Fundamentals of Traffic Operations and Control
WEEK 5

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Different scales of traffic modeling

MACRO-LEVEL
MESO-LEVEL
MICRO-LEVEL

- Cars
- Buses
- Peds.
Why micro?

- Because sometimes details are relevant

In perspective (where micro-models will be really consolidated):

  - Because they could be (potentially) more “behavioral” than other approaches
    - Meso-models are (in part) inherently descriptive
      - “Capacity”, critical density, flow-density/speed curves describe “the average driver”
      - Might be different across different network locations
    - Micro-simulation is potentially behavioral
      - Car following model parameters depends on driver behaviors
      - In principle driver behaviours are stable for extended geographic areas
  - Calibrate drivers’ parameters and use them for all links of all networks
An example of real data

Model the movements and interactions of individual vehicles
General Characteristics of car following models

- Perception
- Decision Making
- Control

- Safety
- Efficiency
- Vehicle Dynamics and Power

Response = \lambda \ast \text{Stimulus}

\ddot{x}_f(t+T) = \lambda [\dot{x}_q(t) - \dot{x}_f(t)]
Driving sub-tasks in the car-following situation

- **Perception** – observation of the leading car motion in relation to the drivers’ car (vehicle speeds, acceleration, inter-vehicle spacing, relative speed, etc.) and interpretation of the situation

- **Decision making** – selection of a proper reaction (acceleration vs. deceleration, magnitude of reaction)

- **Reaction** – change in speed (acceleration, deceleration)
Driving sub-tasks in the car-following situation

One lane is considered
No lane changes and passing
Driver’s behavior is consistent over time

Notation:

\[ x(t) \quad \frac{dx}{dt} = v(t) = \dot{x}(t) \quad \frac{dv}{dt} = a(t) = \ddot{x}(t) \]
Block Diagram of Car Following

[Diagram showing the block diagram of car following with blocks labeled 'Perception & Information Collection', 'Decision Making & Execution', and 'Vehicle Dynamics', with arrows indicating the flow of information and feedback loop.]
Q-K vs. S-V

K: density
Q: flow
V: speed
S: spacing
Newell’s Model

- A simplified car-following theory: a lower-order model
- Very simple (simplistic?)
- minimum number of parameters

- The equation regulating the follower’s behaviour is:
  (Under congested Conditions)
  \[ x_f(t+\tau_n) = x_L(t)-d_n \]
  where \( x_f \) and \( x_L \) represent the positions of the follower and of the leader

- The trajectory of the follower is basically the same of the leader
  - Except for a translation in time and space regulated by parameters \( \tau_n \) and \( d_n \) (which may vary from user to user)
Newell’s Model

According to Newell...

driver selects preferred spacings for given vehicle velocities s.t. vehicle’s trajectory looks like its leader with translations in space & time

\[ \tau_j \& d_j \text{ are …} \]

1) independent of j’s velocity
2) drawn independently from a joint probability distribution

So ...

each wave propagates as a random walk with mean wave speed \( d/\tau \)

There are no instabilities !
Type of driver

Normal Driver

Cautious Driver

Aggressive Driver
Linear car-following model

\[ \dot{x}_2(t) = \frac{1}{\tau} [\dot{x}_1(t) - \dot{x}_2(t)] \]

Due to the time lag in the reaction of the second driver, the following is more appropriate:

\[ \dot{x}_2(t + \tau) = \frac{1}{\tau} [\dot{x}_1(t) - \dot{x}_2(t)] \]

response = sensitivity x stimulus

A general form of the linear model:

\[ \dot{x}_2(t + \tau) = \frac{C}{\tau} [\dot{x}_1(t) - \dot{x}_2(t)] \]
Example Simulation

\[ \dot{x}_2(t + \tau) = \frac{C}{\tau} [\dot{x}_1(t) - \dot{x}_2(t)] \]

\[ \dot{x}_2(0.0 + 1.0) = \frac{0.5}{1.0} [0.00] = 0.00 \text{ ft/s}^2 \]

\[ \dot{x}_2(1.3 + 1.0) = \frac{0.5}{1.0} [-1.50] = -0.75 \text{ ft/s}^2 \]

\[ \dot{x}_2(2.3) = \dot{x}_2(2.2) + \Delta t \cdot \ddot{x}_2(2.2) = \]

\[ \dot{x}_2(2.3) = 73.28 + 0.1 \cdot (-0.50) = 73.23 \text{ ft/s} \]

\[ x_2(2.3) = x_2(t) + \frac{1}{2} \ddot{x}_2(2.2) \cdot \Delta t^2 + \dot{x}_2(2.2) \cdot \Delta t \]

\[ x_2(2.3) = 161.26 + \frac{1}{2} \cdot (-0.50) \cdot 0.1^2 + 73.28 \cdot 0.1 \]

\[ x_2(2.3) = 168.59 \text{ ft} \]
Gazis-Herman-Rothery Model

- GHR model is one of the most famous car-following models in late 50s (General Motors)

- Its assumptions:
  - the acceleration of vehicle is proportional to relative speed and distance with the one in front.
  - the speed of itself has impact on it

\[
\ddot{x}_{n+1}(t + \Delta t) = \left\{ \frac{\alpha(\ell, m)(\dot{x}_{n+1}(t + \Delta t))^m}{(x_n(t) - x_{n+1}(t))^{\ell}} \right\} \left[ \dot{x}_n(t) - \dot{x}_{n+1}(t) \right]
\]
Stability Analysis
Example

Results
<table>
<thead>
<tr>
<th>C Value [C = α(Δγ)]</th>
<th>Local Stability</th>
<th>Asymptotic Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>Nonoscillatory</td>
<td>Damped oscillatory</td>
</tr>
<tr>
<td>(0.37)</td>
<td>Damped oscillatory</td>
<td>Increased oscillatory</td>
</tr>
<tr>
<td>(0.50)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.57</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Change in car spacing**

- **C = 0.50**
- **C = 0.80**
- **C = 1.57**
- **C = 1.60**

**Time**
Vehicle Interactions – Lane Changing

Process
Lane changing vehicle evaluates lead & lag gaps in adjacent lanes(s)
- Supply side: availability of lead and lag gaps
- Demand side: acceptability of lead and lag gaps
Type of Lane Changing

Mandatory: a vehicle MUST exit its current lane

Discretionary: a vehicle attempts to change lanes if moving below its desired speed and adjacent lane(s) move faster
Type of Lane Changing (2)

**Anticipatory:** a vehicle in a lane which may be involved in merging downstream attempts to change upstream in anticipation of congestion in the merge area.

**Cooperation:** vehicle(s) in target lane adjust their speeds to accommodate the lane changing vehicle.
Lane Changing

Mandatory and Discretionary Lane Changes:

- Discretionary lane change of thru vehicle
- Mandatory lane change of vehicle destined for off-ramp
Applicable to models, where an acceleration function can be defined:

\[ \frac{dv_\alpha}{dt} = a^{\text{mic}}(s_\alpha, v_\alpha, \Delta v_\alpha) \]

Safety criterion:

\[ \tilde{a}_n \geq -b_{\text{safe}} \]

Incentive criterion:

\[ \tilde{a}_c - a_c + p(\tilde{a}_n - a_n + \tilde{a}_o - a_o) > \Delta a_{\text{thr}} \]

\( M \) inimizing

\( O \) verall

\( B \) raking decelerations

\( I \) nduced by

\( L \) lane changes
Model Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safe deceleration $b_{\text{safe}}$</td>
<td>$2 \ldots 4 \text{ m/s}^2$</td>
</tr>
<tr>
<td>Politeness factor $p$</td>
<td>$0 \ldots 1$</td>
</tr>
<tr>
<td>Changing threshold $\Delta a_{\text{thr}}$</td>
<td>$0.1 \text{ m/s}^2$</td>
</tr>
</tbody>
</table>
How the Safety Criterion Works

Example: Lane change safe if new follower is not faster

In same situation, a lane change is not safe if follower is faster

Automatically crash-free & consistent with the car-following model

Sophistication of car-following model carries over to lane-change decision
Calibration of Microscopic Models

- Three Step Strategy
  - Capacity calibration
  - Route choice calibration
  - System performance calibration

- Process
  - Select parameters to be calibrated
    - Global
    - Link specific
  - Collect field data
  - Set calibration targets
  - Search for optimal parameter values
Search for optimal parameters

- Minimize “Mean Square Error” Field vs. Model
An interesting simulator

- www.traffic-simulation.de