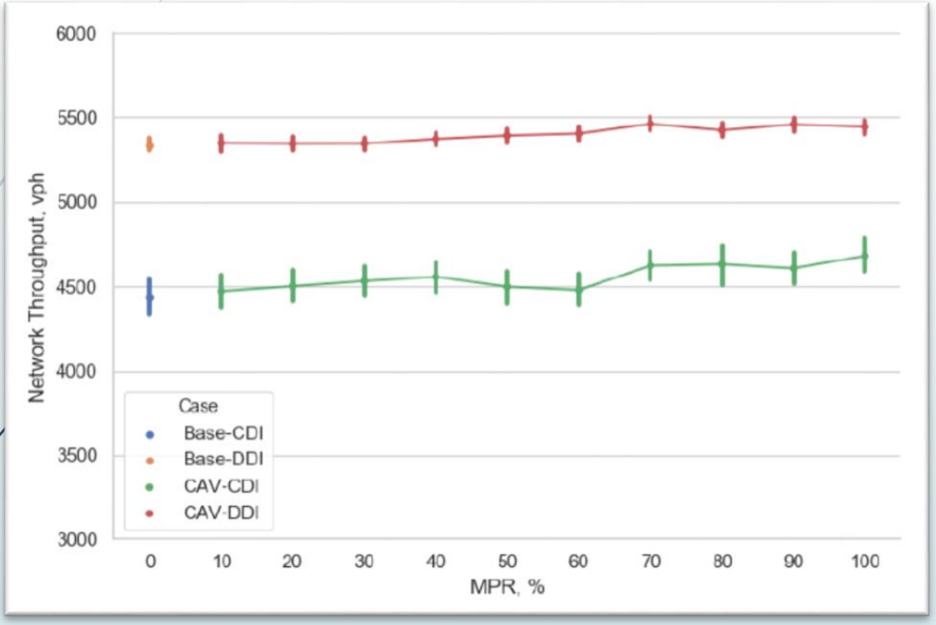
Case	CAV	Percentage of confused drivers
1		5%-20%
2	✓	0%

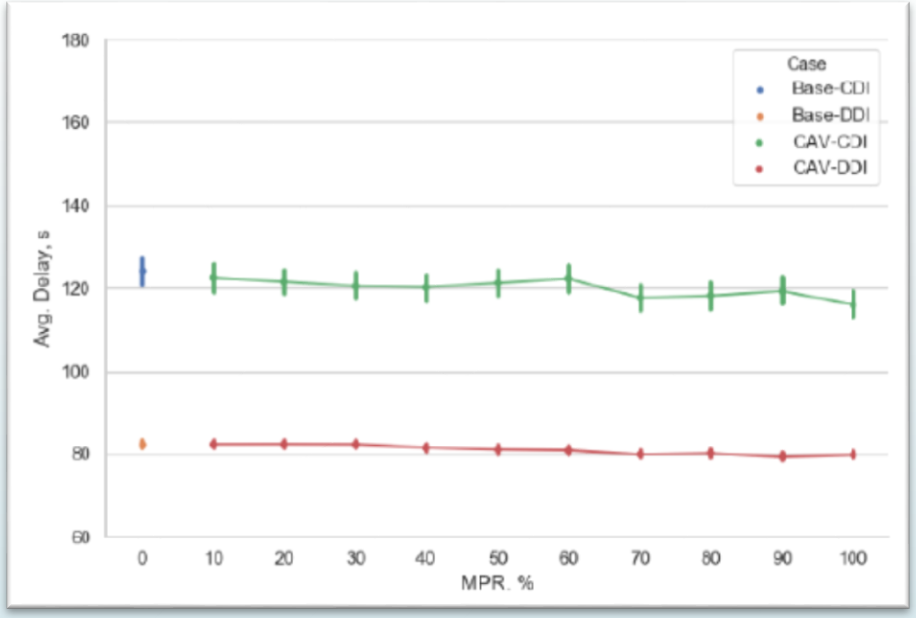
Simulation scenarios



Simulation network

Results-DDI Mobility



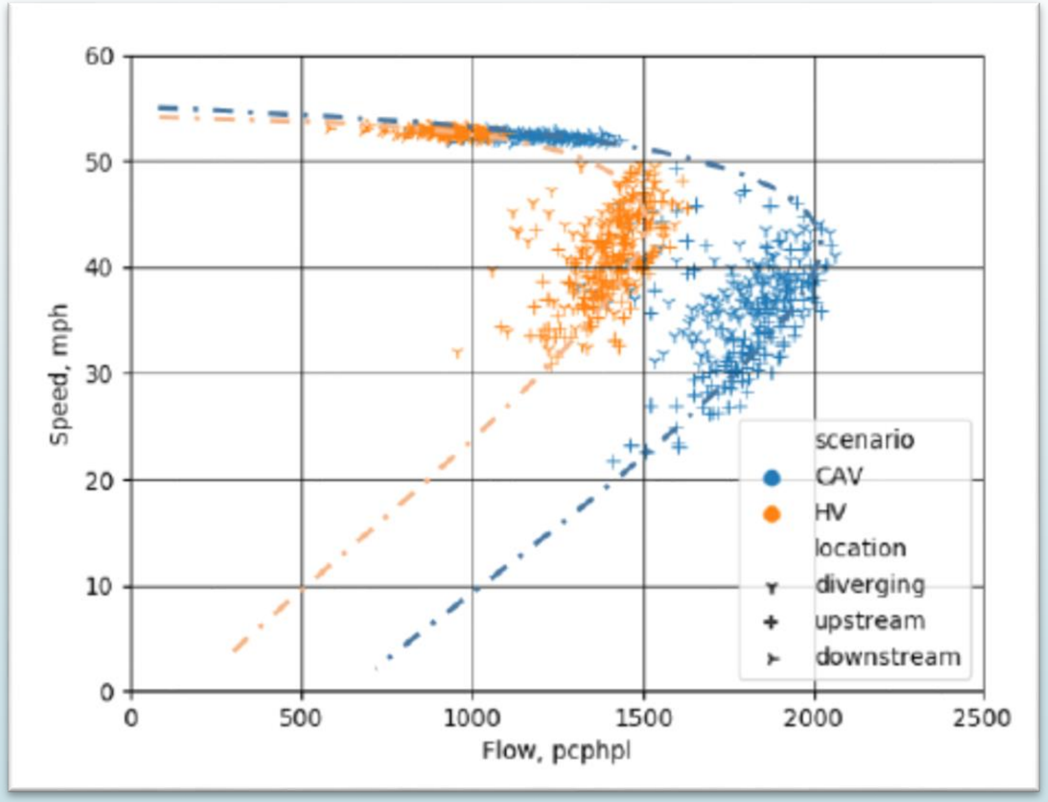


- With DDI, the intersection throughput increases to 5,350 vehicle per hour (vph) from 4,400 vph, with decrease in deviation.
- CAV contributes less to the increase in intersection throughput at tested scenarios

- The average vehicle delay has similar trends.
- The DDI offers a systematic reduction (40 s per vehicle) with less deviation.

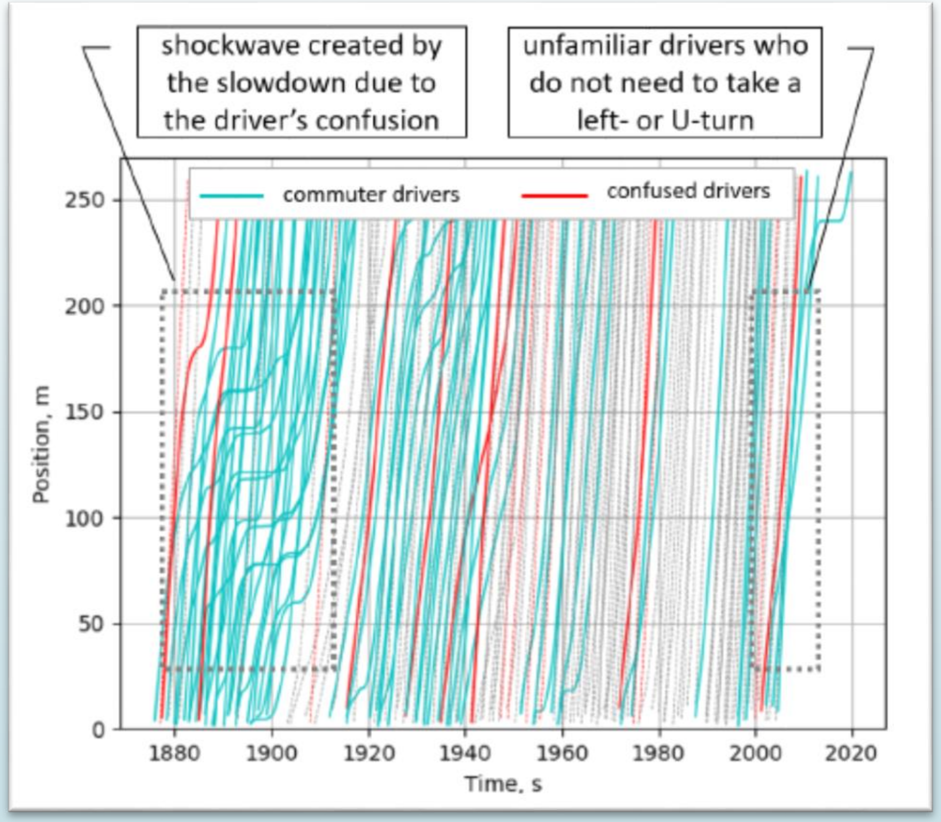
Results-RCUT Traffic Flow

- Flow-speed characteristic is observed at upstream, diverging, and downstream locations.
- The performance increase at the diverging and downstream location with CAV
- The segment carrying capacity increased to 2,100 vph per lane (from 1,500 vph per lane).



Results-RCUT Traffic Flow

- Behavior induced by driver's confusion
  - Sudden slow down
  - Abrupt lane change
- A 250-m section extracted from the diverging area
- The shockwave was created due to the induced behaviors



Results-Impact of Driver's Confusion

- ANOVA test with post-hoc Tukey's method at 95% confidence level
- The pairwise difference among the 5 levels (0% - 20%) of confused driver for DDI and RCUT
- The difference in average vehicle delay are statistically significant.

TABLE IV: ANOVA Test for Average Vehicle Delay in RCUT

Confused Driver Rate	N	Delay, s/veh	Grouping				
0%	360	12.2	A				
5%	360	28.65		B			
10%	360	39.36			C		
15%	360	43.45				D	
20%	360	48.79					E

TABLE V: ANOVA Test for Average Vehicle Delay in DDI

Confused Driver Rate	N	Delay, s/veh	Grouping				
0%	360	81.42	A				
5%	360	82.44		B			
10%	360	83.54			C		
15%	360	84.41				D	
20%	360	85.78					E

Conclusions

- Mobility
  - **DDI:** The introduction of CAV only increase the throughput by 7% for CDI and 2% for DDI
  - **DDI:** The conversion to DDI provides 20% throughput increase (4,400 vph to 5,350 vph)
  - **RCUT:** A flow-stable region in the speed-flow curve with higher capacity (1,500 vph/ln to 2,000 vph/ln)
- Drivers' confusion
  - Significant impact was observed for avg. delay in the presence of driver's confusion.

Future Research

- **SPaT optimization** for AIDs
- **Optimization of CAV operation:** eco-driving, V2I integration, adaptive signal control, signal-free autonomous intersect management
- **Validate** drivers' confusion with field data
- **Simulation scope**: expand evaluation scope to corridor- and network-level

Thank you for your time!

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