Agent-Based Modeling of Traffic Flow and Accident Risk

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INTRODUCTION

Traffic flow emerges from countless local driver decisions under imperfect information and heterogeneous behavior. Any tiny differences in reaction time or preferred gaps amplify along a platoon, producing stop-and-go waves and, at worst, unsafe headways and crashes. Then we have some problems to figure out:

- What is the theoretical motion of vehicles in daily traffic flow?
- What does the traffic flow look like in real life?
- Are there any phenomena that we can observe through simulation?

Based on these propositions, we aim to simulate traffic flow as realistically as possible.

DEFINITIONS AND FORMULAS

Headway Gap

Consider a lane of N cars indexed from right to left.

The headway gap between cars n and $n-1$ is

$$g_n(t) = x_{n-1}(t) - x_n(t),$$

where $x_n(t)$ denotes the position of the car $n = 2, 3, ...N$.

The lead car ($n = 1$) would accelerate to speed v_{max} with a maximal acceleration of $a_{lead} > 0$.

Optimal Velocity Model

The Optimal Velocity Model (OVM) is given by

$$\dot{v}_n(t) = \alpha_n(V(g_n(t)) - v_n(t)),$$

with the following parameters:

- Unitless sensitivity α_n, which differs by the type of driver in the vehicle
- Desired speed function $V(g_n(t))$ [m/s], denoted for clarity as $V(g)$ from now on

α determines how responsive a driver is to unexpected developments on the road.

Desired Speed

The desired speed function relates the speed limit and safe driving distance, given by

$$V(g) = \frac{v_{max}}{2}\left(1 + \tanh\left(\frac{g - d_0}{G}\right)\right).$$

- v_{max} [m/s] is the fixed maximal speed
- $g - d_0$ [m] is the difference between the safe driving distance and the actual headway gap between cars.
- G is the transition width controlling steepness

RULES FOR CHANGING LANES

Gaps

When a fixed car n is about to change lanes, there are three main conditions to consider: (1) the gap between n and the car directly ahead of it in its current lane, (2) the gap between n and the car ahead of it in the target lane, and (3) the gap between n and the car behind it in the target lane.

Safety Function and Worthwhile Lane Changing

The safety function is $s_{\min}(v)\ [\mathrm{m}] = \max(s_0, T_h\, v)$, where s_0 [m] is the standstill safety gap (hard floor; not the OVM parameter $d_{0,i}$), and T_h [s] is the *time headway* (larger T_h demands more space at higher speeds).

$$\Delta V_{\mathrm{ego}}\ [\mathrm{m/s}] = V_i(g_{\mathrm{ahead,tgt}}) - V_i(g_{\mathrm{ahead,cur}}),$$

and with a left/right bias b_{LR} we test

$$\Delta V_{\mathrm{ego}} + b_{\mathrm{LR}} \ \geq\ \Delta V_{\min},$$

where $\Delta V_{\min}$ [m/s] is the minimum advantage required to justify changing lanes.

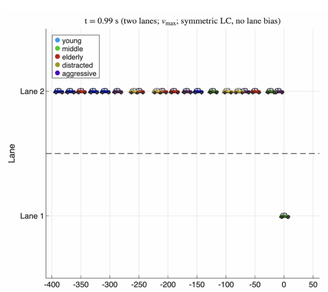
When to change

The vehicle should switch to the target lane if there is a sufficient safety function margin between the vehicle and the cars in the target lane, a velocity advantage by OVM, and an adequate headway gap between all cars involved after the vehicle changes lanes.

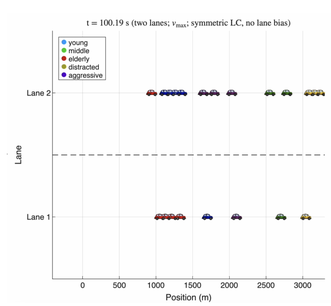
Another condition is when the vehecle is in the Lane 2, it should switch to Lane 1 if the sufficient safety function margin condition is met. This is to reflect the real world situation.

OUR SIMULATION

Original Condition. The following two graphs illustrate **Double Lane-Changing Simulation** without right lane bias. Cars would change lanes if they are too close to the front/back car.



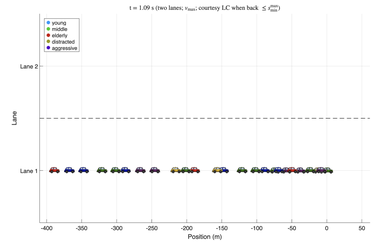
Initial configuration with no lane bias



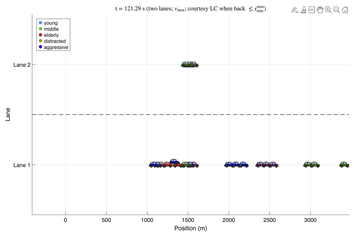
Final state after long simulation, with no lane bias

OUR SIMULATION (CONT.)

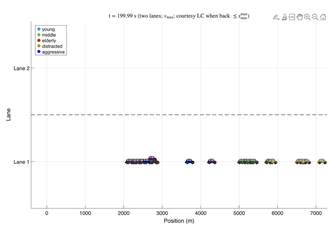
Lane Bias. The following three graphs present **Double Lane-Changing Simulation With Right Lane Bias**. In addition to lane changing when too close, cars would always lane change to the right if possible.



At first, every car will go to the Lane 1 due to the bias



If cars of the same type drive next to each other, it creates a congestion



After a sufficiently long time, cars of the same type tend to clump together

RESULTS

Drivers of the same category drive at similar speeds. Over time, this difference in velocity separates the drivers on the road into their respective categories.

In 87/100 simulations, the vehicles exhibited this behaviour. Aggressive drivers surge ahead of all other types of drivers on the road.

If two drivers are the same type and are adjacent to each other, then there will be traffic jams if their max speed is lower than other types.

Same-type cars maintain similar speeds. If two slower drivers end up side-by-side, they create a persistent block that prevents faster cars from passing, producing traffic congestion.

References

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