Multi-level modeling of highway traffic

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Agenda

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Highway traffic modeling seeks the understanding of the interactions between vehicles, drivers and infrastructure in order to create an optimal road network and reduce traffic congestion problems.
Variables of Traffic flow:

**Vehicle**: velocity, size, separation, acceleration.
**Driver**: politeness, aggressivity, lane changing approach.
**Infrastructure**: traffic control devices, highways, entry and exit points.

Key concepts:

**Velocity**: distance covered per unit of time [km/h].
**Flow**: number of vehicles passing a reference point per unit of time [veh/h]
**Density**: number of vehicles per unit area [veh/km].
Real Data from Belgium Highway

Data obtained from a camera in Belgium, just before an entrance in the highway.
Real Data from Belgium Highway (cont)
The microscopic model consists in two different aspects:

**Lane following model**: indicates how the car advances in the current lane, when it accelerates or decelerates.

**Lane changing model**: indicates when the car should change lane.
Lane Following Model

- Based on the Intelligent Driver Model (IDM).
- Car accelerates or decelerates depending on his own velocity and the vehicle in front of him.

Parameters:

- $v_0$ = desired speed
- $s_0$ = minimum spacing
- $T$ = desired time spacing between cars.
- $a$ = acceleration
- $b$ = comfortable braking deceleration

\[
\frac{dv}{dt} = a \left[ 1 - \left( \frac{v}{v_0} \right)^\delta - \left( \frac{s^*}{s} \right)^2 \right]
\]

\[
s^* = s_0 + \left( vT + \frac{v\Delta v}{2\sqrt{ab}} \right)
\]
Parameters used for the simulation:

Note: for the simulation 10% of trucks is used.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Car</th>
<th>Truck</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_0$ (desired speed)</td>
<td>90 - 120</td>
<td>60 - 80</td>
</tr>
<tr>
<td>$S_0$ (minimum spacing)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$T$ (time between cars)</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>$a$ (acceleration)</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>$b$ (deceleration)</td>
<td>1.5</td>
<td>1.5</td>
</tr>
</tbody>
</table>
Lane Changing Model

- Based on MOBIL Model (Minimizing Overall Braking decelerations Induced by Lane changes)
- Change decision based on all neighboring vehicles.

Criterion to change lane:
- **incentive criterion:** the potential new target lane is more attractive i.e: can accelerate more.
- **safety criterion:** lane change can be performed safely. i.e: deceleration induced is not big.

Note: a politeness factor is included. It balances the positive impact on the car versus the effect it could have on other cars.
Simulation Demo

Note: created using Disim Simulator.
Microscopic Model Data
Macroscopic Model

Created by modeling the highway as segments.
Macroscopic Model (cont)

Formulas used to model the number of cars in each segment and speed they have.

\[
N_{i}^{(t+1)} = N_{i}^{(t)} + n_{i-1}^{(t)} - n_{i}^{(t)} + e_{i}\Delta t
\]

\[
n_{i} = \frac{N_{i}v_{i}\Delta t}{L} \left(1 - \frac{N_{i+1}}{N_{max}}\right)
\]

\[
v_{i}^{(t+1)} = v_{i}^{(t)} + a \left(1 - \left(\frac{v_{i}}{v^{*}}\right)^{6} - \left(\frac{s^{*}}{s}\right)^{2}\right)\Delta t
\]

\[
s^{*} = d_{0} + v_{i}^{(t)}T + \frac{v_{i}^{(t)}(v_{i}^{(t)}-v_{i+1}^{(t)})}{2\sqrt{ab}}
\]
Since the macroscopic model wasn't created considering the lane changes a factor was introduced to model the behavior when the number of lanes is reduced from one segment to the following one. This was done by multiplying by a factor $n$.

\[ s = \frac{n_i}{n_{\text{max}}} \]
\[ \theta = 1 - \frac{W_{i+1}}{W_i} \]
\[ \eta = 1 - 0.5 \frac{s^n}{s^n + \theta^n} \]
Steady State

Obtained when the input flow matches the output flow of each segment in infinity.

\[ N_i^{(t+1)} = N_i^{(t)} \]

\[ N_{i-1} v_{i-1} \left( 1 - \frac{N_i}{N_{\text{max}}} \right) - N_i v_i \left( 1 - \frac{N_{i+1}}{N_{\text{max}}} \right) + L e_i = 0 \]

\[ 1 = \left( \frac{v_i^{(t)}}{v^*} \right)^6 - \left( \frac{s^*}{s} \right)^2 \]
Microscopic vs Macroscopic

Flow and speed with 1000 vehicles per hour and per lane.
Microscopic vs Macroscopic

Flow and speed with 2000 vehicles per hour and per lane.
Congestion Shockwave

Corresponds to the propagation waves created in traffic when a congestion is being released. This phenomena can be visualized plotting the time vs the length of the highway.
Conclusion and Future Work

Conclusions:
- System is complex enough to allow the modeler to play around with different parameters.

Improvements:
- Microscopic model could be modified to include other aspects of reality such as reaction time of drivers, types of drivers
- Model real life traffic inflow.
- Include lane changing into macroscopic model.
References

http://www.vwi.tu-dresden.de/~treiber/MicroApplet/MOBIL.html
http://www.vwi.tu-dresden.de/~treiber/MicroApplet/IDM.html
http://en.wikipedia.org/wiki/Microscopic_traffic_flow_model