Calibrating Car-following Models For Chinese Drivers Using Naturalistic Driving Data From Urban Expressways

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Introduction

- Car-following model
  - Cornerstone for microscopic traffic simulation and intelligent vehicle;
  - The development and investigation of these models have been almost entirely based on experiments conducted in Western countries;
  - Different driving styles, types of vehicles, traffic regulations as well as cultural environments (Lindgren et al., 2008b) may result in considerable differences in driving behavior and traffic operation.
Introduction

Short-following example of Chinese driver

- A car-following model performing well in Western countries may perform poorly in developing countries.
Introduction

Motivation

• How well are the existing models able to model Chinese drivers’ car-following behavior?

• What are the main disparities between car-following behavior in China and that in the US?
Data Preparation

Shanghai Naturalistic Driving Study (SH-NDS)

• From 2012 to 2015;
• Five vehicles with SHRP2 NextGen data acquisition systems
• Each participant drives the vehicle for 2 months;
• Sixty drivers’ data, with a total mileage of 161,055 km, have been collected.
Data Preparation

Data items

- Forward radar data
- Vehicle network data
- GPS data
- Accelerometer data
- Four synchronized camera views
- Collection frequency: 10-50 Hz

Four camera views from the SH-NDS
Data Preparation

- **Forward radar data**
  - Track, at most, 8 vehicles simultaneously
  - T0 to T7
  - Unique target ID
  - X and Y positions
  - X and Y velocities
Data Preparation

- Car-following periods extraction

- Initial criteria followed Ervin et al. (2005) and Higgs and Abbas (2013);
- Iterative adjustment:
  - Extract potential car-following periods;
  - Review corresponding video material to adjust the criteria.
- Final criteria:
  - Radar target’s identification remained constant;
  - $7m < \text{range} < 120m$, and speed of the research vehicle $> 5m/s$;
  - $-2.5m < \text{lateral distance} < 2.5m$;
  - $-2.5m/s < \text{relative speed} < 2.5m/s$;
  - Length $> 15s$. 
## Data Preparation

### Car-following periods analyzed

- Focusing on car-following periods on urban expressways

<table>
<thead>
<tr>
<th>Road type</th>
<th>Urban expressway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Num. of drivers</td>
<td>42</td>
</tr>
<tr>
<td>Num. of periods each driver</td>
<td>50 in total, 40 for calibration and 10 for validation</td>
</tr>
<tr>
<td>Total car-following periods</td>
<td>2,100</td>
</tr>
<tr>
<td>Cumulative time length</td>
<td>863 minutes</td>
</tr>
</tbody>
</table>
Model Calibration and Validation

**Procedure**

- **Calibration data**
- **Car-following models**
- **Genetic algorithm**
- **Validation data**

- Calibration errors
- Optimal parameters
- Validation errors
Model Calibration and Validation

Car-following models investigated

- Five represtantive car-following models

  a) Gaxis-Herman-Rothery (GHR) model: stimulus-based model

  b) Gipps model: safety-distance model

  c) Intelligent Driver Model (IDM): desired measures model

  d) Full Velocity Difference (FVD) model: optimal velocity model

  e) Wiedemann car-following model: psycho-physical model
Model Calibration and Validation

Genetic algorithm: objective function

- Calibration based on spacing is more robust and efficient than speed or acceleration (Punzo and Montanino, 2016).
- Root mean square percentage errors (RMSPE) of spacing:

\[
RMSPE = \sqrt{\frac{\sum_{i=1}^{N} (S_{i}^{\text{sim}} - S_{i}^{\text{obs}})^2}{\sum_{i=1}^{N} (S_{i}^{\text{obs}})^2}}
\]

- \(i\): observation
- \(S_{i}^{\text{sim}}\): the \(i\)th modeled spacing
- \(S_{i}^{\text{obs}}\): the \(i\)th observed spacing
- \(N\): is the number of observations
Model Calibration and Validation

Genetic algorithm: implementation

- The Genetic Algorithm Toolbox in MATLAB® was used;
- Optimization repeated 12 times for each driver, minimum error (i.e., RMSPE) was selected;
- Tested with synthetic data:
  - Set the GHR parameters as: $\tau_n = 1$, $\alpha = 1$, $\beta = 1$, and $\gamma = 1$
  - Generate synthetic car-following data were generated.
  - Calibration result: RMSPE = 0.003

<table>
<thead>
<tr>
<th>Algorithm setting</th>
<th>Method used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population size</td>
<td>300 (500 for Wiedemann)</td>
</tr>
<tr>
<td>Maximum num. of generations</td>
<td>300 (1300 for Wiedemann)</td>
</tr>
<tr>
<td>Stall generations</td>
<td>100 (150 for Wiedemann)</td>
</tr>
<tr>
<td>Convergence tolerance</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>Fitness scaling</td>
<td>Rank</td>
</tr>
<tr>
<td>Parent selection</td>
<td>Stochastic uniform</td>
</tr>
<tr>
<td>Children reproduction</td>
<td>Elite, crossover and mutation</td>
</tr>
<tr>
<td>Mutation</td>
<td>Gaussian</td>
</tr>
<tr>
<td>Crossover</td>
<td>Scatter</td>
</tr>
</tbody>
</table>
Model Calibration and Validation

 Calibration and validation errors

The FVD performed best:
1) second lowest calibration error and lowest validation error;
2) smallest standard deviation of error;
3) no occurrences of collision or backward movement.
## US and China Comparison

### Description of the two studies

<table>
<thead>
<tr>
<th>Item</th>
<th>Current study</th>
<th>Sangster et al. (2013)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Database</td>
<td>Shanghai Naturalistic Driving Study (SH-NDS)</td>
<td>VTTI 100-car Naturalistic Driving Study (VTTI 100-Car)</td>
</tr>
<tr>
<td>Num. of car-following periods</td>
<td>2100</td>
<td>More than 2000</td>
</tr>
<tr>
<td>Num. of drivers</td>
<td>42</td>
<td>8</td>
</tr>
<tr>
<td>Road</td>
<td>Inner Ring, Middle Ring, and Outer Ring expressways, Shanghai</td>
<td>Dulles Airport Access Road, multilane expressways, near Washington, D.C.</td>
</tr>
<tr>
<td>Objective function</td>
<td>RMSPE of space</td>
<td>RMSPE of space and speed</td>
</tr>
<tr>
<td>Optimization method</td>
<td>Genetic algorithm</td>
<td>Genetic algorithm, the maximum acceleration and comfort deceleration were observed from data</td>
</tr>
</tbody>
</table>
US and China Comparison

Parameters of the IDM model

- Desired time headway one second shorter than that of VTTI 100-Car Study; the most influential IDM parameter (Punzo et al., 2015)

<table>
<thead>
<tr>
<th>Name</th>
<th>SH-NDS Mean</th>
<th>VTTI 100-Car Mean</th>
<th>t value</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desired speed (km/h)</td>
<td>108.0</td>
<td>101.9</td>
<td>0.16</td>
<td>0.8734</td>
</tr>
<tr>
<td>Desired time headway (s)</td>
<td>0.8416</td>
<td>1.72</td>
<td>-7.53</td>
<td>0.0001</td>
</tr>
<tr>
<td>Maximum acceleration (m/s^2)</td>
<td>0.6747</td>
<td>5.948</td>
<td>-6.57</td>
<td>0.0003</td>
</tr>
<tr>
<td>Comfortable deceleration (m/s^2)</td>
<td>0.9198</td>
<td>5.961</td>
<td>-6.76</td>
<td>0.0002</td>
</tr>
<tr>
<td>Acceleration exponent</td>
<td>7.8837</td>
<td>16.79</td>
<td>-2.56</td>
<td>0.0276</td>
</tr>
<tr>
<td>Standstill gap (m)</td>
<td>3.0912</td>
<td>2.3713</td>
<td>2.29</td>
<td>0.0355</td>
</tr>
</tbody>
</table>
US and China Comparison

- Fundamental Diagram derived by the IDM model

\[
Q = \frac{v}{s + l}
\]

\[
\rho = \frac{1}{s + l}
\]

\[
s_e = \frac{s_{jam} + \tilde{T}}{\sqrt{1 - \left(\frac{v_e}{\tilde{v}}\right)^\beta}}
\]

- \( s_e \): equilibrium gap
- \( v_e \): equilibrium gap
- \( s_{jam} \): standstill gap
- \( \tilde{T} \): desired time headway
- \( \beta \): acceleration exponent
- \( \tilde{v} \): desired speed
- \( l \): the vehicle length, 5m
- \( s \): following gap
US and China Comparison

- Fundamental Diagram derived by the IDM model
  - Shoter following gap
US and China Comparison

- Fundamental Diagram derived by the IDM model
  - Larger capacity
Discussion

Better car-following models for simulation in China

• The Wiedemann model is used by the most popular microscopic traffic simulation tool in China—VISSIM®.

• Compared to the Wiedemann, the FVD model showed:
  - Higher performance
  - More stable performance
  - More easily to calibrate: number of parameters 5 vs. 13

• The FVD may be more suitable than Wiedemann to be applied for microscopic traffic simulation in China.
Discussion

Why Chinese drivers following tightly

• Aggressive: lower perception of risk?
• Cultural environment: in a rush?
• Avoiding cut-in?
Conclusions

• The full velocity difference (FVD) model performed best in modeling Chinese drivers’ behavior compared to the GHR, Gipps, IDM, and Wiedemann models.

• According to the IDM model, Chinese drivers adopt shorter desired time headways and following gaps than US drivers.

• Simulation models and components of intelligent vehicles must be calibrated to Chinese conditions before used in China.
THANKS

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