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Automated Car Following in Congestions Do They Work Well?

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Why Car Following Models?

Car following is a common scenario that can be modeled with few parameters. In high speed freeflow scenarios, Adaptive Cruise Control has been widely used, but its usage remains limited in low-speed congestions.

Feature	Freeflow	Congestion
Speed Variation	Small	Large
Gap between Vehicles	Large	Small
Interaction with Adjacent Vehicles	Simple	Complex

Table 1. Difference in Freeflow and Congestion Car Following Scenarios

OBJECTIVE

- Identify where Parametric Car Following models fail in congestion.
- Qualitatively analyze scenes to reveal factors worthy of improvements.

Car Following Models

As safety is a top concern in practical Car-Following, we decide to review the following five explainable parametric models: Intelligent Driver Model (IDM) [3], ACC Model, Gipps Model, Optimal Velocity Model (OVM), Full Velocity Difference Model (FVDM).

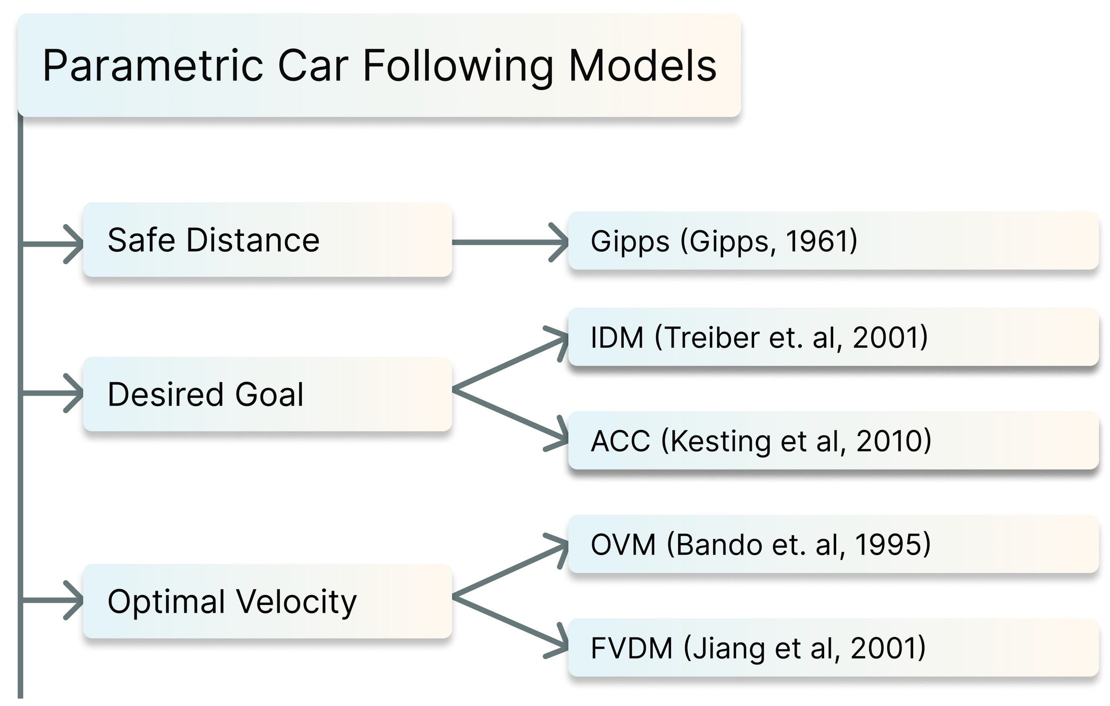


Figure 1. Parametric Car Following Models, an Overview

Congestion Dataset

Our dataset is queried from the IVBSS [2] database maintained by the University of Michigan Transportation Research Institute, which contains two weeks of naturalistic driving data from 140 drivers. From all driving histories, we identified

1. **160** unique congestion events from all drivers' trips. Of those, **24** are highway congestions free of factors such as traffic lights, which make up our dataset.
2. **60** Unique Car Following events are identified with continuous tracking of a lead vehicle, totaling 7440.8 seconds (124 minutes) of recorded data.

Simulation and Calibration

Model parameters are calibrated to reflect the best performance of the models under our dataset.

1. The simulation of all five models are programmed from scratch using Python and PyTorch to support GPU-based parallel simulation.
2. The PyGAD library is used to implement parameter optimization with Genetic Algorithm [1] to search for optimal parameter combinations.
3. The RMSNE criterion is used on the predicted and ground-truth of space gap between ego and lead vehicle. This criterion normalizes the error against the true value to tolerate larger deviation when the ground truth is large.

$$RMSNE(\bar{x}, \bar{y}) = \sqrt{\frac{1}{n}\sum_{1}^{n}(\frac{x-y}{y})^2} \quad (1)$$

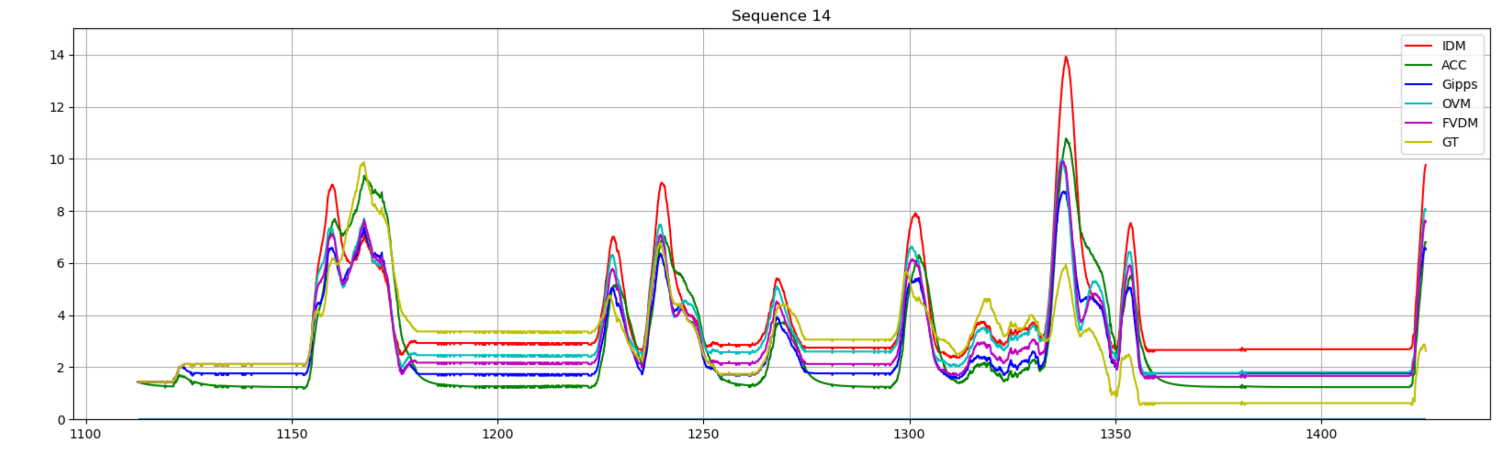


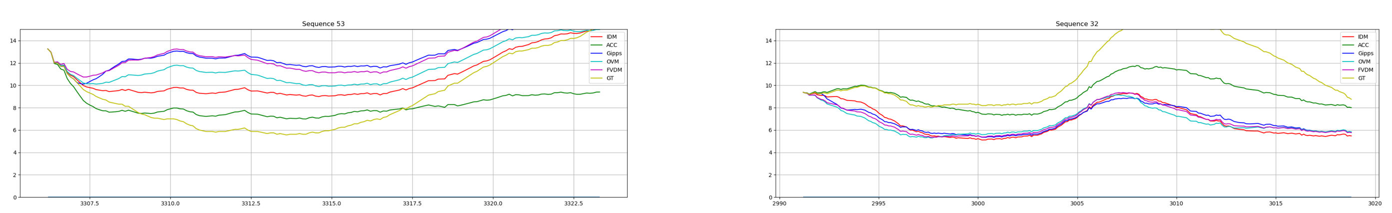
Figure 2. Sequence 13 Calibrated Space Gap: Model Prediction and Ground Truth

While the five models are developed with different heuristics, they largely agree when optimized over the same objective, as can be seen in Figure 2.

A detailed look at Model Behaviors

Where Models Fail

While the Car Following models perform well in many cases, we noticed mismatch between driver behavior and model outputs with the following patterns:



(a) Gaps for sequence 52 (b) Gaps for sequence 31

Figure 3. Plots of gap with large driver-model disagreement

We observe that

1. Models actively accelerate/decelerate to maintain an "optimal" gap, whereas human drivers are more flexible and prefers to maintain current gap unless otherwise incentivized (Figure 3a).
2. Drivers anticipate cut-in intentions from adjacent lanes and actively maintains the gap for those vehicles, while models lack such input (Figure 3b).

Coasting and Idle Creep

Furthermore, we noticed an important technique that drivers employ in congestions, missing in all Car-Following models we are aware of: **Coasting and Idle-Creeping**.

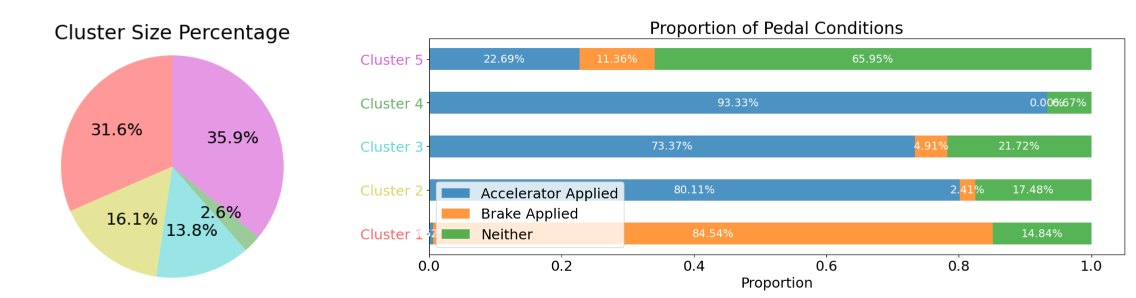


Figure 4. Results of time-series clustering.

Time series clustering is done on the erroneous sequences manually labeled, and patterns of clustering results are shown: some drivers employ coasting and idle-creep over extended period of time, and it is often accompanied by braking blocks, indicating that brake pedal is commonly where driver's foot rests.

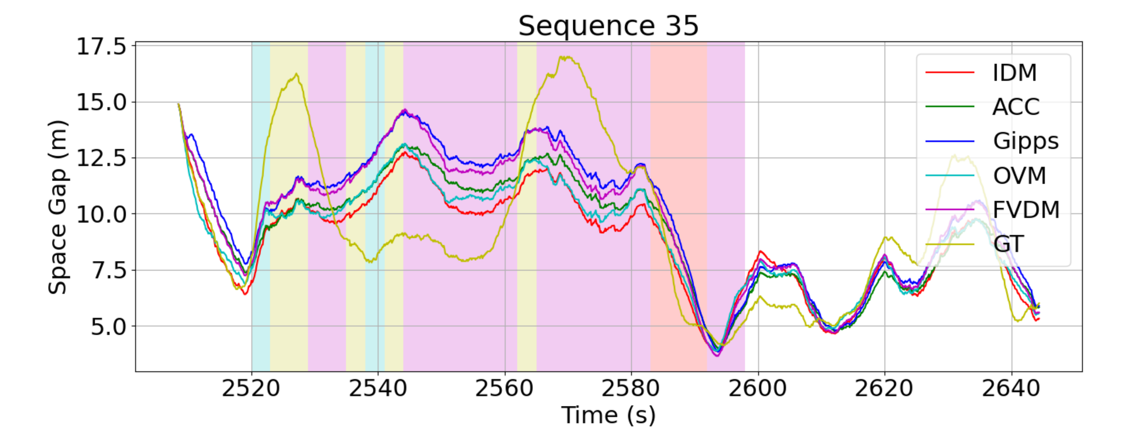


Figure 5. Space gap of Calibrated Sequence 35 with clustering results overlapped. Each of the color strips represent a clustering results of that time-series chunk with the colors matching definitions in Figure 4

Suggestions for Future Research

1. Regarding coasting and idle-creep, we suggest research in time-series clustering to investigate timing and potential triggers for coasting and idle-creeping.
2. Regarding psychological modeling of human behaviors, consider driver's assumption in lead vehicle consistency.
3. Regarding optimization, consider multi-objective optimization, rather than single-objective calibration of models and parameters.

References

[1] Arne Kesting and Martin Treiber. Calibrating Car-Following Models by Using Trajectory Data: Methodological Study. *Transportation Research Record: Journal of the Transportation Research Board*, 2088(1):148–156, January 2008.

[2] J. Sayer, D. LeBlanc, S. Bogard, D. Funkhouser, S. Bao, M. L. Buonarosa, A. Blankespoor, and University of Michigan. Transportation Research Institute. Integrated Vehicle-Based Safety Systems Field Operational Test : Final Program Report. Technical Report FHWA-JPO-11-150;UMTRI-2010-36, June 2011.

[3] Martin Treiber and Arne Kesting. *Traffic Flow Dynamics: Data, Models and Simulation*. Springer Berlin Heidelberg, Berlin, Heidelberg, 2013.