Probabilistic Modeling of Driver Behaviors At Urban Crossroads

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Introduction : How do we cross an intersection ?

1) How are the decisions made ?
2) Can the mechanism be formulated ?

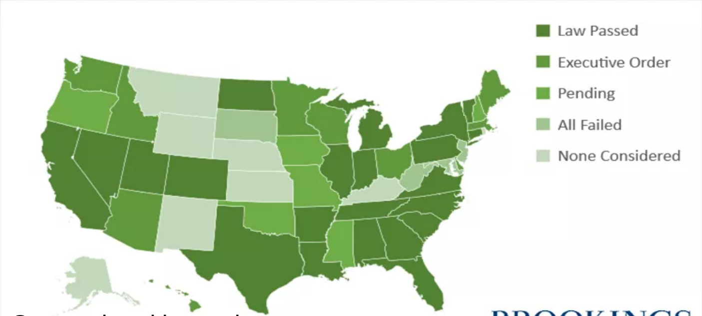
Outline

- Introduction
- Literature Review
- Thesis Objectives
- Driver Behavior Modeling
  - Model Validation
  - Summary
- Applications
- Conclusions
- Future Works

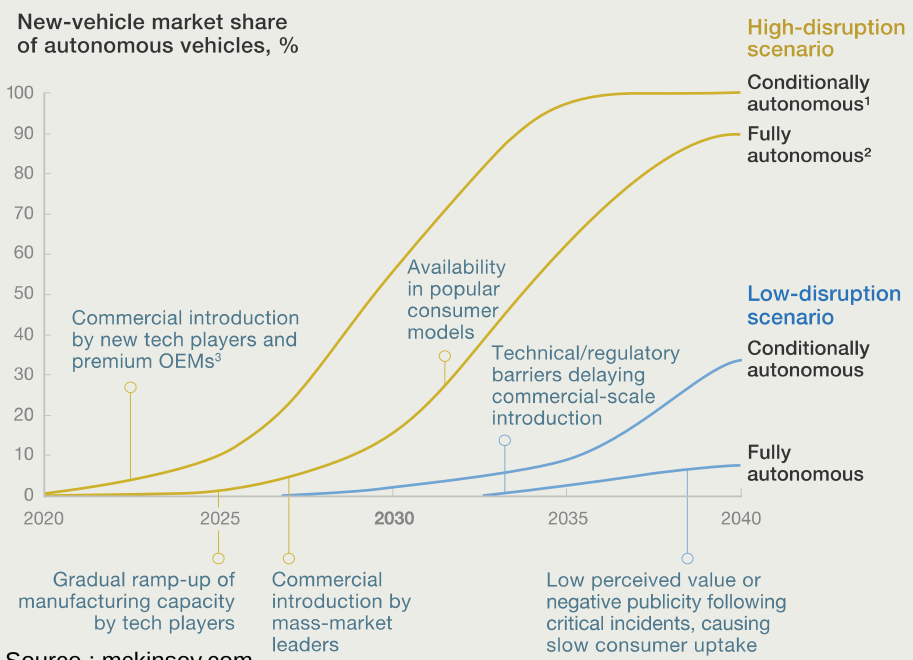
Introduction : Why are crossroads important ?

At least in the next 30 years, interactions with human drivers are unavoidable for autonomous vehicles [1].

- Autonomous vehicle industry has been growing rapidly while public road testings are all over the US.
- There are intensive interactions among traffic participants at the crossroads, especially those without signals.



Source :brookings.edu



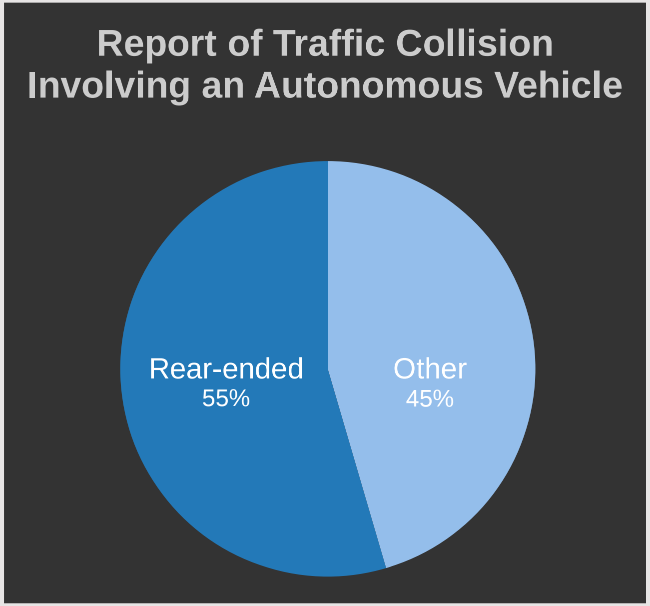
Source : mckinsey.com

[1] Bansal, P. et al. (2017)

Introduction : How do autonomous vehicles overcome unsignaled crossroads ?

Over-cautious maneuvers are not necessarily safe.

- Autonomous vehicles **being** rear-ended accounts for 18 out of 33 filed reports, which is mainly due to unexpected stops. [2] (as of June 17, 2019)
- Almost all of these rear-ended accidents are due to abrupt brakes that the following vehicle can not understand.



[2] Department of Motor Vehicles, State of California

Literature Review : How to predict the behaviors of surrounding vehicles?

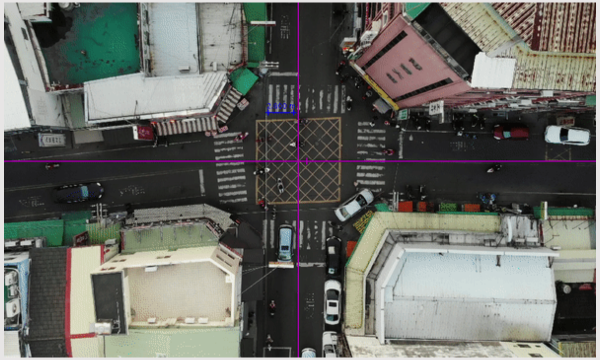
- Some are too simple ([7]) to generate long-term prediction while some are too complicated ([14, 15]) to be applied real-time.
- Driver behavior models are more rational and more practical ; however, models using pre-trained data are site-specific [16, 17].
- A more **straight forward** model without learning steps and applicable to different scenarios is needed.

[7] Ammoun, S. et al. (2009); [14] Foka, A. et al. (2010); [15] Hubmann, C. et al. (2018); [16] Liebner, M. et al. (2012); [17] Graf, R. et al. (2014)

Thesis Objectives

Driver behavior model based on the cognitive information.

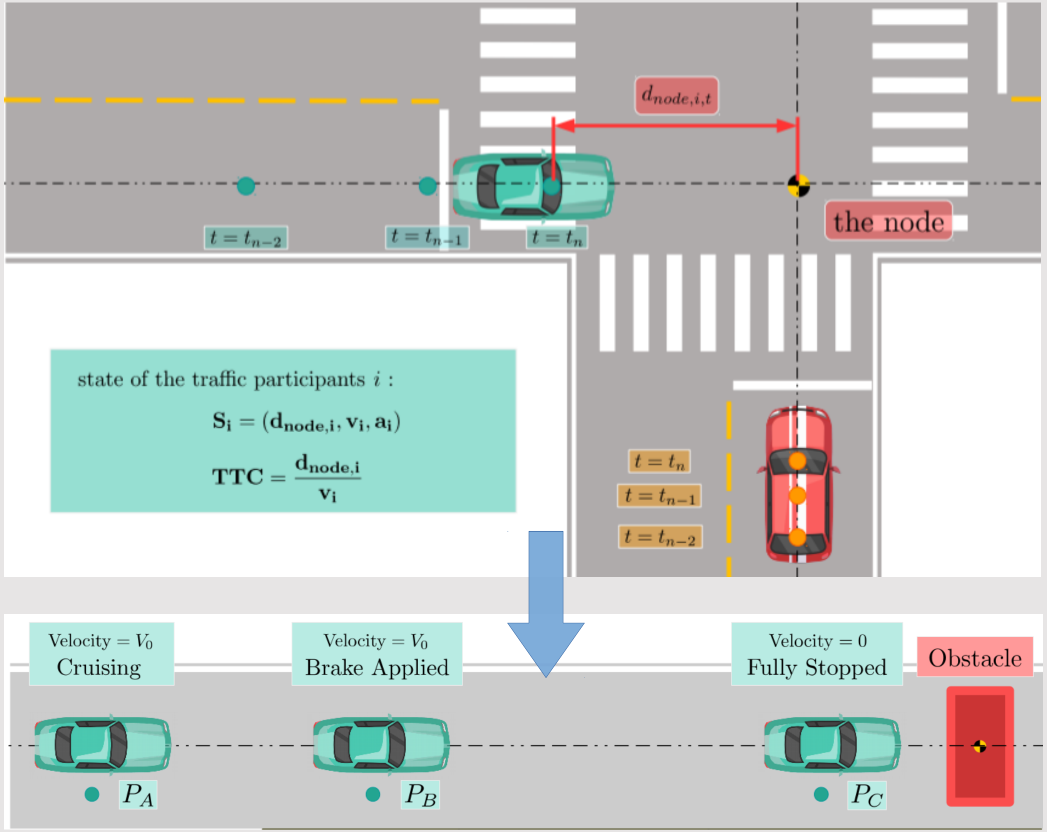
1) How are the decisions made ?
   - ➔ **How decisions are made by drivers at urban crossroads.**
2) Can the mechanism be formulated ?
   - ➔ **How to use the mechanism to predict the behaviors ?**



Driver Modeling : How are the decisions made ?

Scenarios:

- 2 participants at the scene
- Fixed path for both cars
- **Pass / Yield**
- Collision is unavoidable if velocities remain the same
- The node



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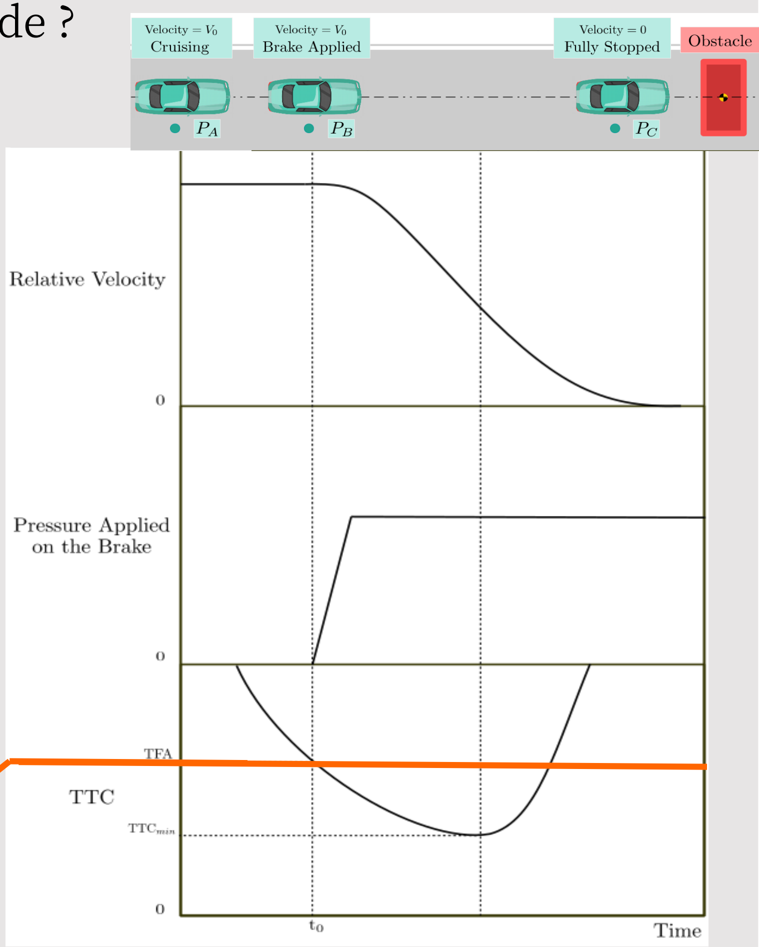
Driver Modeling : How are the decisions made ?

Time to Collision (TTC) [22]

- It is the tool drivers use to decide the moment of braking.
- Formulation : $TTC = \dfrac{\text{distance to obstacle}}{\text{speed}}$

Time for Action (TFA)

- TTC threshold for a driver to brake.
- Vary from person to person.

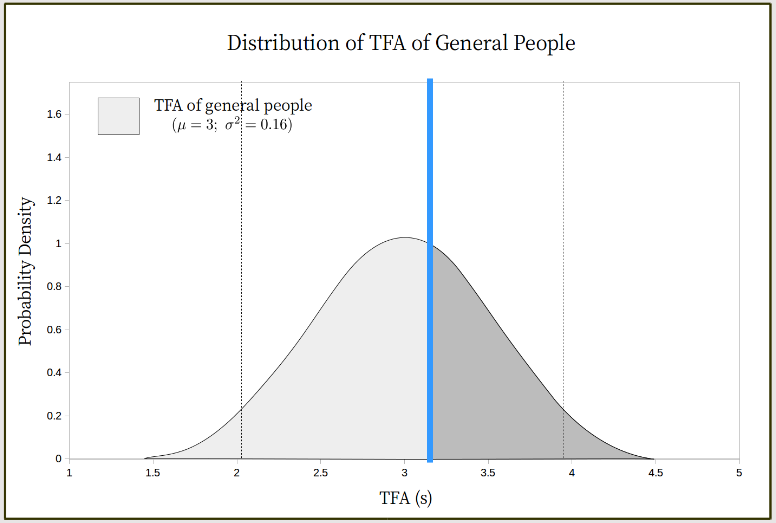


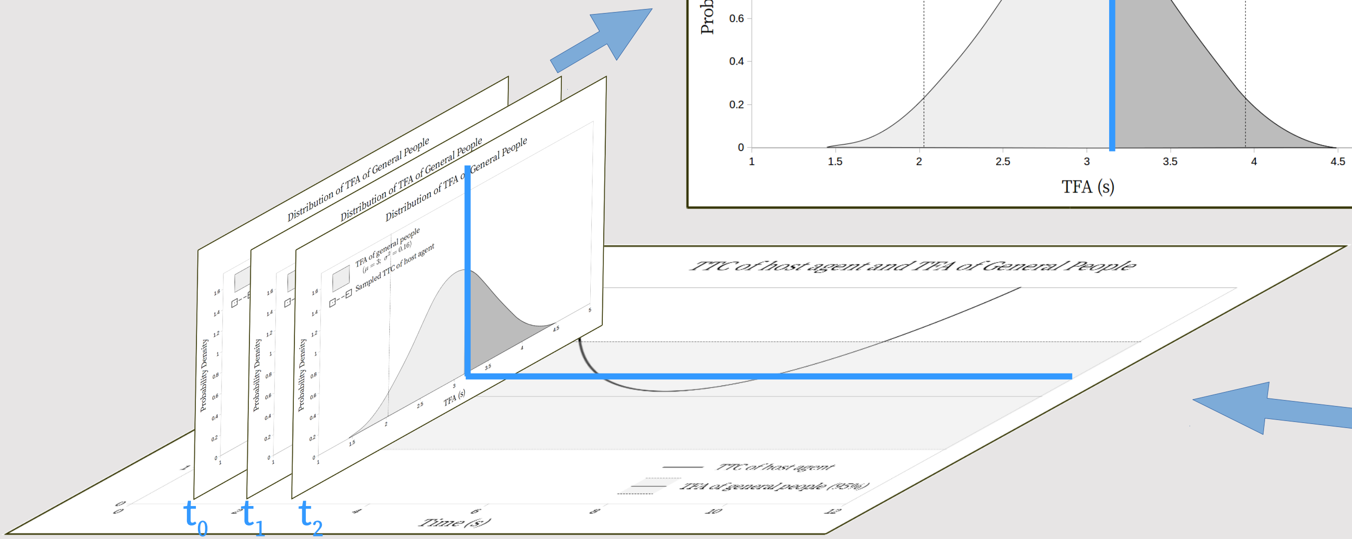
TFA
Threshold to Brake

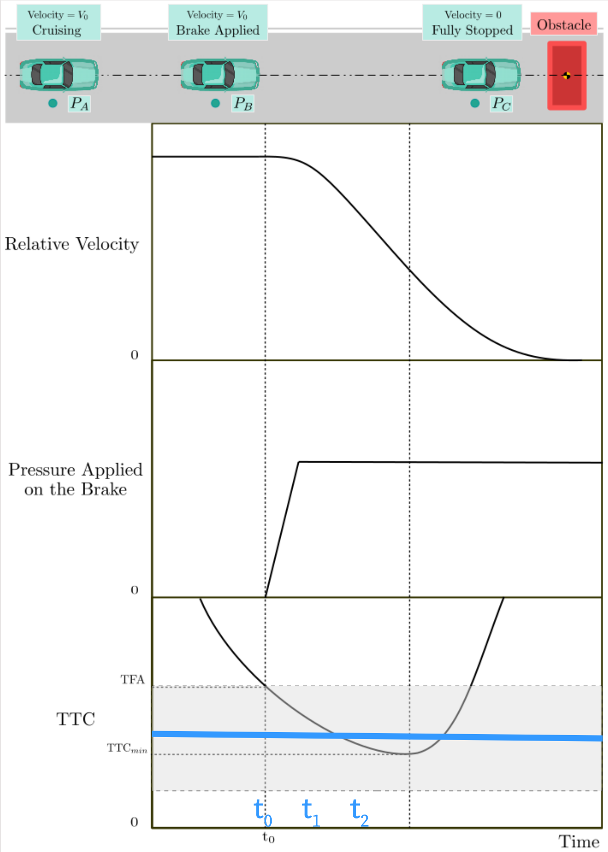
[22] Cavallo, V. et al. (1988)

Driver Modeling : How are the decisions made ?

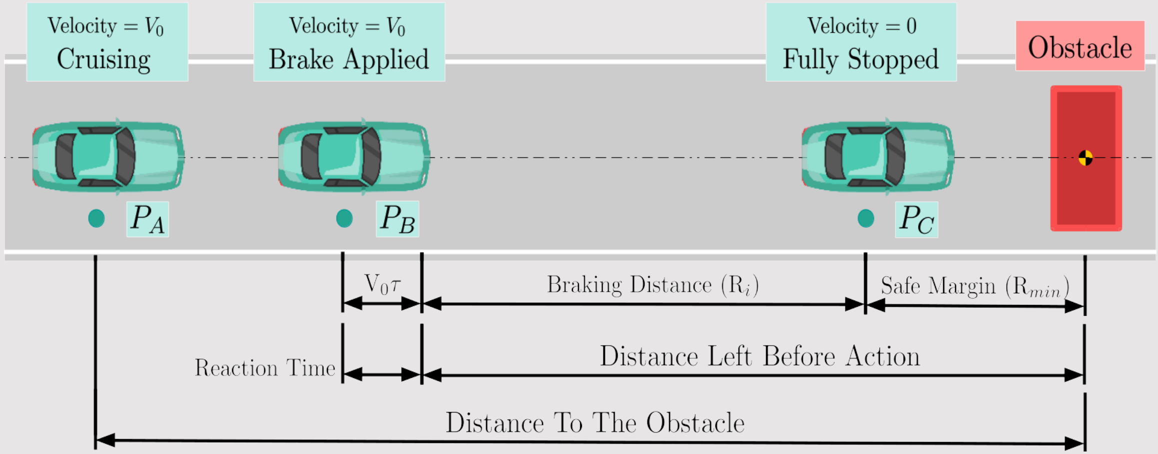
- TFA is a distribution.







Driver Modeling : Can the mechanism be formulated ?



Estimated TFA :

$$\mathrm{TFA}_{est} = \frac{v_i\tau + R_i + R_{min}}{v_i}$$

Reaction Distance

Braking Distance (R_i)

Safe Margin

$$\frac{\text{Distance Left Before Braking}}{\text{Velocity}} = \frac{v_i\tau + \dfrac{v_i^2}{2a_{dec}} + R_{min}}{v_i}$$

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Driver Modeling : Can the mechanism be formulated ?

- TFA distribution modeling

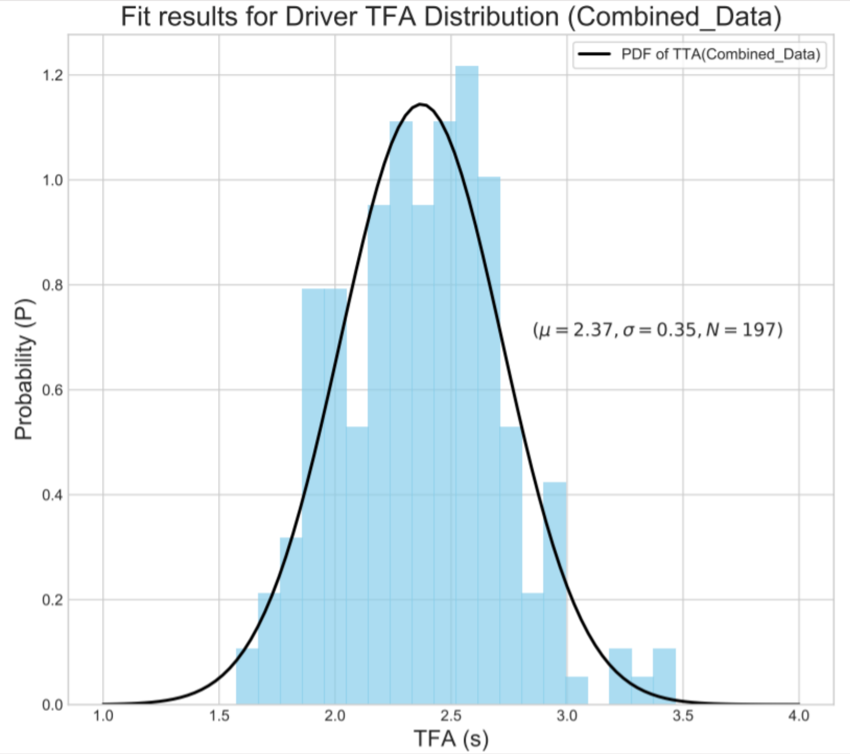
mean : $\text{TFA}_{est} = \frac{R_i + v_i \tau + R_{min}}{v_i}$

standard deviation : $\sigma = \gamma \cdot \text{TFA}_{est}$

(R_{min} and a_{dec} are functions of v_i.)

$$\begin{cases} R_{min} = C1_{Rmin} v_i + C2_{Rmin} \\ a_{dec} = C1_{adec} v_i + C2_{adec} \end{cases}$$

Parameters	**Average**
Safe Margin Coefficient ($C1_{Rmin}$)	0.295
Safe Margin Constant ($C2_{Rmin}$)	5.47
Deceleration Coefficient ($C1_{adec}$)	0.458
Deceleration Constant ($C2_{adec}$)	0.877
Standard Diviation Parameter (γ)	0.148



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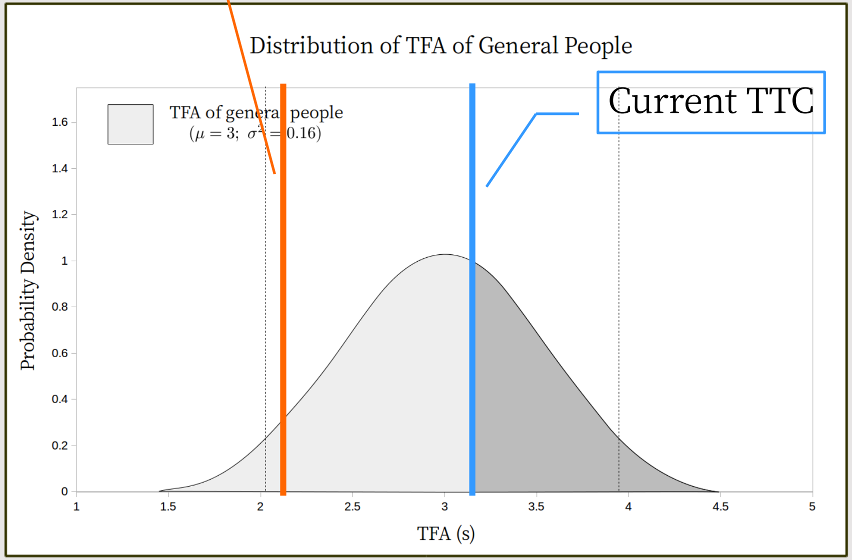
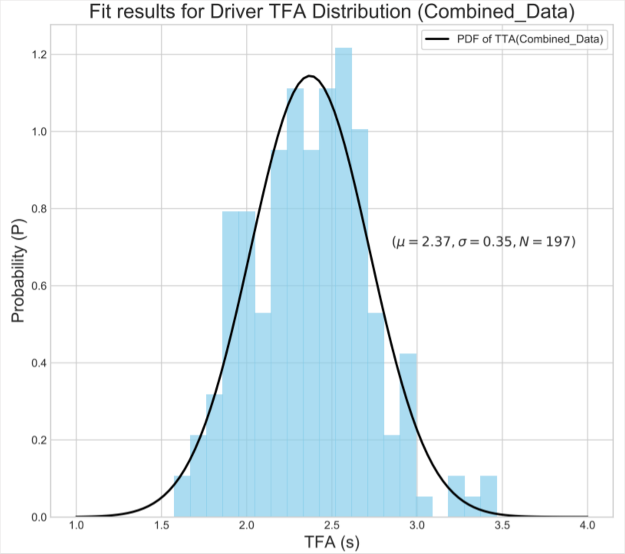
Driver Modeling : Can the mechanism be formulated ?

$$P_{yield,t} = \left(1 - \Phi_{\mu,\sigma^2}(minTTC_t)\right)$$

Accelerating ?





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Driver Modeling : Can the mechanism be formulated ?

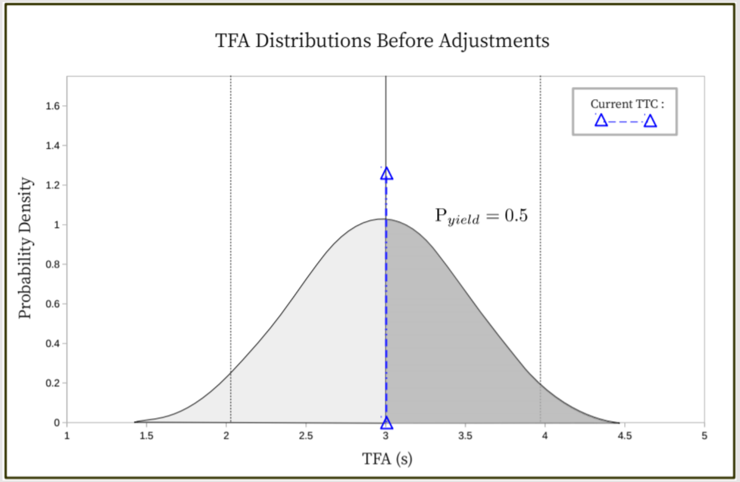
- To account for : 1. Accelerating or at high speed and 2. Deceleratingor at low speed, the adjustment term A_t is added.

To emphasize on the acceleration term

To keep the value greater than 1

$$|A_t| \propto |minTTC_t - TFA_{est,t}| \cdot \ln\left(\left(|TTC'_t| + 1 \right) \cdot e \right)$$

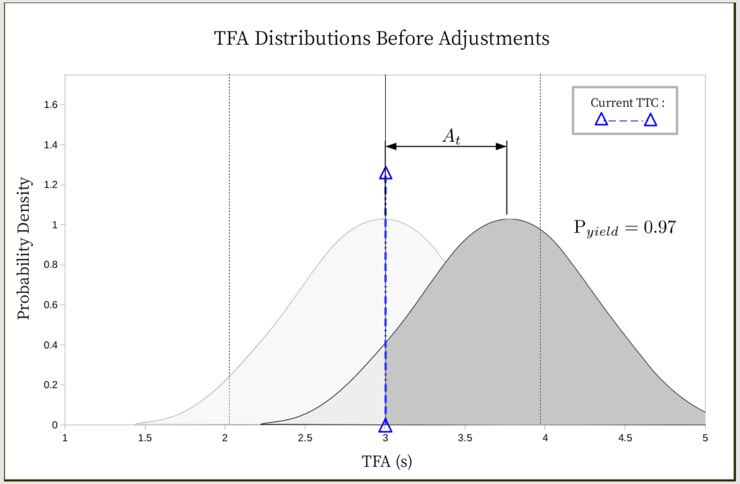
Larger the acceleration larger the adjustment



$+A_t$ if decelerating

ADJUSTMENT

$-A_t$ if accelerating

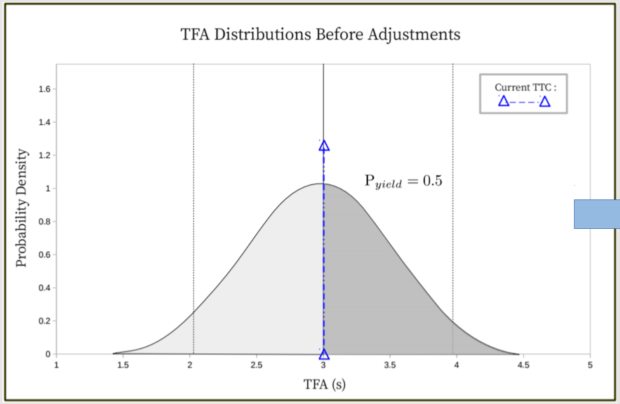


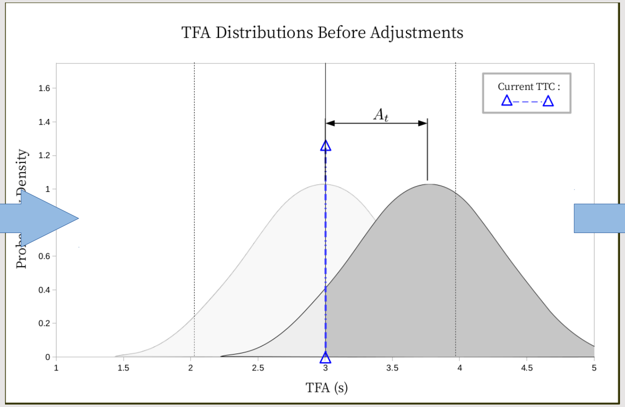
Driver Modeling : Can the mechanism be formulated ?

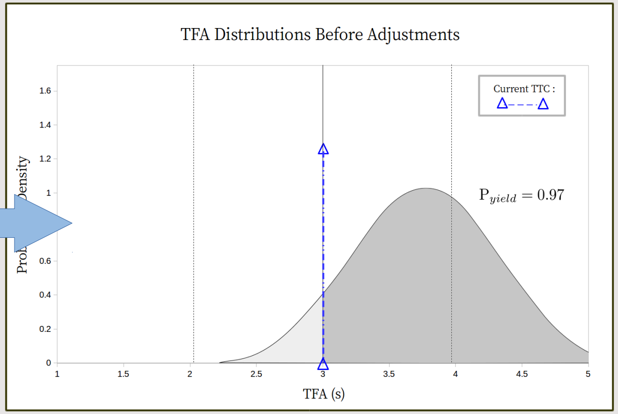
$$\mathrm{TFA}_{est} = \frac{R_i + v_i\tau + R_{min}}{v_i}$$

$$\mathrm{TFA}_{est} = \mathrm{TFA}_{est} \pm A_t$$

$$P_{yield,t} = \left(1 - \Phi_{\mu,\sigma^2}(minTTC_t)\right)$$

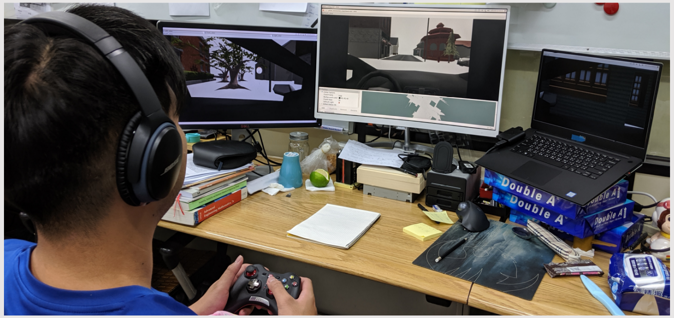


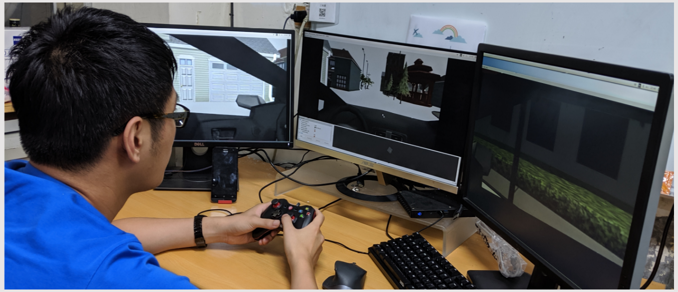




Validation : Driver behaviors model

- In every trial, 2 human drivers try to cross the crossroad without any collision.
- The command velocities are sent from the joysticks controlled by each participant.
- There are 168 trials in total, each is labeled with #001, #002, #003 and so on.

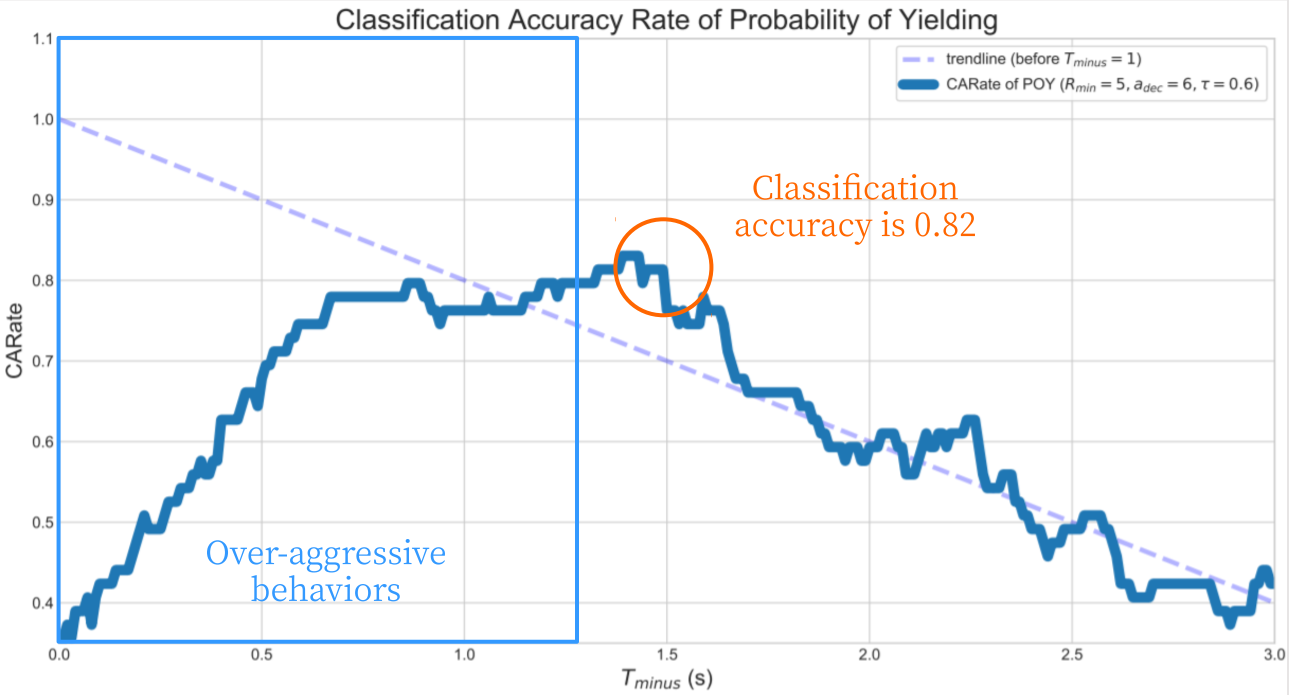




Validation : Driver behaviors model

$$\text{CARate} = \frac{\text{no. of correctly classified cases}}{\text{no. of all situations}}$$

- The time lines are reversed since the duration of trials are different.
- Prediction accuracy is 0.82 when T_{minus} is 1.5 sec.
- The drop from 0.0 to 1.3 is due to the over-aggressive behaviors at the simulated crossroad.



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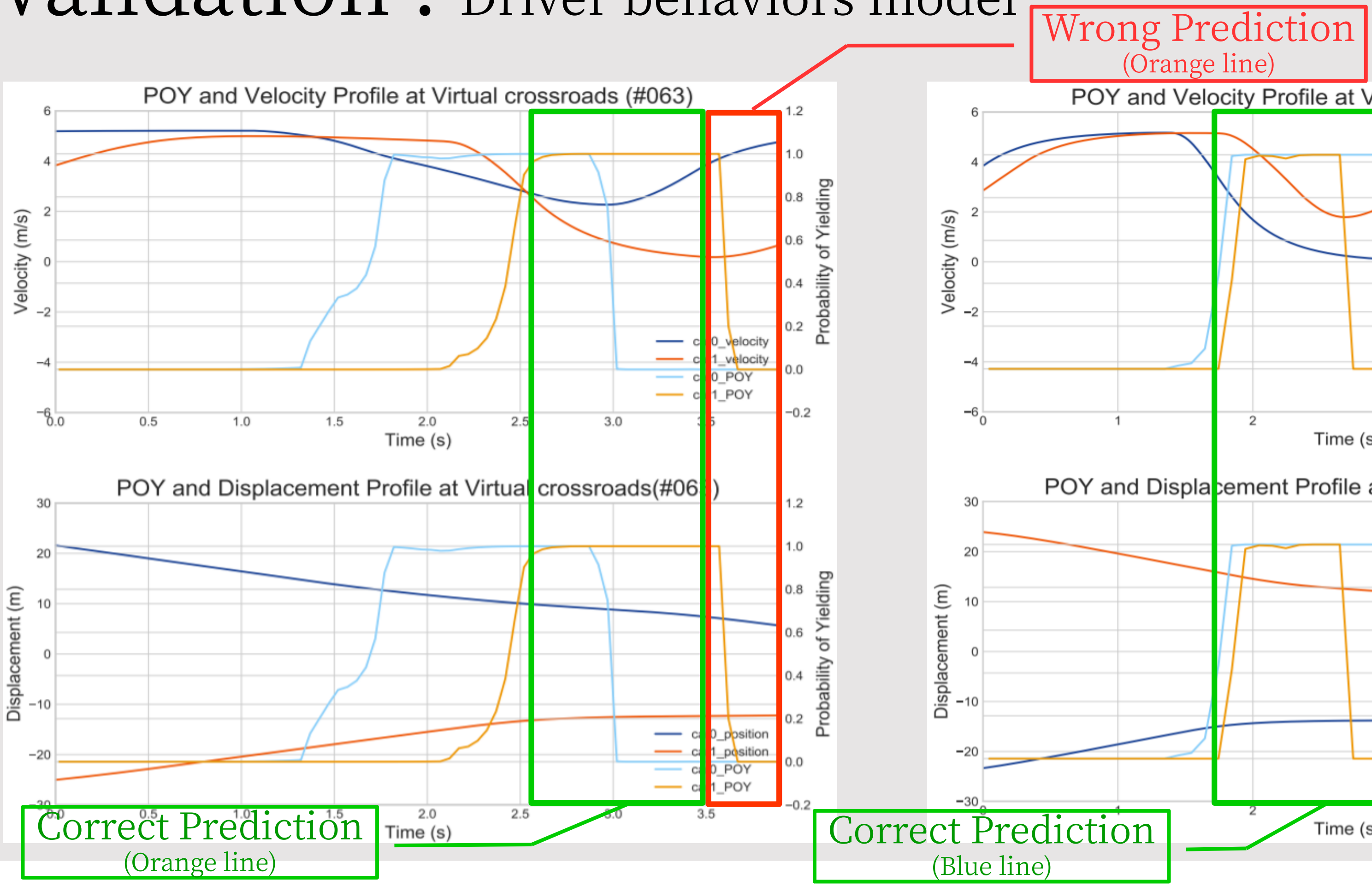
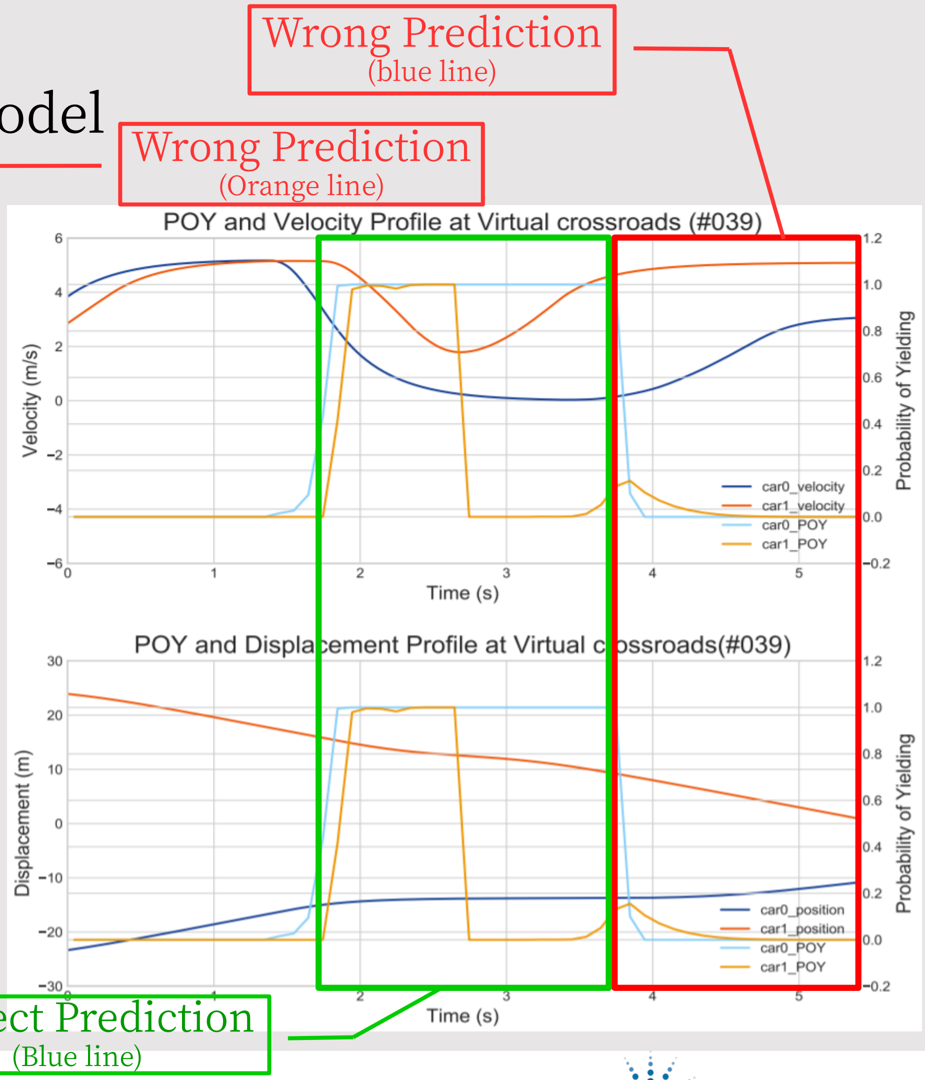
Validation : Driver behaviors model





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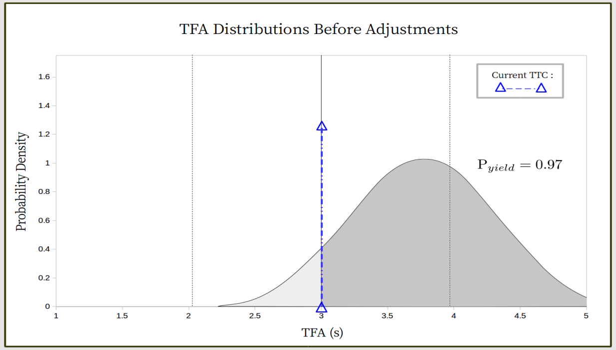
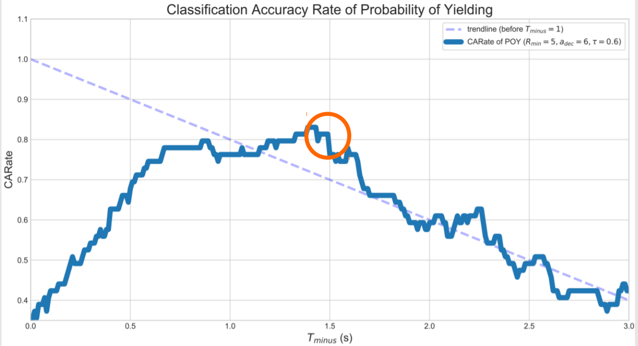
Summary

- A probabilistic driver behaviors model is proposed.
- The prediction for the yielding behavior is reasonable.
- The validation experiments are conducted in virtual crossroad.
- The Classification Accuracy Rate is 0.82 at 1.5 sec before the interactions end.





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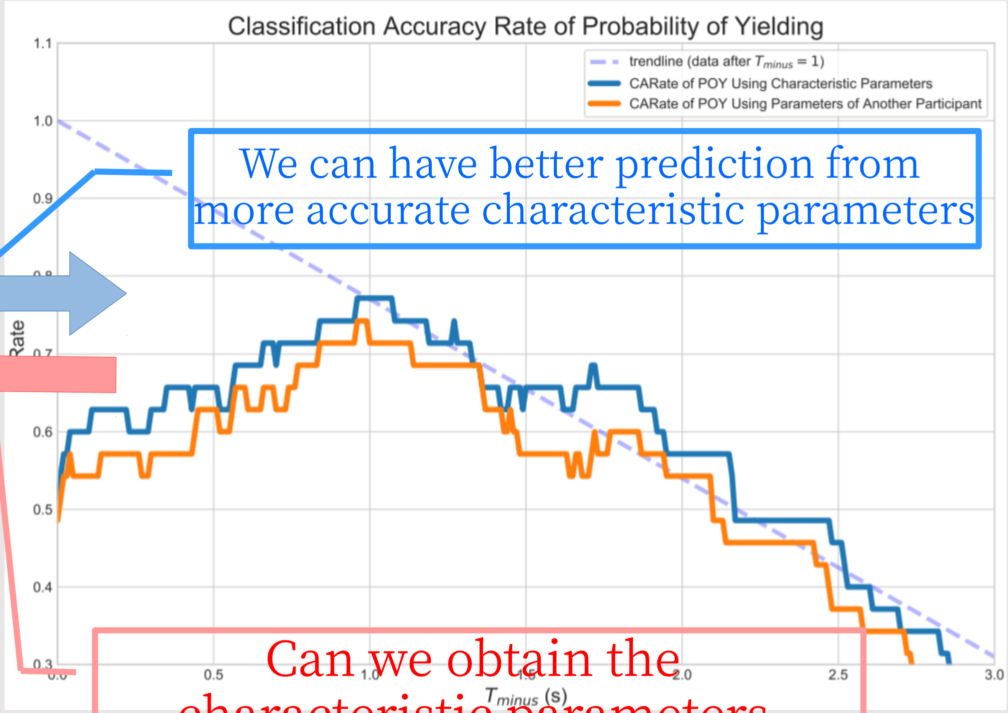
Application : Parameter identification

- Characteristic parameters in the formulation of TFA distribution.

Parameters	Average	Participant 1	Participant 3
Safe Margin Coefficient ($C1_{Rmin}$)	0.295	0.166	0.390
Safe Margin Constant ($C2_{Rmin}$)	5.47	6.19	5.54
Deceleration Coefficient ($C1_{adec}$)	0.458	0.465	0.710
Deceleration Constant ($C2_{adec}$)	0.877	0.377	0.813
Standard Diviation Parameter (γ)	0.148	0.115	0.102

$$\text{Mean : } \mathrm{TFA}_{est} = \frac{R_i + v_i\tau + R_{min}}{v_i}$$

$$\begin{cases} R_{min} = \boxed{C1_{Rmin}} v_i + \boxed{C2_{Rmin}} \\ a_{dec} = \boxed{C1_{adec}} v_i + \boxed{C2_{adec}} \end{cases}$$



We can have better prediction from more accurate characteristic parameters

Can we obtain the characteristic parameters by optimizing the CARate curve ?

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Application : Parameter identification

$$\underset{w}{\text{minimize}} \quad \frac{1}{M}\sum_{j=1}^{M}\sum_{i=1}^{N_j} -f(POY_j(t_i, w))$$

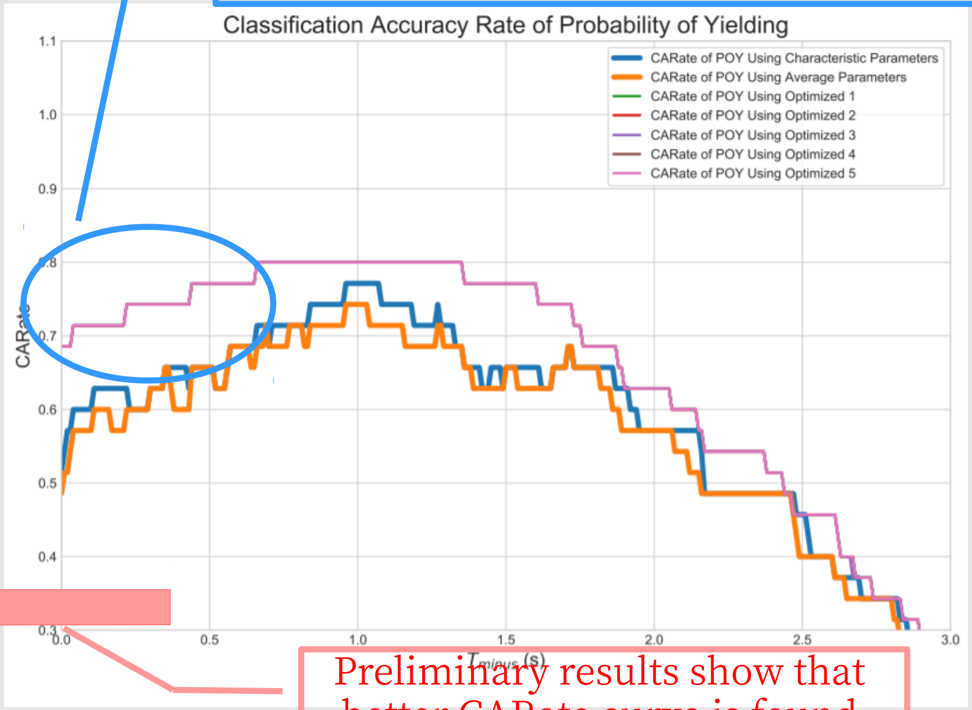
$$\begin{aligned} \text{subject to} \quad & 2.0 \cdot C1_{Rmin} + C2_{Rmin} \geq 4.48, \\ & 5.2 \cdot C1_{Rmin} + C2_{Rmin} \leq 12.0, \\ & 2.0 \cdot C1_{adec} + C2_{adec} \geq 0.01, \\ & 5.2 \cdot C1_{adec} + C2_{adec} \leq 3.5, \\ & 0.01 \leq \gamma \leq 0.5 \end{aligned}$$

Optimization : Simulated Annealing

(w : the parameters set; M : number of trials; N_j : time steps in trial j)

Optimization Number	$C1_{Rmin}$	$C2_{Rmin}$	$C1_{adec}$	$C2_{adec}$	γ	Area
1st Optimization	0.362	7.91	0.0460	0.954	0.460	-205.40
2nd Optimization	0.401	7.86	0.224	0.563	0.443	-205.37
3rd Optimization	0.322	7.91	0.106	0.941	0.434	-205.23
4th Optimization	0.456	7.49	0.102	0.824	0.444	-205.37
5th Optimization	0.346	7.95	0.145	0.812	0.448	-205.37
Characteristic	**0.166**	**6.19**	**0.465**	**0.377**	**0.114**	**-183.89**

Results here is unreasonable. Modifications for objective function could be designed.



Preliminary results show that better CARate curve is found but the parameters are far off.

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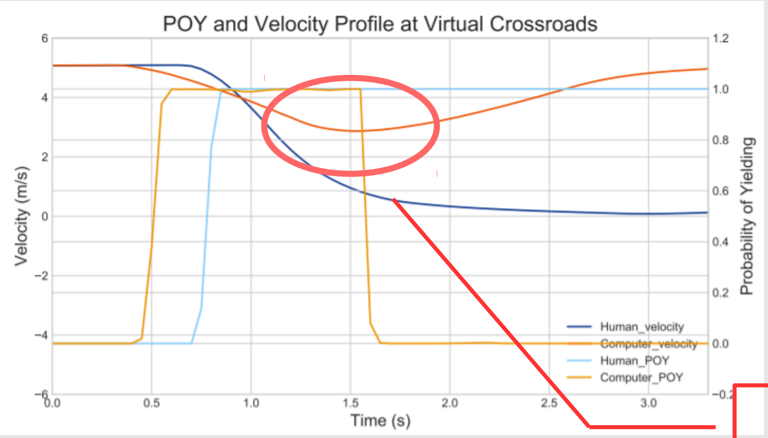
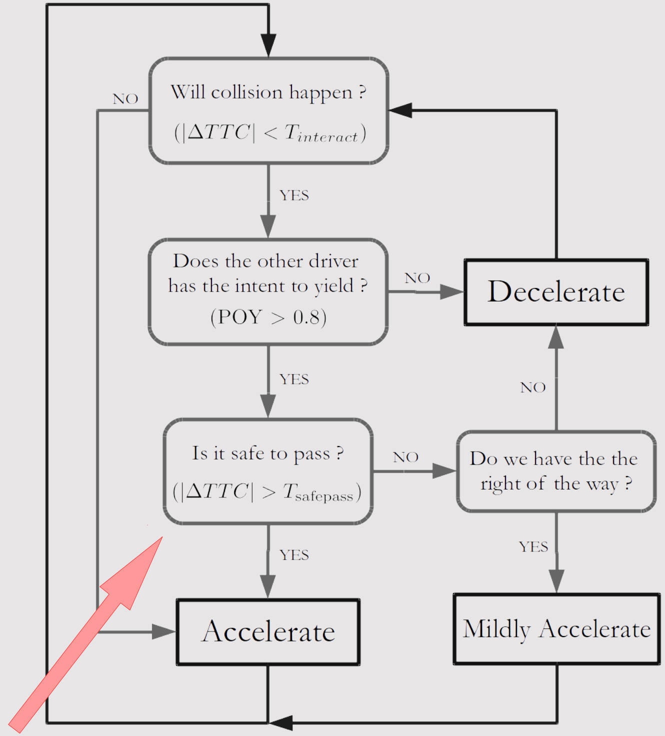
Application : Procedure for handling complex interaction

- A procedure is developed for autonomous vehicle to handle **complex interaction.** (e.g. when both traffic participants are yielding)
- After the proposed model was applied, the autonomous vehicle understand that the gesture of yielding, so it passed.





The autonomous vehicle waited until it was safe to pass before it finally passed.

Contributions

- The **driver decision making process** at unsignalized crossroads is identified
- A **probabilistic driver behaviors model** is proposed and the validation result suggests the accuracy rate at 1.5 secs before interactions end is **0.82**.
- Possible application are explored and preliminary attempts show promising results.
- This paper has been accepted by 2019 ASME IDETC/CIE .

Future Works

- **Multi-agents behaviors** prediction could be a great extension.
- The control method in the simulated environment can be more realistic to prevent over aggressive actions.
- More data from **urban crossroads** should be collected to verify the applicability of the proposed model.
- Modifications for the parameter identification.
- Construct a **hardware platform** and apply the proposed model to the autonomous devices.

Thank You !