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An Analysis of Car-Following Behavior Heterogeneity as a Function of Road Type and Traffic Condition

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Summary

Microsimulation modeling is a tool used to predict and evaluate the flow of traffic. These models are used in practice to inform decisions and thus must reflect a high level of accuracy.

This research utilizes data collected by the FHWA Living Laboratory instrumented research vehicle (IRV) to produce evidence of global trends in car-following (CF) behavior. **Unlike similar studies, this analysis focuses on the physical action taken by the driver—the acceleration—rather than the outcome of that action—speed selection or temporal/spatial gap**. This approach enables better analysis of CF behavior in varying driving environments: that is, on different roadway functional classifications (i.e., freeway, interstate), operational conditions (i.e., work zones, non-work zones), and traffic conditions (i.e., congested, uncongested).

This analysis produces conclusive evidence that intra-driver CF behavior is heterogeneous and is a function of the driving environment. Trends in acceleration behavior are examined on an aggregated psychophysical plane and statistical analyses identify regions of significantly different behavior. Lastly, acceleration behavior heterogeneity in work zones (WZs) and non-work zones (non-WZs) was also verified. These findings have important implications for microsimulation model calibration efforts.

Methodology

Data Processing

This research was completed using **the 2013 FHWA Living Laboratory IRV data**. Trip files from 62 drivers were processed to extract CF events. CF events were then sorted and aggregated by similarities in the driving environment (see Table 1) to create frameworks (FWs).

Data Analysis

The limitation of many studies investigating trajectory-level CF behavior is that they often **limit evaluations to an individual driver or a small sample of drivers, which doesn't enable the identification of collective behavioral tendencies**. Generally, CF behavior on a psychophysical plane represents a single CF event (see Figures 1 and 2A); however, when considering hundreds of CF events for a single framework, this becomes difficult to interpret (see Figure 2B).

This study introduces an approach to account for inter-driver heterogeneity inherent in a large group of drivers leveraging the psychophysical relative velocity – relative distance ($dV - dX$) car-following plane (see Figure 1).

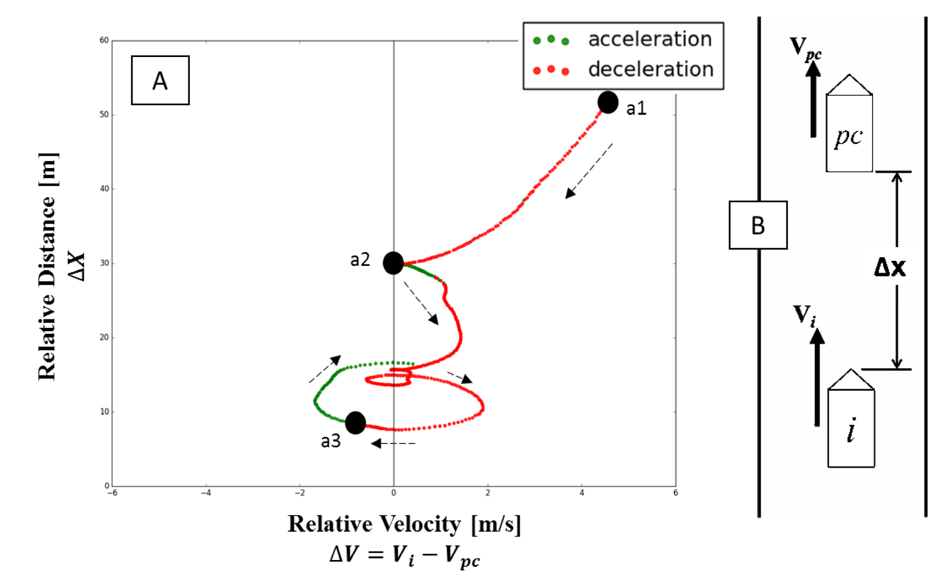

Figure 1: CF Event

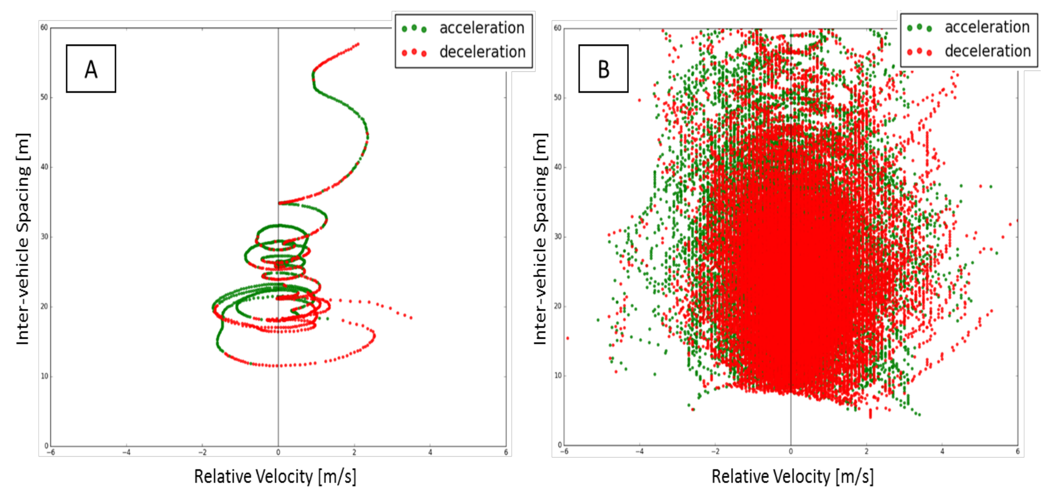

Figure 2: (A) Single CF Event | (B) Multiple CF Events

Table 1: FW Classification

Framework (FW) #	Functional Classification	Operational Condition	Traffic Condition
1	Freeway (2 lane divided)	Non-WZ	C
2	Freeway (2 lane divided)	Non-WZ	U
3	Interstate (IS)	Non-WZ	C
4	Interstate (IS)	Non-WZ	U
5	IS Advanced Warning (AW)	WZ	C
6	IS Advanced Warning (AW)	WZ	U
7	IS Taper Zone (TZ)	WZ	C
8	IS Taper Zone (TZ)	WZ	U
9	IS WZ 1 (WZ1) (lane closure)	WZ	C
10	IS WZ 1 (WZ1) (lane closure)	WZ	U
11	IS WZ 2 (WZ2) (shoulder closure)	WZ	C
12	IS WZ 2 (WZ2) (shoulder closure)	WZ	U

The $dV - dX$ space was divided into a grid creating bins (see Figure 3). Each bin represents the average acceleration of all points within the bin.

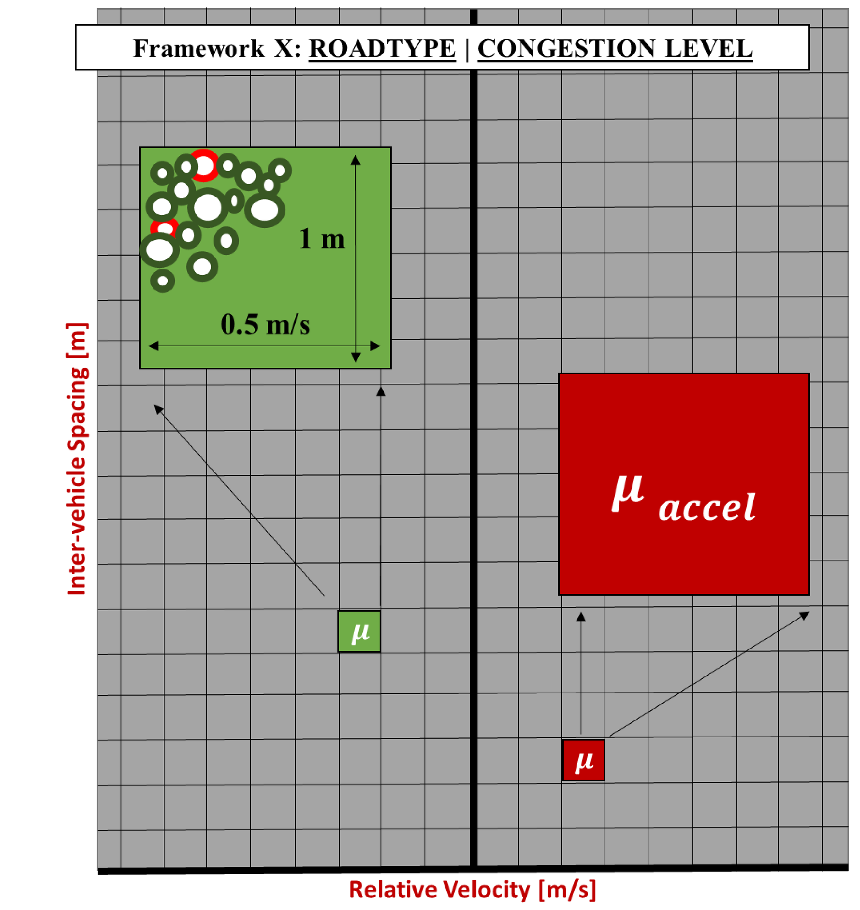

Figure 3: Aggregated $dV - dX$ plane

To ensure bins of the $dV - dX$ plane with limited data or outliers do not skew results, minimum frequency and maximum standard deviation of points within each bin were established. If a bin failed either criterion, it was removed and null values were reported.

Results

Driver Behavior by Road Type in Congested Conditions

- Deceleration magnitudes are stronger at closer following distances (see Figure 4).
- Each FW shows a clear diagonal originating on the plane where relative distance is small and relative velocity is positive and moves towards a larger relative distance and a more positive relative velocity (see Figure 4). This trend illustrates the following drivers' recognition of their speed differential.
- The "cleanest" spirals are detected in the interstate FW.
- In the AW and TZ FW (see Figure 4C&D), strong acceleration patterns are prevalent at greater following distances, indicating that drivers began to accelerate (to close the gap) more quickly than in other conditions.
- Deceleration behavior within both WZ FWs (see Figure 4E&F) is stronger at smaller relative velocities. This indicates that in WZs drivers react more quickly to perceived velocity "gains" on the lead vehicle.
- When comparing WZ 1 (lane closure) and WZ 2 (shoulder closure) (see Figure 4E&F), a difference in acceleration magnitude and location is observed. In WZ 2, acceleration behavior is stronger on the outer boundary, but propagates inward at lower following distances; strong acceleration is less frequently detected in WZ 1. This reduction in strong accelerations in WZ 1 is attributable to a decreased urgency to maintain drivers' following gap, as the adjacent lane is closed.

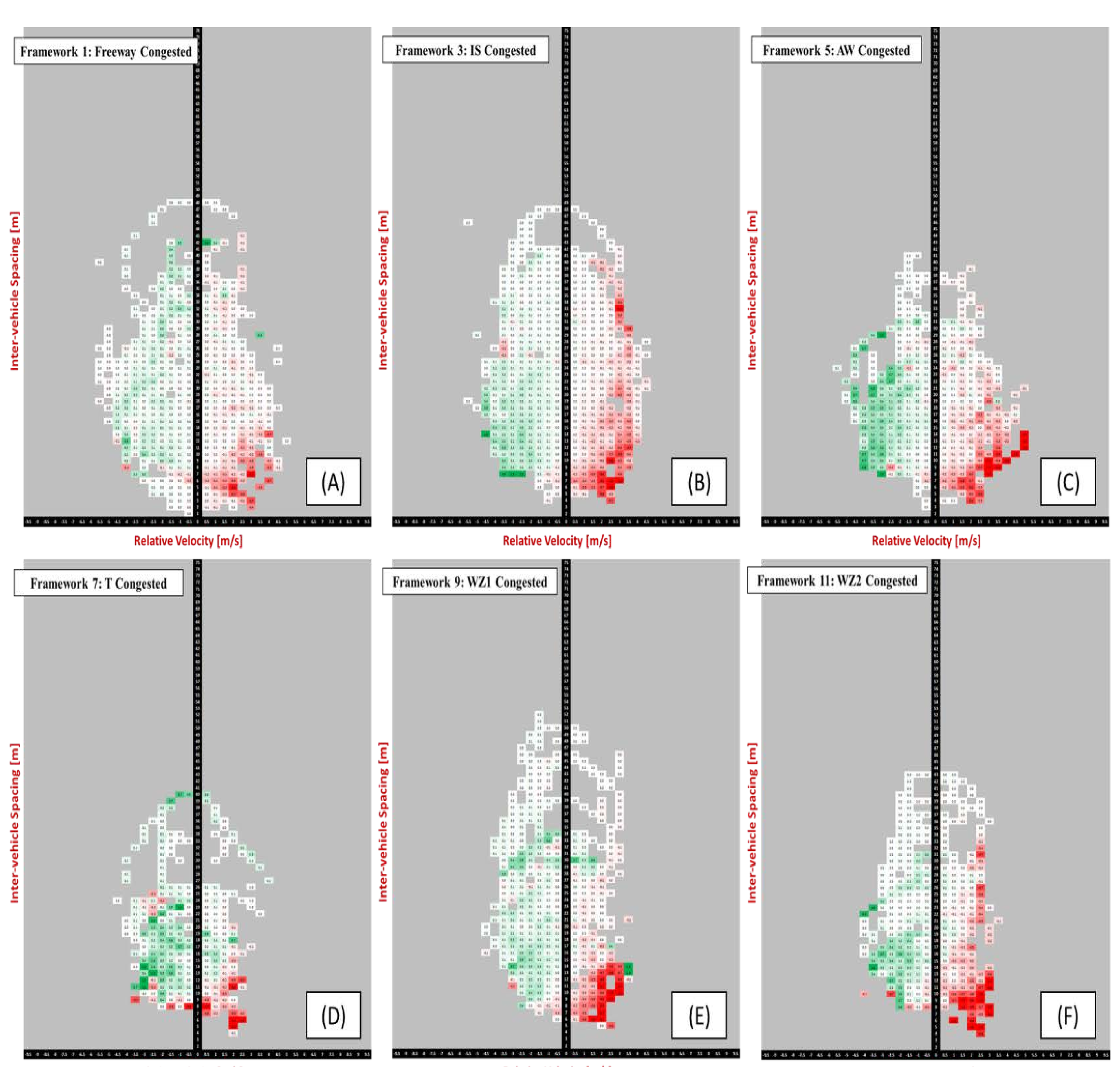

Figure 4: Analysis of Behavior by Road Type in Congested Conditions

Driver Behavior by Congestion Level

- Uncongested conditions are more dispersed over the $dV - dX$ plane. Behavioral trends (i.e., car-following spirals) are less prominent in uncongested conditions (see Figure 5).
- Heavy deceleration is detected at larger following distances in uncongested WZ 1 (lane closure) and WZ 2 (shoulder closure) (see Figure 5B&D) FWs. This indicates that roadway factors cause drivers to decelerate, even when the lead vehicle is not an imminent threat.
- WZ 1 in uncongested conditions (see Figure 5B) shows significant behavioral similarities to congested conditions; it is the only FW to do so.

The analysis shows non-WZ interstate conditions produce the cleanest CF spirals, while acceleration behavior in TZs is the most sporadic. Strong trends in WZ FWs indicate drivers' desire to maintain closer following distances, especially in AW zones.

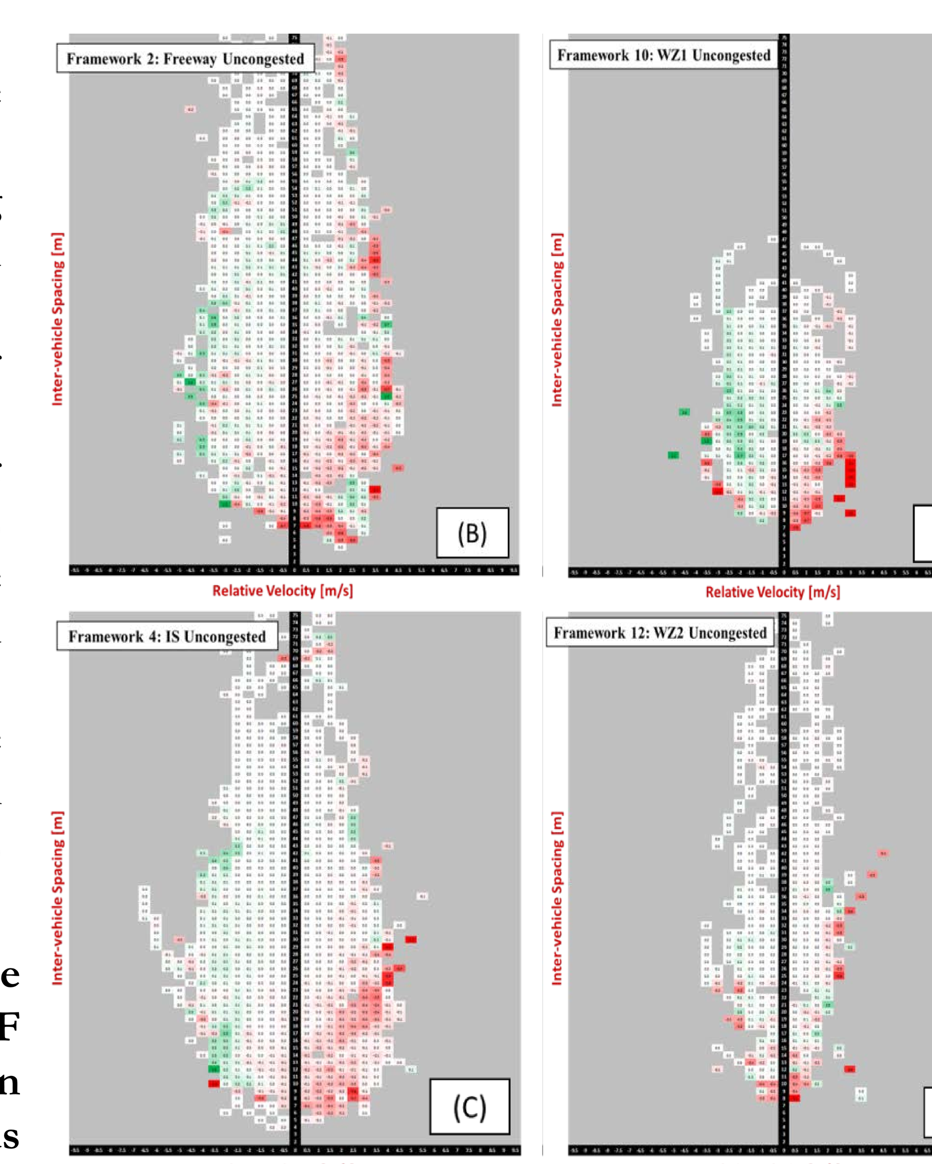

Figure 5: Analysis of Behavior by Road Type in Uncongested Conditions

Conclusions

Given the necessity of microsimulation models to optimally evaluate investment decisions, the accuracy of microsimulation models in depicting traffic conditions is important.

This research presents conclusive evidence—generated from a robust, trajectory-level dataset—that drivers' car-following actions vary while traveling in different driving environments (intra-driver heterogeneity). This finding is presented in an innovative manner, which aggregates CF acceleration behavior from 62 drivers, to account for inter-driver heterogeneity, and enables the identification of global trends in driver behavior.

These results serve as the foundation for continued research into the development of predictive driver behavior models capable of representing heterogeneous behavior in various driving environments. Current and future research is focused on developing the trends portrayed in this paper to calibrate the FHWA Driver Model.

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