Characterizing Human-Automated Vehicle Interactions: An Investigation into Car-following Behavior

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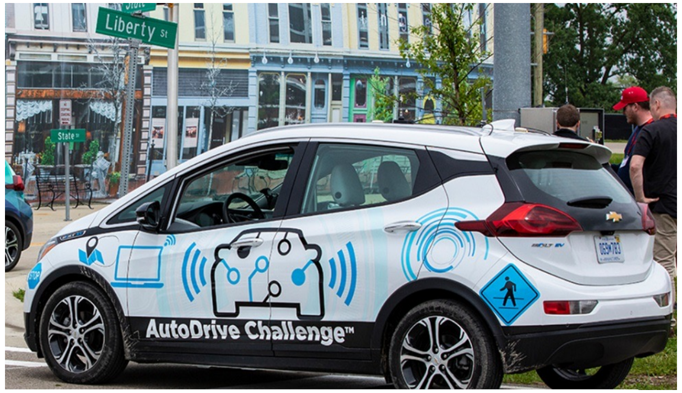
Outline

1. Introduction

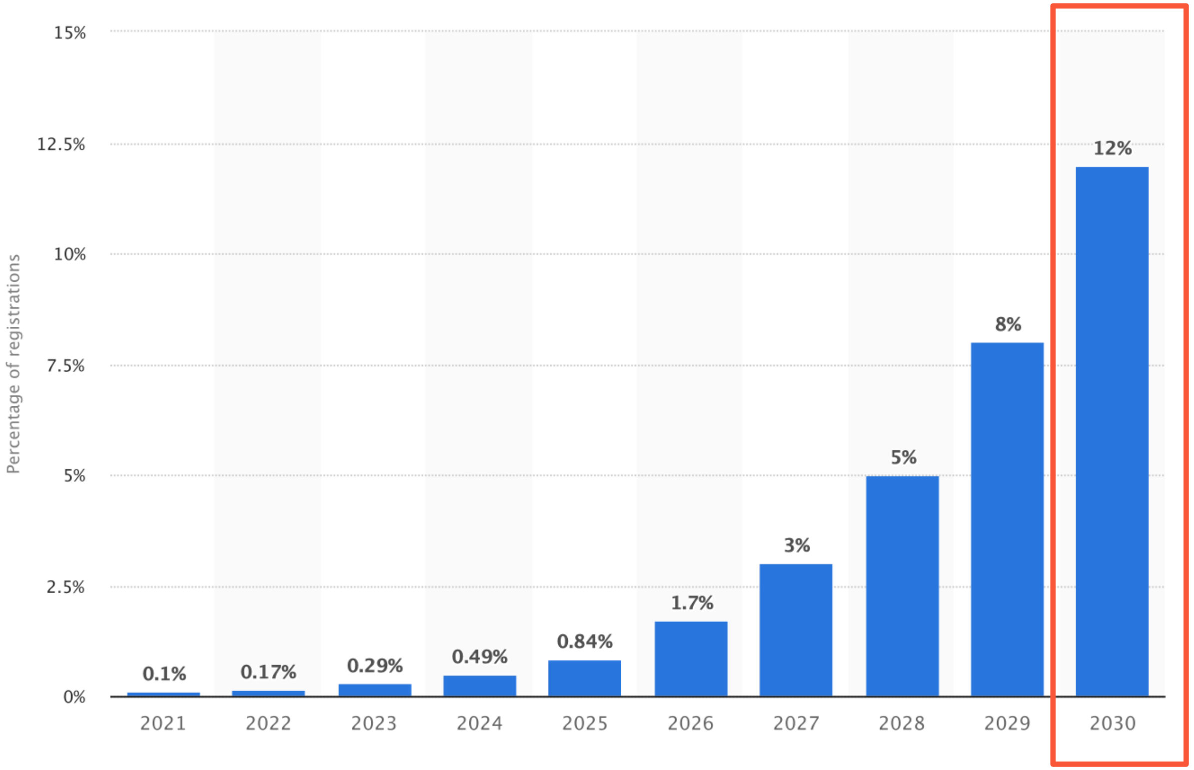
1.1 Background

- **Automated vehicles build their presence**



[Figures: waymo.com, sae.org]

- **Mixed autonomy traffic will remain for decades**

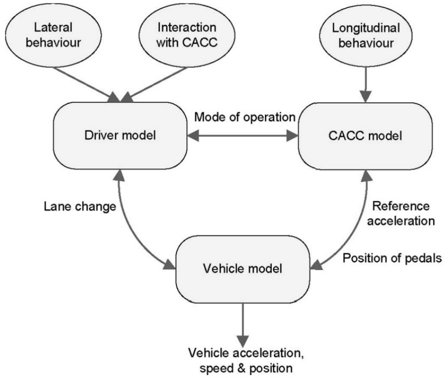


[Data source: Statista 2022]

1.2 Motivation: human's behaviors in HV-AV interactions are essential

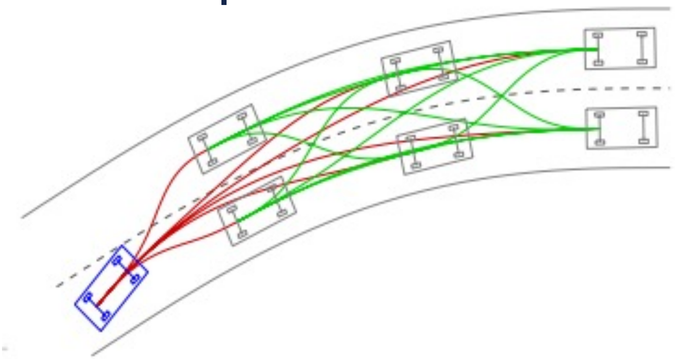
- **Research was focusing on AV motion planning and trajectory design**

ACC / CACC



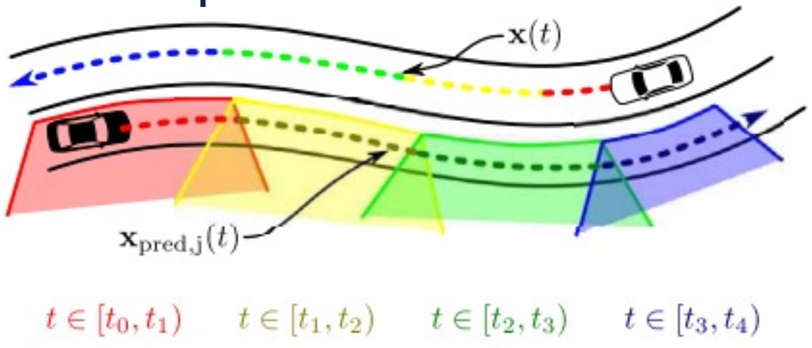
(Van Arem, et al., 2006)

Curve interpolation



(Xu, et al., 2012.)

Function optimization

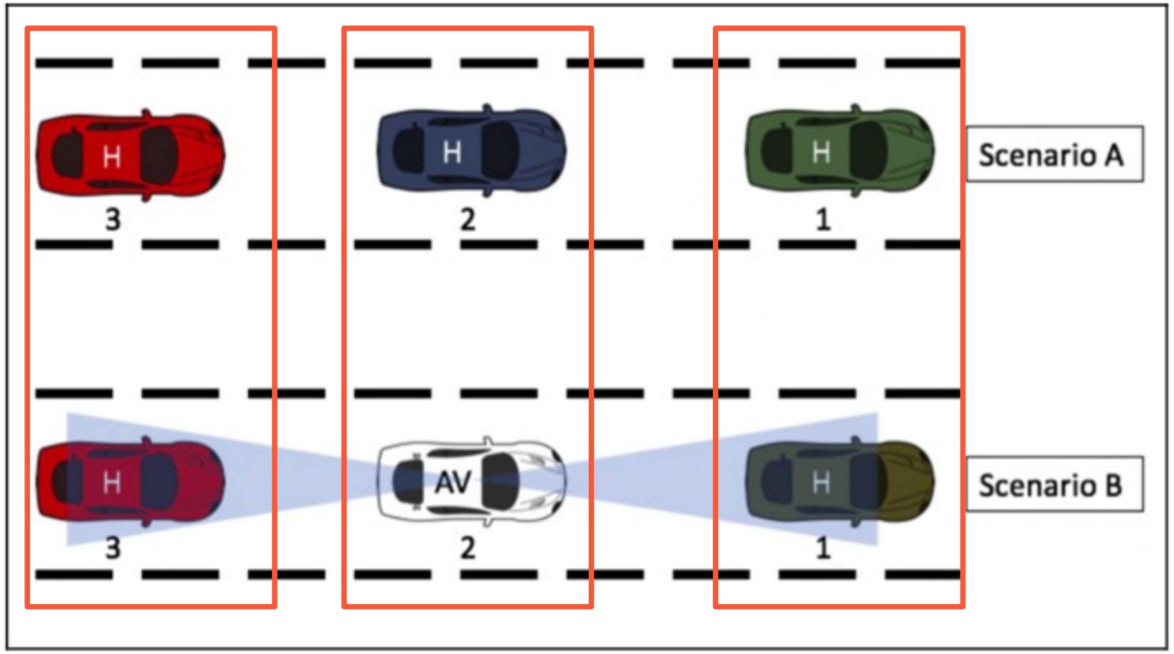


(Ziegler, et al., 2014)

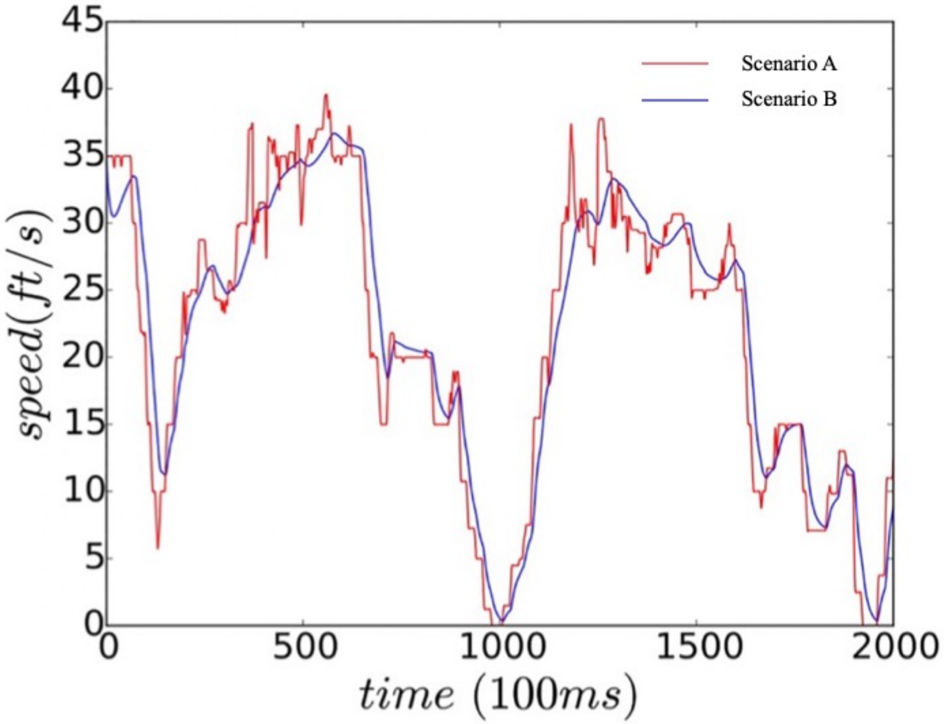
- **Evidence revealed that ACC-equipped vehicles lead to string instability** (Ciuffo, et al., 2021)
- **Significant difference was observed on human drivers' behavior on conventional cars when following an AV** (Rahmati, et al., 2019)

Which parameter / model can best capture such behavioral changes?

2.1 Data description: a car-following experiment



Experiment settings



Sample Speed profile

Rahmati, Y., Khajeh Hosseini, M., Talebpour, A., Swain, B., & Nelson, C. (2019). Influence of autonomous vehicles on car-following behavior of human drivers. Transportation research record, 2673(12), 367-379.

2.2 Data-driven methods: DTW analysis

- **Which parameter can best capture such behavioral changes?**

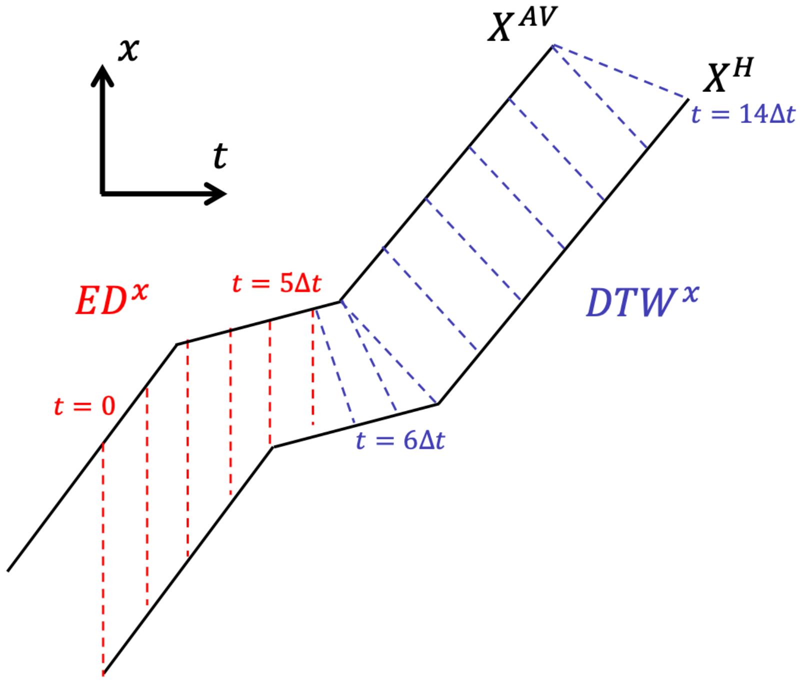
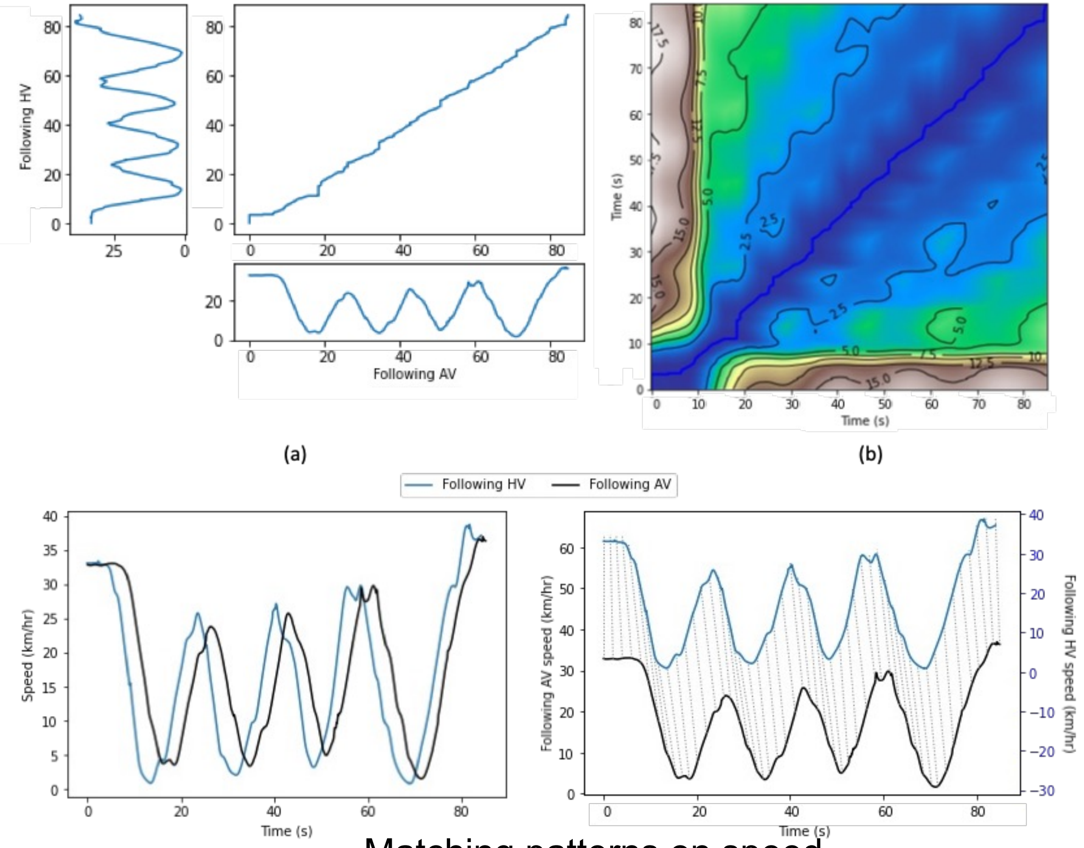


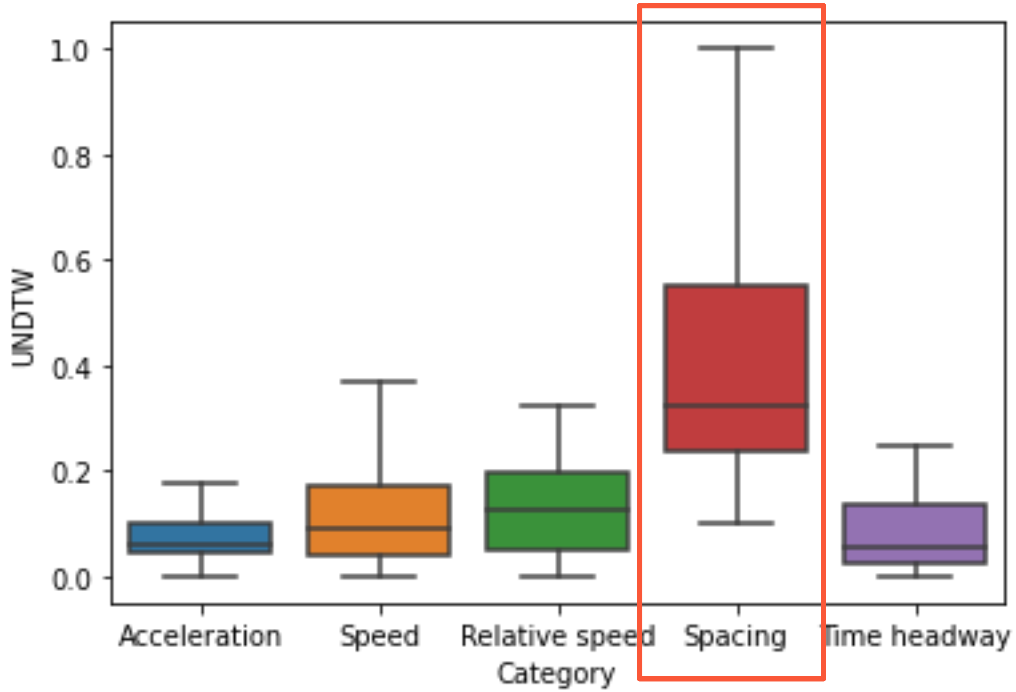
Illustration of dynamic time warping



Matching patterns on speed

2.2 Data-driven methods: DTW analysis

- **Which parameter can best capture such behavioral changes?**



Spacing has the best performance in measuring the changes in human drivers' behavior

2.3 Model-based method: GA calibration

- **Which model can substantiate behavioral changes?**

Intelligent driver model (IDM) (Treiber et al., 2000)

$$a_n(t) = a_{max}\left[1 - \left(\frac{v_n(t)}{v_{des}}\right)^4 - \left(\frac{s_{min} + v_n(t)T_{des} + \frac{v_n(t)\Delta v_n(t)}{2\sqrt{a_{max}b_{des}}}}{x_{n+1}(t) - l_{n+1}(t) - x_n(t)}\right)^2\right]$$

Model 1: IDM

	Human following			AV following			K-S test
	mean	sd	obs.	mean	sd	obs.	p-value
v_des	85.2503	27.7736	42	92.6560	22.6403	43	0.3432
t_des	1.5205	0.3932	42	1.5280	0.3678	43	0.9821
s_min	3.0963	1.2173	42	2.9840	1.3073	43	0.7993
a_max	1.0013	0.0010	42	1.0015	0.0013	43	0.6094
b_des	2.3426	0.3331	42	2.4161	0.2571	43	0.2823

Stochastic intelligent driver model
(Treiber & Kesting, 2017)

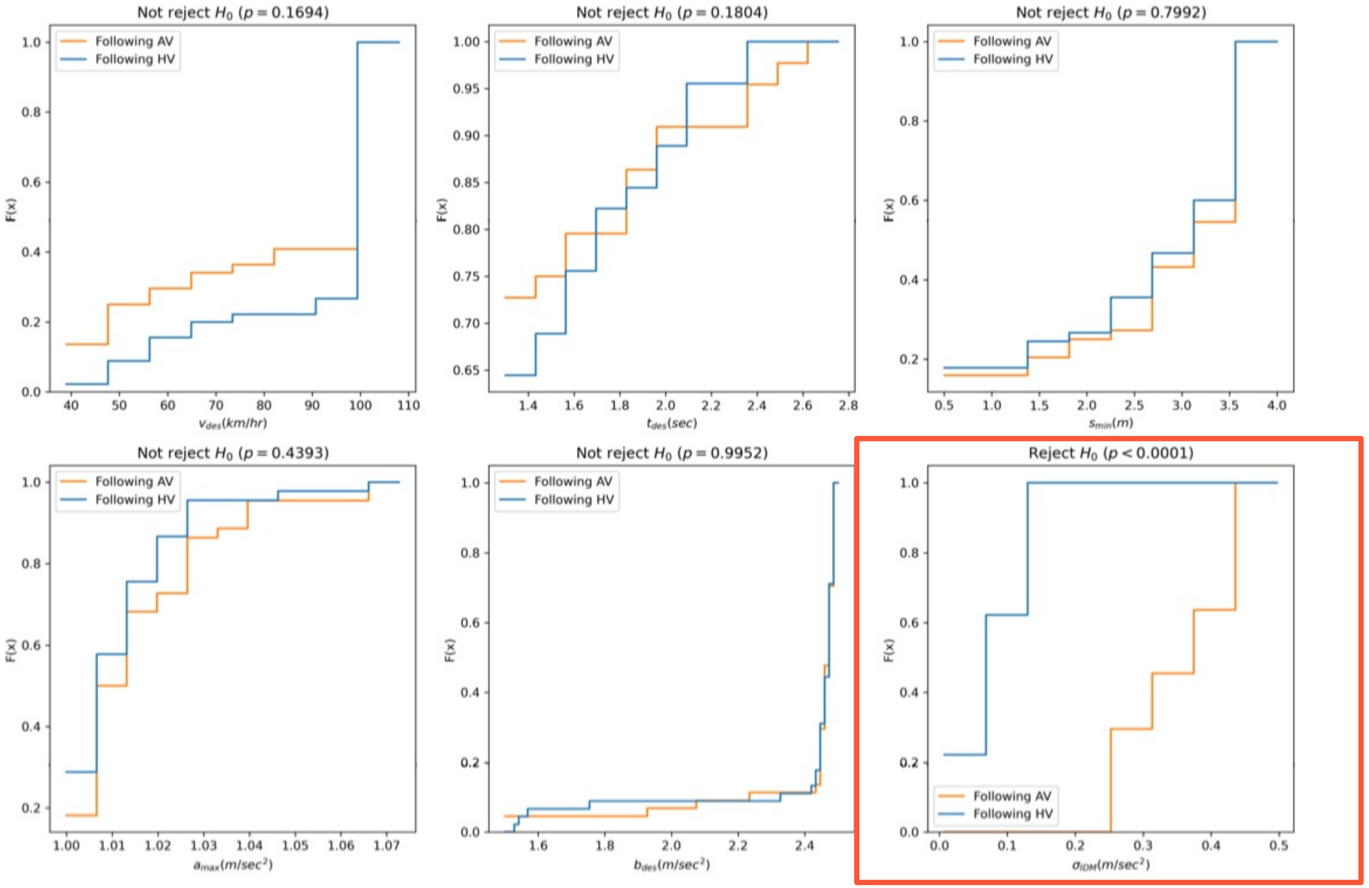
$$a \sim N(a | a_{IDM}, \sigma_{IDM}^2)$$

$$v_{t+1} \sim N(v_t + a_{IDM}\Delta t | \Delta t^2 \sigma_{IDM}^2)$$

$$v_{t+1} = v_t + a_t \Delta t$$

2.3 Which model can substantiate behavioral changes?

- **Which model can substantiate behavioral changes?**



3. Conclusion

- √ **Evidence from experiments reveals that human drivers' behaviors will change when following an AV**
- √ **The spacing parameter can best substantiate such phenomenon**
- √ **A stochastic extension to IDM can better model the car-following behavior in mixed autonomy traffic, and following an AV leads to less uncertainty for a human driver**

Thank You!
Any Questions?

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Reference

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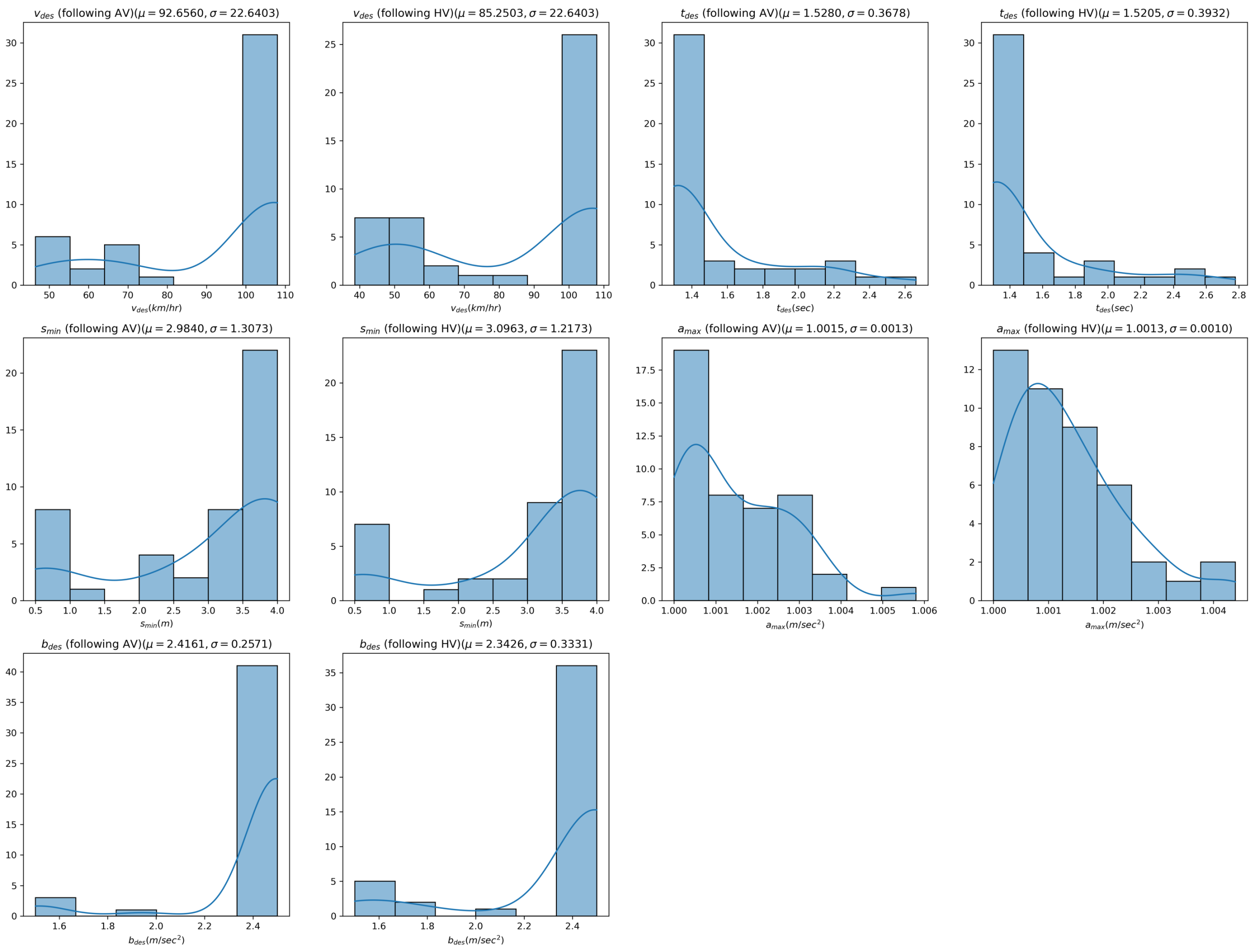
Backup



v_{des} (following AV)($\mu = 92.6560, \sigma = 22.6403$)
$v_{des}(km/hr)$
v_{des} (following HV)($\mu = 85.2503, \sigma = 22.6403$)
$v_{des}(km/hr)$
t_{des} (following AV)($\mu = 1.5280, \sigma = 0.3678$)
$t_{des}(sec)$
t_{des} (following HV)($\mu = 1.5205, \sigma = 0.3932$)
$t_{des}(sec)$
s_{min} (following AV)($\mu = 2.9840, \sigma = 1.3073$)
$s_{min}(m)$
s_{min} (following HV)($\mu = 3.0963, \sigma = 1.2173$)
$s_{min}(m)$
a_{max} (following AV)($\mu = 1.0015, \sigma = 0.0013$)
$a_{max}(m/sec^2)$
a_{max} (following HV)($\mu = 1.0013, \sigma = 0.0010$)
$a_{max}(m/sec^2)$
b_{des} (following AV)($\mu = 2.4161, \sigma = 0.2571$)
$b_{des}(m/sec^2)$
b_{des} (following HV)($\mu = 2.3426, \sigma = 0.3331$)
$b_{des}(m/sec^2)$