Alternative explanations for shorter time headway when human drivers follow AVs

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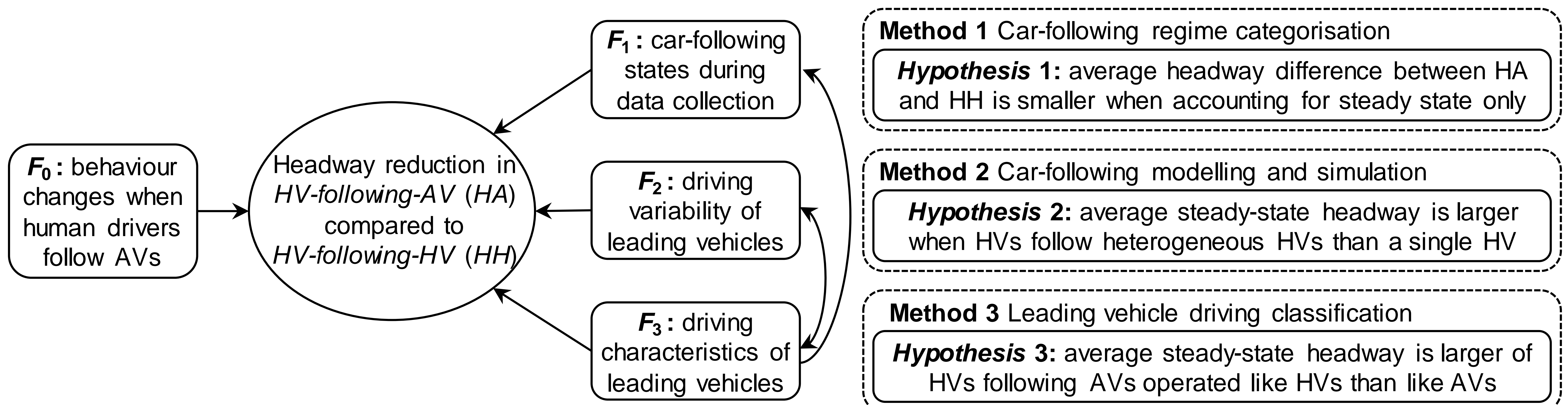s.c.calvert@tudelft.nl

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Recent empirical studies find reduced headways when human drivers follow an automated vehicle (AV) compared to following a human driving vehicle (HV), and attribute this reduction to behaviour changes of following vehicle drivers. However, more factors may be at play. This study scrutinises three alternative explanations:
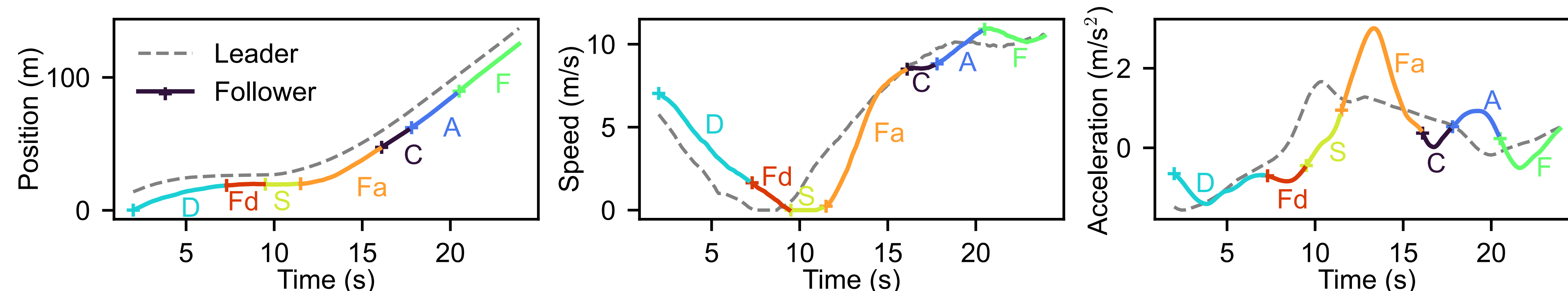- the car-following states during data collection,
- the driving variability of leading vehicles, and
- the unique driving characteristics of leading AVs.

CONCEPTUAL FRAMEWORK

F_0 : behaviour changes when human drivers follow AVs

Headway reduction in *HV-following-AV* (*HA*) compared to *HV-following-HV* (*HH*)

F_1 : car-following states during data collection

F_2 : driving variability of leading vehicles

F_3 : driving characteristics of leading vehicles

Method 1 Car-following regime categorisation

Hypothesis **1**: average headway difference between HA and HH is smaller when accounting for steady state only

Method 2 Car-following modelling and simulation

Hypothesis **2**: average steady-state headway is larger when HVs follow heterogeneous HVs than a single HV

Method 3 Leading vehicle driving classification

Hypothesis **3**: average steady-state headway is larger of HVs following AVs operated like HVs than like AVs

METHODS

Method 1 Car-following regime categorization (regime examples shown below)

Method 3 Leading vehicle driving classification

AV leading vehicles

HV leading vehicles

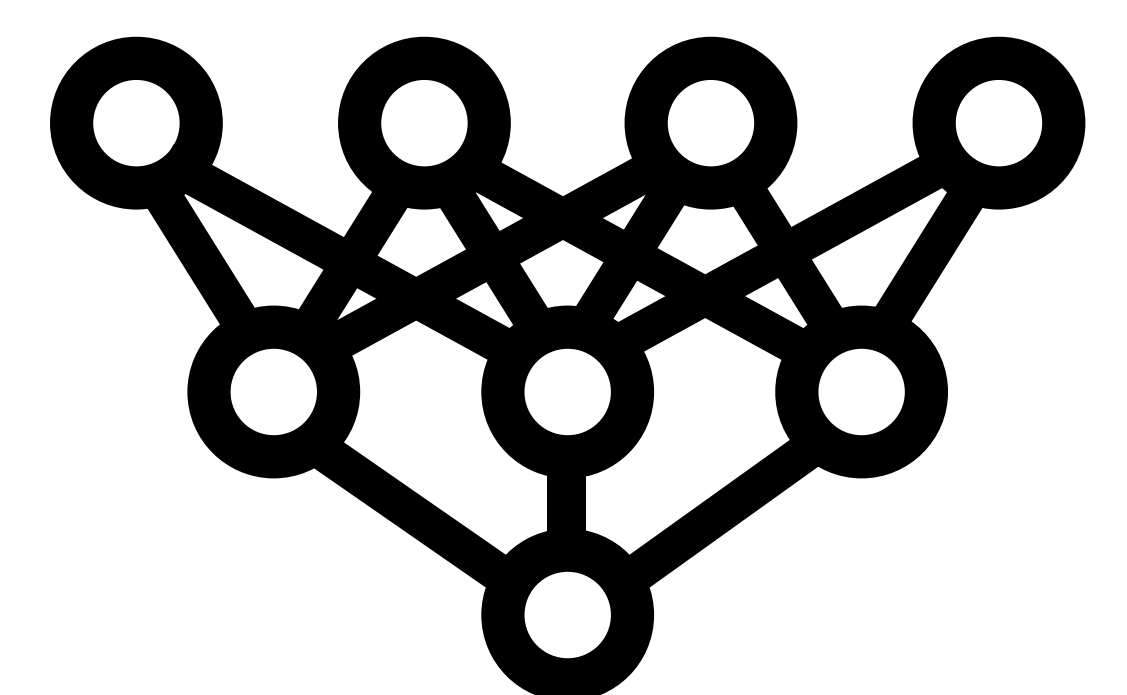AVs driving like HV

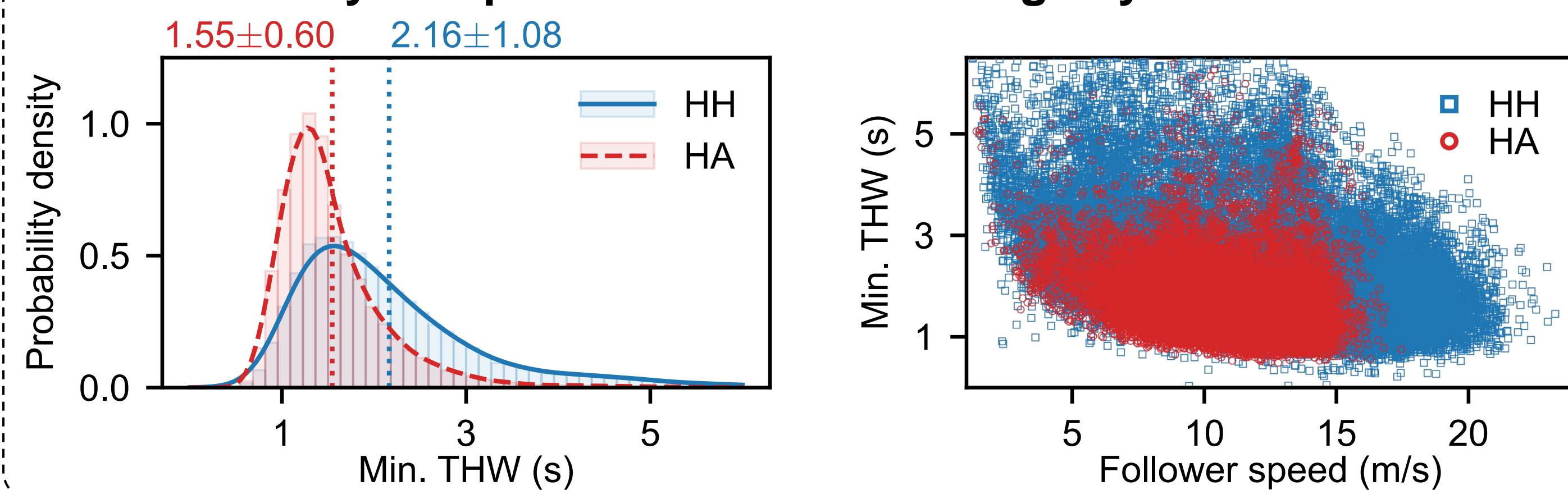AVs driving like AV

Method 2 Car-following modelling (IDM) and simulation (experiments design shown below)

Variability	Number of leader(s)	Number of followers	Note
Uniform	1	$N_{HH} - 1$	Repeated for 4 times with 4 different leaders,
Heterogeneous	$N_{HH} - 1$	$N_{HH} - 1$	and no followers follow their factual leaders

DATA

Data source	Collection time	Category	Number of cases
Lyft	Oct. 2019 – Mar. 2020	AV following HV	9,172
		HV following AV	29,449
		HV following HV	42,892
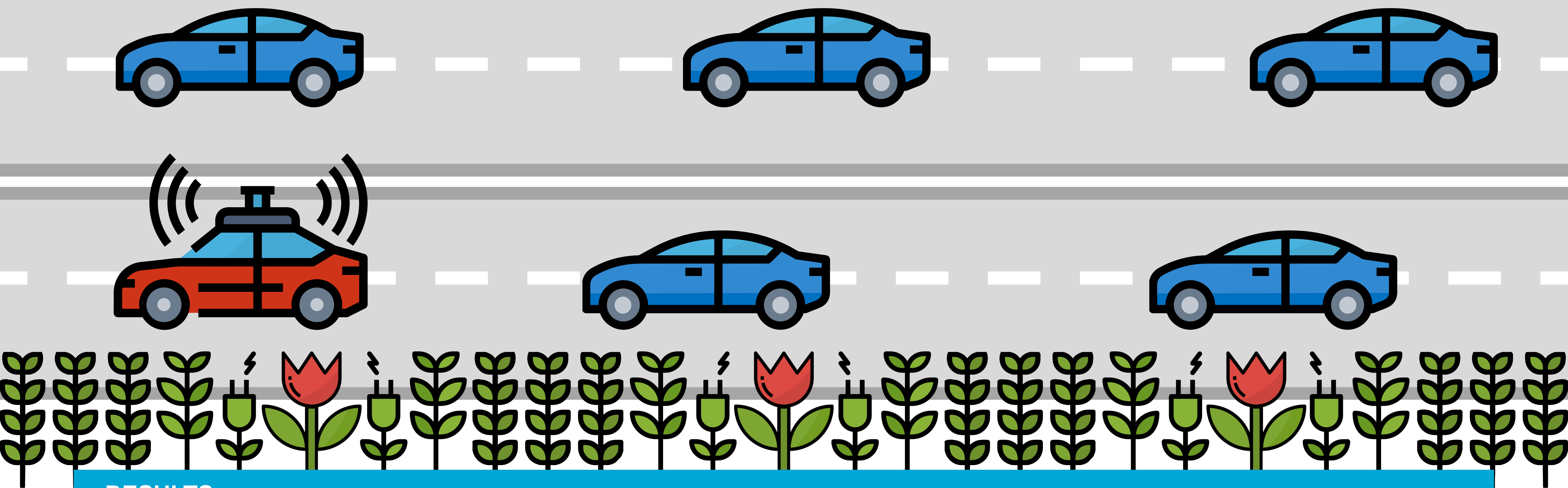
Time headway comparison *without* isolating any factors

1.55±0.60   2.16±1.08

- HH
- HA

Probability density / Min. THW (s)
Min. THW (s) / Follower speed (m/s)

- HH
- HA

H1 Comparison with *car-following states* isolated

- HH
- HA

14.1% 7.4%   5.2% 5.8%   18.3% 16.3%   9.8% 6.9%   7.9% 9.5%   27.4%   41.3%   17.4% 12.7%

Fa   Fd   C   A   D   F   S

Car-following regimes

1.46±0.50   1.79±0.77

Probability density / Min. THW in steady state (s)
Min. THW in steady state (s) / Follower speed (m/s)

- HH
- HA
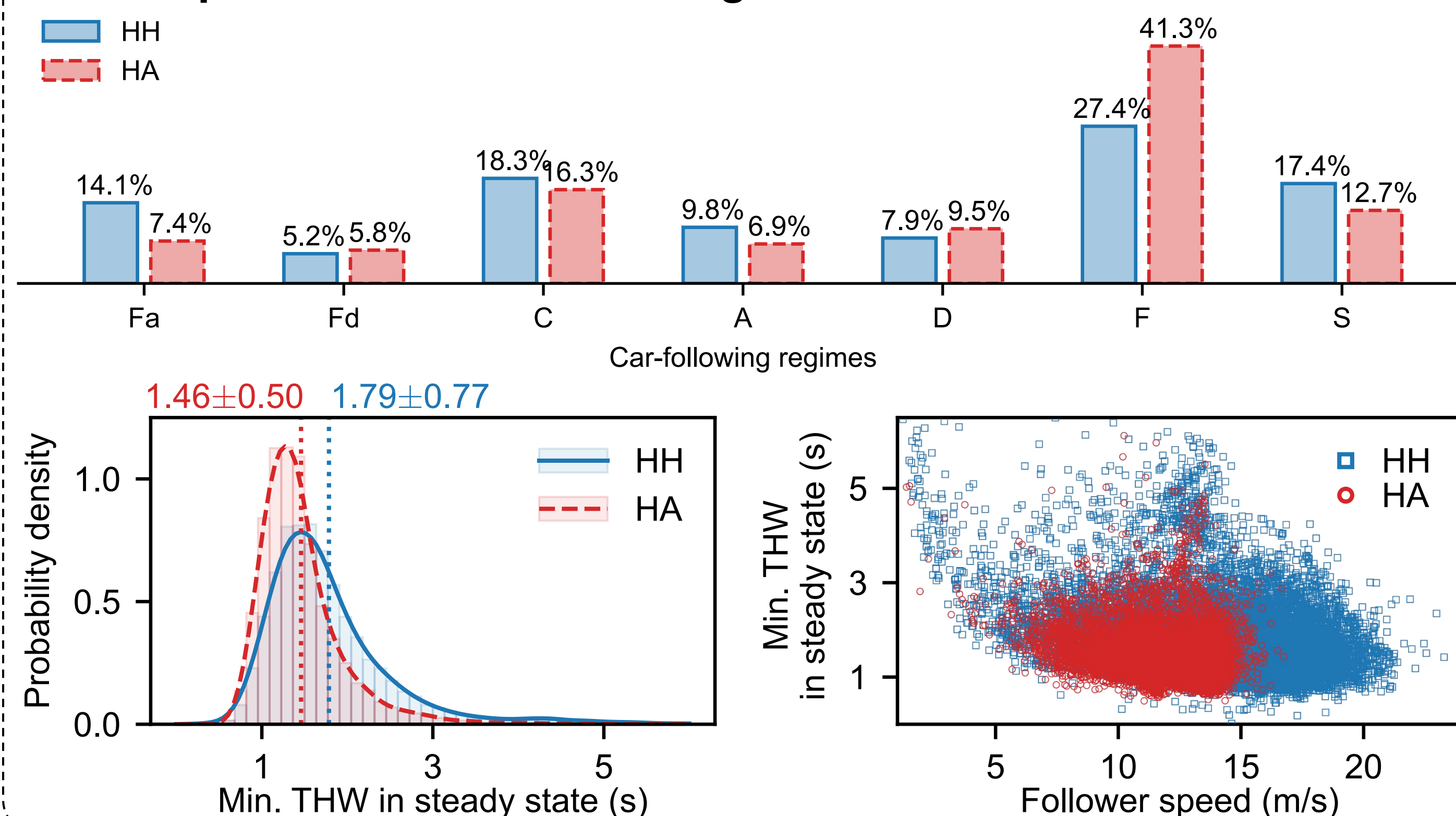
H2 Comparison with *leading vehicle variability* isolated

The same HV followers in HH following

2.01±0.37   2.39±1.33   K-S p-value: 0.000   HA ≠ HH

2.04±0.29   2.26±0.78   K-S p-value: 0.000   HA ≠ HH

2.32±1.30   2.43±1.55   K-S p-value: 0.000   HA ≠ HH

2.22±0.56   2.42±1.54   K-S p-value: 0.061   HA = HH

Probability density / Min. THW in steady state (s)
Min. THW in steady state (s) / Follower speed (m/s)

- 1,497 leaders in HH
- 1 leader in HH
- 1,497 leaders in HH
- 1 leader in HH

H3 Comparison with *driving characteristics* isolated

AV / Classification / HV
Epoch 10   Epoch 85   Epoch 145   Epoch 200
Added noise

Case-based classification according to p_c

1.45±0.51   1.58±0.56   K-S test p-value: 0.000   HA ≠ HH

Probability density / Min. THW in steady state (s)
Min. THW in steady state (s) / Follower speed (m/s)

Operation-based classification according to $p_c^{(t)}$

1.45±0.51   1.55±0.53   K-S test p-value: 0.000   HA ≠ HH

Probability density / Min. THW in steady state (s)
Min. THW in steady state (s) / Follower speed (m/s)

- HV leader operation classified as HV
- AV leader operation classified as AV
- HV leader operation classified as HV
- AV leader operation classified as AV

CONCLUSION

- **Car-following states during data collection**: time headway varies across different car-following states. Non-steady states generally have larger time headways, reducing overall average time headway. Focusing on steady-state following, the average time headway reduction shrinks from **0.61**s to **0.33**s.
- **Driving variability of leading vehicles:** homogeneity in leading vehicles' driving styles narrows time headway variance, shortening averages. Following a single HV reduces average time headway by **0.17**s compared to following heterogeneous HVs. This suggests human drivers' time headway reduction behind AVs is influenced by uniform AV driving algorithms.
- **Unique driving characteristics of AVs:** AVs' specific driving significantly impacts reduced time headways. Human drivers following AVs with stable driving characteristics have around **0.10**s shorter time headway than when following AVs mimicking HVs. Supporting evidence: No headway reduction observed when humans followed a "Wizard of Oz" AV (operated by a human but perceived as an AV), compared to an HV.
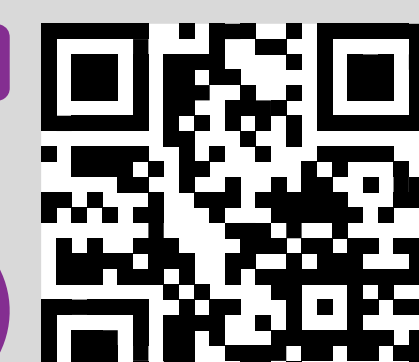
These quantifiable findings cannot be directly combined due to their interplay, which necessitates further research. Additionally, behavioral aspects like driver perception and desire to interact with AVs, lacking direct evidence, remain unquantified and warrant future investigation.

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