



Committee on Traffic Flow Theory and Characteristics
(TRB ACP50)

ACC Webinar Series

Response times in ACC car-following experiments: comparison between datasets and determination methods

Ian Metelski, Carlos Gomez-Patino, Christine Buisson

Thursday, July 29th, 2021



A detour before we start

- All this research (what I'll present but many recent papers about ACC) is possible thank to the **sharing** of efficient teams' efforts
- We practice open data (OD) and open source (OS) now much more than before
- But we have to keep in mind that OD and OS are only 2 of the 6 pillars of truly open science which are:



6 pillars of Open Science

OD

Open Data

RR

Reproducible research

RA

Research Assessment

OS

Open Source

KS

Knowledge Sharing

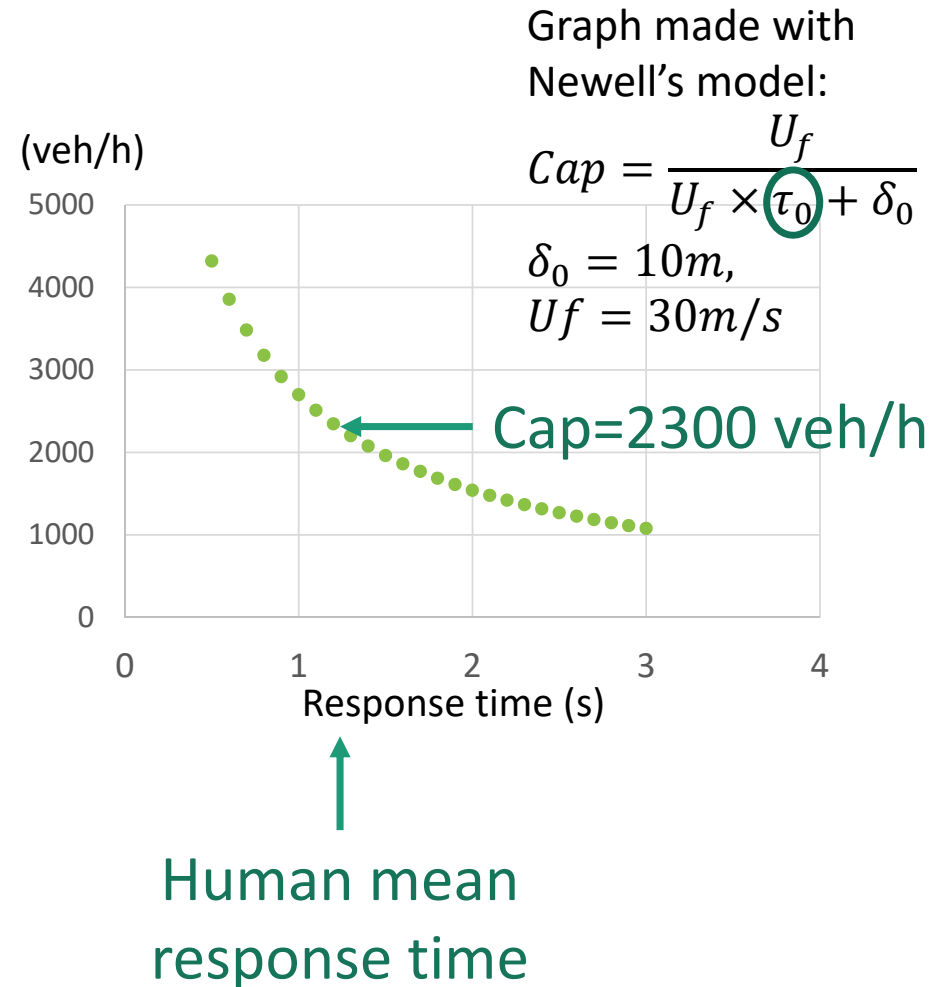
OA

Open Access

For further reading about reproducible research in transportation, read Zuduo Zheng's paper: <https://arxiv.org/abs/2105.06743>

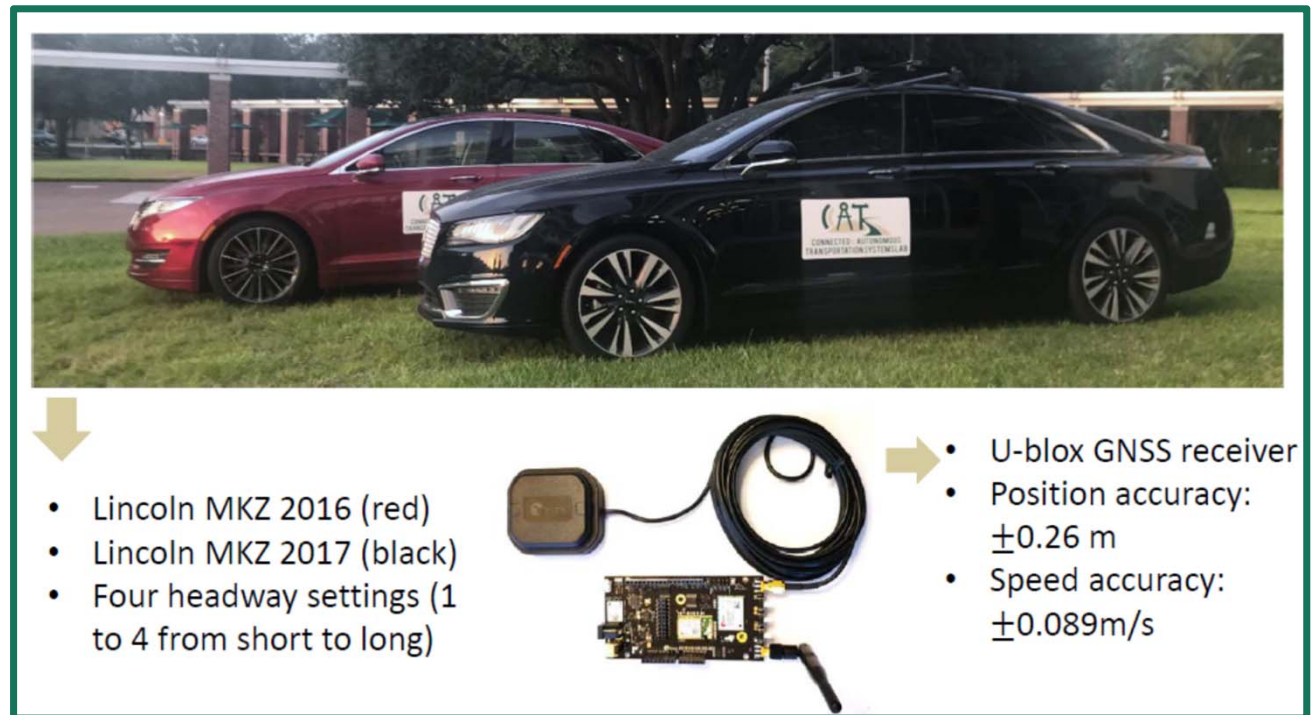
Why studying response times of ACC vehicles?

- Because of its direct impact on capacity if 100 % of the vehicles are ACC (Adaptive Cruise Control)
- Because of the impact a mixture of ACC and human driven vehicles will have on global traffic both in
 - **Capacity** and
 - In **Safety**
- Because, as researchers, we have to provide advices to DoTs (and citizens) about the regulations of such vehicles



Many authors contributed on experimental ACC reaction times determination

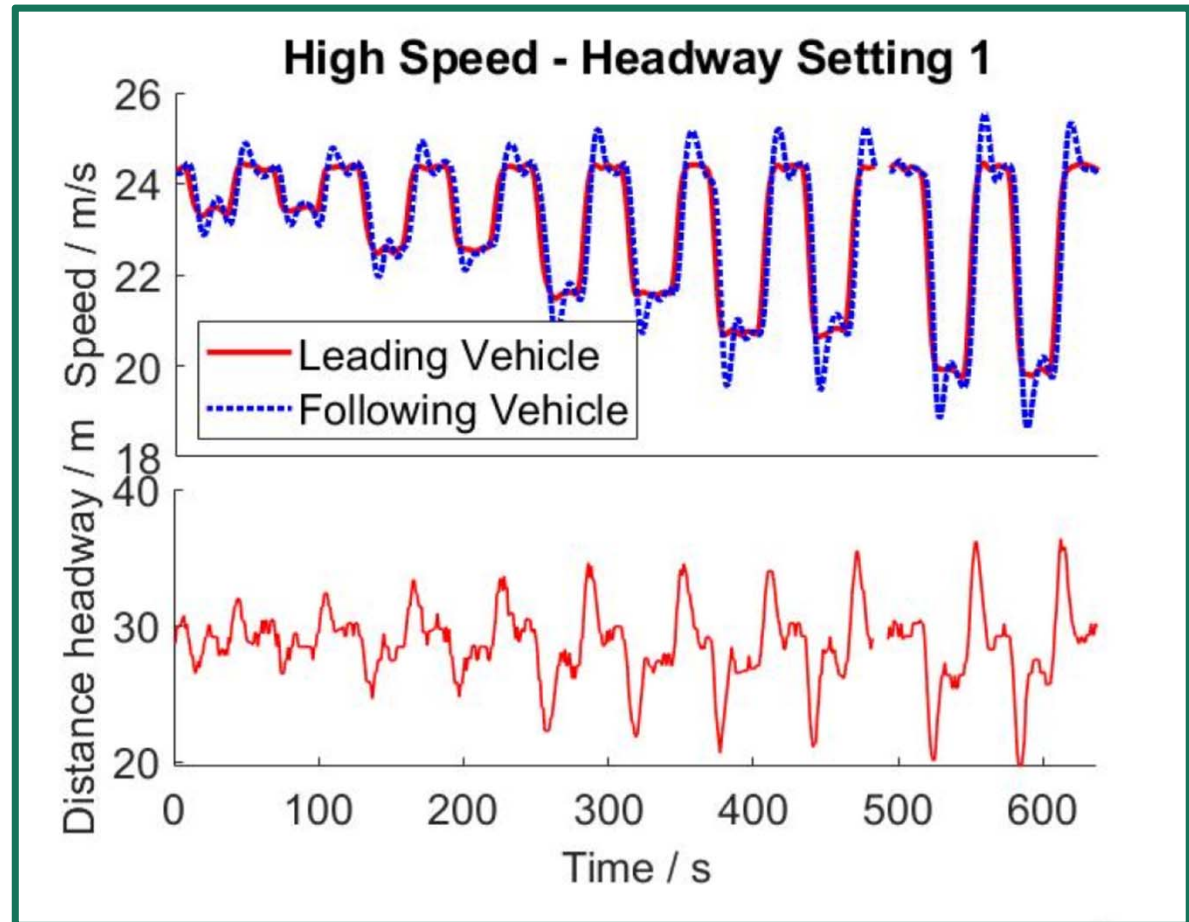
- The experimental setup is rather common (here's the one presented by Prof. Li during the TFTC webinar last April) →
- The GNSS positions measurements are precise enough to permit a detailed analysis⁽¹⁾



(1): this is significantly different to the US DoT experiments, conducted during 2016, used in our recent paper (Lanaud et al, 2021)

Many authors contributed on experimental ACC reaction times determination

- Typical observations (here, some of the ones presented by Prof. Li during the TFTC webinar last April)



Many authors contributed on experimental ACC reaction times determination. A selection of recent works:

Ref.	Method	Data source			
		Work's (Gunter et al. 2020)	OpenACC (Makridis et al, 2021)	CatsLab (Shi & Li, 2021)	MA and GA (Li et al, 2021)
(Gunter et al, 2020)	Calibrate the Optimal Velocity model (with Relative Speed) relationship, all the trajectory is used	X			
(Makridis et al, 2021)	Identify through covariance, over all leader and follower trajectories, the optimal RT: selection of reaction periods		X		
(Shi & Li, 2021)	Retrofit a simple linear relationship, coherent with a simplistic assumption: all the trajectory is used			X	
(Li et al, 2021)	Select and use the stable periods to fit a linear relationship in the s-v plane (coherent with Newell's model)	X	X	X	X

Our aim is to compare

- Various response time determination methods

On

- Various datasets
- For the moment, we used only two datasets:
 - OpenACC (Makridis et al, 2021)
 - CatsLab (Shi & Li, 2021)
 - **(Warm thanks to them and their teams for sharing!)**
 - **(Note that we welcome any new database!)**

We selected 4 response time (RT) identification methods, being inspired by others' work

An adaptation Makridis's et al.

method: RT_m^*

is defined such as it maximizes normalized covariance of speed difference and acceleration

An adaptation of TN Li's et al.

method: Select the stable periods, if you have enough points, fit the s-v relationship, obtain τ_0 and δ_0 of Newell's relation, $RT_n^* = \tau_0$

Prof. Li's et al. method:

Use at least 4 minutes of a trajectory with as much variations as possible and calibrate eq. 2 pf Shi and Li, 2021. $RT_l^* = \tau$

Gipps's method:

Use at least 4 minutes of a trajectory with as much variations as possible and calibrate Gipps's model parameters

$$RT_g^* = \tau_{Gipps}$$

We selected 4 response time (RT) identification methods, the first 3 being inspired by others' work

<p><i>Makridis's et al. method:</i></p> <p>RT_m^*</p> <p>is defined such as it maximizes the normalized covariance between speed difference and acceleration</p> <p><i>Select periods when the ACC reacts</i></p>	<p><i>An adaptation of TN Li's et al. method:</i> Select the stable periods if you have enough data to fit the s-v relationship behind Newell's model. The relationship between τ_0 and δ_0 of Newell's model is $RT_n^* = \tau_0$</p> <p><i>Select stable periods and fit the stable relationship behind Newell's model</i></p>
<p><i>Prof. Li's et al. method:</i></p> <p>Use at least 4 minutes of trajectory with as many observations as possible to calibrate eq. 2 of Shladover et al. (2021). $RT_l^* = \tau_{Li}$</p> <p><i>Calibrate a car-following model parameters where response time is an explicit parameter</i></p>	<p><i>Gipps's method:</i></p> <p>Use at least 4 minutes of trajectory with as many observations as possible and calibrate the model parameters $RT_g^* = \tau_{Gipps}$</p> <p><i>Calibrate car-following parameters where response time is one explicit parameter</i></p>

Two car following models and their calibration to obtain RT_l^* and RT_g^*

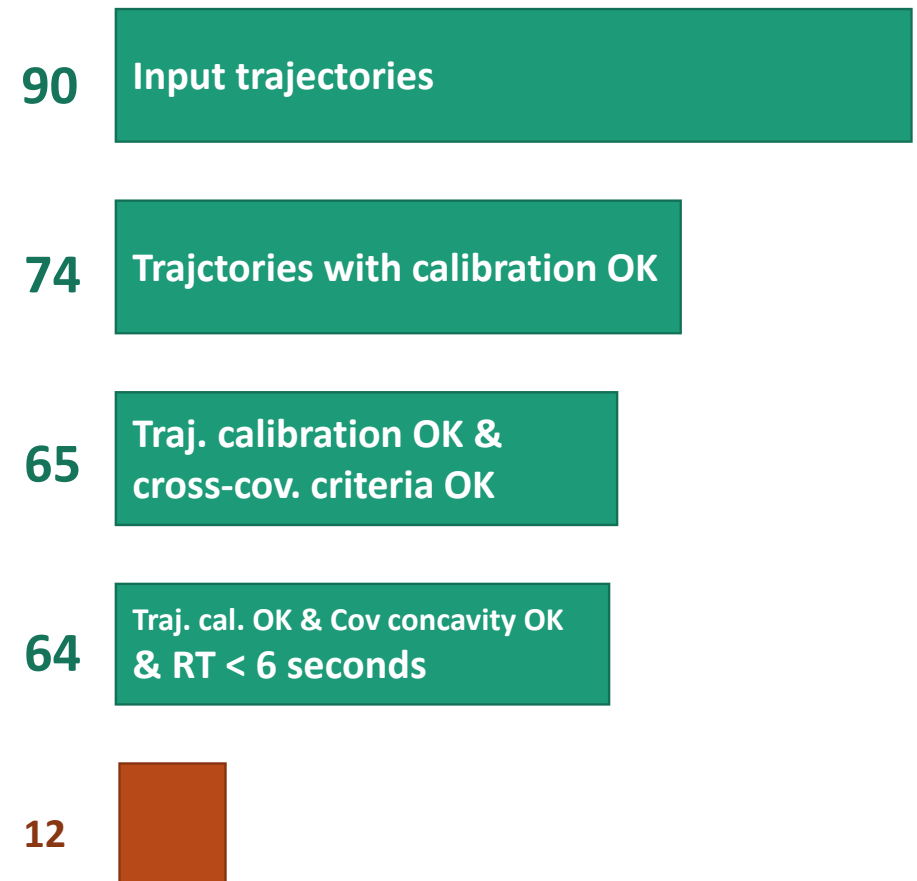
- Shi & Li, 2021: $\dot{v}_i(t) = k_1 [x_{i-1}(t) - l_i - \Delta_i - \tau_i \times v_i(t)] + k_2 [v_{i-1}(t) - v_i(t)]$
- This equation is very similar to
 - Newell's one, especially if $k_2 = 0$
 - If we add a third term with a proportion of the inter-vehicular distance, it is equivalent to Tampere's model

Two car following models and their calibration to obtain RT_i^* and RT_g^*

- Shi & Li, 2021: $\dot{v}_i(t) = k_1 [x_{i-1}(t) - l_i - \Delta_i - \tau_i \times v_i(t)] + k_2 [v_{i-1}(t) - v_i(t)]$
- Gipps, 1991:
$$v_i(t + \tau_i) = \min \left(v_i(t) + 2.5 \tilde{a}_i \tau_i (1 - v_i(t)/\tilde{v}_i) \times \sqrt{0.025 + v_i(t)/\tilde{v}_i}; \frac{\tilde{b}_i \tau_i + \sqrt{\tilde{b}_i^2 \tau_i^2 + \tilde{b}_i [2(s_i(t) - \Delta_i - l_i) - v_i(t) \tau_i - v_{i-1}(t)^2/b]}}{2} \right)$$
- To calibrate,
 - We use (Punzo, Zheng and Montanino's, 2021)
 - Genetic Algorithm (Punzo, Montanino, 2016) to explore parameters space
 - Goodness of Fit measure = Normalized Root Mean Square Error of a combination of spacing and speed.

Data selection

- We want to approach a description of the future ACC population in interaction with HDV
 - We select only the first ACC vehicle of the platoons
 - We don't care about headway settings
 - We consider each trajectory (whatever its duration) as representative of one vehicle
 - We consider, for each trajectory the same duration: 4 minutes
- We reject the trajectories where calibration is too bad (for all models) or the covariance concavity is too low, or the reaction time is bigger than 6s.
- To determine RT_n^* , we need, in addition, a sufficient speed range



Origin and duration of the 64 selected trajectories

Origin	Type of road	Number of trajectories	Duration in total (min)	Mean speed (km/h)
CatsLab (BB Downs Blvd)	Classic	12	51	61.1
OpenACC (Zala zone)	Test	29	318	49.2
OpenACC (Vicolungo)	Classic	11	290	87.5
OpenACC (Chersaco)	Test	11	52	40.6
OpenACC (asta zero)	Test	11	9	28.7

We estimate RT_m^* , applying Makridis's method

(Makridis et al, 2021)

- In addition, we reject trajectories with a cross-covariance function evolving less than 1% in the 2 seconds surrounding τ

Given the two stationary signals $\Delta v_{l-f,t}$ and $a_{f,t}$, we apply a time delay T on the acceleration of the follower and we compute the cross-covariance function between these two signals as follows:

$$\sigma_{\Delta v, a_f}(T) = \frac{1}{N-1} \sum_{t=1}^N (\Delta v_{l-f,t} - \mu_{\Delta v})(a_{f,t-T} - \mu_a) \quad (1)$$

where $\mu_{\Delta v}$ and μ_a are the means of each time series and N is the number of measurements. The cross-correlation derives from the following normalization:

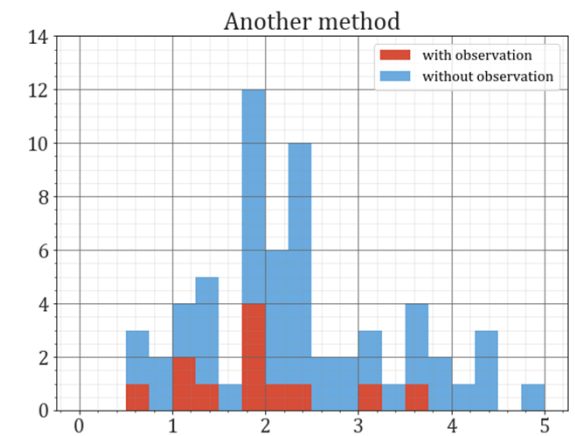
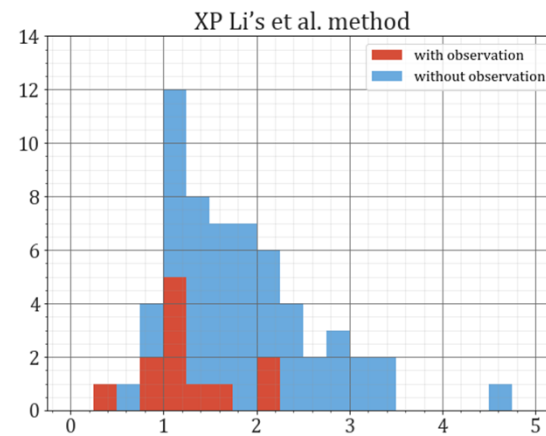
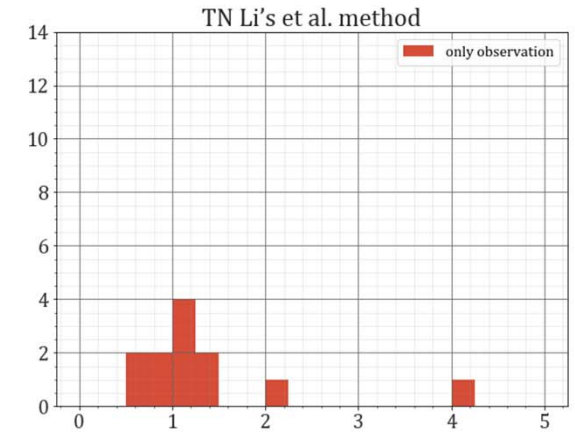
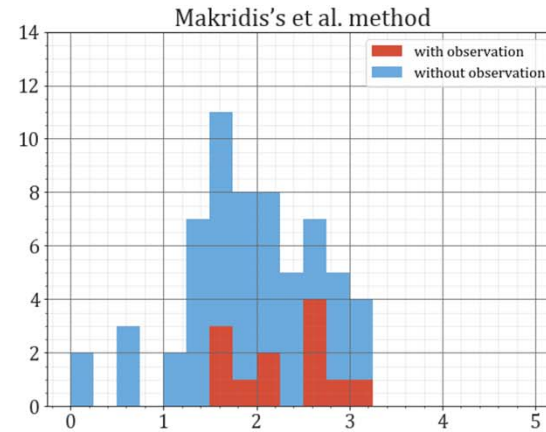
$$r_{\Delta v, a_f}(T) = \frac{\sigma_{\Delta v, a_f}(T)}{\sqrt{\sigma_{\Delta v, \Delta v}(0) \sigma_{a_f, a_f}(0)}} \quad (2)$$

where $\sigma_{\Delta v, \Delta v}(0) = \sigma_{\Delta v}^2$ and $\sigma_{a_f, a_f}(0) = \sigma_{a_f}^2$ are the variances of each signal. The peak frequency corresponds to the estimated delay, i.e. response time for the corresponding test lap. In other words, the response time of the controller is derived by the following:

$$\tau_{delay} = \underset{T = \{0, 0.1, \dots, T_{max}\}}{\operatorname{argmax}}(r_{\Delta v, a_f}(T)) \quad (3)$$

Results

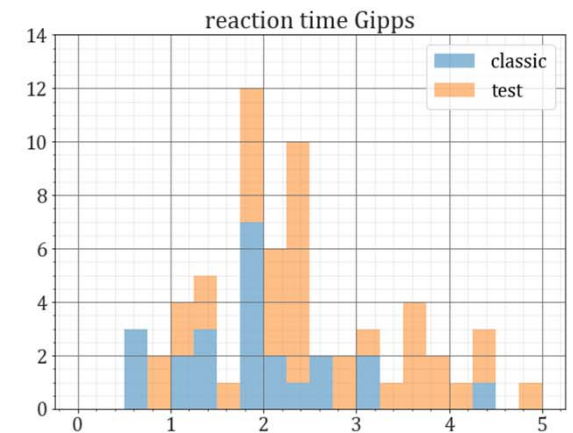
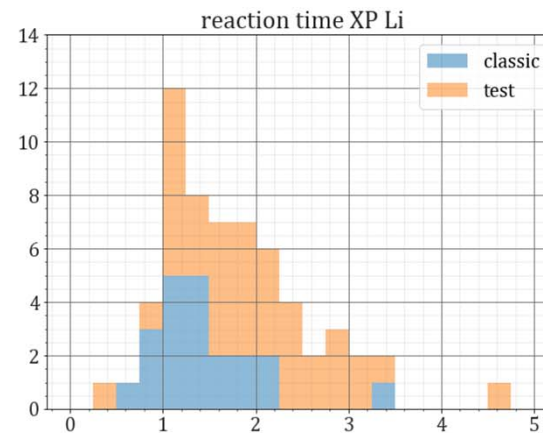
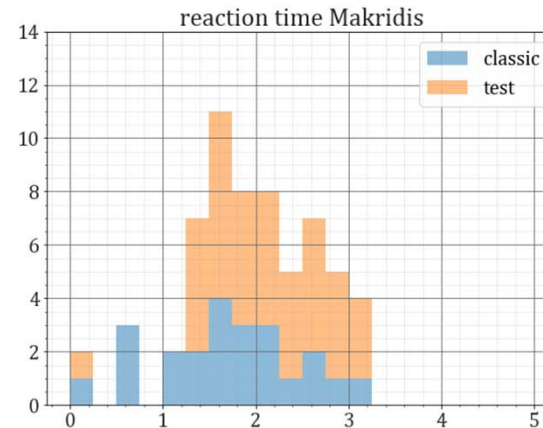
reaction time distribution with 4 identification methods



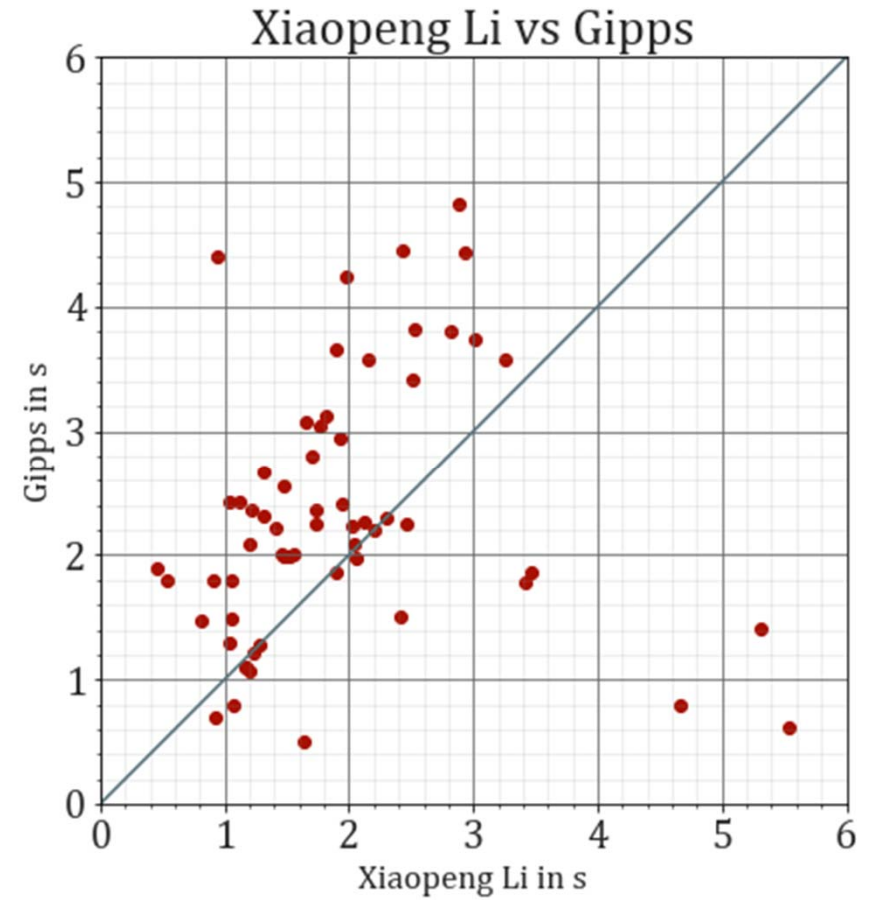
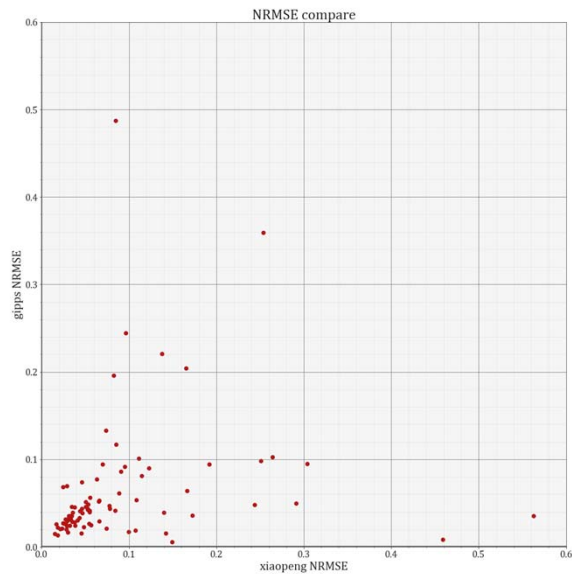
Type of road?

- road type has an impact
- it can be a speed impact

reaction time distribution C1 classic vs test road



Comparison of calibration-based methods

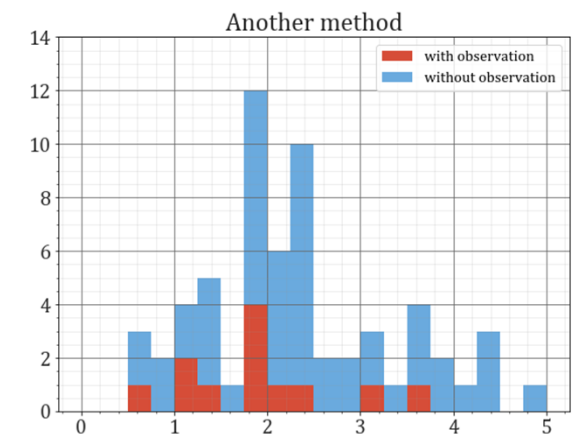
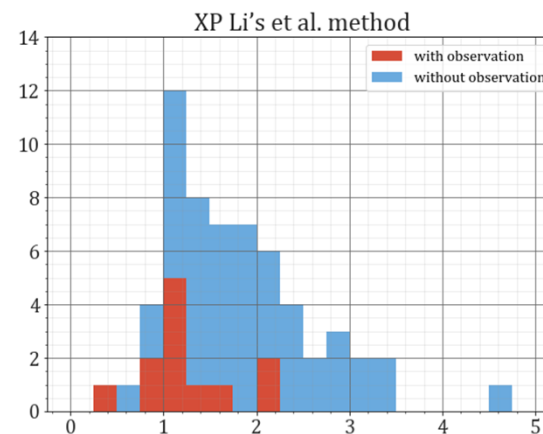
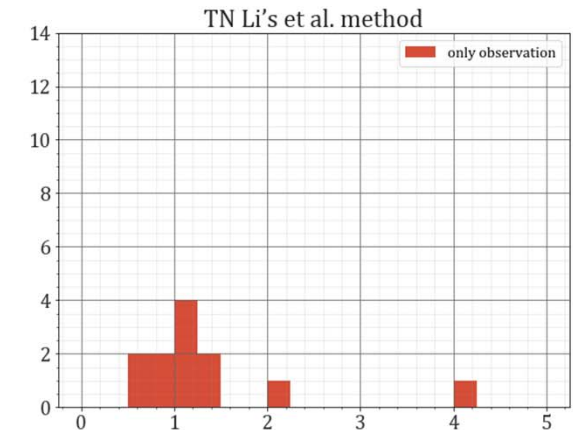
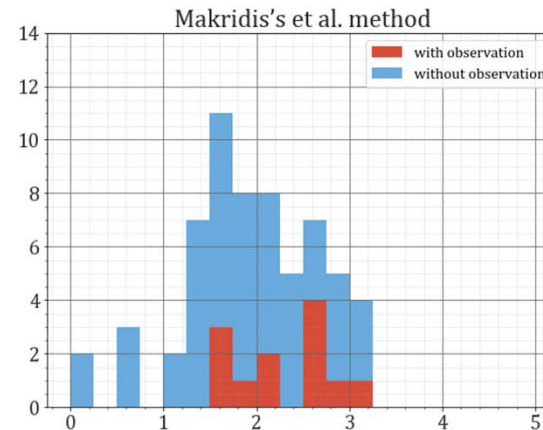


Mean and SD

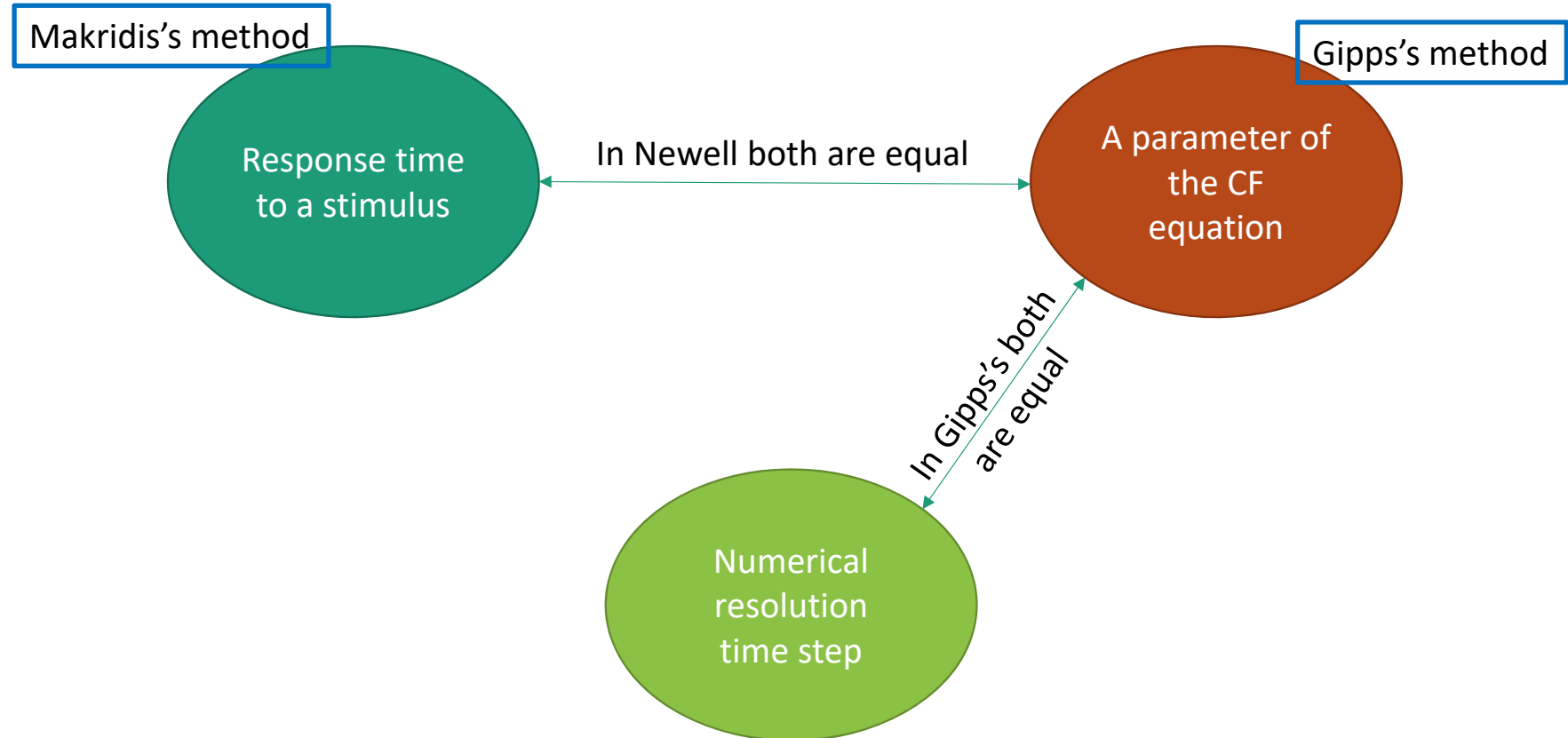
(s)	Makridis	XP Li	Gipps
mean	1,98	1,91	2,38
SD	0,72	1,00	1,09

→ Whatever the method,
Mean values
 > HDV (1.2 to 1.5)
 → Different methods
 produce different
results (as we could expect)
 Why?

reaction time distribution with 4 identification methods



Discussion: What is Response time ?



Preliminary conclusions

- For all methods and all databases, response times are larger than the ones reported for human driven vehicles (confirmation of previous results)
- The difference of the results depending on the method can be explained as the difference in underlying definitions of response times
- When we will receive more data, we can confirm those conclusions.

Some of the references

- Chen, D., Laval, J., Zheng, Z., & Ahn, S. (2012). A behavioral car-following model that captures traffic oscillations. *Transportation Research Part B: Methodological*, 46(6), 744-761. <https://doi.org/10.1016/j.trb.2012.01.009>
- Gipps, P. G. (1986). A model for the structure of lane-changing decisions. *Transportation Research Part B: Methodological*, 20(5), 403-414. [https://doi.org/10.1016/0191-2615\(86\)90012-3](https://doi.org/10.1016/0191-2615(86)90012-3)
- Gunter, G., Gloudemans, D., Stern, R. E., McQuade, S., Bhadani, R., Bunting, M., Monache, M. L. D., Lysecky, R., Seibold, B., Sprinkle, J., Piccoli, B., & Work, D. B. (2020). Are Commercially Implemented Adaptive Cruise Control Systems String Stable? *IEEE Transactions on Intelligent Transportation Systems*, 1-12. <https://doi.org/10.1109/TITS.2020.3000682>
- Kesting, A., & Treiber, M. (2006). Influence of reaction times and anticipation on the stability of vehicular traffic flow. *IFAC Proceedings Volumes*, 39(10), 205-210. <https://doi.org/10.3182/20060710-3-IT-4901.00034>
- Lanaud, E., Ladino, A., & Buisson, C. (2021). First Observations about Response Times and Connectivity in a Vehicles Platooning Experiment. *Findings*, 21190. <https://doi.org/10.32866/001c.21190>
- Li, T., Chen, D., Zhou, H., Laval, J., & Xie, Y. (2021). Car-following behavior characteristics of adaptive cruise control vehicles based on empirical experiments. *Transportation Research Part B: Methodological*, 147, 67-91. <https://doi.org/10.1016/j.trb.2021.03.003>
- Makridis, M., Mattas, K., Anesiadou, A., & Ciuffo, B. (2021). OpenACC. An open database of car-following experiments to study the properties of commercial ACC systems. *Transportation Research Part C: Emerging Technologies*, 125, 103047. <https://doi.org/10.1016/j.trc.2021.103047>
- Newell, G. F. (2002). A simplified car-following theory : A lower order model. *Transportation Research Part B: Methodological*, 36(3), 195-205. [https://doi.org/10.1016/S0191-2615\(00\)00044-8](https://doi.org/10.1016/S0191-2615(00)00044-8)
- Punzo, V., Zheng, Z., & Montanino, M. (2021). About calibration of car-following dynamics of automated and human-driven vehicles : Methodology, guidelines and codes. *Transportation Research Part C: Emerging Technologies*, 128, 103165. <https://doi.org/10.1016/j.trc.2021.103165>
- Shi, X., & Li, X. (2021). Empirical study on car-following characteristics of commercial automated vehicles with different headway settings. *Transportation Research Part C: Emerging Technologies*, 128, 103134. <https://doi.org/10.1016/j.trc.2021.103134>



Committee on Traffic Flow Theory and Characteristics
(TRB ACP50)

ACC Webinar Series

Response times in
ACC car-following experiments:
comparison between datasets and
determination methods

Ian Metelski, Carlos Gomez-Patino, Christine Buisson
Thursday, July 29th, 2021

Thank you!
Don't hesitate to share databases,
critics, suggestions...

christine.buisson@univ-eiffel.fr



Annexes

Same graph as before, but with in green (large headway setting) and yellow (small headway setting) the values of Newell's reaction time provided in table 2 of Li et al, 2021

reaction time distribution with 4 identification methods

