A Data-Driven Comparison of Car-Following Behaviors of Autonomous and Human-Driven Vehicles and Their Traffic Flow Impacts Under Naturalistic Traffic Conditions

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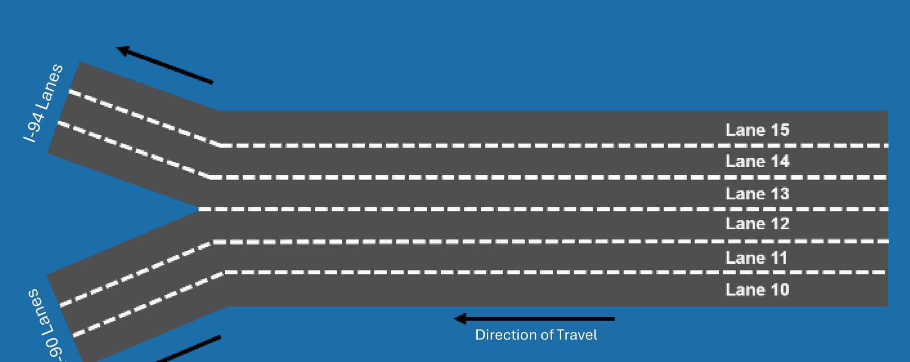
Introduction

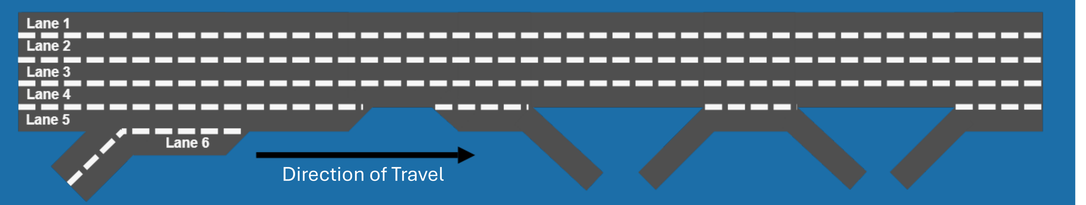
- Microscopic simulation is a valuable tool for traffic system analysis and design.(1)
- Car-following models' characteristics and parametric distributions dictate safety and mobility performance of traffic streams.(2)

Goals

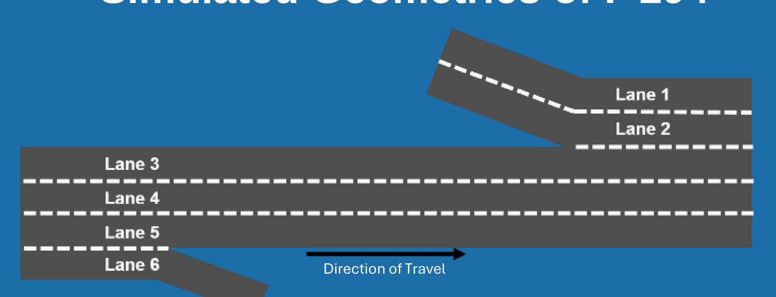
- Empirically test the difference between longitudinal movement dynamics of automated vehicles (AVs) and human-driven vehicles (HDVs) in complex naturalistic freeway settings.
- Collect, extract, and mine detailed naturalistic trajectory data specific to three vehicle types: nonheavy HDVs, heavy HDVs, and nonheavy AVs.
- Calibrate the intelligent driver model (IDM)(3) parameters with such data and use for statistical testing and simulation.



Simulated Geometries of I–90/ I–94



Simulated Geometries of I–294



Simulated Geometries of I–395

Dataset

Third-generation simulation (TGSIM):(4)

- Location:
  - Chicago, IL (I–90/I–94).
  - Near Hinsdale, IL (I–294).
  - Washington, DC (I–395).
- Analysis: Small vehicles and autonomous vehicles

TGSIM can be accessed through this link.(4)

https://urldefense.proofpoint.com/v2/url?u=https-3A__catalog.data.gov_dataset_-3Fq-3DThird-2BGeneration-2BSimulation-2BData-26sort-3Dviews-5Frecent-2Bdesc-26publisher-3DFederal-2BHighway-2BAdministration-26organization-3Ddot-2Dgov-26ext-5Flocation-3D-26ext-5Fbbox-3D-26ext-5Fprev-5Fextent-3D&d=DwIFAg&c=euGZstcaTDllvimEN8b7jXrwqOf-v5A_CdpgnVfiiMM&r=lGbI8AlAH_hHOjqaSFU1IBw02pDmmapIAZXRiFFieh0&m=5jzSPOy9MUpOto-YIDDpe5zpw9yUrHaDigD28A-PIlLKLdEOFZS2zfwlDSk_07v0&s=1aFEnFdpeSdVBPtgynxedE9ilOK6YM3jLXBeT85WYj8&e=

Methodology

Modeling:

To simulate user movement, IDM was utilized:

- Widely used for longitudinal movement analysis in transportation research.
- Describes acceleration based on current speed, desired speed, headway, and relative speed with the leading vehicle.

$$\dot{v}_n(t) = a\left(1 - \left(\frac{v_n(t)}{v_0}\right)^{\delta} - \left(\frac{s\big(v_n(t), \Delta v_n(t)\big)}{s_0}\right)^2\right)$$

$$s\big(v_n(t), \Delta v_n(t)\big) = s_0 + v_n(t).T + \frac{v_n(t)\Delta v_n(t)}{2\sqrt{ab}}$$

Key parameters: v_n (current speed), t (time), v_0 (desired speed), δ (parameter), s_0 (minimum gap), s (desired gap), T (safe headway), $\Delta v_n(t)$ (relative speed), a and b (acceleration parameters).

Calibration approach:

- Parameters are calibrated for each leader–follower pair.
- Parameters optimized $\{T, a, b, v_0, \delta, s_0\}$ using genetic algorithm with the following fitness function:

$$f(\Theta_i) = \frac{1}{1 + \sum_j \left(\left|p_{obs,j} - p_{sim,j}(\Theta_i)\right| + \left|v_{obs,j} - v_{sim,j}(\Theta_i)\right|\right)}$$

Where:

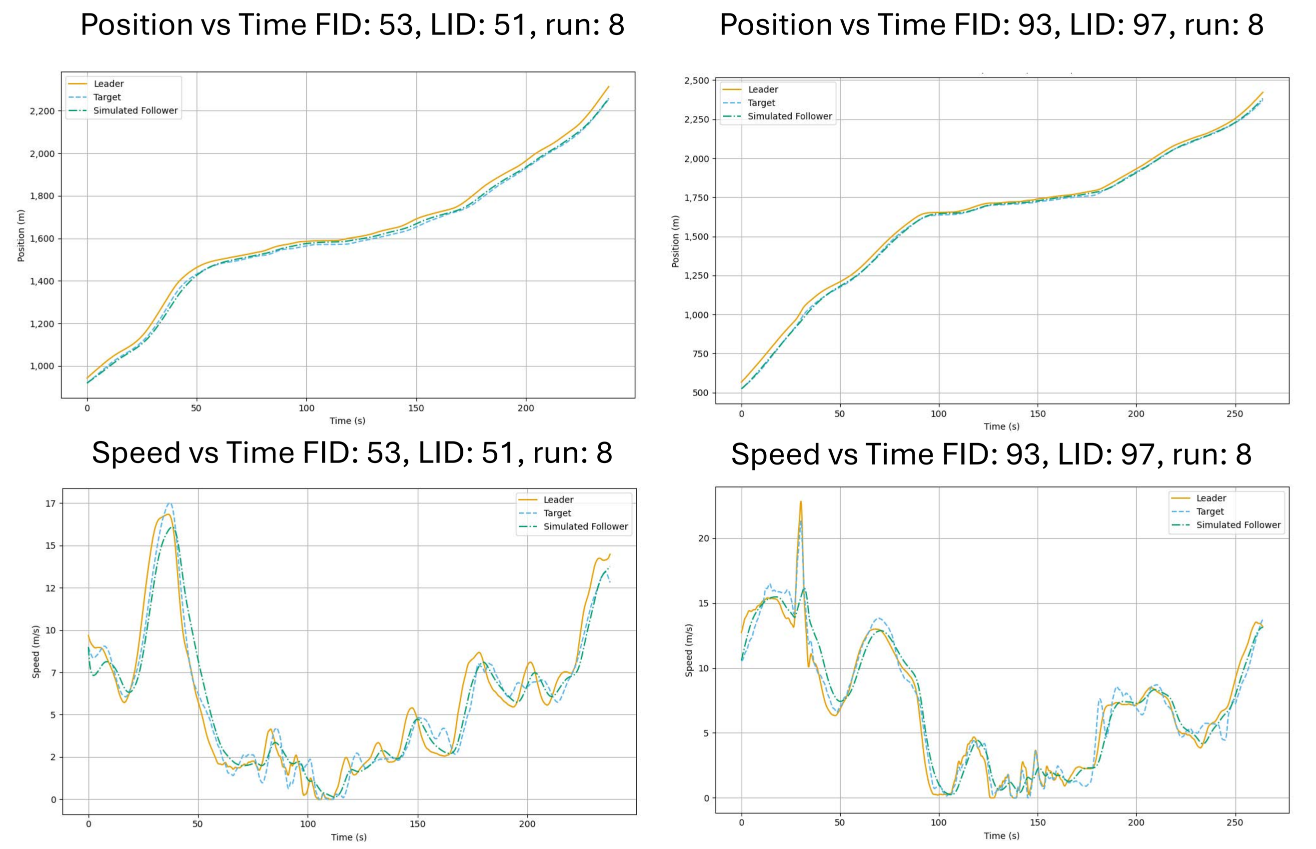
$p_{obs,j}$ and $v_{obs,j}$ = observed positions and velocities at time j, respectively.

$p_{sim,j}(\Theta_i)$ and $v_{sim,j}(\Theta_i)$ = simulated positions and velocities using parameters Θ_i, respectively.

Calibration data:

59 AVs, 59 small vehicles, and 59 large vehicles (LVs) used.

Research Results



FID = follower impedance distance; LID = lead impedance distance.

Simulated (Nonsmoothed) Versus Observed Position and Speeds for Four Samples of Leader and Follower

Summary of Error Metrics for IDM

Vehicle Type	RMSE	MAE	*R*-squared
Small Vehicles	3.386	2.826	0.9481
LVs	5.493	4.741	0.9211
AVs	3.122	2.528	0.9530

RMSE = root mean square error; MAE = mean absolute error.

Parameter Calibration Results

Parameter	Range	Small Vehicles	LVs	AVs
T	(0.5, 2.5)	1.462	1.871	1.529
a	(0.3, 3.0)	1.447	1.435	1.497
b	(0.5, 3.0)	1.652	1.303	1.871
v_0	(5, 35)	27.986	24.803	27.977
s_0	(1, 5)	3.623	3.537	3.639
δ	(3.8, 4.2)	4.186	4.021	4.059

Conclusions

- IDM is a better fit for AVs than HDVs, showing the lowest calibration errors
  - LVs are most cautious, with significantly longer time headways than small vehicles.
  - AVs, while maintaining conservative following distances, are programmed with more responsive deceleration compared to LVs.
- Simulations show that higher AV penetration improves traffic capacity, whereas a higher share of LVs degrades it.

All images are sourced: FHWA.

References

1. Chung, E., and A.-G. Dumont. 2009. *Transport Simulation: Beyond Traditional Approaches.* Lausanne, Switzerland: EPFL Press.
2. Zhang, H. M., and T. Kim. 2005. "A Car-Following Theory For Multiphase Vehicular Traffic Flow." *Transportation Research Part B: Methodological* 39, no. 5: 385–399.
3. Treiber, M., A. Hennecke, and D. Helbing. 2000. "Congested Traffic States in Empirical Observations and Microscopic Simulations." *Physical Review E* 62, no. 2: 1805.
4. General Services Administration. n.d. "Data Catalog" (web page). https://catalog.data.gov/dataset/?q=Third+Generation+Simulation+Data&sort=views_recent+desc&publisher=Federal+Highway+Administration&organization=dot-gov&ext_location=&ext_bbox=&ext_prev_extent=, last accessed August 20, 2025.

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