Impact Of The Different Distance Settings of Autonomous Vehicles on Flow Stability and Longitudinal Safety

Tanmay Das (Presenter)
Graduate Research Assistant
Tel: 919-592-4234; Email: tdas@ncsu.edu

Dr. Billy Williams
Professor

Dr. Nagui Rouphail
Distinguished University Professor Emeritus

Department of Civil, Construction, and Environmental Engineering
North Carolina State University
909 Capability Drive, Raleigh, NC 27606

Outline

- Motivation
- Research Questions
- Method
- Description of Dataset
- Results and Discussion
- Conclusion and Future Direction

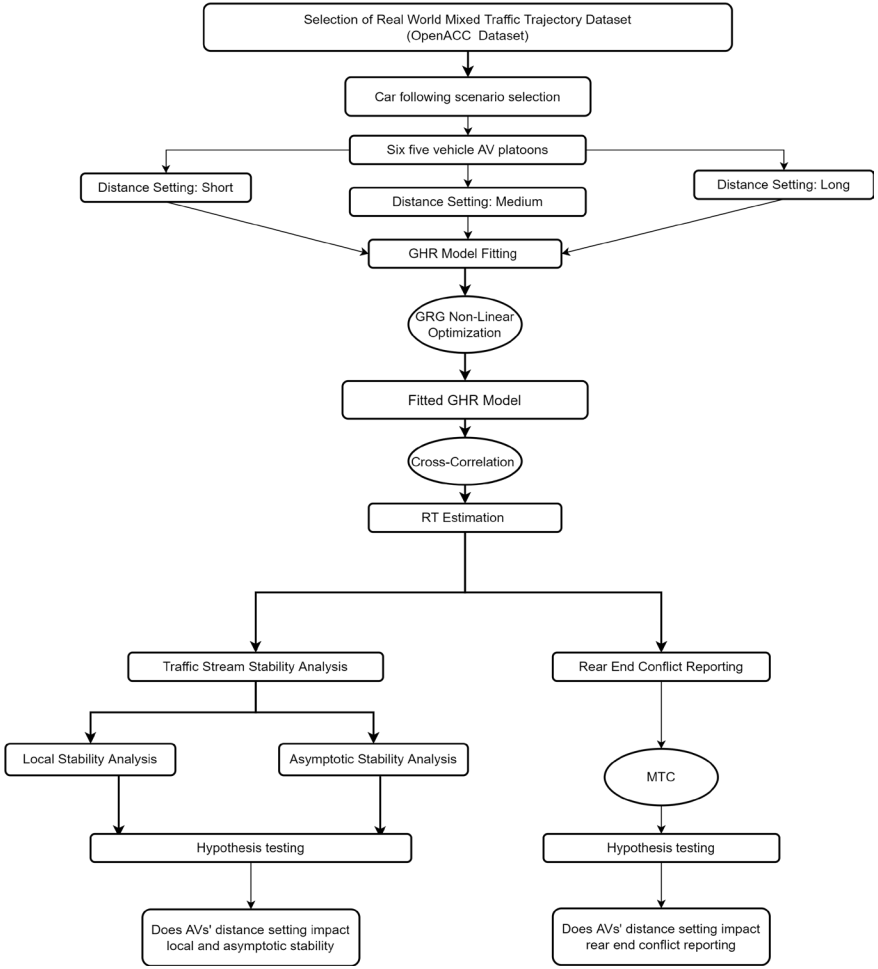
Motivation

- Users of adaptive cruise control (ACC) enabled autonomous vehicles (AVs) can choose the following distance (short, medium, or long) between their vehicle and the vehicle ahead.
- Ample research is done to assess AVs' impact on flow stability, hardly any of them considered AVs' different distance settings.
- User heterogeneity is largely ignored in simulation-based study.
- Limited research effort using real world data.

Research Questions

- Do ACC-AVs' distance settings impact the local and asymptotic stability of an AV platoon?
- Do ACC-AVs' distance settings impact rear-end conflict reporting for AV platoons?

Method

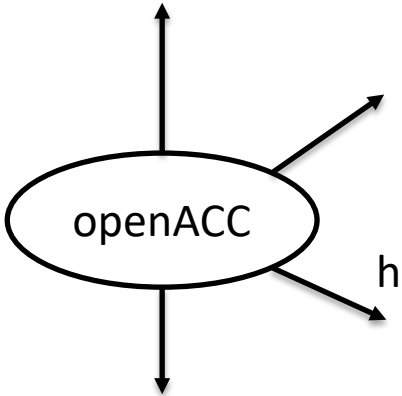

Selection of Real World Mixed Traffic Trajectory Dataset (OpenACC Dataset)
Car following scenario selection
Six five vehicle AV platoons
Distance Setting: Short
Distance Setting: Medium
Distance Setting: Long
GHR Model Fitting
GRG Non-Linear Optimization
Fitted GHR Model
Cross-Correlation
RT Estimation
Traffic Stream Stability Analysis
Rear End Conflict Reporting
Local Stability Analysis
Asymptotic Stability Analysis
MTC
Hypothesis testing
Hypothesis testing
Does AVs' distance setting impact local and asymptotic stability
Does AVs' distance setting impact rear end conflict reporting

Real World Trajectories

openACC

- Open Database of car-following experiments involving **vehicles with Adaptive Cruise Control systems (ACC)**.
- Provide data about ACC behavior to better understand ACC vehicles and to understand how their widespread use may influence traffic dynamics.
- The database contains **vehicle trajectories** from different car-following experiments.

27 different vehicles among which
17 ACC equipped



Controlled leading vehicle speed profile

Two campaigns on highways and two on test beds

Autonomous Vehicle operates in platoon with and without traditional vehicles

Access to Data Base: https://data.jrc.ec.europa.eu/dataset/9702c950-c80f-4d2f-982f-44d06ea0009f/resource/ecf3de9e-0370-431f-80ed-019b8912197f

Description of the Experiment

- Tests were scheduled for non-peak hours .
- Leader was instructed to perform occasional random deceleration and accelerations over a desired speed in a realistic way
- No overtaking was performed

Description of the Experiment

We chose six five-vehicle platoons :

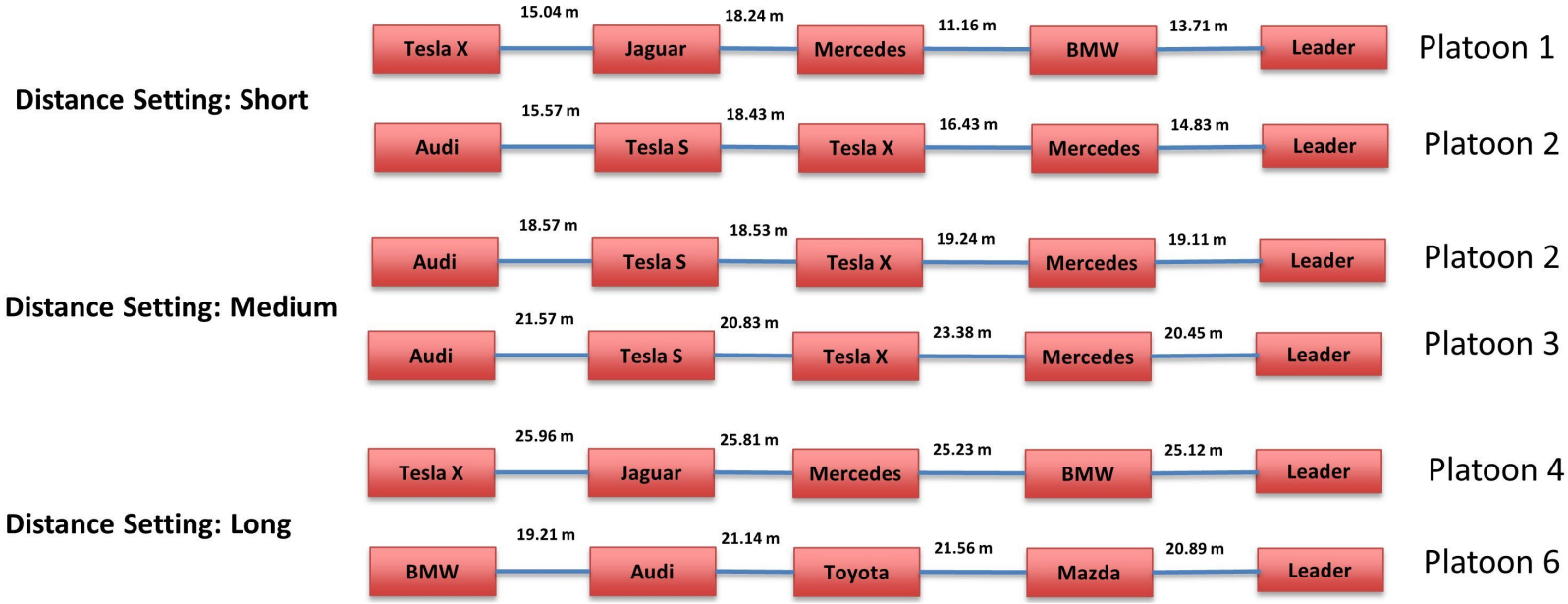


Figure: Average inter-vehicular spacings (IVSs) in Test Platoons

Gasiz-Herman-Rothery Model

- Response of the following vehicles in the traffic stream is accelerate, decelerate of do nothing in proportion to the magnitude of the stimulus at time t and it will begin at a time lag T.

$$Response\ (t+T) = Sensitivity * Stimulus\ (t)$$

$$\ddot{x}_i(t+T) = \alpha \frac{\dot{x}_{i+1}(t)^l}{\left(x_i(t) - x_{i+1}(t)\right)^m}\left(\dot{x}_i(t) - \dot{x}_{i+1}(t)\right)$$

$\ddot{x}_i(t+T)$ = response of the following vehicle
T= response time of the following vehicle
$\dot{x}_i(t)$=speed of the following vehicle at time t
$\dot{x}_{i+1}(t)$= speed of the leading vehicle at time t
$x_i(t) - x_{i+1}(t)$=inter-vehicular distance between the leading and following vehicle at time t
α = sensitivity term
l =distance headway exponent
m= speed difference exponent
Feasible range is defined where $0 \leq m < 1$; $l > 1$ and $\alpha > 0$

Cross Correlation

- Presents a technique for comparing two time series and finding objectively how they match up with each other, and in particular where the best match occurs.

- The lag refers to how far the series are offset, and its sign determines which series is shifted.

- Cross correlation coefficient will be positive and have large values when the two series are in phase (peaks aligned with peaks)

Cross Correlation

- Consider, two time series $x(t) = Stimulus(t)$ and $y(t) = Response\ (t + T)$ lag by a time interval T, where $t \in \{0,1,2,3, \ldots \ldots \ldots . n\}$. The cross-correlation r at lag d, $r(T)$ as follows:

$$r(d) = \frac{\Sigma_t[(x(t) - \mu_x) * (y(t - d) - \mu_y)]}{\sqrt{\Sigma_t(x(t) - \mu_x)^2}\ \sqrt{\Sigma_t(y(t - d) - \mu_y)^2}}$$

- The value of the lag with the highest correlation coefficient represents the best fit between the two series.

Fitted Model

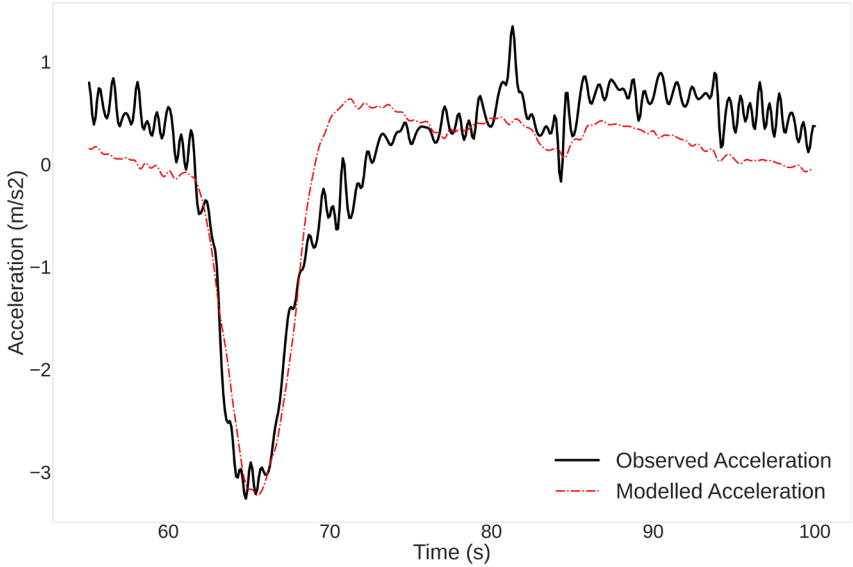
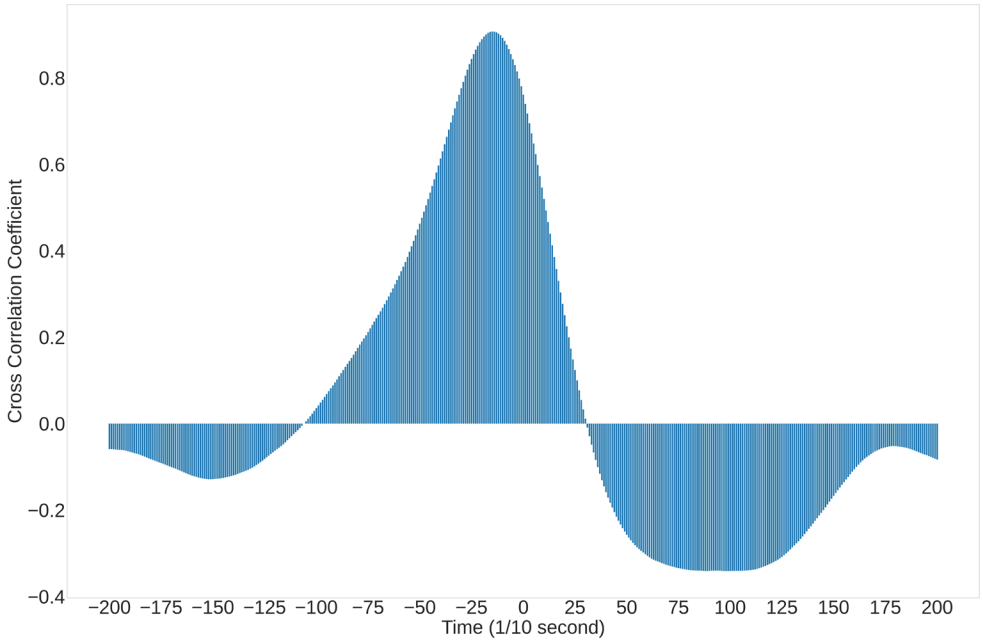


Figure: Fitted acceleration profile of AV following TV (Time Step 50.1 s to 100 s) (R^2 =0.83, RMSE=0.43)

- To fit the following vehicle's acceleration profile to GHR model, in other words to fit α, l and m, we used generalized reduced gradient (GRG) optimization method.
- Similarly, we fitted the model for other time steps.

Response Time Estimation



- AV-AV scenario for time step 50.1 s to 100 s.
- Correlation coefficient between acceleration of the following vehicle and the speed difference of leader and follower is highest at -16(1/10)=-1.6 s.
- Similarly, we estimated response time for all other scenarios.

Local and Asymptotic Stability

$$C = \alpha \frac{\dot{x}_{i+1}(t)^m}{\left(x_i(t) - x_{i+1}(t)\right)^l} RT$$

- Traffic stream to be asymptotically stable, C must be less than or equal to 0.5.
- Traffic stream to be local stable C must be less than or equal to 1.57.
- Within the range of C value of 0.5 to 1.57 the vehicle platoon will be string unstable however local stable.

Traffic Conflict Detection

Margin to collision $(MTC_i(t)) = \frac{D(t)+SSD_L(t)}{SSD_F(t)}$

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

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

$SSD_L(t)$= Safe stopping distance of the leading vehicle at time t in m

$SSD_F(t)$= Safe stopping distance of the following vehicle at time t in m

$D(t)$= Inter-vehicular spacing of the vehicle pairs at time t in m

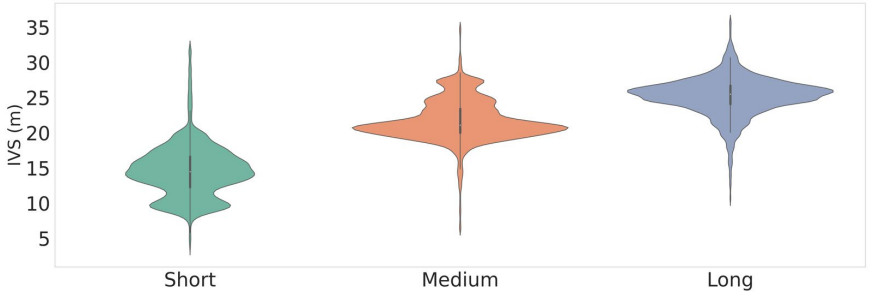
V_F(t)= Speed of the following vehicle at any time instant t in m/s

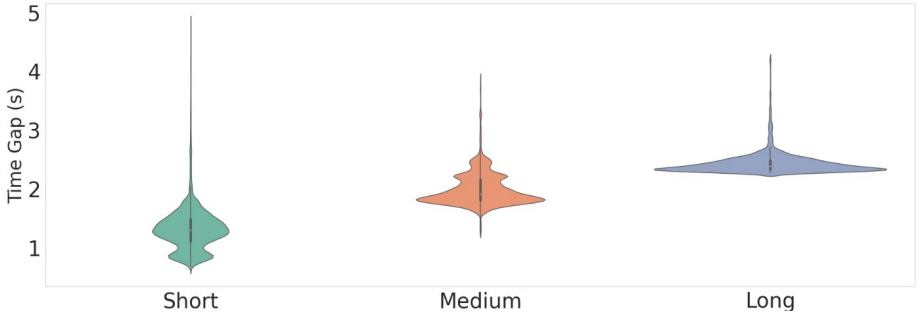
V_L(t)= Speed of the leading vehicle at any time instant t in m/s

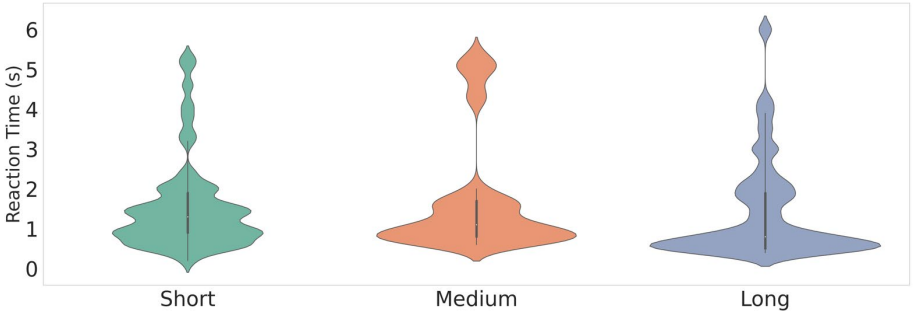
RT_F = Response time of following vehicle in s

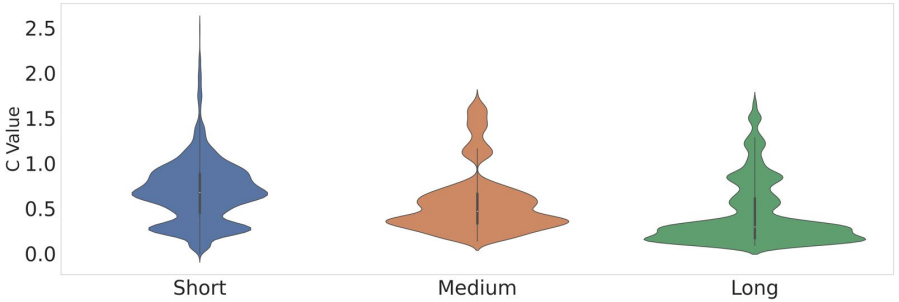
d_{Lmax}, d_{Fmax} = Maximum deceleration rate applied by leading and following vehicles. A value of 3.40 m/s^2 suggested by AASTHO is used for passenger cars

Preliminary Statistics

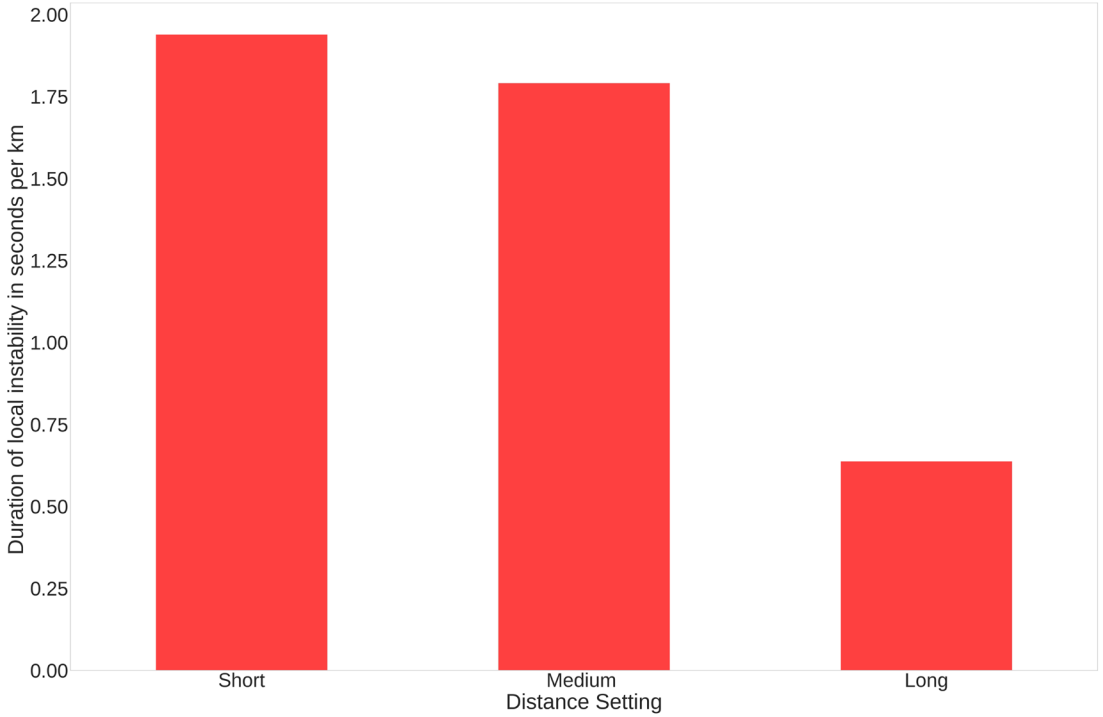




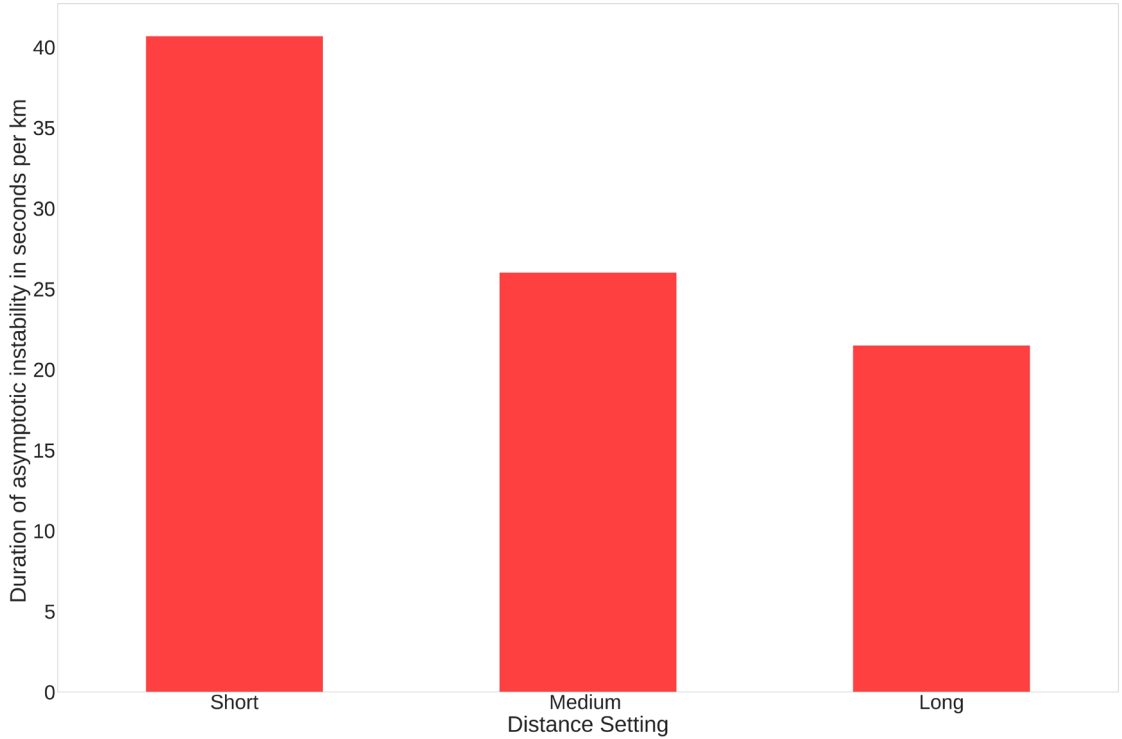




Impact of distance setting on local stability



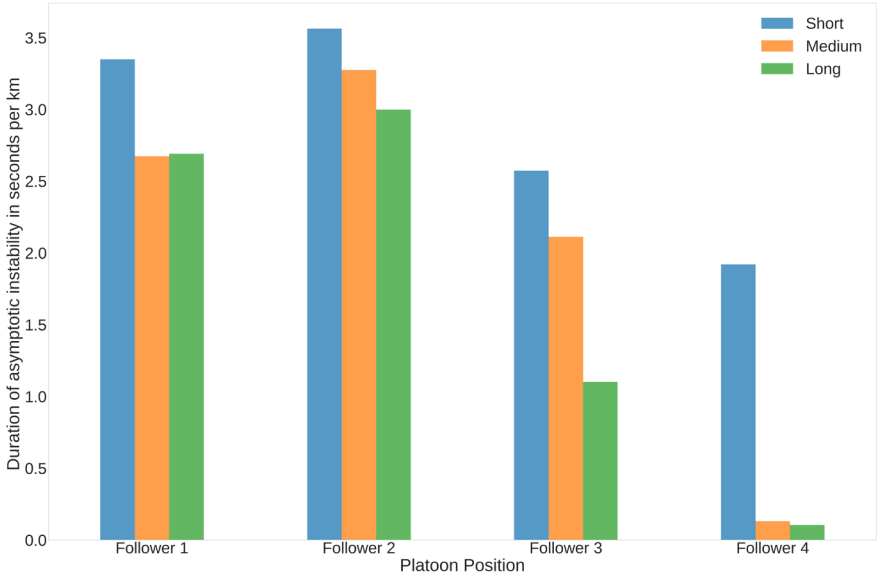
Impact of distance setting on asymptotic stability



Hypothesis test results regarding traffic stability

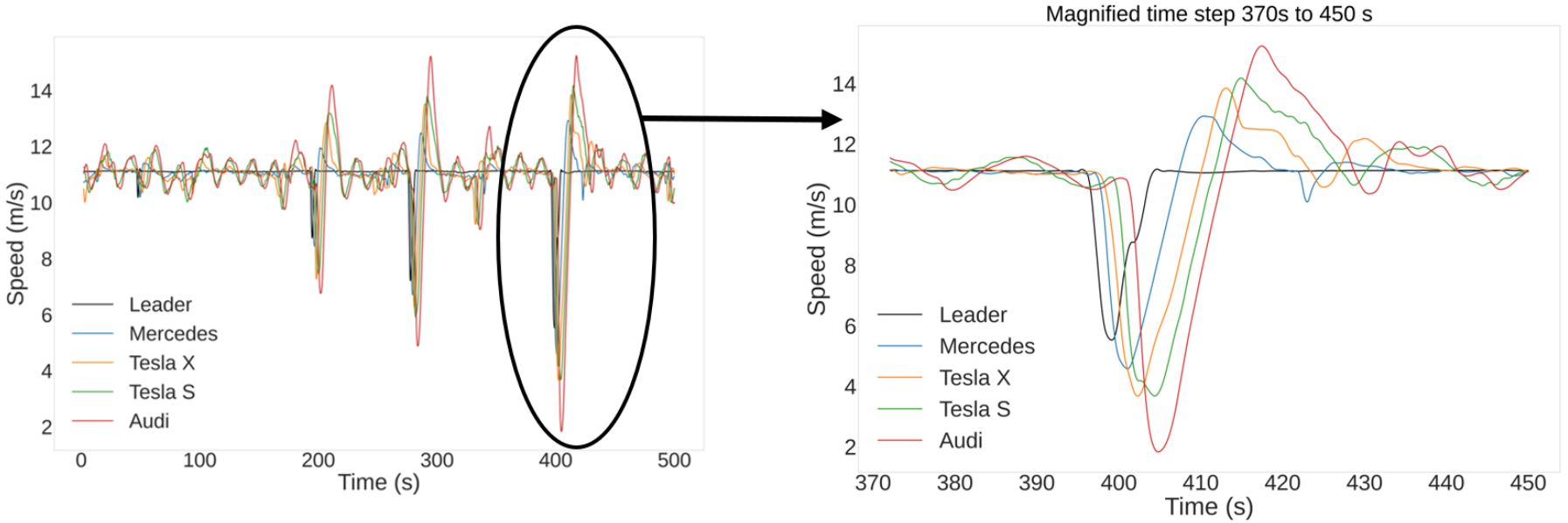
Local Stability				
Sample 1	**Sample 2**	Null hypothesis	Two side test p value	Hypothesis test result
Duration of local instability per km for short distance setting	**Duration of local instability per km for medium distance setting**	Duration of local instability per km for short-distance setting and medium-distance setting are not significantly different at 95 % confidence interval	0.0106	Null hypothesis cannot be rejected
Duration of local instability per km for medium distance setting	**Duration of local instability per km for long distance setting**	Duration of local instability per km for medium-distance setting and long-distance setting are significantly different at 95 % confidence interval	0.00	Null hypothesis rejected
Duration of local instability per km for short distance setting	**Duration of local instability per km for long distance setting**	Duration of local instability per km for short-distance setting and long-distance setting are significantly different at 95 % confidence interval	0.00	Null hypothesis rejected
Asymptotic Stability				
Duration of asymptotic instability per km for short distance setting	**Duration of asymptotic instability per km for medium distance setting**	Duration of asymptotic instability per km for short-distance setting and medium-distance setting are not significantly different at 95 % confidence interval	0.00	Null hypothesis rejected
Duration of asymptotic instability per km for medium distance setting	**Duration of asymptotic instability per km for long distance setting**	Duration of asymptotic instability per km for medium-distance setting and long-distance setting are significantly different at 95 % confidence interval	0.00	Null hypothesis rejected
Duration of asymptotic instability per km for short distance setting	**Duration of asymptotic instability per km for long distance setting**	Duration of asymptotic instability per km for short-distance setting and long-distance setting are significantly different at 95 % confidence interval	0.00	Null hypothesis rejected

Impact of platoon position on asymptotic stability



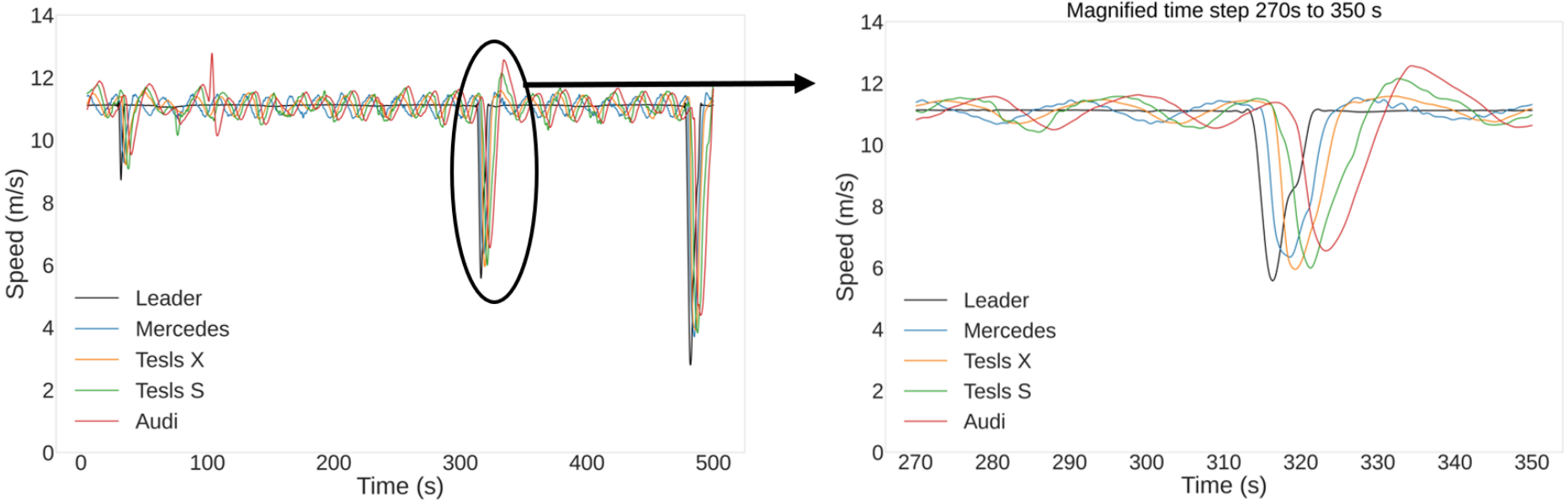
- Up to follower 2, the disturbance imposed by the leader is amplified for all distance settings.
- After that, the disturbance is damping for medium and long-distance settings.
- Follower four of short-distance settings shows significantly higher instability than follower four of medium and long-distance settings.

Impact of platoon position on asymptotic stability



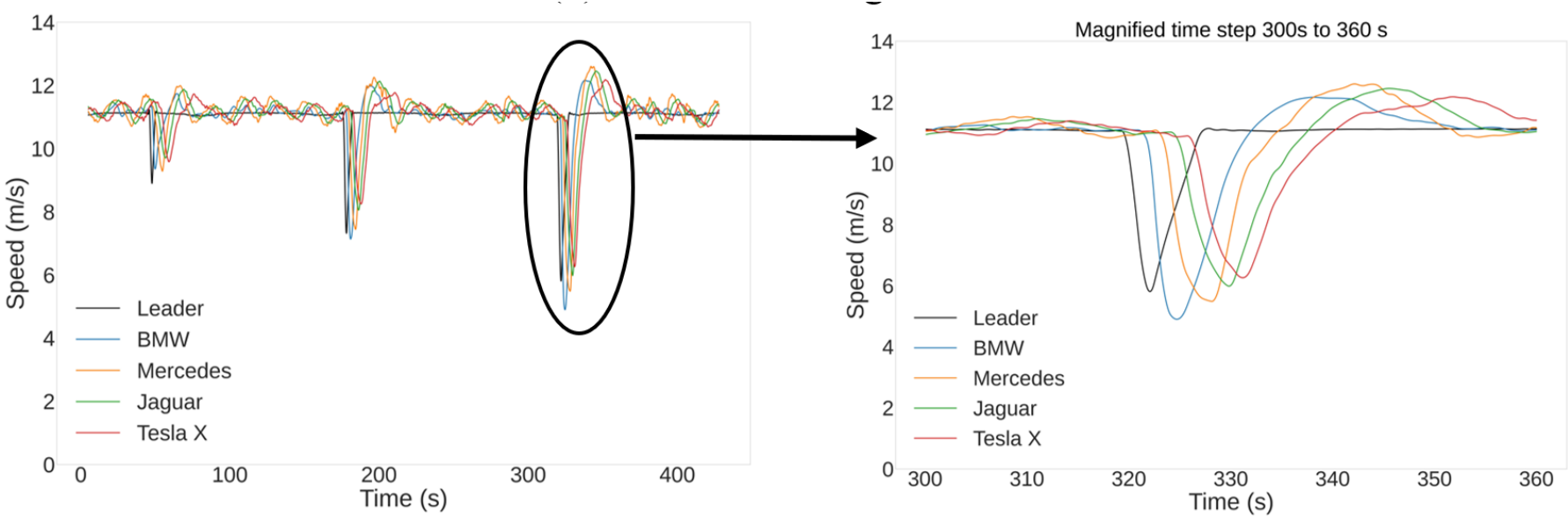
(a): Distance setting: Short

Impact of platoon position on asymptotic stability



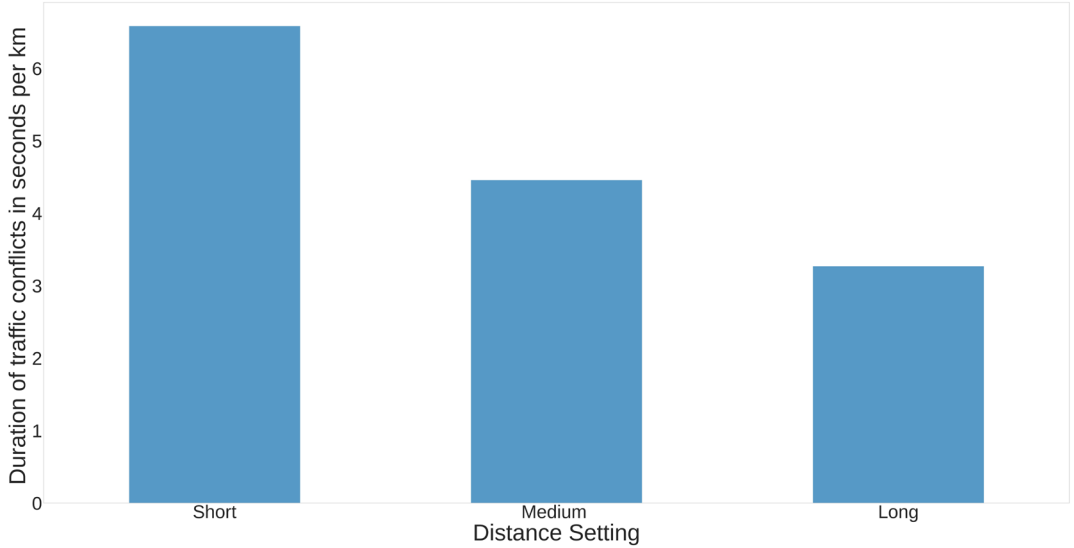
(b):Distance setting: Medium

Impact of platoon position on asymptotic stability



(c): Distance setting: Long

Impact of distance setting on traffic conflicts



- Increasing distance setting from short to long, reduces the duration of traffic conflicts.
- AVs with short distance setting reported around 6 seconds of traffic conflict per km, which is almost double of the reported traffic conflict by AVs with long distance setting (3 seconds)

Hypothesis test results regarding traffic safety

Sample 1	Sample 2	Null hypothesis	Two side test p value	Hedge's g	Hypothesis test result
Number of traffic conflicts per km for AVs with short distance setting	Number of traffic conflicts per km for AVs with medium distance setting	Number of traffic conflicts per km for AVs with short and medium distance setting are not significantly different at 95 % confidence interval	0.00	0.1763	Null hypothesis rejected
Number of traffic conflicts per km for AVs with medium distance setting	Number of traffic conflicts per km for AVs with long distance setting	Number of traffic conflicts per km for AVs with medium and long-distance setting are not significantly different at 95 % confidence interval	0.00	0.4365	Null hypothesis rejected
Number of traffic conflicts per km for AVs with short distance setting	Number of traffic conflicts per km for AVs with long distance setting	Number of traffic conflicts per km for AVs with medium and long-distance setting are not significantly different at 95 % confidence interval	0.00	0.5535	Null hypothesis rejected

Conclusion

- Our results reveal that different distance settings significantly impact flow stability and longitudinal safety.
- The AVs with short-distance settings increased flow instability both locally and asymptotically.
- AVs with long-distance setting significantly reduces both local and asymptotical instability.
- AVs with long-distance settings outperform medium and short-distance settings in terms of longitudinal safety.