Simulating traffic and the effect of lane chaning

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1 Introduction

2 Method

2.1 Model Description

This section describes a simulation model for vehicular traffic on a multi-lane, periodic road. In this model, each vehicle is characterized by its position p and velocity v. The vehicle dynamics are governed by discrete updates, with position and velocity evolving according to the Euler Forward Method.

The position of a car at the next time step, denoted as p_{i+1}, is calculated using its current position p_i and velocity v_i, and is constrained by the length of the road. This is mathematically represented as:

$$p_{i+1} = (p_i + v_i \cdot dt) \bmod \textit{road length}$$

Similarly, a vehicle's velocity is updated considering its maximum acceleration, maximum deceleration, and a dynamically calculated target velocity. This target velocity is a crucial safety parameter, computed based on the distance to the preceding vehicle. It ensures that a car can decelerate safely to avoid collision, even in scenarios where the leading car stops abruptly. The target velocity is given by:

$$\textit{target velocity} = \sqrt{2 \cdot \textit{decelaration} \cdot \textit{distance}}$$

subject to the constraints:

$$0 \leq \textit{target velocity} \leq \textit{max velocity}$$

This model aims to prevent collisions by adjusting each car's velocity, within the bounds of zero and the pre-defined maximum velocity, according to the computed target velocity. In the event of a potential collision, the trailing vehicle will halt until its no longer colliding.

2.1.1 Spontaneous Braking

To introduce variability in vehicular velocities, a mechanism of spontaneous braking is incorporated. At each time step, there exists a minor probability that any given vehicle will be compelled to brake instantaneously. This aspect introduces an additional layer of complexity to the traffic dynamics, enhancing the realism of the simulation. It also underscores the strategic advantage of lane changing, particularly in response to the abrupt stopping of a preceding vehicle.

2.1.2 Lane chaning

In our model, each vehicle is assigned to a specific lane and can switch to adjacent lanes. Lane-changing decisions are algorithmically determined based on the following safety criteria:

- There must be no vehicle occupying the same road segment in the target lane, as this would result in a collision.
- The vehicle following the lane-changing car must have sufficient distance to brake safely and avoid a collision.
- Post lane-change, the lane-changing vehicle must be able to brake in time if the vehicle ahead in the new lane is moving slower.

Once a vehicle determines that a lane change is feasible, it evaluates the benefits of switching lanes. The model calculates a 'lane score' (ranging from 0 to 1) for three options: switching to the right, to the left, or remaining in the current lane. The vehicle then selects the option with the highest score.

Two main strategies are used for calculating the lane score:

1. *Forward-Looking*: The lane score is determined based on the target velocity achievable in the new lane.
2. *Bi-directional* method, the lane score combines the achievable target velocities for the lane-switching vehicle and the vehicle behind it in the new lane. This approach ensures that lane changes are beneficial for both the switching vehicle and the trailing vehicle in the target lane.

In the simulation, both strategies will be assessed. Additionally, a bias is introduced to discourage unnecessary lane changes, favoring the vehicle's current lane. This bias significantly influences car behavior. To identify the optimal lane-switching behavior, different bias values will be tested.

2.2 Model Configuration

In this report, we detail the configuration of the model utilized for each iteration of the traffic simulation. Parameters are specified in standardized units where lengths are multiples of car lengths and time is measured in simulation steps.

2.2.1 Simulation Parameters

The simulation is configured with a set of parameters outlined in Table 1. These parameters are integral to the behavior and outcome of the simulation, dictating the dynamics of vehicle movement and interaction within the simulated environment.

Parameter	**Description**
Total Road Length	The length of the simulated road, expressed in multiples of a car's length.
Lane Count	The number of traffic lanes available on the road.
Vehicle Density	The proportion of the road occupied by vehicles.
Acceleration Rate	The rate of acceleration for vehicles. A value of 1 signifies full acceleration to maximum velocity in one time step.
Deceleration Rate	The rate of deceleration for vehicles. A value of 1 signifies full deceleration to a halt in one time step.
Maximum Per-Step Movement	The maximum distance a vehicle can travel in a single simulation step. This is the product of the maximum velocity and the time step (delta time).
Spontaneous Stop Probability	The probability of a vehicle randomly coming to a halt at any given step.
Current Lane Bias	The bias towards remaining in the current lane when evaluating potential lane-switching maneuvers.
Simulation Duration (Steps)	The total number of steps (time intervals) for which the simulation will run.

Table 1: Simulation Run Configuration Parameters

Not every possible permutation of these parameters can be practically analyzed. Therefore, a subset is selected based on intuitive reasoning, observation of simulation runs, and evaluation of parameter convergence.

Through intuition and observation of the simulation, the following default parameters were established, as shown in Table 2.

Parameter	Default Value
Total Road Length	200
Lane Count	20
Vehicle Density	0.05
Acceleration Rate	0.005
Deceleration Rate	0.05
Maximum Per-Step Movement	0.1
Spontaneous Stop Probability	0.001
Current Lane Bias	0.1
Simulation Duration (Steps)	10000

Table 2: Default Simulation Parameters

In this study, the focus is not on the Total Road Length and Lane Count, as variations in these do not significantly impact the results due to convergence effects. The Maximum Per-Step Movement parameter mainly influences the simulation's temporal resolution. Lower values yield finer granularity but necessitate a longer duration to simulate equivalent vehicular travel, demanding more computational resources. It was observed that beyond 10,000 iterations, there is no significant change in traffic flow, allowing the Simulation Duration to be capped at this value.

This analysis concentrates on the impact of the following parameters on traffic flow dynamics:

- Vehicle Density
- Acceleration Rate
- Deceleration Rate
- Spontaneous Stop Probability
- Current Lane Bias

These parameters are hypothesized to have a more pronounced effect on the simulation's outcome and are thus the primary subjects of investigation in this report.

3 Results

4 Discussion