Smoothing Traffic Flow via Autonomous Vehicles

Python Simulations and Numerical Experiments

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Outline

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- Conclusions
- Future Goals
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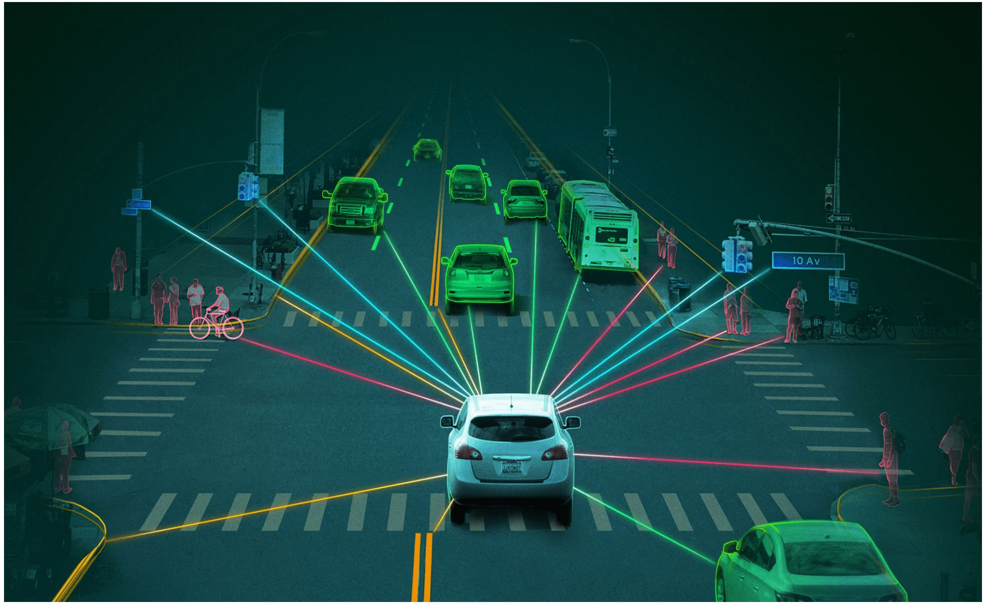
BACKGROUND

Traffic congestion is a constant safety and efficiency hazard.

- Burdens on existing transportation infrastructure.
- Loss of fuel economy, low travel efficiency, risk of accidents.
- Increasing costs of road infrastructure and petrol.

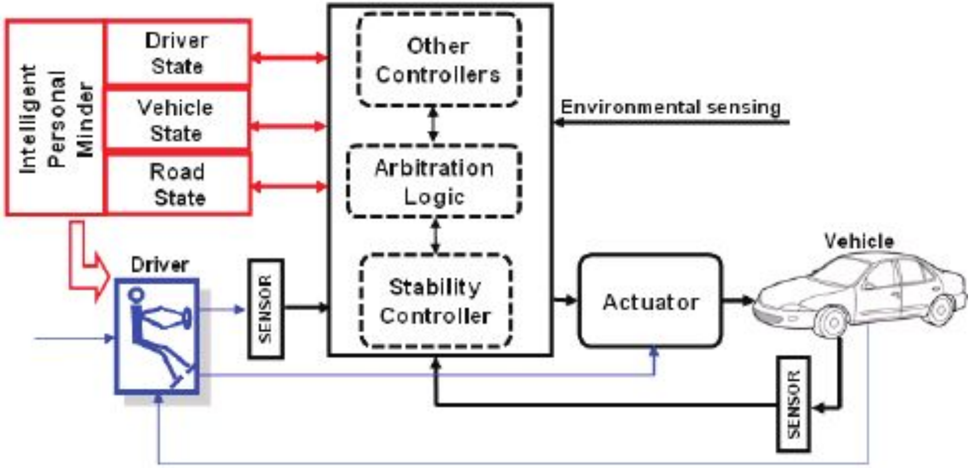
‘Mixed Traffic’ seems to be the current norm.



- AVs (autonomous vehicles) are used alongside HDVs (human-driven vehicles).
- Can stabilize traffic waves and alter speed. [1]
- Allows for better control over the state of traffic.

Many strategies have been developed to control traffic.

- Controllers already exist :
  - FollowerStopper [2]
  - PI with Saturation [2]
  - Linear Optimal Control [2]
  - L-ACC Controller [3]
  - …
- These models are compared to get the “best” model.



PROJECT

Goals

Creating a Python-based simulation framework in order to compare various controllers.

Get more insight on control strategies, test efficacy with varying penetration rate.

- Create a ring-road model in Python to simulate an N-vehicle mixed traffic system.
- Use the framework to test and implement more control strategies.
- Gather and analyze numerical data.
- Expand simulation size.
- Create a webpage.

Problem

- How can we quantify the comparison of several controllers?
- “Phantom Traffic Jams” : Common occurrence on highways, easy to settle with AVs.

EXPERIMENT & DATA

Setup - Models

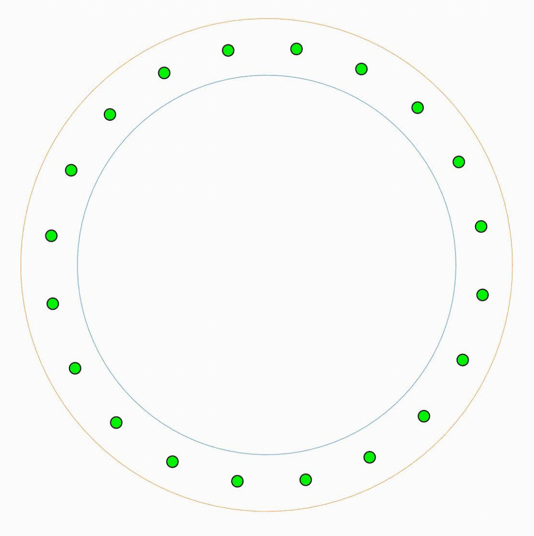
- HDVs follow ‘Optimal Velocity Model’. [2]
- AVs create optimization problem with input data.
- Optimization problem solved with MOSEK solver.
- Solution used to create controller.

Setup - Experiment

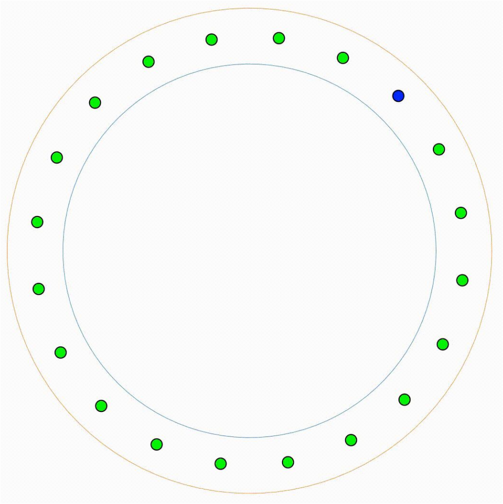
- Desired speed : 15m/s , Minimum speed : 8m/s
- Maximum Acceleration : 2 m/s^2
- At t = 20 sec, vehicle #4 slowed to 8m/s
- Simulation Time :
  - For N = 20 & 45 : 100 sec
  - For N = 70 : 200 sec
- Calculate settling time, maximum spacing and energy [4]

Step 1 : Simulation - Animation

All HDVs

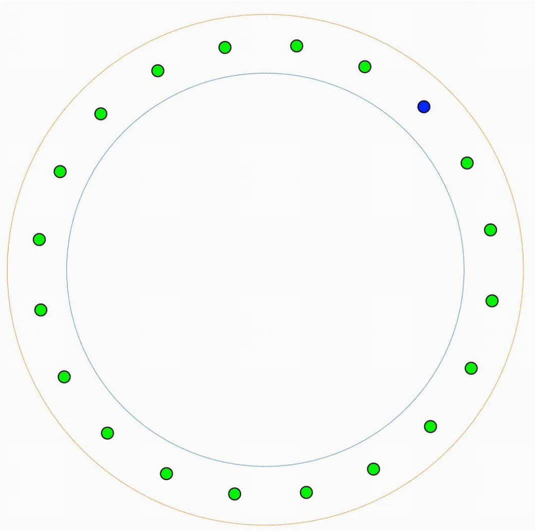


1 AV - Linear Optimal

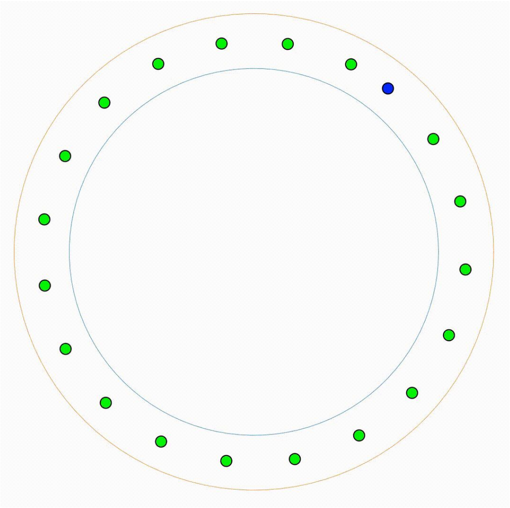


Step 1 : Simulation - Animation

1 AV - FollowerStopper

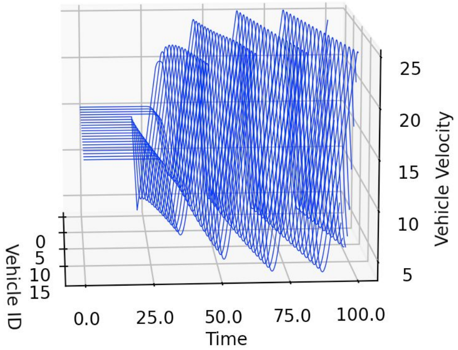


1 AV - PI w/ Saturation

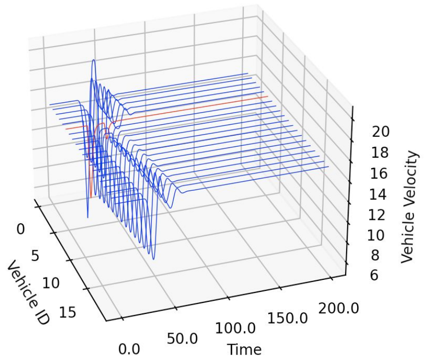


Step 1 : Simulation - Graphs

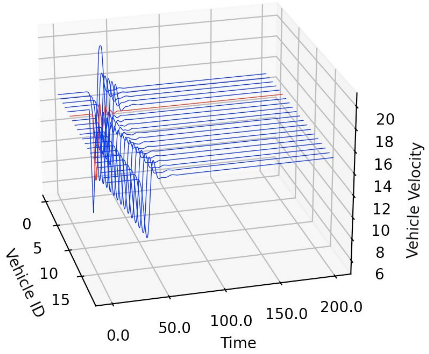
All HDVs



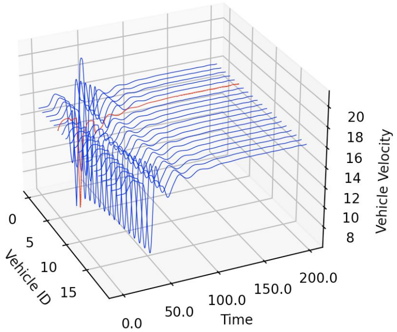
1 AV - FollowerStopper



1 AV - Linear Optimal



1 AV - PI w/ Saturation

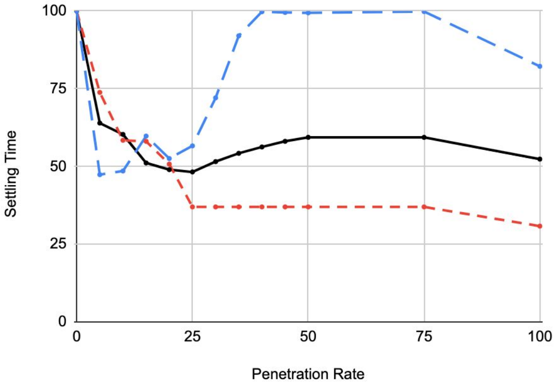


Step 2 : Data Collection - Settling Time

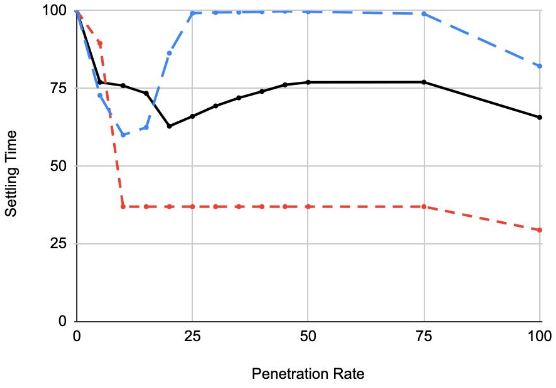
Platoon Formation

- Linear Optimal
- FollowerStopper
- PI with Saturation

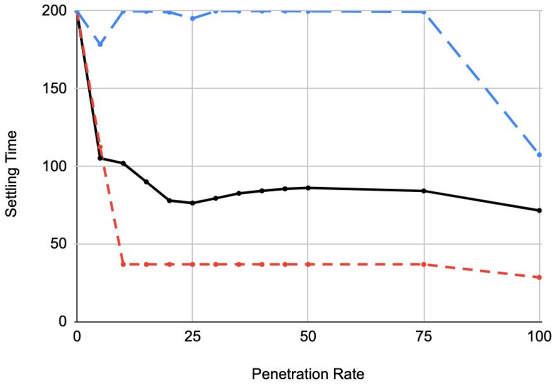
N = 20



N = 45



N = 70

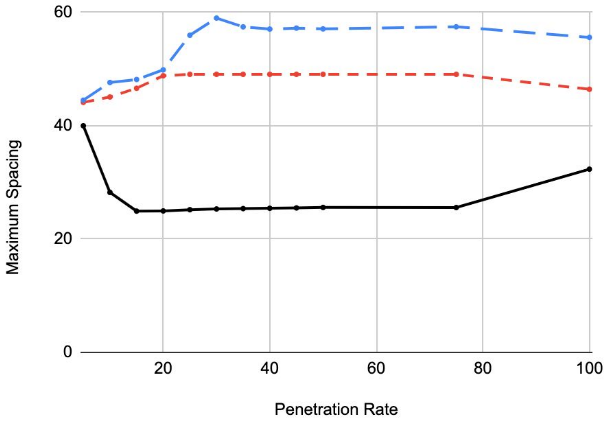


Step 2 : Data Collection - Maximum Spacing

Platoon Formation

Linear Optimal
FollowerStopper
PI with Saturation

N = 20



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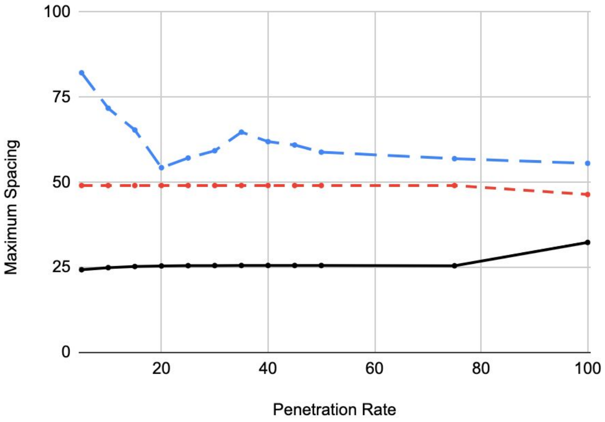

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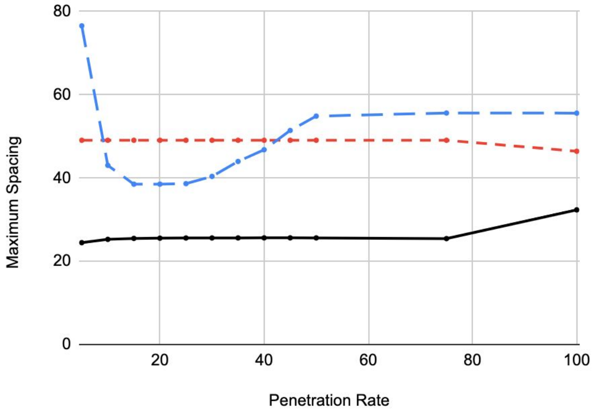
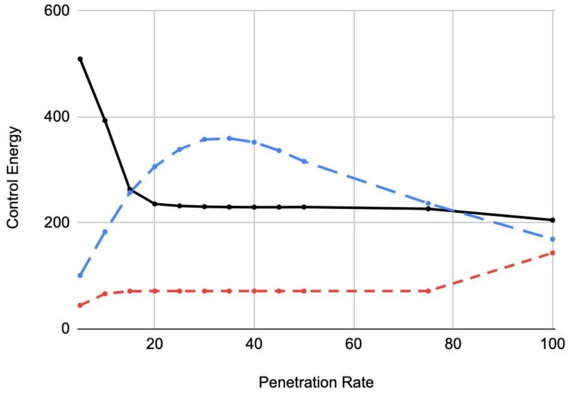


Step 2 : Data Collection - Energy

Platoon Formation

N = 20



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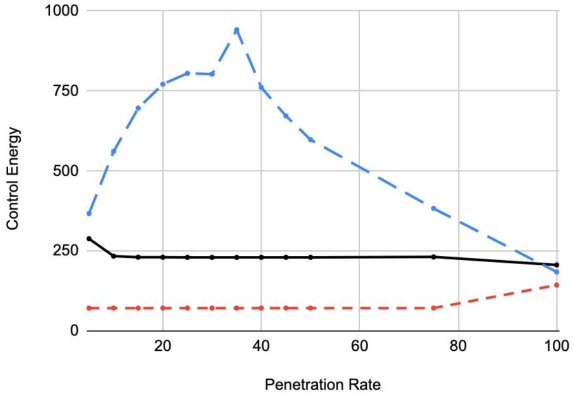

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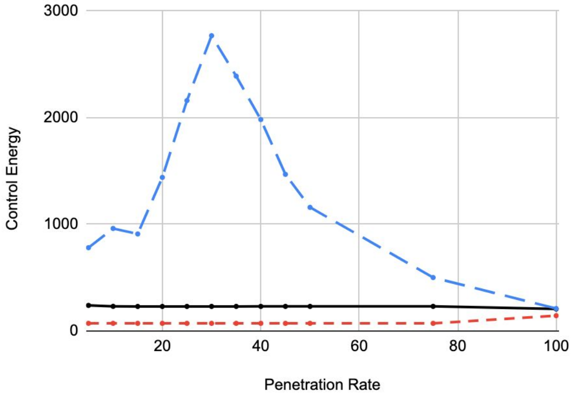
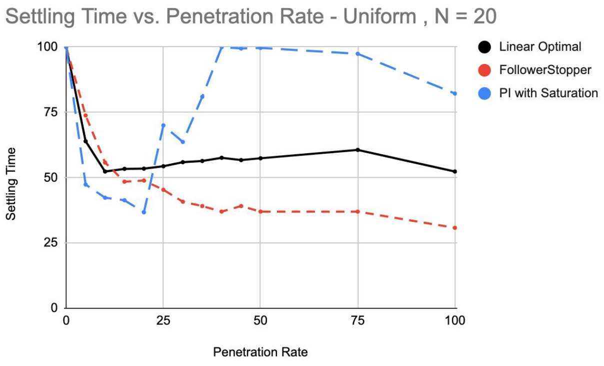


Step 2 : Data Collection - Settling Time

Uniform Distribution

N = 20



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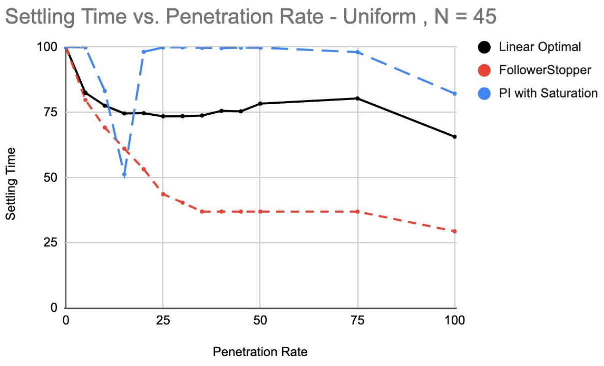

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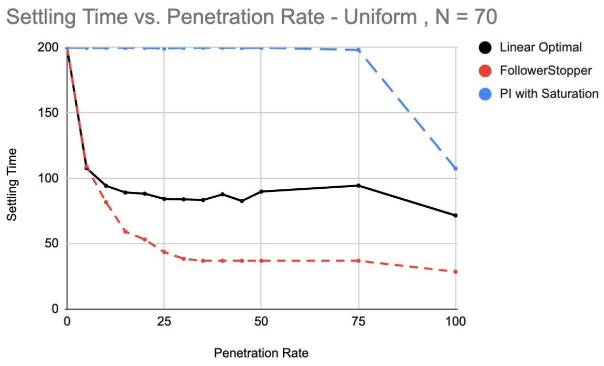
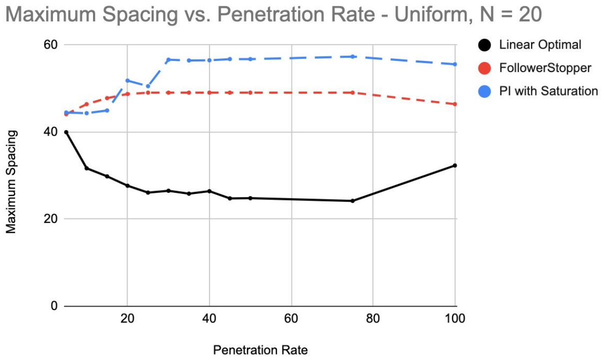


Step 2 : Data Collection - Maximum Spacing

Uniform Distribution

N = 20



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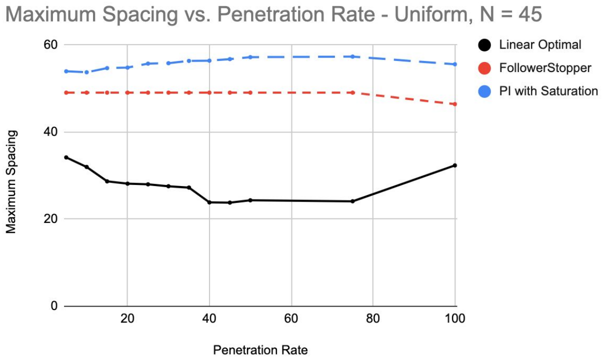

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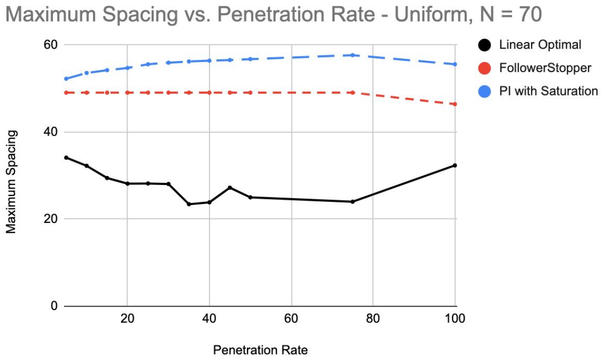
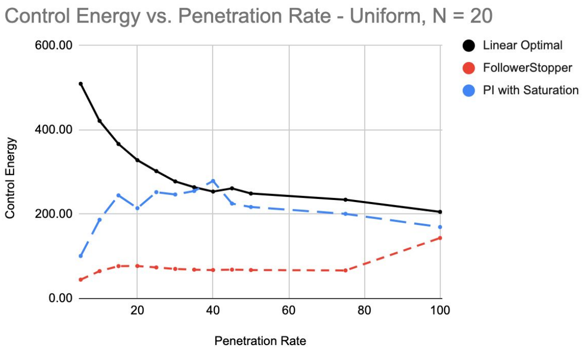


Step 2 : Data Collection - Energy

Uniform Distribution

N = 20



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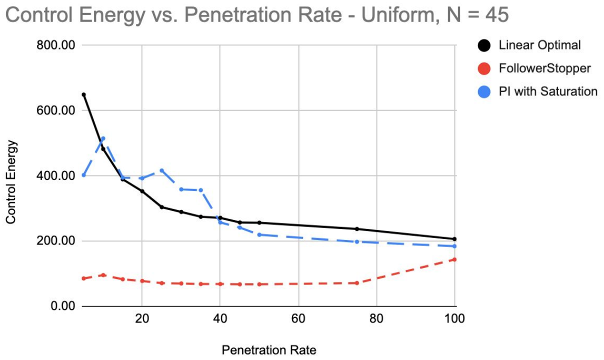

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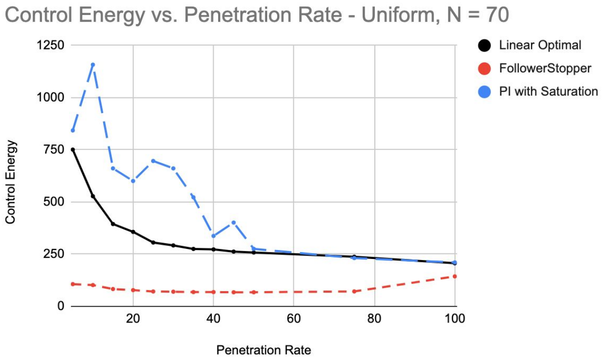

Step 3 : Data Analysis

- FollowerStopper Controller :
  - Smallest settling time
  - Best in a platoon

- Linear Optimal Controller :
  - Smallest spacing requirement
  - Decreasing energy trend

- PI with Saturation :
  - Controller designed to increase speed

CONCLUSIONS

Conclusions and Summary

- Best results : FollowerStopper
- Most practical : Linear Optimal
- Simplified model, reflects larger result

Webpage

https://soc-ucsd.github.io/mixed-traffic/smoothing_traffic_flow/

Welcome to Mixed traffic control's documentation!

Contents

- Smoothing Traffic Flow
  - Getting Started
  - Experiment Results
- Structured Optimal Control
  - Getting Started
  - Experiment Results
- Cooperative Formation Multiple
  - Getting Started
  - Experiment Results

Getting Started

Matlab Implementation

Main File

DEMO_SMOOTHING TRAFFIC_FLOW.M

Add path and initialization

```
clc;
clear;
close all;
addpath('_fcn');
addpath('_data');
```

Key parameters setting:

'mix' is set to 0 by default, which means there's no AV. While 'mix = 1' means the mixed traffic scenario. 'controllerType' set the control strategies for mixed traffic control.

'controllerType' value to strategies:

- 1.Optimal Control
- 2.FollowerStopper
- 3.PI with Saturation

```
mix = 0;
controllerType = 1;
```

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- Matlab Implementation
  - Main File
    - demo_smoothing traffic_flow.m
  - Functions
    - lqr_sdp.m
    - ring_traffic_model.m
- Python Implementation
  - Functions

Experiment Results

Reference

Future Goals

- Even more control strategies
- Additional traffic data in simulation model
- Straight-road model, larger scale.
- Keep optimizing code for faster simulations.

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SRIP Co-ordinator

References

[1] S. E. Shladover, C. A. Desoer, J. K. Hedrick, and et al., “Automated vehicle control developments in the path program,” IEEE Transactions on vehicular technology, vol. 40, no. 1, pp. 114–130, 1991.

[2] Y. Zheng, J. Wang and K. Li, "Smoothing Traffic Flow via Control of Autonomous Vehicles," in IEEE Internet of Things Journal, vol. 7, no. 5, pp. 3882-3896, May 2020, doi: 10.1109/JIOT.2020.2966506.

[3] Monache Maria Laura Delle, Liard Thibault, Rat Anais, Stern Raphael, Badhani Rahul, Seibold Benjamin, Sprinkle Jonathan, Work Daniel, and Piccoli Benedetto. 2019. Feedback control algorithms for the dissipation of traffic waves with autonomous vehicles. In *Computational Intelligence and Optimization Methods for Control Engineering*. Springer, 1–20.

[4] R. E. Stern, S. Cui, M. L. Delle Monache, R. Bhadani, M. Bunting, M. Churchill, N. Hamilton, H. Pohlmann, F. Wu, B. Piccoli et al., “Dissipation of stop-and-go waves via control of autonomous vehicles: Field experiments,” Transportation Research Part C: Emerging Technologies, vol. 89, pp. 205–221, 2018.

Thank you for listening!