Evaluation of Weather-Related Freeway Car-Following Behavior using the SHRP2 Naturalistic Driving Study

Britton E. Hammit Ph.D. Candidate1 | Ali Ghasemzadeh, Ph.D.1 | Rachel M. James Ph.D. Candidate2 | Mohamed M. Ahmed, P.E. Ph.D.1 | Rhonda Kae Young, P.E. Ph.D.3
1University of Wyoming, 2The University of Texas at Austin, 3Gonzaga University

Motivation

Adverse weather conditions negatively impact the safety, mobility, and reliability of the transportation network. Weather Responsive Traffic Management (WRTM) strategies have been developed to counteract the hazards and discontinue of adverse weather on the transportation system. In order to ensure investments for applications designed to mitigate the negative impacts of adverse weather, explicit evidence of the perceived benefits and challenges are required. Microsimulation modeling is a common tool used to anticipate those impacts and has more recently been introduced in real-time operational strategies. However, for reliable outcome results, realistic driving behavior must be represented in the models.

The purpose of this paper is to present findings related to intra-driver heterogeneity as a function of weather, or the adjustment in driving behavior to compute for different adverse weather conditions. This study provides an evaluation of drivers’ car-following behavioral changes in various adverse weather conditions—rain, snow, fog—and calibrates the Gipps car-following model to identify the modularity of those behavioral nuances.

The results produce conclusive evidence that intra-driver heterogeneity exists in different adverse weather conditions and indicates that the heterogeneity can be captured by calibrated Gipps parameters. This study supports a greater consideration of weather in current microsimulation modeling practices and constructs a novel trajectory validation methodology that can be used to compare observed and modeled behaviors.

Data

SHRP2 Naturalistic Driving Study (NDS) data were used to conduct this study. As part of the SHRP2 Implementation Assistance Program, WYDOT acquired a subset of the NDS database to enable the identification of driving behavior nuances present in adverse weather conditions. Preliminary data reduction and processing was completed using the WYDOT NDS Data Analysis Tool, which is a python-based analytic tool developed by the research team to efficiently process the NDS data. Automatic Identification of “Car-Following Events”, or instances of data for which the subject vehicle is following a single lead vehicle, was completed when the following event was met:

- Minimum of 20 seconds in length
- Minimum of 60 meters apart

- Minimum subject vehicle speed 1 m/s

Gipps Car-Following Model Calibration

The Gipps car-following model is a safety distance car-following model introduced in 1981, and has been used in many research studies and practical applications since. The Gipps Model has six input parameters:

1. Reaction Time
2. Desired Velocity
3. Desired Acceleration Rate
4. Desired Deceleration Rate
5. Predicted Lead Vehicle’s Max Deceleration Rate
6. Minimum Separation Gap as a Stop (s=0)

Model calibration requires the systematic adjustment of model parameters to improve output prediction of car-following behavior. The following calibration procedures were used:

a. Objective Function: RMSE
b. Measure of Performance: Following distance

The average calibrated parameters values for each condition are shown below. These analysis indicates how the calibrated parameters values among clear and adverse weather conditions.

<table>
<thead>
<tr>
<th>Weather Condition</th>
<th>Adjusted Time Gap</th>
<th>Observed Average Time Gap</th>
<th>Calibrated Average Time Gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Severe Weather</td>
<td>1.45 s</td>
<td>1.15 s</td>
<td>1.00 s</td>
</tr>
<tr>
<td>Medium Rain</td>
<td>1.54 s</td>
<td>1.52 s</td>
<td>1.48 s</td>
</tr>
<tr>
<td>Heavy Rain</td>
<td>1.65 s</td>
<td>1.49 s</td>
<td>1.25 s</td>
</tr>
<tr>
<td>Medium-Heavy Snow</td>
<td>1.58 s</td>
<td>2.24 s</td>
<td>1.91 s</td>
</tr>
<tr>
<td>Low Visibility</td>
<td>1.58 s</td>
<td>1.12 s</td>
<td>1.72 s</td>
</tr>
</tbody>
</table>

The observed car-following behavior from the original data are compared with the calibrated behavior using the validation trajectory.

Comparison of Time to Collision

From a safety perspective, time-to-collision (TTC) is a common metric used to quantify collision potential. Various forms of TTC are often used in microsimulation model analyses to evaluate the safety of a specific corridor or intersection. In this study, the basic definition of time-to-collision—only accounting for a near-end collision with the lead vehicle—is considered.

A negative value indicates a larger magnitude during the adverse condition, compared with the clear condition (e.g., a negative mean time gap in fog conditions indicates the mean time gap is larger in fog than in the matching clear trip).

The RMSE results for following distance show a clear positive trend indicating that the average difference between Gipps predicted behavior increases with weather intensity. The Pearson’s R correlation coefficient results for following distance also show greater trend variance as the weather intensity increases. Results for relative velocity and acceleration are similar.

Discussion & Conclusions

Chapter 11 of the 2016 Highway Capacity Manual (HCM) provides Weather Adjustment Factors (WAFFs), which can be used to predict reduced network speeds, travel capacity, and estimated delay at any given time and weather conditions. WAFFs are reported as a function of:

- (a) weather type and intensity
- (b) facility free flow speed (FFS)
- (c) observed average time gap from the HCM (with the exception of medium-heavy snow), while the calibrated average time gap is higher (derived from the trajectory validity procedure).

Both observed and calibrated conditions suggest a greater deviation from clear conditions as weather intensity increases. When comparing actual and calibrated driving behavior, very light, light, and medium rain conditions follow similar trends in both the actual and validation trajectories, while fog, heavy rain, and snow conditions are less similar. The reason for this difference is likely related to the sample size available for fog, heavy rain, and snow conditions.

The differences in headway estimations between the HCM, observed data, and calibrated conditions are not surprising, as there are many factors and assumptions impacting the deployment of the HCM (WAFFs), as well as limitations in applying the HCM using high resolution driving data. A few of these elements are discussed below:

- Discretization of weather conditions into explicit categories is extremely challenging due to the number of elements impacting a driver’s perception of and reaction to adverse weather (e.g., visibility, road surface quality, and vehicle performance).
- Heterogeneity in driver behavior among different geographic locations is a common assertion (e.g., drivers from X State are more timid than drivers from Y nation), which is why some models are not always representative of the entire state. Nonetheless, these results still contribute to the understanding of how drivers adjust their behaviors in specific weather conditions.

This work was conducted under the second Strategic Highway Research Program (SHRP) project, which is administered by the Transportation Research Board (TRB) of the National Academics, and it was sponsored by the Federal Highway Administration (FHWA) in cooperation with the American State Highway and Transportation Officials (AASHTO).

Acknowledgements

Data from the following sources were used:

- SHRP2 Naturalistic Driving Study (NDS) data were used to conduct this study. As part of the SHRP2 Implementation Assistance Program, WYDOT acquired a subset of the NDS database to enable the identification of driving behavior nuances present in adverse weather conditions.
- Automatic Identification of “Car-Following Events”, or instances of data for which the subject vehicle is following a single lead vehicle, was completed when the following event was met:

- Minimum of 20 seconds in length
- Minimum of 60 meters apart
- Minimum subject vehicle speed 1 m/s