Co-operative Autonomy

Introduction

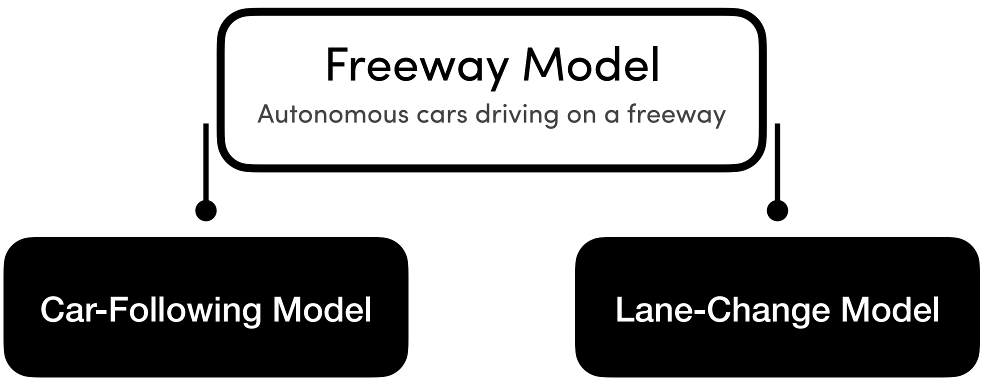
This model presents an autonomous, two-lane driving environment with a single lane-closure that can be toggled. The four driving scenarios - two baseline cases (based on the real-world) and two experimental setups — are as follows:

- **Baseline-1** is where cars are not informed of the lane closure.
- **Baseline-2** is where a Red Zone is marked wherein cars are informed of the lane closure ahead.
- **Strategy-1** is where cars use a co-operative driving strategy - FAS.[1]
- **Strategy-2** is a variant of Strategy-1 and uses comfortable deceleration values instead of the vehicle's limit.

To simulate autonomous car-following behavior, we use the widely accepted Intelligent Driver Model (IDM) by Treiber (2000). In order to allow cars modeled with IDM to make lane changes in our two-lane freeway, we use a lane change model - Minimizing Overall Braking Induced by Lane changes (MOBIL) — by Kesting et al. (2007).

The results folder contains a spreadsheet where we compare each driving scenario with the others. Every metric is also tested for statistical significance. For more details, refer [1].

Components



1. Intelligent Driver Model

To simulate autonomous car-following behaviour, we use the widely accepted **Intelligent Driver Model** (IDM) by Treiber (2000). IDM models both human and Adaptive cruise control (ACC) assisted driving accurately. It uses elegant and simple parameters used make it fairly suitable for microscopic simulations. Also, IDM has already been used extensively to model autonomous cars.[4][5]

- Equation for Acceleration

$$a = a_{\max}\left(1 - \left(\frac{v}{v_0}\right)^{\delta} - \left(\frac{s^*(v,\,\Delta v)}{s}\right)^2\right)$$

where,

a_{max} is the max acceleration of the vehicle

v and v_0 are current and desired speeds

δ is the acceleration exponent (set to 4) s^* is the desired minimum gap

Δv is the speed difference to the car ahead s is the gap to the car ahead

- Equation for Desired Minimum Gap

$$s^*(v,\,\Delta v) = s_0 + vT + \frac{v\Delta v}{2\sqrt{a_{\max}b}}$$

where,

s_0 is jam-distance

T is safe time headway

b is comfortable deceleration

2. Lane-Change Model

To allow cars to make lane changes, we use **Minimizing Overall Braking Induced by Lane changes** (MOBIL) by Kesting et al. (2007). Lane changes are based on two criteria — a safety criterion; and an incentive criterion. MOBIL has a politeness factor which takes a value ranging from 0 to 1 and can be interpreted as a degree of altruism. A lower politeness factor resembles the behaviour of inconsiderate lane-hoppers. A higher politeness factor stops cars from making lane changes that would deteriorate the overall traffic situation.

- Safety Criterion

$$\tilde{a}_n \geq -b_{safe}$$

- Incentive Criterion

$$\tilde{a}_v - a_v + p\left(\tilde{a}_n - a_n + \tilde{a}_o - a_o\right) > \Delta a_{\mathrm{th}}$$

where,

$\tilde{a}$ and a are current and future accelerations

p is the politeness factor

Δa_{th} is the acceleration threshold

Environment Specifics

Car

Cruising speed [6]	70 mph
Max acceleration [7]	0.97 m/s^2
Max deceleration [8]	3.97 m/s^2
Comfortable deceleration [8]	2.59 m/s^2

Road

Observed Length	1500 m
Blockade mark	1250 m
Distance between sign and blockade [9]	1000 m

The values used in this model have real-world relevance [6-9]. All values are scaled as:

1 Patch = 5 meters
1 Tick = 100 milliseconds

Usage

Click on the SETUP button to set up the world. Click on GO to start the simulated traffic flow. The GO ONCE button simulates the traffic flow for one tick of the clock (100ms).

The TOGGLE-BLOCKADE button toggles the presence of a blockade (and a Red Zone).

The POLITENESS-FACTOR-MEAN and POLITENESS-FACTOR-DEVIATION sliders control the Normal (Gaussian) distribution of politeness factor p values of the cars on the road. The politeness factor p determines the degree to which a car's neighbors influence its lane-changing decisions. [3]

The SCENARIO dropdown lets you choose the driving scenario to be simulated.

You may wish to slow down the model with the speed slider to watch the driving and lane-changing decisions of certain cars more closely.

The NUMBER OF CRASHES and NON-REALISTIC BRAKING OCCURRENCES monitors help validate the simulation. Ideally, a driving strategy for autonomous cars should not give rise to crashes. Similarly, no car should be asked to decelerate over its braking limit.

The MEAN SPEED monitor shows the average speed in m/s for the cars currently in the world.

The quality of traffic flow can be measured with the following monitors:

- **Throughput (cars/min):** The number of cars that exit the world per tick.
- **Mean Halt Time (min):** The average time that a car remains stationary for while transiting through the world.
- **Mean Car Density (cars/15000 m^2):** The average number of cars present in the world, which has an area of 15000 m^2, at any given instance.
- **Spawn Rate (cars/min):** The number of cars that enter the world per minute.
- **Mean Travel Time (min):** The average time that a car takes to transit through the entire length of the world.

The MEAN TRAVEL TIME plot helps visualize the evolution of the quality of traffic flow over time.

References

[1] Mohammed, Hani, Venkat Himavanth Reddy, and Subu Kandaswamy. "A Decentralized Strategy for Cooperative Driving among Autonomous Cars at Lane Closures." 2020 IEEE 32nd International Conference on Tools with Artificial Intelligence (ICTAI). IEEE, 2020.

[2] Treiber, Martin, Ansgar Hennecke, and Dirk Helbing." Congested traffic states in empirical observations and microscopic simulations." Physical review E 62.2 (2000): 1805.

[3] Kesting, Arne, Martin Treiber, and Dirk Helbing." General lane-changing model MOBIL for car-following models." Transportation Research Record 1999.1 (2007): 86-94.

[4] Zhou, Mofan, Xiaobo Qu, and Sheng Jin, "On the impact of cooperative autonomous vehicles in improving freeway merging: a modified intelligent driver model-based approach," IEEE Transactions on Intelligent Transportation Systems 18.6 (2016): 1422-1428.

[5] Treiber, Martin, Ansgar Hennecke, and Dirk Helbing, "Microscopic simulation of congested traffic," Traffic and granular flow'99, Springer, Berlin, Heidelberg, (2000): 365-376.

[6] "Speeding and Aggressive Driving." Governors Highway Safety Association. https://www.ghsa.org/state-laws/issues/speeding%20and%20aggressive%20driving/

[7] Yang, Guangchuan, et al. "Acceleration characteristics at metered on-ramps." Transportation Research Record 2484.1 (2015): 1-9.

[8] Bokare, P. S., and A. K. Maurya. "Acceleration-deceleration behaviour of various vehicle types." Transportation research procedia 25 (2017): 4733-4749.

[9] Portable Changeable Message Sign Handbook. Report No. FHWA-RD-03-066. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. https://www.fhwa.dot.gov/publications/research/infrastructure/pavements/ltpp/reports/03066/index.cfm