Longitudinal traffic conflict analysis of autonomous and traditional vehicle platoons in field tests

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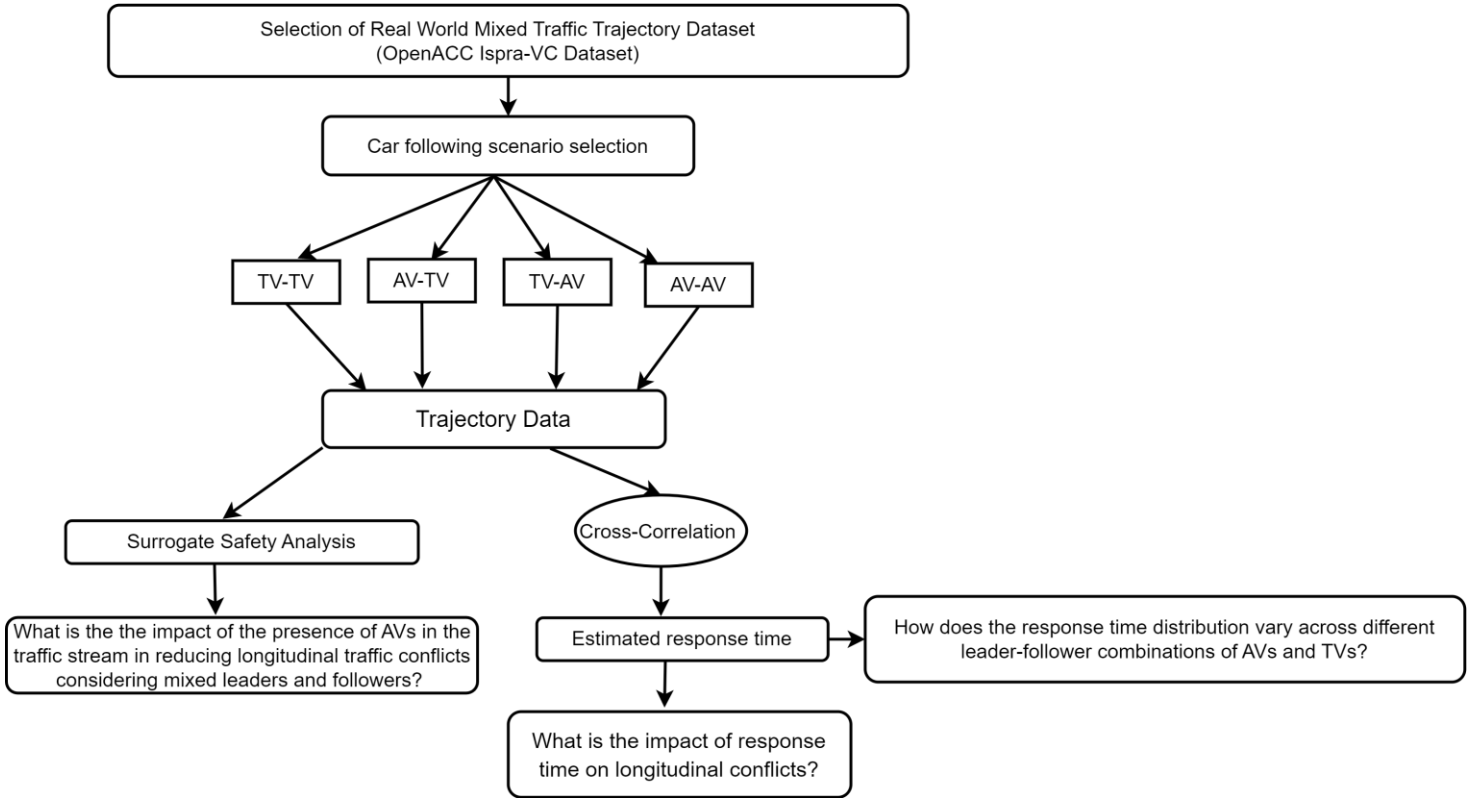
Highlights

- Investigates the impact of the presence of SAE level 2 autonomous vehicles (AVs) in the traffic stream in reducing *longitudinal traffic conflicts* using *Surrogate Safety Measures (SSMs)* on a *real-world open-source database*.

- Analysis is conducted on both *exclusive and mixed vehicle platoons.*

- The impact of vehicular *response time* on longitudinal traffic conflicts are explored.

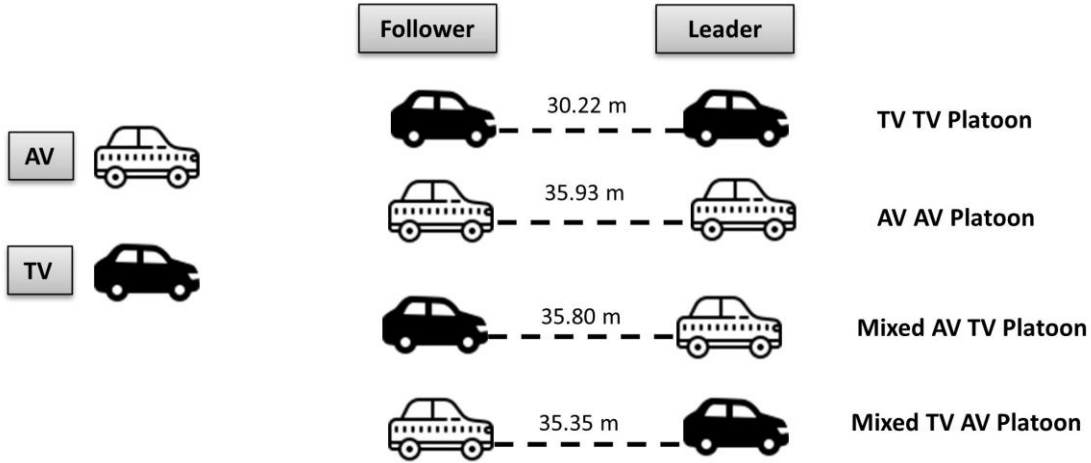
Workflow


Selection of Real World Mixed Traffic Trajectory Dataset
(OpenACC Ispra-VC Dataset)
Car following scenario selection
TV-TV
AV-TV
TV-AV
AV-AV
Trajectory Data
Surrogate Safety Analysis
Cross-Correlation
What is the the impact of the presence of AVs in the traffic stream in reducing longitudinal traffic conflicts considering mixed leaders and followers?
Estimated response time
How does the response time distribution vary across different leader-follower combinations of AVs and TVs?
What is the impact of response time on longitudinal conflicts?

Mixed Traffic Composition

- **Mixed Traffic**
  - Traffic stream contains a mixture of different vehicle types such as connected automated vehicles (CAVs), AVs, connected vehicles (CVs), and traditional, human-driven vehicles (TVs).
- **Autonomous vehicles (AVs):**
  - Driverless, uses adaptive cruise control (ACC) for car-following.
- **Traditional vehicles (TVs):**
  - Human driven vehicles

Exclusive and Mixed Vehicle Platoons



Leader		Follower		Study Site	Automation Level of AVs (SAE,2018)	Total Experimental Time (s)	Total Distance (m)
Vehicle Type	Model	Vehicle Type	Model				
TV	Hyundai Ioniq hybrid 2019	TV	Kia Niro 2019	Highway	N/A	374.40	11075
AV	Mitsubishi SpaceStar 2019	AV	Ford S Max 2019	Highway	Level 2	734.80	22401
TV	Hyundai Ioniq hybrid 2019	AV	Ford S Max 2019	Highway	Level 2	734.80	22401
AV	Mitsubishi SpaceStar 2019	TV	Kia Niro 2019	Highway	Level 2	734.80	22401

 Data Source: https://data.europa.eu/data/datasets/9702c950-c80f-4d2f-982f-44d06ea0009f?locale=en

Brief Description of The Experiment

- Tests were scheduled for non-peak hours
- Leader was instructed to drive manually and perform occasional random deceleration and accelerations over a desired speed in a realistic way
- Shortest time headway setting for each vehicle driven by the ACC system was used
- No overtaking was performed

Response Time

- Response time (RT) shows how long it takes for a driver to respond to a situation by accelerating, decelerating or doing nothing in response to the action of the leading vehicle.

$$Response\ (t + RT)\ \alpha\ Stimulus\ (t)$$

Acceleration of the follower → $a_F(t + RT)$

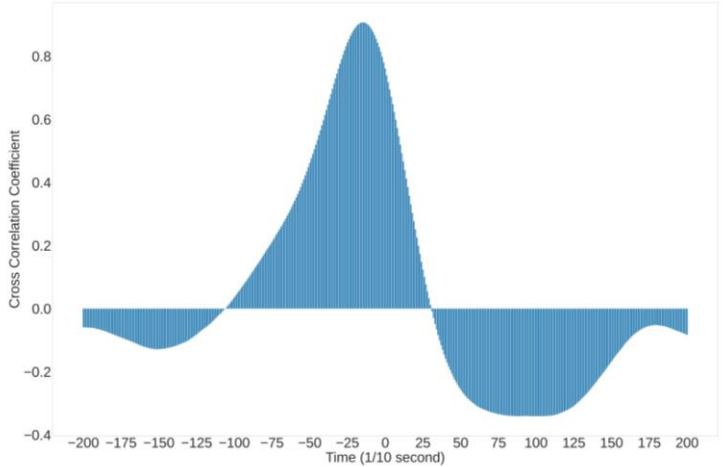
$(V_L(t) - V_F(t))$ ← Speed difference between leader and follower at time *t*

- Response of the follower lags the stimulus by follower's RT.

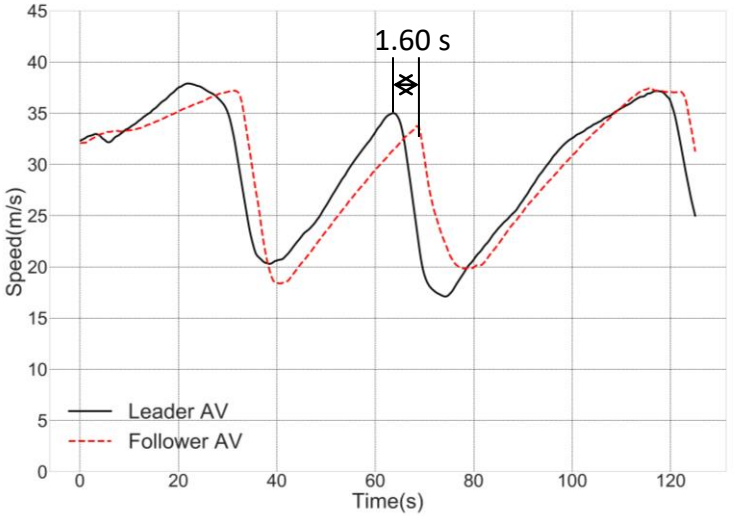
Cross Correlation

- Cross-correlation takes the two-time series and lines them up to determine the lag that produces the highest similarities between the two series.
- Consider, two time series $x(t) = Stimulus(t)$and $y(t) = Response\ (t + RT)$ lag by a time interval RT, where $t \in \{0,1,2,3, \ldots\ldots\ldots n\}$. The cross-correlation r at lag d, $r(d)$ as follows: $r(d) = \frac{\sum_t [(x(t)-\mu_x)*(y(t-d)-\mu_y)]}{\sqrt{\sum_t (x(t)-\mu_x)^2}\sqrt{\sum_t (y(t-d)-\mu_y)^2}}$
- The value of the lag with the highest correlation coefficient represents the best fit between the two series therefore the RT.

Response Time Estimation (AV-AV)

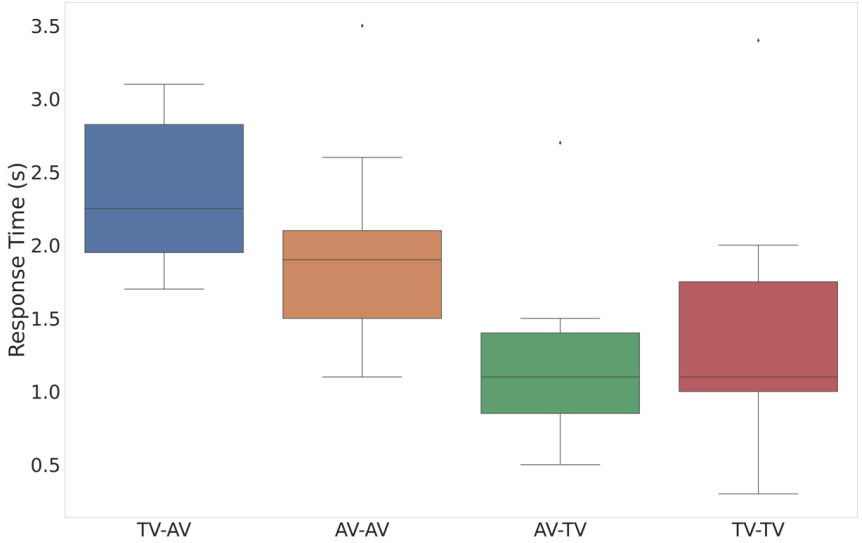


Cross-Correlogram



- Correlation coefficient between response of the following vehicle and the stimulus is highest (0.88) at -16(1/10)=-1.6 s.
- Similarly, we estimated response time for all other time steps for TV-AV, AV-TV and TV-TV scenario.

Response time findings



Sample 1 Follower's RT (s)	Sample 2 Follower's RT (s)	Null Hypothesis	t test p Value	At 95% CI
AV-TV (1.15 s*, 0.59 s**)	TV-TV (1.56 s*, 1.06 s**)	RT for TV is independent of lead vehicle type	0.305	Cannot reject
TV-AV (2.36 s*, 0.58 s**)	AV-AV (1.99 s*, 0.61 s**)	RT for AV is independent of lead vehicle type.	0.1829	Cannot reject
AV (2.15 s*, 0.59 s**)	TV (1.31 s*, 0.76 s**)	RT for AV and TV is similar	0.0003	Reject

**Mean; **Standard deviation*

- Response time for TVs or AVs was independent of lead vehicle type
- AV response time (2.15 s) was significantly higher than the TV response time (1.31 s)

Traffic Conflict and SSMs

- Traffic conflict shows the probability of crash
- SSMs use pairwise velocity and spacing attributes derived from vehicular trajectories to flag or report a traffic interaction as a conflict.
- SSMs assume that the closer vehicles are to each other in terms of temporal or spatial proximity metrics, the nearer they are to a potential collision

Surrogate Safety Analysis

Rear End Crash Index (RCRI): To avert a rear end crash the stopping distance of the following vehicle should be smaller than the leading vehicle. Therefore, RCRI can be mathematically expressed as follows:

$$RCRI_i(t) = \begin{cases} 1, \ when \ SSD_F(t) \geq SSD_L(t) \\ 0, Otherwise \end{cases}$$

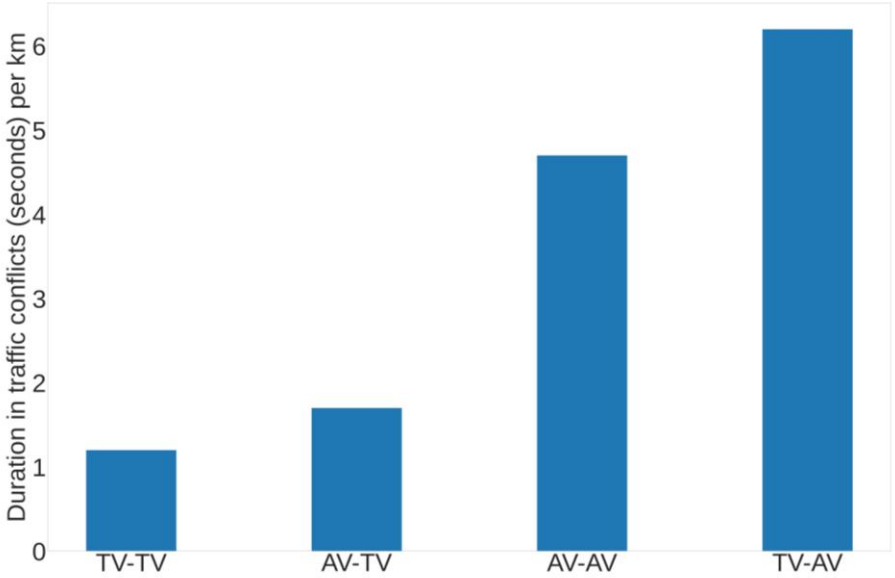
$$SSD_L(t) = D(t) + \frac{V_L(t)^2}{d_{Lmax}}$$

$$SSD_F(t) = V_F(t) * RT_F + \frac{V_F(t)^2}{d_{Fmax}}$$

RT_F	s	Response time of following vehicle
$RCRI_i(t)$	m	Rear end crash risk index of the i^{th} (following) vehicle at time instant t
$SSD_L(t)$	m	Safe stopping distance of the leading vehicle at time t
$SSD_F(t)$	m	Safe stopping distance of the following vehicle at time t

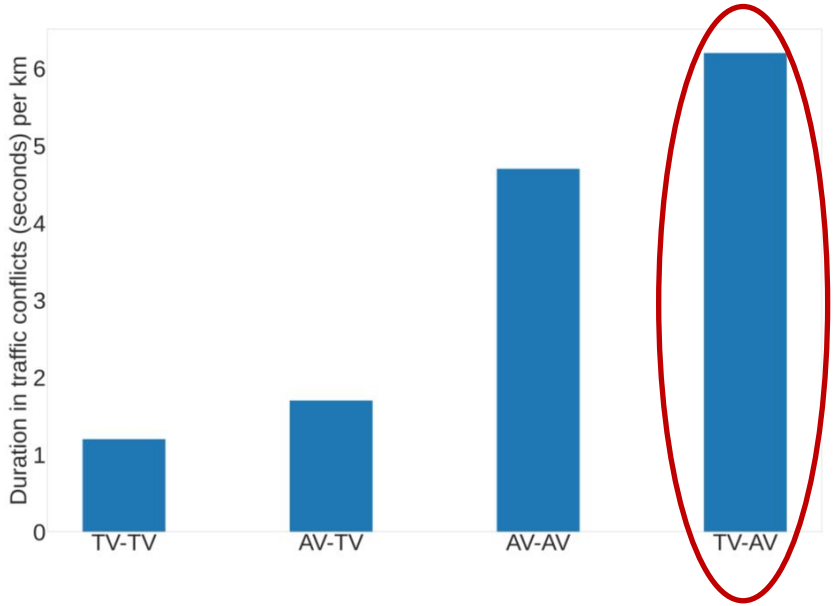
$V_L(t)$	m/s	Speed of the leading vehicle at any time instant t
$V_F(t)$	m/s	Speed of the following vehicle at any time instant t
$D(t)$	m	Inter-vehicular spacing of the vehicle pairs at time t

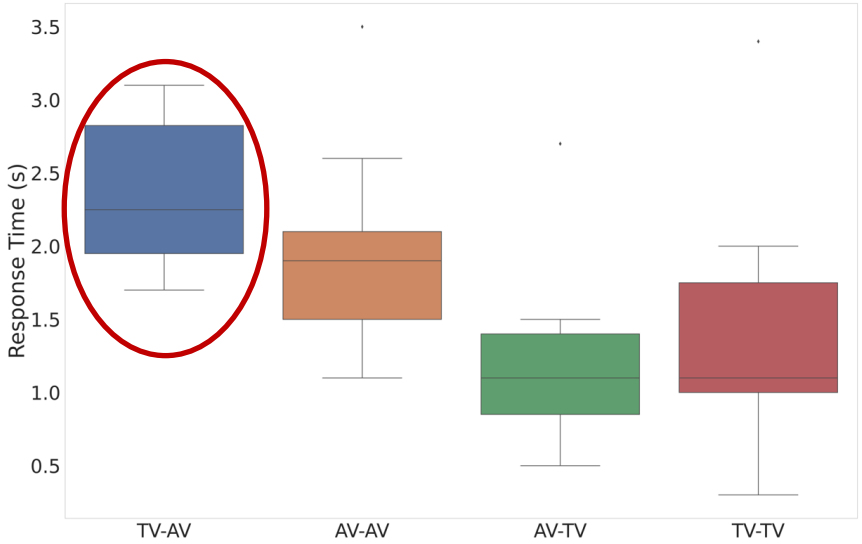
Traffic Conflict Analysis Results



- AV as a following vehicle reported more duration of in traffic conflicts irrespective of the leader

Traffic Conflict Analysis Results





- The highest average response times for an AV (in the TV-AV scenario) contributed directly to the longest period of traffic conflicts per km.

Conclusion and Future Research

- The ACC equipped AVs show larger response time than TVs.
- TVs show larger variability response time than ACC equipped AVs.
- Relation of response time with traffic conflicts is significant.
- Findings are constrained to the dataset.
- More testing AVs of different brands operating in mixed is needed to make a generalization.

Published Work