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Learning From Real-World Trajectories: A Hybrid Genetic Algorithm and Reinforcement Learning Approach for Vulnerable Road User Model Calibration

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Introduction

- Microscopic simulation models require accurate calibration to reflect real-world dynamics.
 - Vulnerable road user (VRU) model calibration is challenging due to:
 - Complex interactions and behaviors.
 - Mode-specific interactions.
 - Diversity in infrastructure and the existence of shared spaces.
 - Existing calibration methods, relying solely on numeric loss functions, often fail to capture realistic, human-perceived behavior.
- ## Goals
- Introduce a calibration methodology to systematically adjust model behavior to include expert opinion:
 - Match model output with expected behavior.
 - Be reproducible across different models and platforms.
 - Develop a hybrid genetic algorithm (GA) plus reinforcement learning (RL) calibration framework with human-in-the-loop preference modeling.

Dataset

Third-generation simulation (TGSIM):⁽¹⁾

- Location:
 - Washington, DC, Foggy Bottom area.
 - Intersection of 1st Street NW and 23rd Street NW.
- Location characteristics: High VRU volume near George Washington University campus and Washington, DC, Metro station.
- Analysis: Pedestrians and bicyclists included.

TGSIM can be accessed through this link.⁽¹⁾



https://urldefense.proofpoint.com/v2/url?u=https://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&e=euGZsteaTDIvImEN8b7jXrwqOf-vSA_CdpanVfiMM&r=Igb8AIAH_hHOiqaSFU1IBw02pDmmaplAZXRIFFieh0&m=5jzSPOy9MUpOto-YIDDpe5zpw9yUrHaDigD28A-PIILKdEOFSZ2zfwIDSk_07v0&s=1aFEnFdpeSdVBPigvnxedE9iOK6YM3jLXBcT85WYj8&e=

Methodology

To simulate user movement, two models were utilized:

- Social force model (SFM):⁽²⁾
 - Models motion via attractive (goal-oriented) and repulsive (collision-avoidance) forces between agents and obstacles.
- Prospect theory (PT)-based model:⁽³⁾
 - Provides a framework to capture decisionmaking under uncertainty.
 - Assumes gains and losses influence decisionmaking differently.

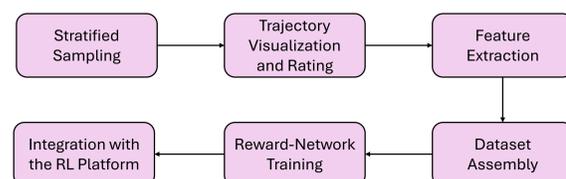
A two-step calibration approach is proposed:

- Step 1: Calibrating using GA, minimizing discrepancy between simulated and observed speeds.

$$f(\theta_i) = \frac{1}{1 + \sum (v_i^{observed} - v_i^{predicted}(\theta_i))}$$

Where $v_i^{observed}$ is the observed velocity at time i , and $v_i^{predicted}(\theta_i)$ is the velocity based on the model output using the parameter set θ_i

- Step 2: Fine-tuning using an RL setup:
 - State: Acceleration, speed, heading, and parameter offset.
 - Action: Small, simultaneous nudge to each tunable dimension.
 - Reward: Expert rating of model performance.



Research Results

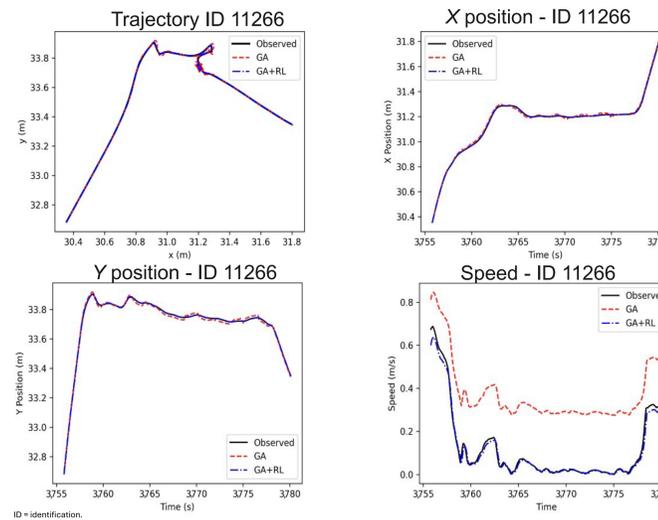


Figure 1. Predicted versus observed position and speeds along two axes for a sample agent using the SF.

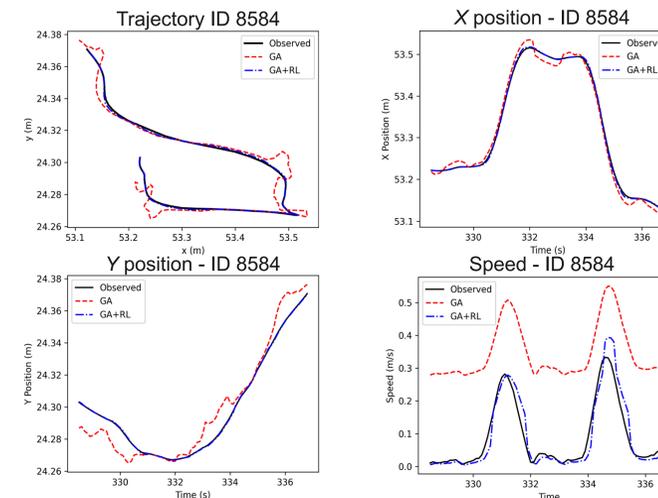


Figure 2. Predicted versus observed position and speeds along two axes for a sample agent using the PT.

Conclusions

- Calibration significantly improved different error metrics across both models and modes.
- SFM generally outperformed PT for pedestrians, whereas PT performed better for bicycles in noisy environments.
- Noisy input analysis showed robust model performance, although accuracy dropped compared to clean data, especially in PT bicycle simulations.
- Correlation analysis confirmed stronger parameter stability for SFM across varying noise levels.

References

1. 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.
2. Helbing, D., and P. Molnár. 1995. "Social Force Model for Pedestrian Dynamics." *Physical Review E* 51, no. 5: 4282–4286.
3. Hamdar, S. H., A. Talebpour, K. D'sa, V. Knoop, W. Daamen, and M. Treiber. 2022. "Behavioral-Based Pedestrian Modeling Approach: Formulation, Sensitivity Analysis, and Calibration." *Transportation Research Record* 2676, no. 4: 334–347.

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