Cognitive modeling of decision making in human drivers

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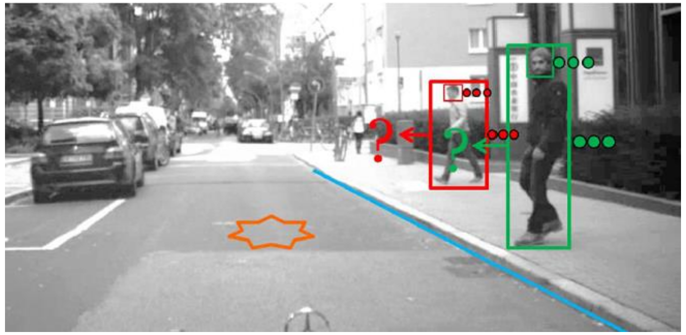
About me

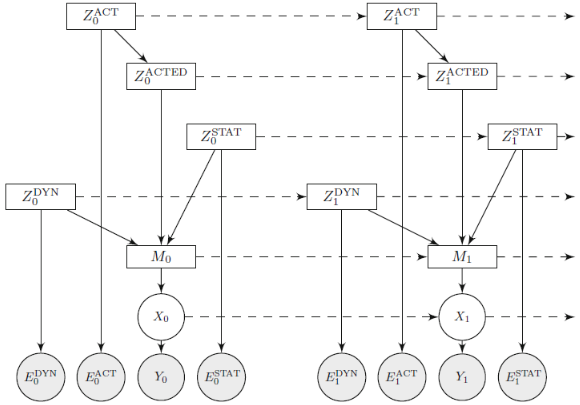
- MSc in applied mathematics
- PhD on modeling human control behavior
  - Virtual balancing tasks
  - Car following, steering
- Previous postdoc in cognitive psychology
  - Decision making
  - Interplay between motor behavior and cognition
- Postdoc @ Cognitive Robotics (3mE) & AiTech
  - <u>Modeling & managing human-AV interactions</u>
  - Meaningful human control: how to?

Human-AV interaction

Human-AV interaction: existing approaches

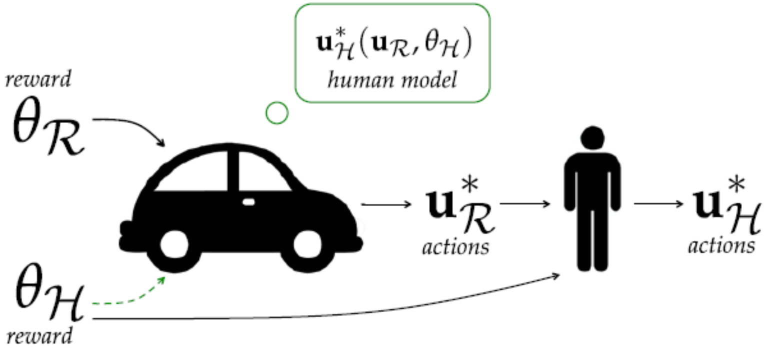
- Intention recognition





Kooij, J. F. P. et al. "Context-Based Path Prediction for Targets with Switching Dynamics." *International Journal of Computer Vision* 127, no. 3 (March 2019): 239–262.

- Game-theoretic motion planning

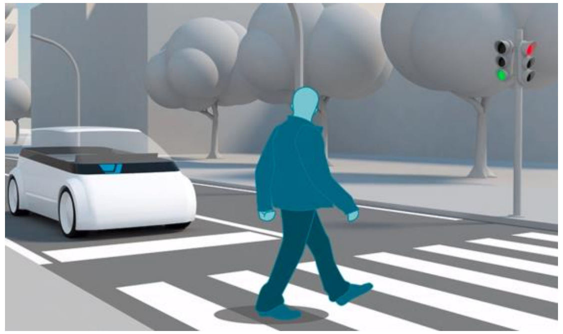


Sadigh, D. et al, "Planning for cars that coordinate with people: Leveraging effects on human actions for planning and active information gathering over human internal state." *Autonomous Robots*, *42*(7), 1405–1426. (2018)

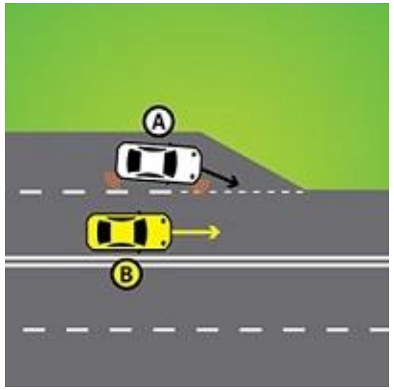
Limitations of current approaches

- Human models are chosen based on computational convenience
- Basic assumptions of these models are not cognitively plausible
  - “humans are moving obstacles”
  - “humans operate like on-off switches”
  - “humans optimize a utility function”
  - “all traffic behavior can be captured by one utility function”
- Models are not validated against the actual driver behaviour
- Alternative way?
  - Utilize the available knowledge about human behavior
  - Check how well the model describes the humans
  - No silver bullet: Focus on context-specific models of stereotypical interactions

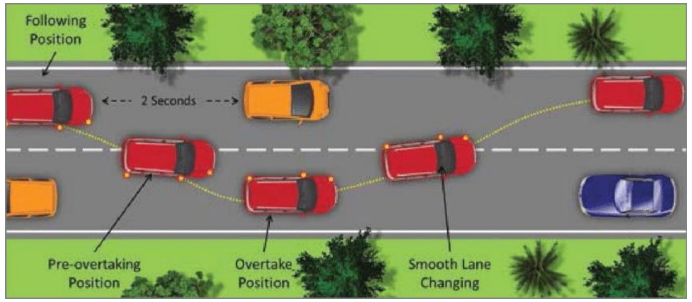
Stereotypical human-AV interactions



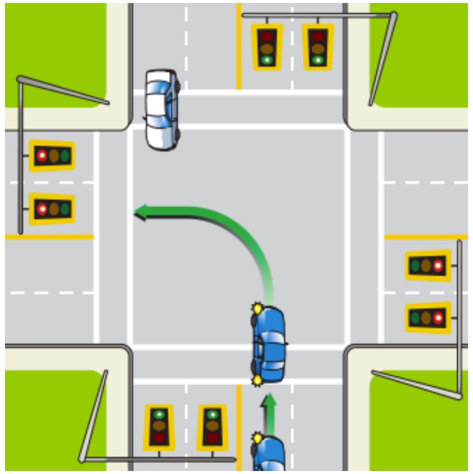
Pedestrian crossing



Lane merging



Overtaking

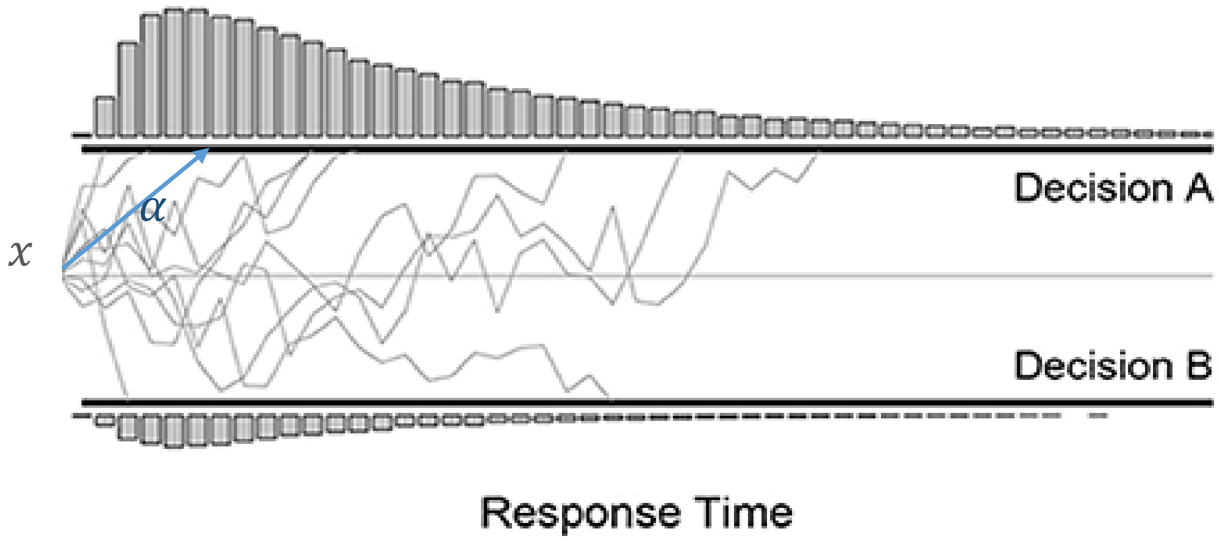


Left turn across path

- In all these interactions, a human faces a binary decision-making task
- What do we know about human decision-making?

Decision making: Evidence accumulation model

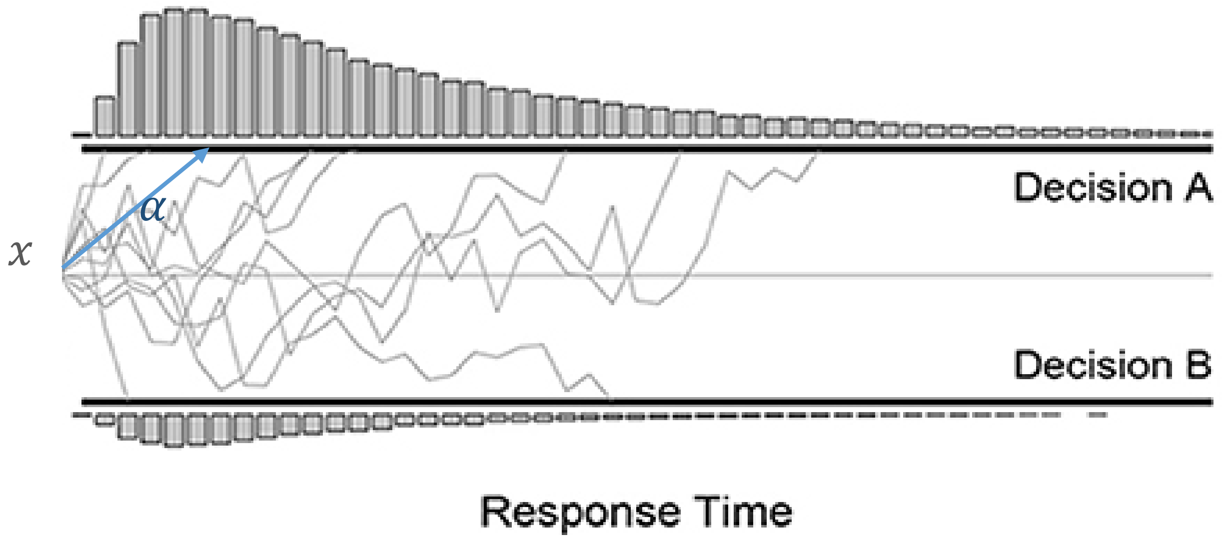
$$dx = \alpha dt + dW$$



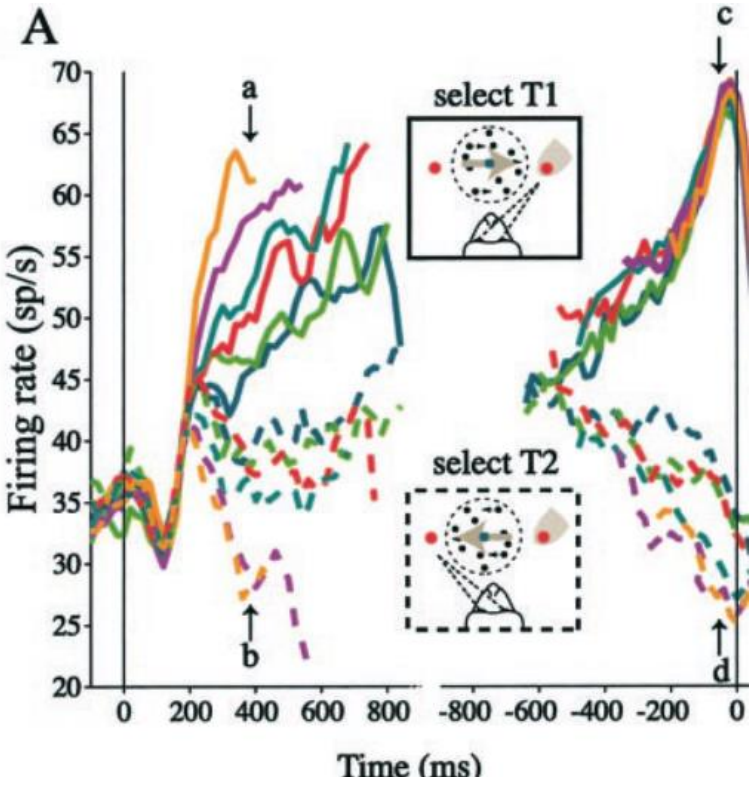
Ratcliff, R. (1978). A theory of memory retrieval. *Psychological review*, *85*(2), 59.

Decision making: Evidence accumulation model

$$dx = \alpha dt + dW$$



Ratcliff, R. (1978). A theory of memory retrieval. *Psychological review*, *85*(2), 59.



Roitman, J. D., & Shadlen, M. N. (2002). Response of neurons in the lateral intraparietal area during a combined visual discrimination reaction time task. *Journal of neuroscience*, *22*(21), 9475-9489.

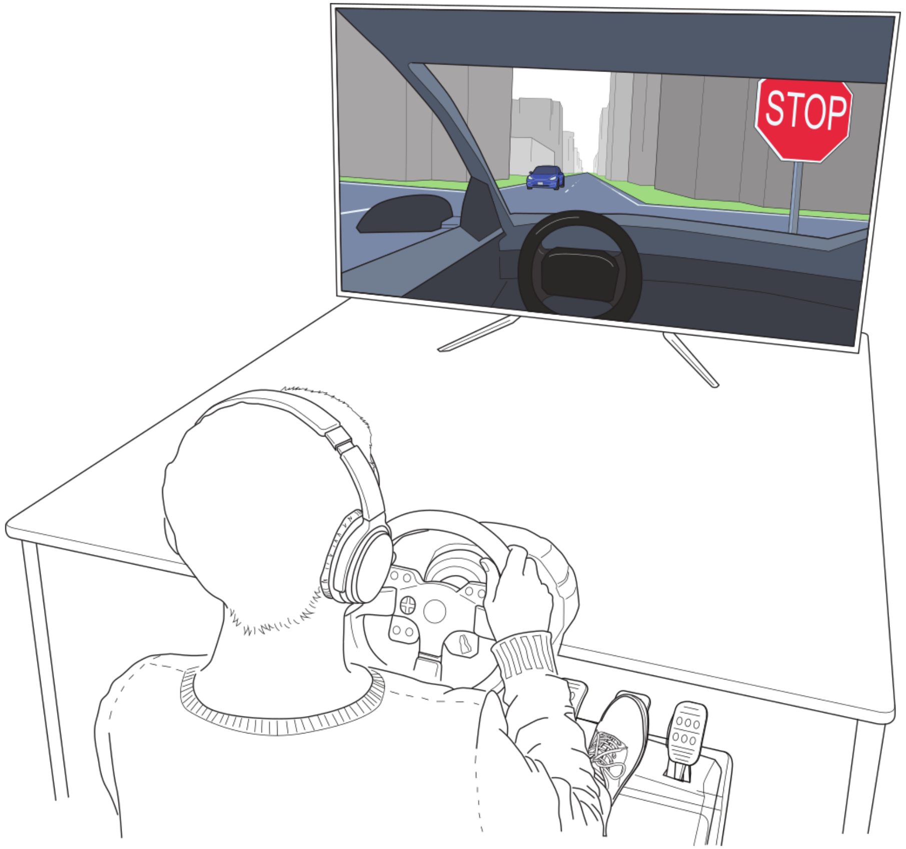
- Can evidence accumulation explain decisions in traffic?

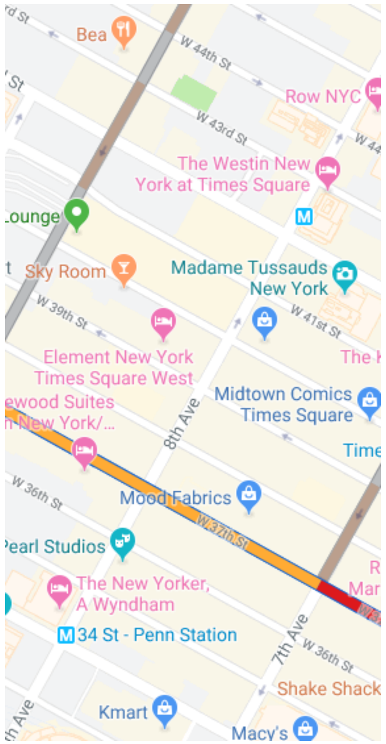
Experimental study

Gap acceptance in left turns across path

Experimental setup

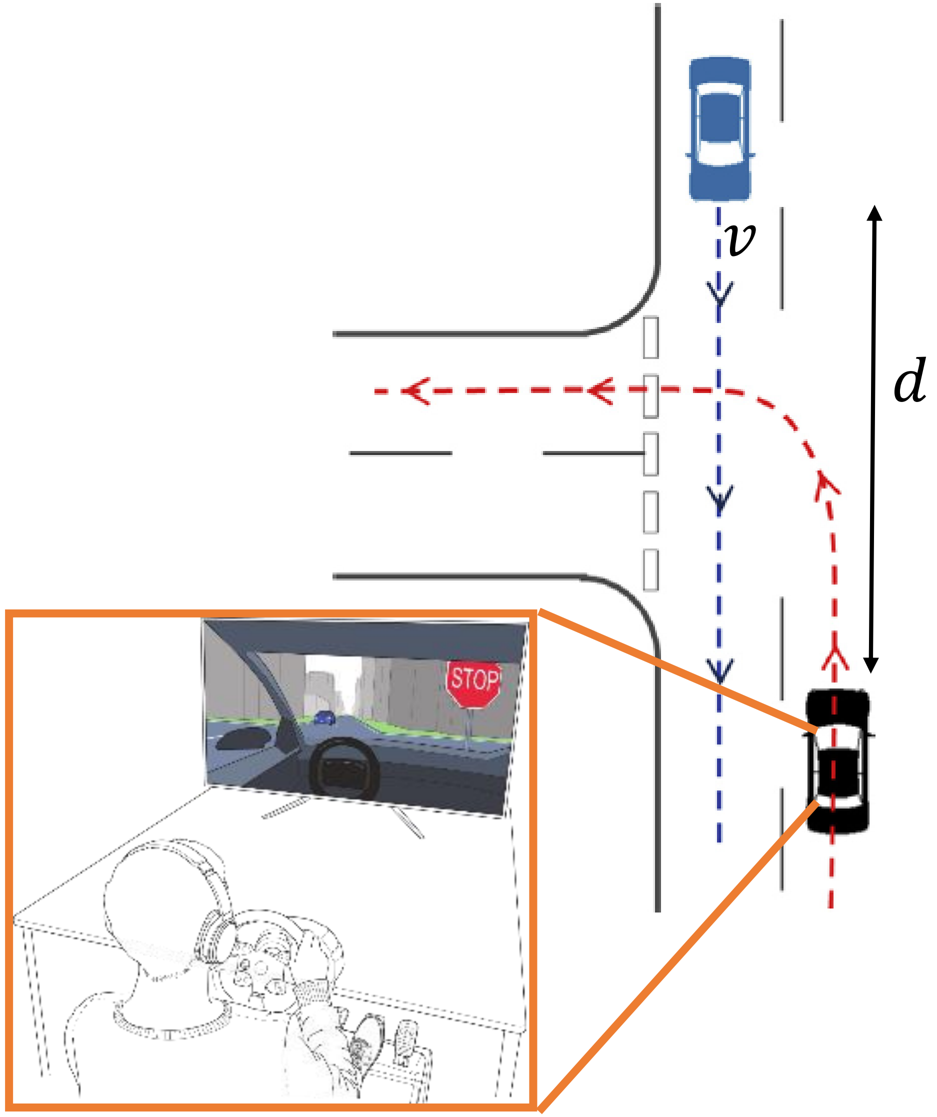
- Virtual driving simulator
- 7 participants
- Two sessions, about 60 min each
- Each session: four routes 10 min each
- Auditory navigation cues
- Each route: 15 <u>left turns</u>, 5 right turns, 5 go straight



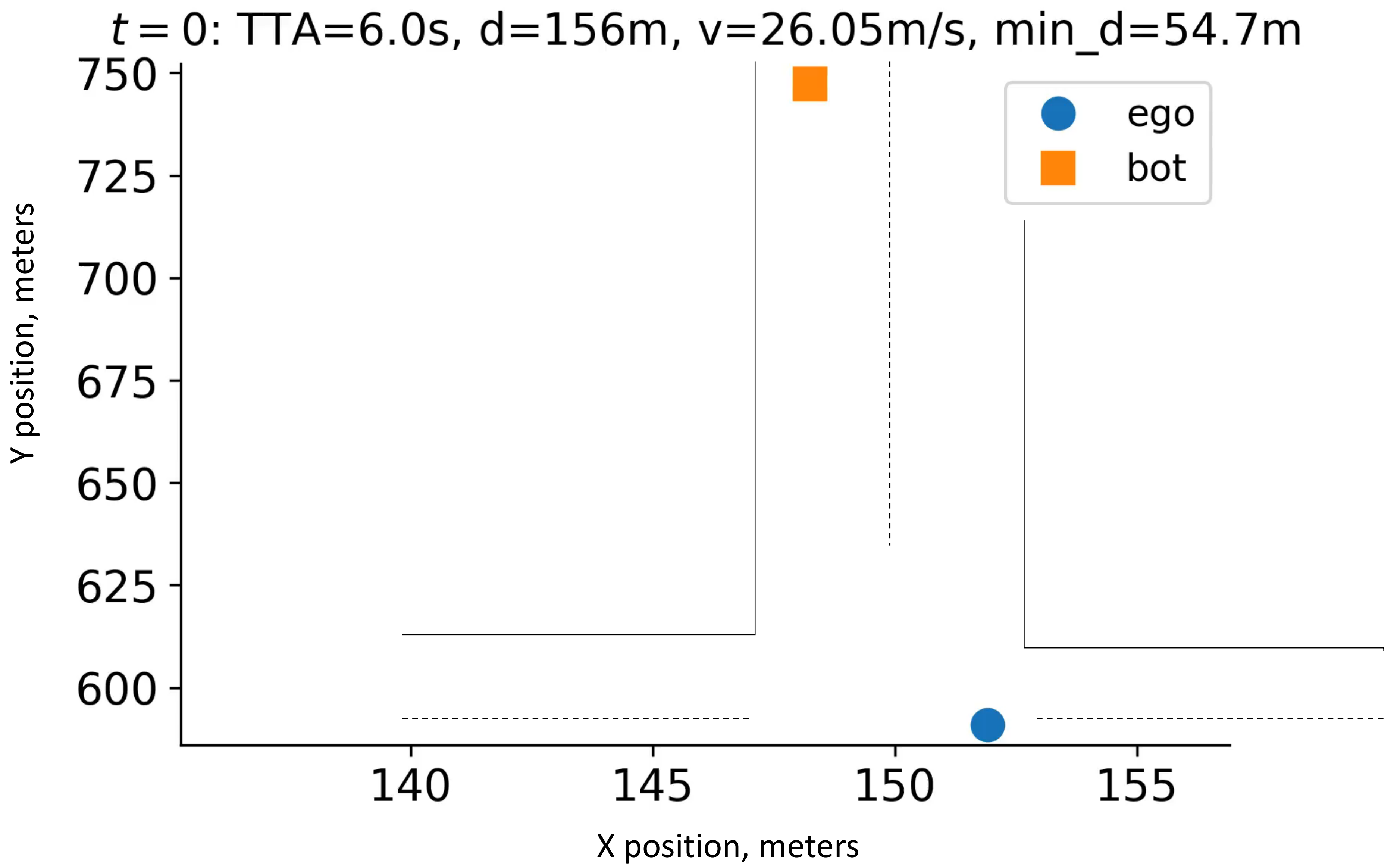


Left turns

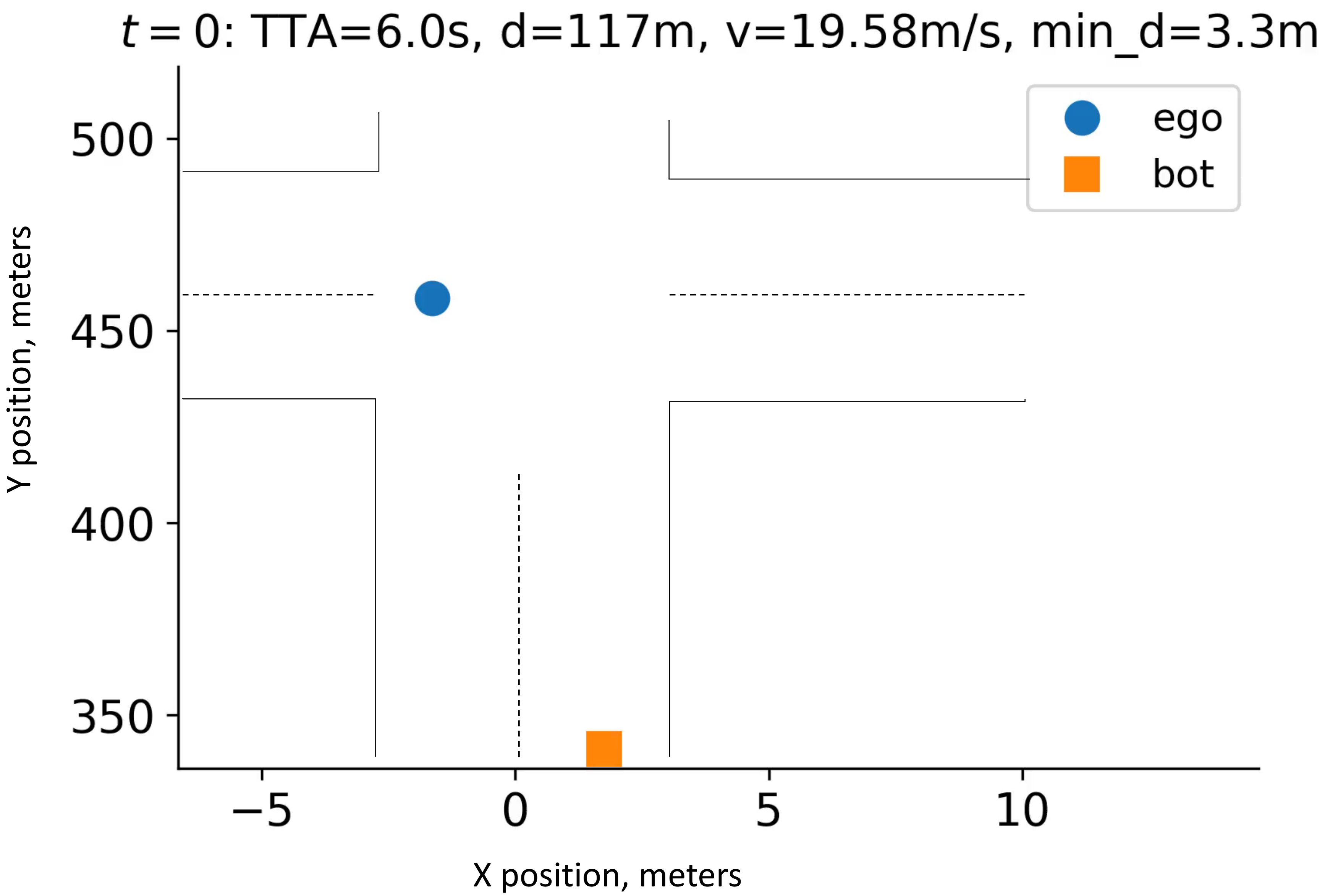
- The driver is instructed to stop at the intersection before making a left turn
- When the driver stops, the oncoming car appears
- Oncoming car starts at
  - distance (d) = {90,120,150}s
  - fixed speed v chosen such that
  - time-to-arrival (TTA) = {4,5,6}s
- Distance and TTA conditions are independent variables



Turn trajectory

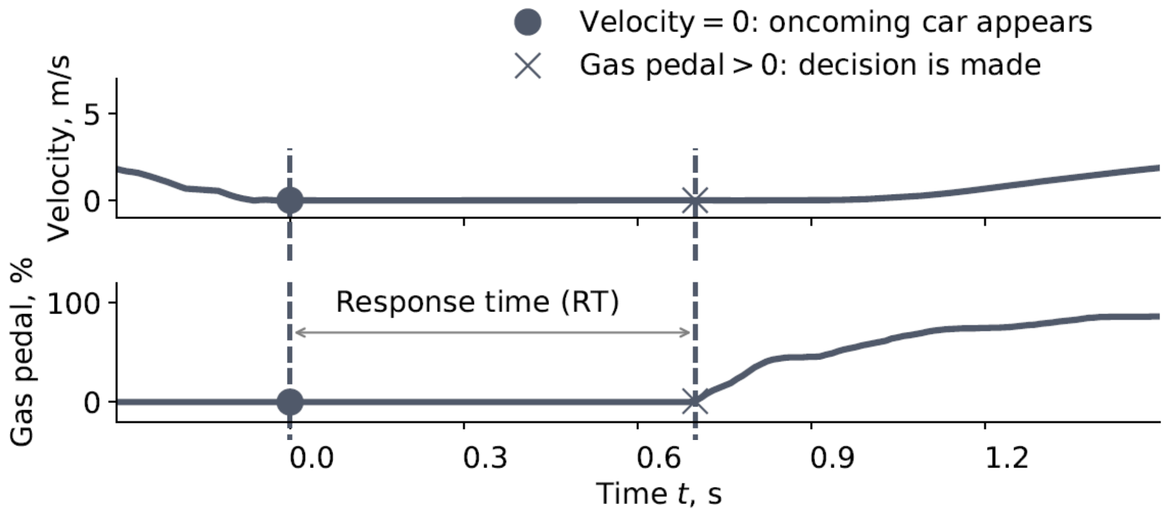


Wait trajectory



Dependent variables

- Decision (turn/wait)
  - Hypothesis: probability of turning will increase with TTA and distance
- Response time (turn decisions only)

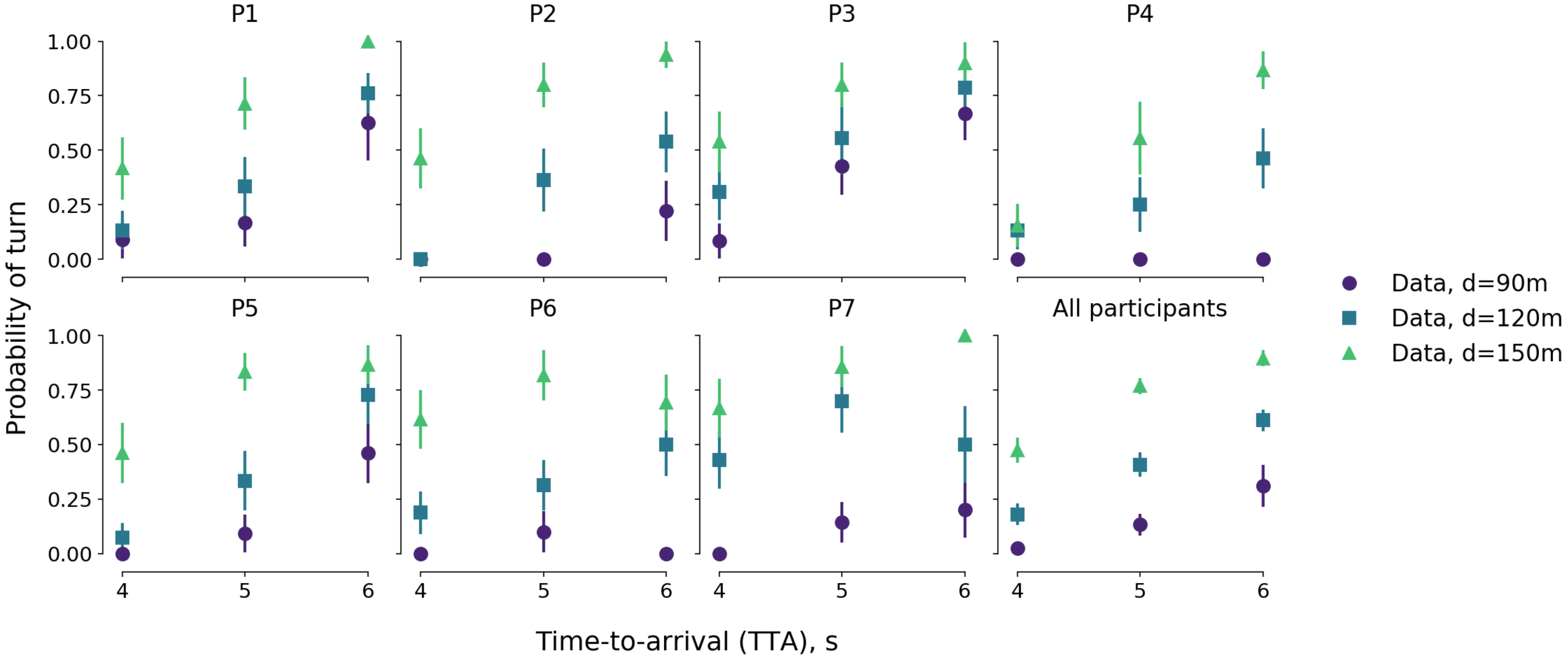


  - Hypothesis: RT will decrease with time and distance gaps
    - For large gaps, evidence in favour of turning is very strong → fast response
    - For small gaps, relative evidence favours waiting → takes more time to arrive to "turn" decision

Results

decision ~ TTA + distance + (d|subject)

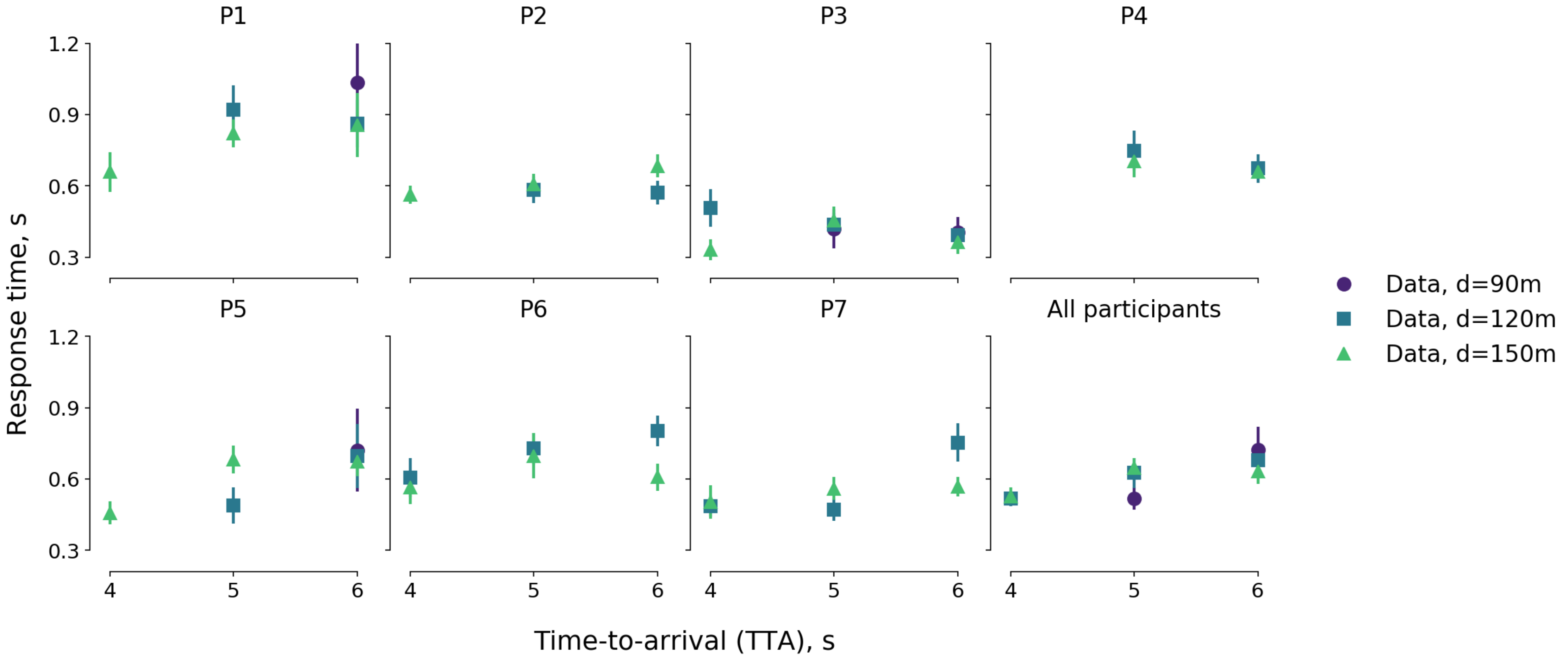
	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-0.5	0.24	-2	0.042
TTA	0.96	0.098	9.8	1.2×10^{-22}
distance	1.4	0.17	8.2	1.7×10^{-16}



Results

RT ~ TTA + distance + (1|subject)

	Estimate	Std. Error	df	t value	Pr(>|t|)
Intercept	-0.72	0.033	6.8	-22	1.4×10^{-7}
TTA	0.028	0.0089	3.4×10^{2}	3.2	0.0017
distance	-0.0052	0.01	3.4×10^{2}	-0.52	0.6



Interim conclusions

- Probability of turning increases with distance and time gap
- Response time increases with time gap
- Substantial individual differences in effect magnitudes
- What *processes* lead to the observed behavior?

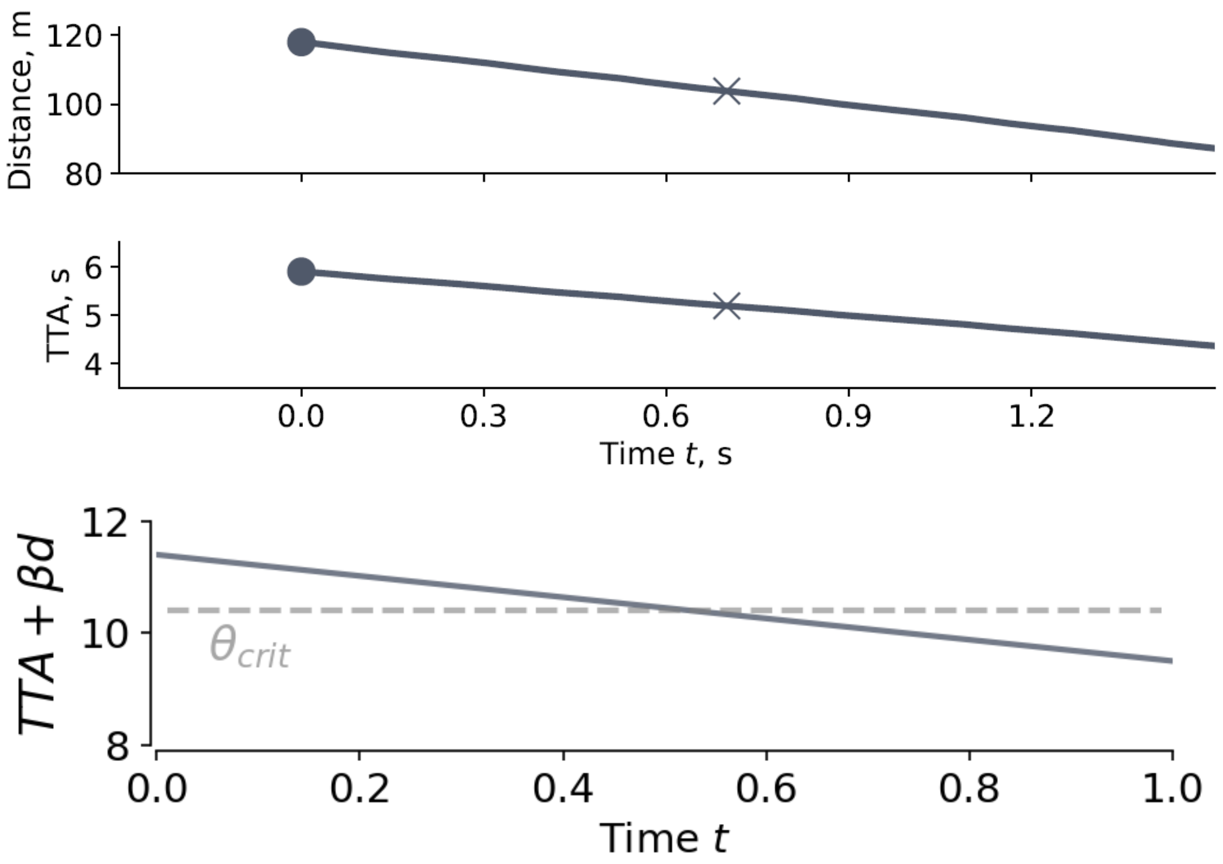
Cognitive process model

Mechanism 1: dynamic accumulation of perceptual information

- Previous studies suggest both distance and time gap affect the decision
- Perceptual information (combination of TTA and distance) is accumulated over time…
- … and is subject to noise

  $$\mathrm{dx} = \alpha\big((TTA + \beta d) - \theta_{crit}\big)dt + dW$$

  $\alpha, \beta, \theta_{crit}$: free parameters

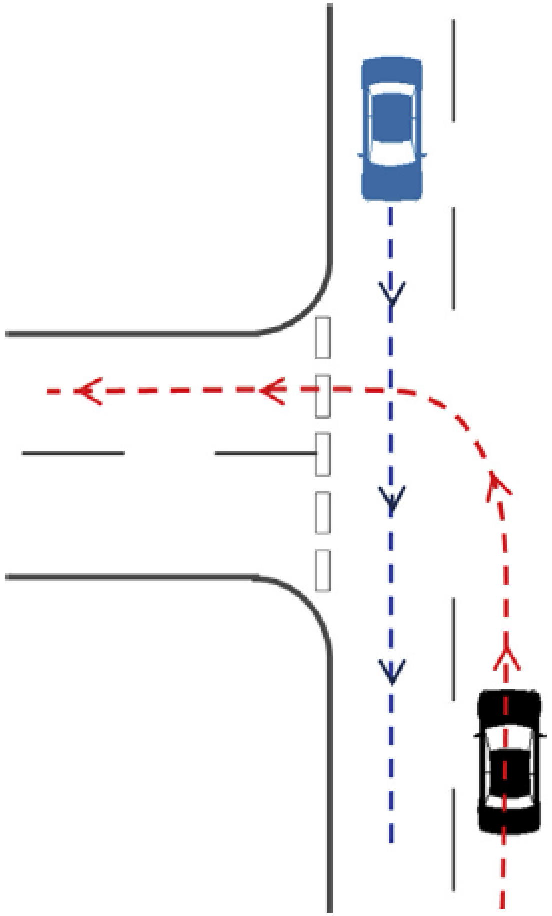


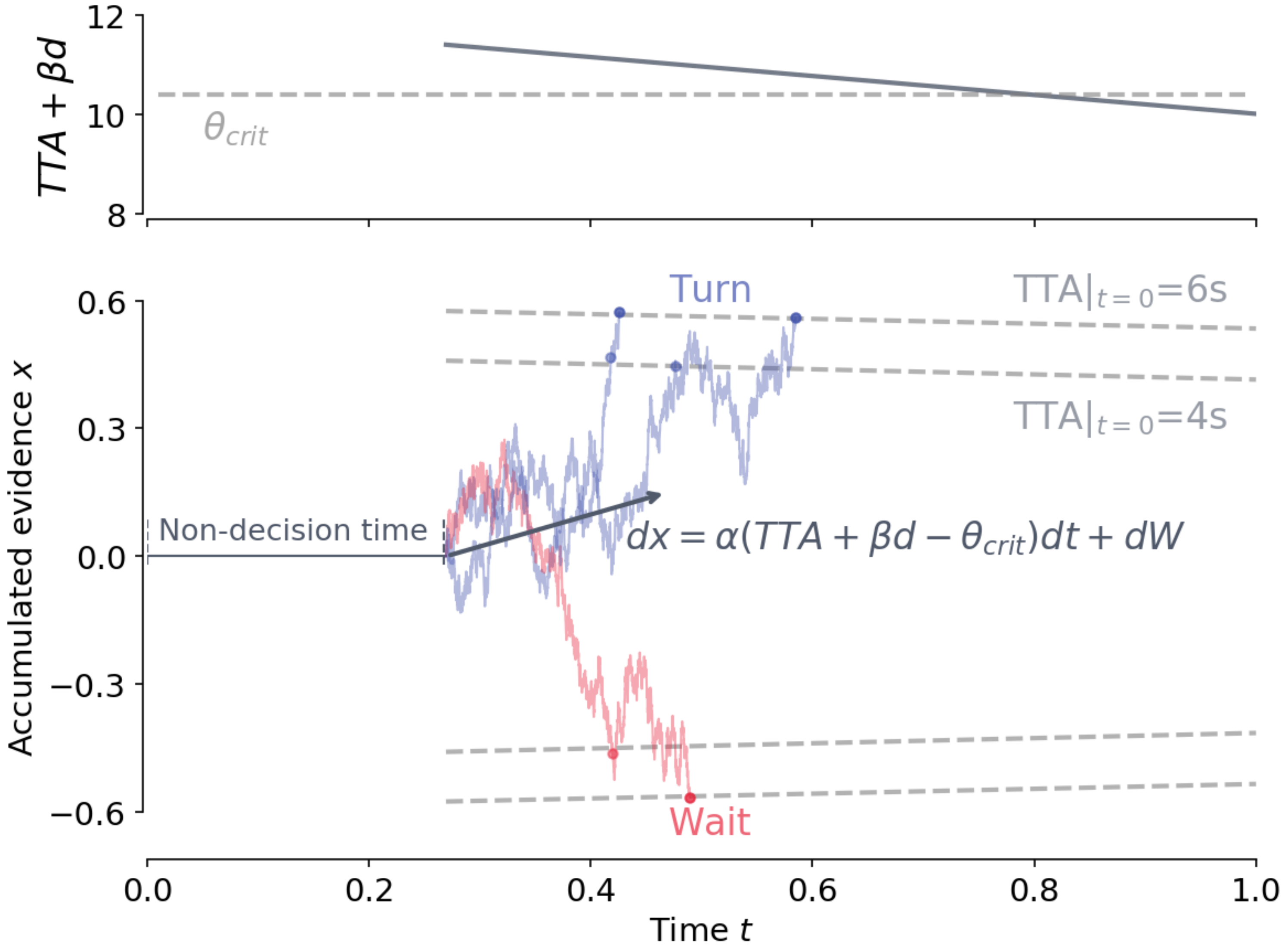
Mechanism 2: collapsing decision boundary

- Response is constrained by the environment
  - At small gaps, the driver has to accumulate the evidence faster, or there will be no time left to complete the maneuver
- Task constraints (oncoming car) induce urgency signal
- Decision boundaries collapsing with closing gap

$$b(t) = \pm b_0 f(TTA)$$

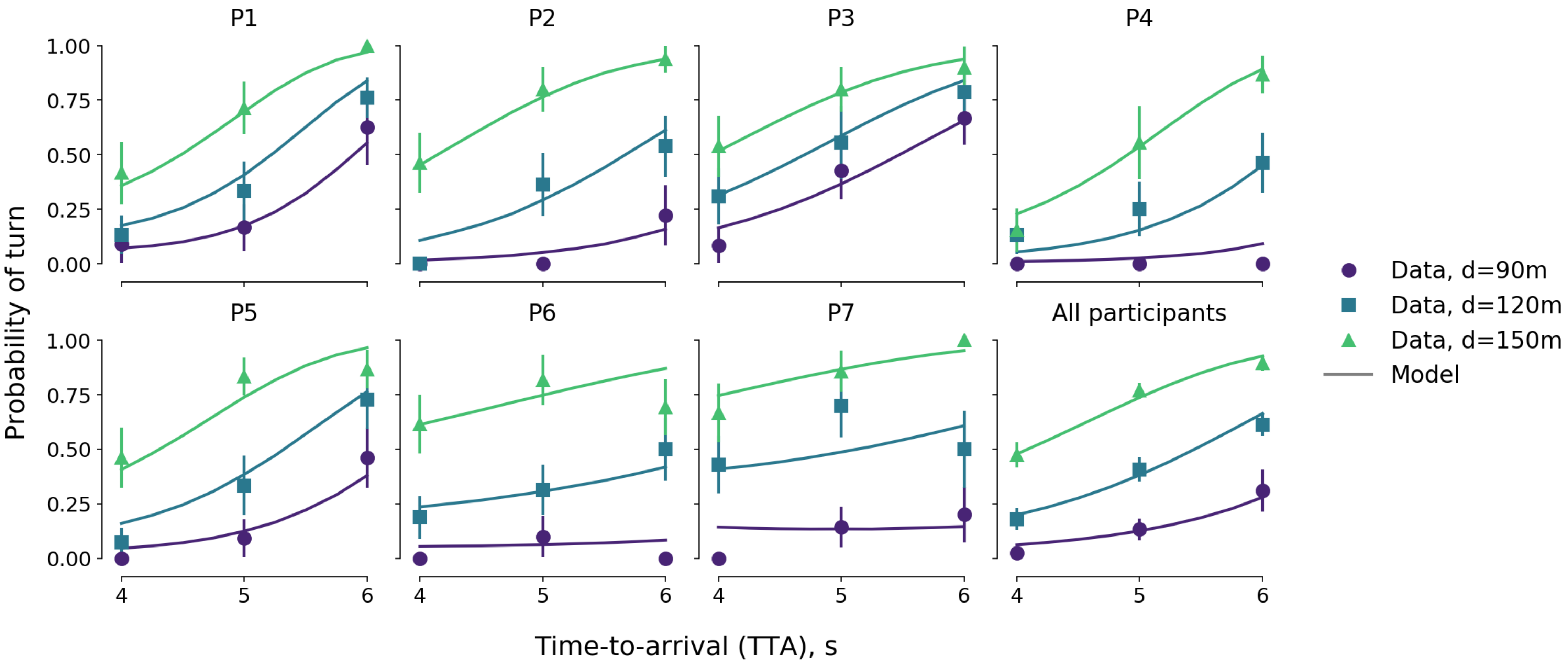
where f decreases with TTA



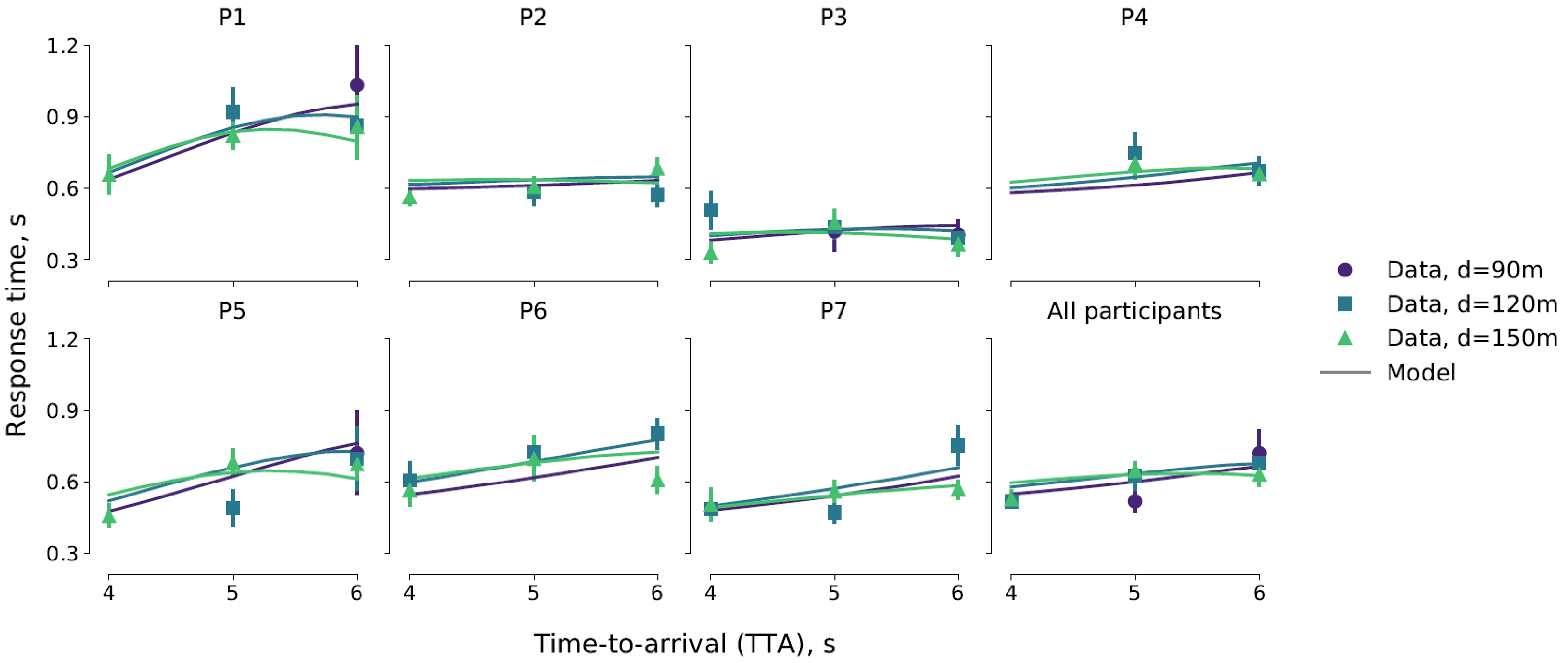


$TTA + \beta d$
θ_{crit}
Turn
$\mathrm{TTA}|_{t=0}$=6s
$\mathrm{TTA}|_{t=0}$=4s
Non-decision time
$dx = \alpha(TTA + \beta d - \theta_{crit})dt + dW$
Wait
Accumulated evidence x
Time t

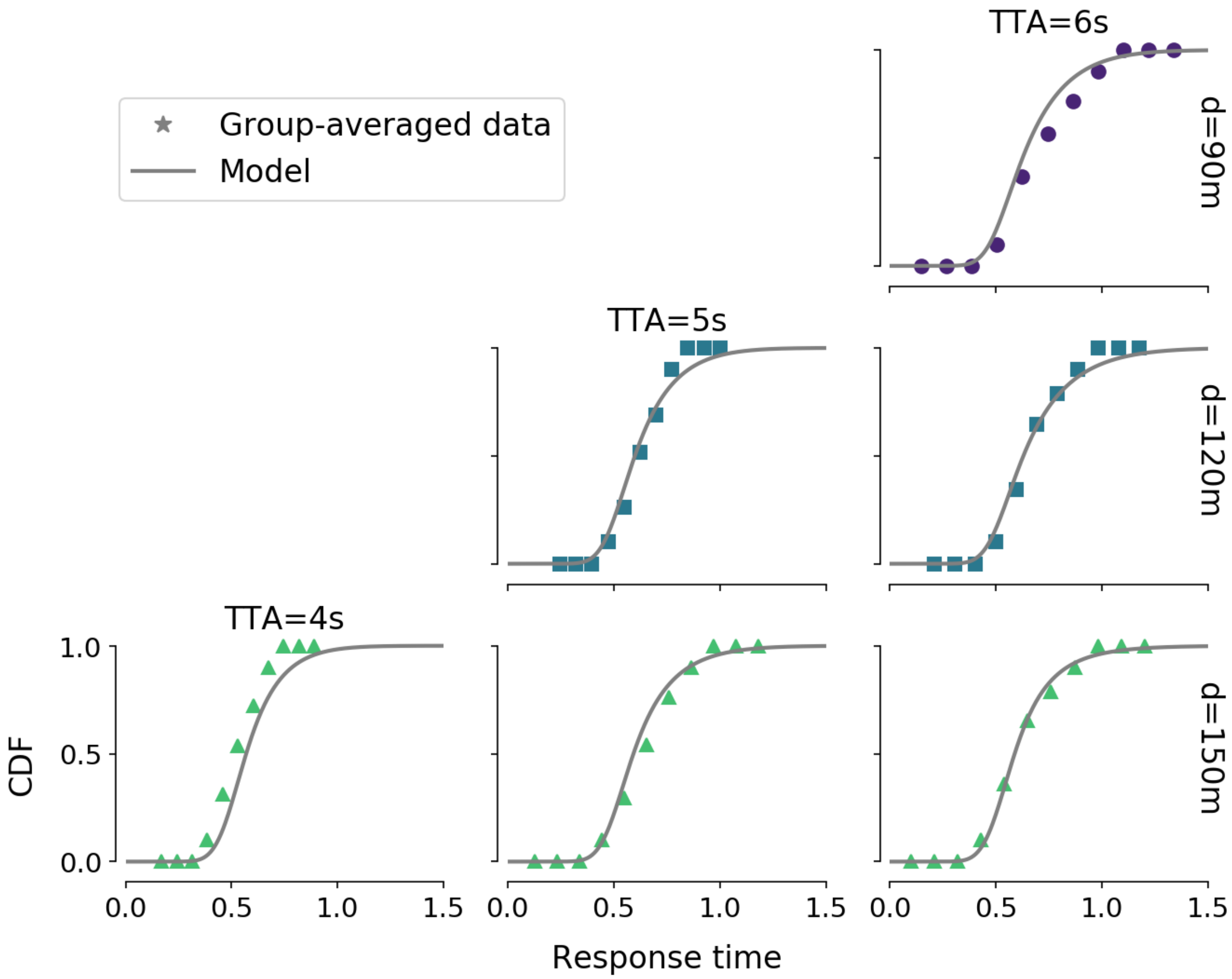
Model results



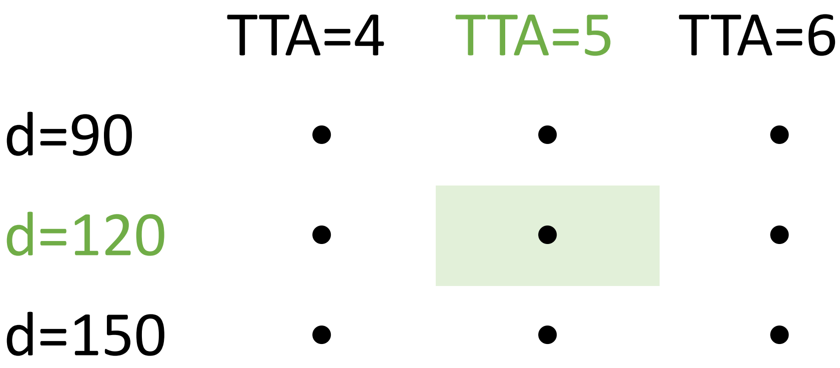
Model results



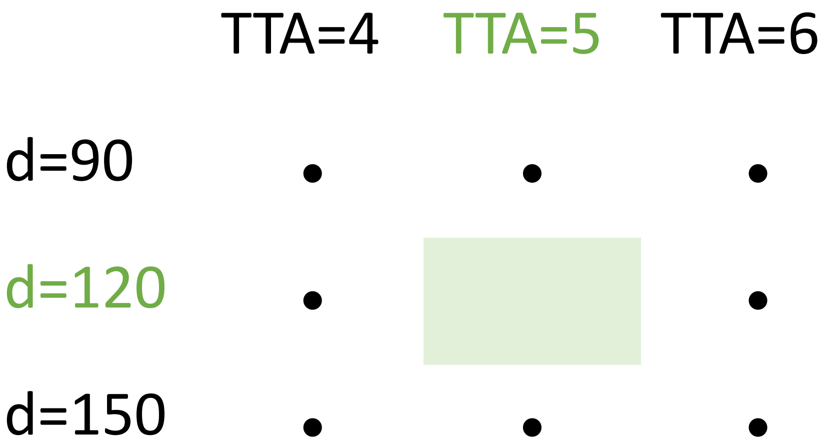
Full RT distributions



Model cross-validation

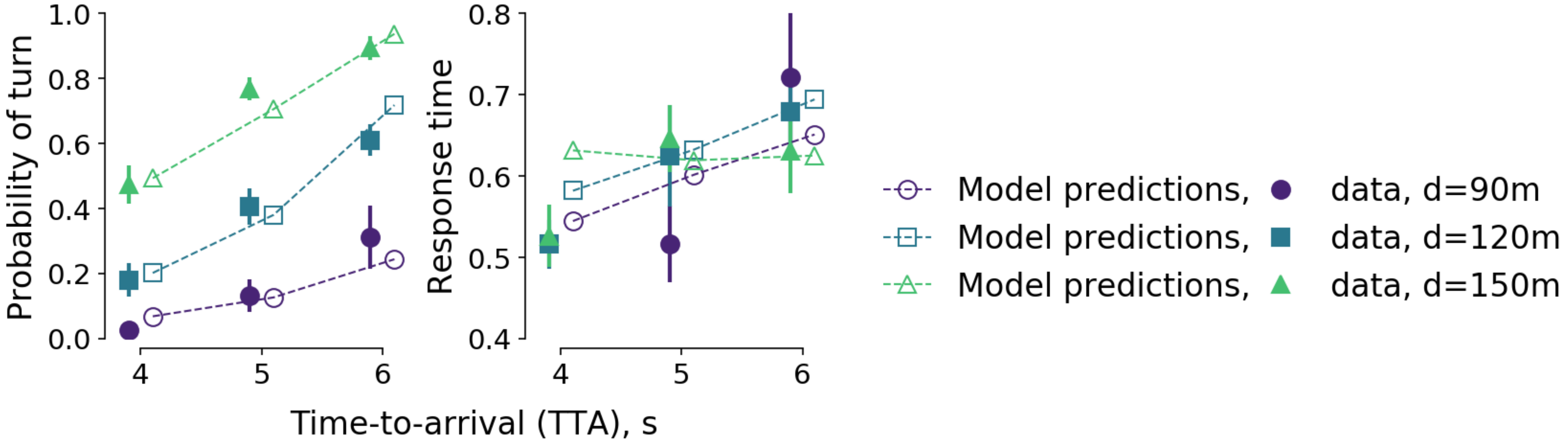


Fit using all data (9 conditions)



Hold-one-condition-out: fit using all data except the condition to be predicted

Model cross-validation



Summary

- Decisions and response times in left-turn gap acceptance decision can be explained by
  - Accumulation of dynamically varying evidence
  - … constrained by closing window of opportunity to turn
- Proof-of-concept of how cognitive process models can help to understand and predict human road user behavior

Discussion

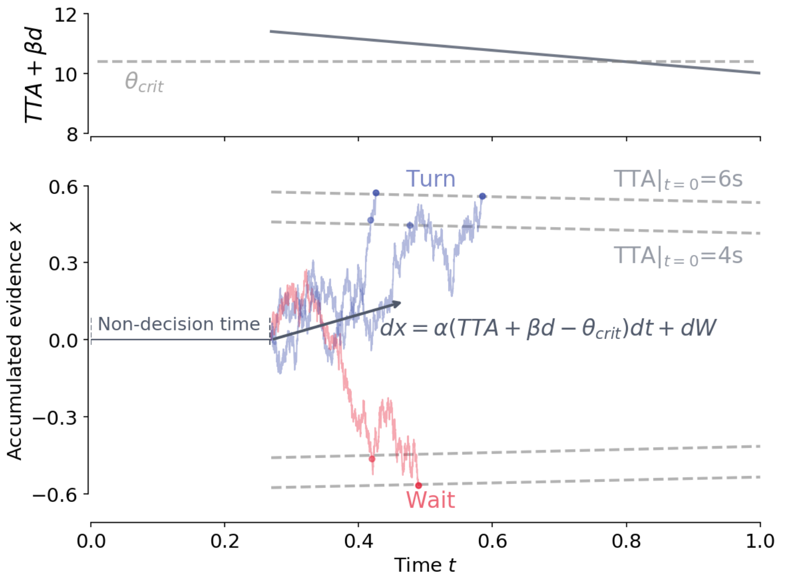
Discrete choice vs process models

- Numerous *discrete choice* models of gap acceptance
  - Effect of kinematic variables (distance, velocity, time gap)
  - Sociodemographic effects (age, sex, driving experience)
  - Sequential effects (waiting time)
- *Discrete choice* models vs cognitive *process* models
  - <u>What</u> (which gaps are accepted, and under which conditions) vs <u>How?</u> (cognitive mechanism, i.e. how the information is processed over time)
  - Static vs dynamic
  - Simplicity vs fidelity
- For human-robot interaction, dynamic, high-fidelity models are needed in order to be able to predict how humans react to different control policies

$$G^{cr}_{n,i} = 34.01 - 0.30 \cdot \mathrm{SS} + 5.15 \cdot \mathrm{FG} + 0.42 \cdot \mathrm{FS} - 0.14 \cdot \mathrm{OS} - 2.35 \cdot \mathrm{RG} - 7.00 \cdot \mathrm{Age}_1 - 4.95 \cdot \mathrm{Age}_2 - 2.84 \cdot G + 0.23 \cdot P + 1.05 \cdot \mathrm{Km} - 7.5 * E - 5 \cdot \mathrm{CD}$$

$$P_{n,i}(\text{accept gap}) = \frac{1}{1 + \exp\left[-0.22 \cdot \left(G_{n,i} - G^{cr}_{n,i}\right)\right]}$$

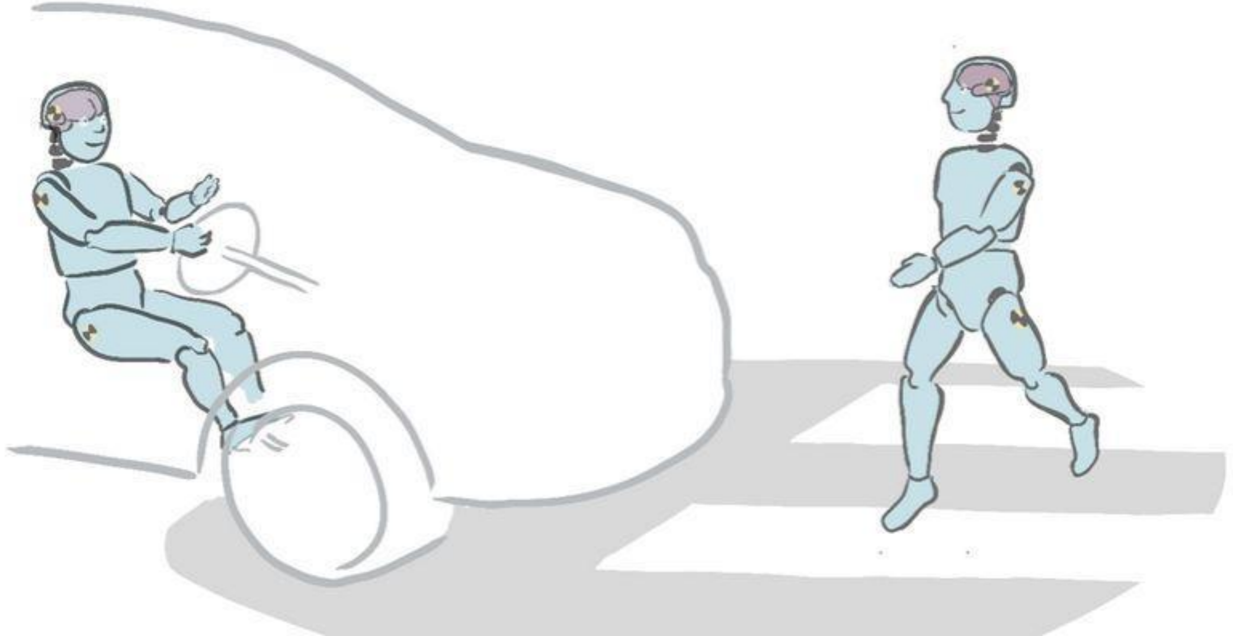
Farah et al. (2009). A passing gap acceptance model for two-lane rural highways. *Transportmetrica*, *5*(3), 159–172.



Cognitive models for virtual AV testing

COMMOTIONS: Computational Models of Traffic Interactions for Testing of Automated Vehicles (£1.4M)

PI: Gustav Markkula
University of Leeds



aimsun.
A Siemens Company

Next steps

- Finer-grained modeling
  - Response times for “wait” decisions
  - Incorporating acceleration/deceleration
  - Changes-of-mind
- Developing cognitive models for other interactions
  - Attention / situation awareness
- Integrating dynamic model predictions in motion planning

Meaningful human control over automated systems

- Increased autonomy of AI → Need to ensure human responsibility
- MHC as tracing and tracking (Santoni de Sio & van den Hoven, 2018)
  - Tracing: humans remain morally responsible for AI's actions
  - <u>Tracking</u>: AI is responsive to relevant human reasons (i.e. "control" signals)
- Hot take: In high-stakes, time-critical human-AI interactions, in order for AI to correctly interpret human actions (and identify the reasons behind them), it should have an adequate mental model of human

Collaborators

David Abbink

Gustav Markkula

Preprint

SHOULD I STAY OR SHOULD I GO? EVIDENCE ACCUMULATION DRIVES DECISION MAKING IN HUMAN DRIVERS

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