CS166 Location-Based Project

Traffic Intersections

Table of contents

Overview

Traffic engineering is an important field in urban design. Cities plan roads to make the flow of traffic as smooth and safe as possible. Since there are many possible strategies and rules that could be implemented, we can use modeling and simulation to compare the strategies to see which one works best.

For this assignment, you are acting as a traffic engineer in your city. Your mission is to find and compare different strategies to optimize traffic flow in a particular section of the city.

When you write your project report, you should think of the city as your client. Think about what their needs are and how you would best address those needs. Make clear what your modeling assumptions are, how you arrived at your results, what your interpretation of those results is, and what your conclusions are. Be professional.

Feedback and grading

In a short paragraph near the beginning of your project report, describe which part or parts of your work you would like feedback on most. Your request can be specific or vague but you should expect the feedback you get to match your request. Specific requests will get feedback that is detailed and narrow in scope. Vague requests will get feedback that is general and broad in scope. Both types of feedback can be useful. You should decide and explain what you want. Your instructor has limited time to provide feedback (and you have limited time to read and process it) so use this as an opportunity to get what you need out of your instructor.

You will get 1 grade on each of the 6 course learning outcomes plus some HC grades. Be sure to address all 6 LOs as well as the foregrounded HCs. All course LOs are graded using the grading policy you were given at the start of the course.

Collecting data

To account for COVID-19 regulations and precautions, there are two options – one outside and one inside – for the location-based component of this assignment.

Option 1: Outside

If you can go outside for a short walk, collect some traffic data in your area.

Choose a section of the city you live in with multiple intersecting streets. Use Google Maps (or a similar tool) to get a bird's eye view of the streets in your chosen section of the city. Note the street names, and the allowed direction of travel in each street. Take a screenshot of your chosen area and include it in your project report.

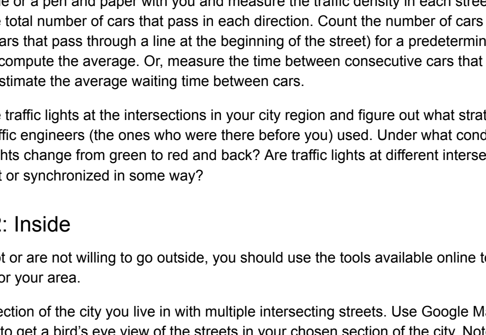

Figure 1. San Francisco streets in a grid layout. One-way streets are labeled with arrows. All other streets are bidirectional.

Take a phone or a pen and paper with you and measure the traffic density in each street by counting the total number of cars that pass in each direction. Count the number of cars that enter the street (cars that pass through a line at the beginning of the street) for a predetermined amount of time and compute the average. Or, measure the time between consecutive cars that enter the street and estimate the average waiting time between cars.

Observe the traffic lights at the intersections in your city region and figure out what strategy the previous traffic engineers (the ones who were there before you) used. Under what conditions do the traffic lights change from green to red and back? Are traffic lights at different intersections independent or synchronized in some way?

Option 2: Inside

If you cannot or are not willing to go outside, you should use the tools available online to collect traffic data for your area.

Choose a section of the city you live in with multiple intersecting streets. Use Google Maps (or a similar tool) to get a bird's eye view of the streets in your chosen section of the city. Note the street names, and the allowed direction of travel in each street. Take a screenshot of your chosen area and include it in your project report.

Then, use Google Maps (or a similar tool) to estimate the traffic density/flow rate along each street. On Google Maps, this can be estimated by activating the Traffic layer from the menu.

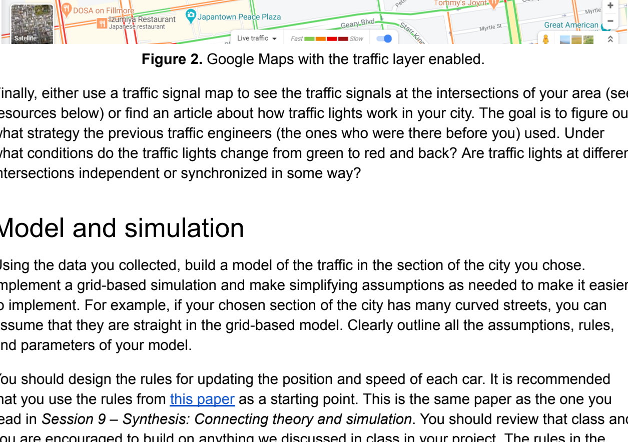

Figure 2. Google Maps with the traffic layer enabled.

Finally, either use a traffic signal map to see the traffic signals at the intersections of your area (see resources below) or find an article about how traffic lights work in your city. The goal is to figure out what strategy the previous traffic engineers (the ones who were there before you) used. Under what conditions do the traffic lights change from green to red and back? Are traffic lights at different intersections independent or synchronized in some way?

Model and simulation

Using the data you collected, build a model of the traffic in the section of the city you chose. Implement a grid-based simulation and make simplifying assumptions as needed to make it easier to implement. For example, if your chosen section of the city has many curved streets, you can assume that they are straight in the grid-based model. Clearly outline all the assumptions, rules, and parameters of your model.

You should design the rules for updating the position and speed of each car. It is recommended that you use the rules from this paper as a starting point. This is the same paper as the one you read in *Session 9 – Synthesis: Connecting theory and simulation*. You should review that class and you are encouraged to build on anything we discussed in class in your project. The rules in the paper show how you can model the acceleration and deceleration of cars on a straight road. You still need to design additional rules for when and how cars turn left or right at an intersection, and for traffic lights.

Once your simulation is ready, adjust the parameters of your model (for example, parameters governing the probability distributions you choose to use) to match the data you collected about the traffic density and traffic light behavior in each street. You don't necessarily need to match the real-world data perfectly but you should show how you determined which parameter settings to use to get a reasonably realistic result.

Next, implement at least one additional traffic light strategy and apply it to your city section. You can either create your own strategies or find some online. Run simulations to compare the efficiency of your strategies using a metric of your choice – for example, average traffic flow or average waiting times of cars at intersections.

Frequently asked: What is the simplest traffic grid I can use?

For better grades on #Modeling, you should try to build something more complicated but, you can implement 4 one-way streets, meeting at 4 intersections, like in the figure below.

- Cars travel in the direction of the arrows.
- Cars can go straight or turn right at each intersection.
- Traffic lights determine which cars are allowed to cross and turn at an intersection and which cars have to wait.
- Cars will enter the system at a right you should determine from your data collection.

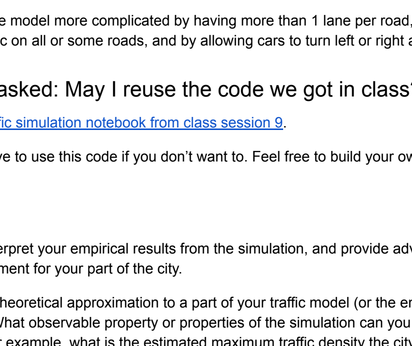

Figure 3. The simplest road system that you should aim to build.

You can make the model more complicated by having more than 1 lane per road, by having bidirectional traffic on all or some roads, and by allowing cars to turn left or right at intersections.

Frequently asked: May I reuse the code we got in class?

Yes. See the traffic simulation notebook from class session 9.

But you don't have to use this code if you don't want to. Feel free to build your own simulation.

Analysis

Describe and interpret your empirical results from the simulation, and provide advice on the best strategy to implement for your part of the city.

Come up with a theoretical approximation to a part of your traffic model (or the entire model if you are ambitious). What observable property or properties of the simulation can you estimate theoretically? For example, what is the estimated maximum traffic density the city can handle before traffic jams form? Or, how many cars do you expect to wait for the light to change at an intersection? These are just two ideas, you may theoretically model any part of your simulation.

Visualize, describe, and analyze your empirical results. Run the simulations several times and produce confidence intervals for the outputs of interest. Since this is a Monte Carlo simulation, different simulation runs will give different, random results.

Comment on whether your confidence intervals are wide (high uncertainty) or narrow (low uncertainty). Comment on how many more simulations or simulation steps you would need to reduce the widths of your confidence intervals.

Compare your empirical results to your theoretical results and comment on how well they match. If they do not match, try to explain why not.

Frequently asked: How should I do a theoretical analysis?

There are two topics we covered in class that you can try out here. You are not expected to apply the theoretical analysis to your whole model/simulation (that will almost certainly be too complicated). You can instead focus on one part of your simulation.

The important thing is that you make predictions using a mathematical model, and compare those predictions with your empirical results.

1. Mean-field approximation of a traffic model. Revisit class session 9 and figure out how to apply the mean-field approximation we discussed there to one lane in your simulation. How does the car density in a lane correspond to the traffic flow in that lane? Car density won't be fixed since cars are entering and exiting the road so try to take that into account.
2. Revisit class session 2 on queueing theory and figure out how to model the queues forming at traffic lights. Based on how long lights stay red and green, and on the arrival rate of cars at a traffic light, what do you expect the average queue length to be?

Resources

These resources are all optional. You may but do not have to use or refer to them in your work. Please remember to cite all sources you do decide to use.

Maps and traffic

- Google Maps
- SF traffic Signals Map
- London Traffic Signals Map
- Berlin Traffic Map

Videos and interactive simulations

- Grey, C.G.P. (2016). The simple solution to traffic. *YouTube*. This short video describes some interesting features of driver behavior and how they cause traffic problems. It also describes how we might be able to improve traffic problems by changing driver behavior – or getting rid of drivers altogether.
- Treiber, M. (n.d.) Microsimulation of traffic flow. This browser-based simulator shows a fairly sophisticated traffic model. Use it to experiment with different road conditions and get a sense of what is possible using a detailed traffic simulator. Use it for inspiration. You are not expected to build an interactive simulation like this one.

Papers and videos on traffic modeling

- Nagel, K., Schreckenberg, M. (1992). A cellular automaton model for freeway traffic. *Journal de Physique I*.

  A classic cellular automaton traffic flow and traffic jam model.
- The Nagel-Schreckenberg traffic model on Wikipedia
- Rickert, M., et al. (1996). Two lane traffic simulations using cellular automata. *Physica A: Statistical Mechanics and its Applications*, 231(4), 534–550.

  An extension of the Nagel-Schreckenberg traffic model to multiple lanes.
- Schadschneider, A., Schreckenberg, M. (1995). Cellular automata for traffic flow: Analytical results.

  This paper outlines two approaches for doing a mean-field analysis of the traffic flow models above.

How to submit your deliverables

- You need to submit 2 files – one a .pdf file with your project report and one a .ipynb (or .zip) file with your Python notebook.
- Typeset your work using Google Docs, LaTeX, or something similar and submit your project report as a PDF file.
  - Do not simply upload a PDF version of your Python notebook as your project report. The purpose of the report is to present your model and summarize your results. The purpose of the Python notebook is to show how the simulation generated your results and to ensure the reader can reproduce your results.
  - Do not zip your PDF report. (If you do, your instructor can't anchor feedback to the relevant part of the report.)
- The Python notebook must include any output (text or plots) generated by running the code. Make sure your code runs without bugs/errors. Your instructor needs to be able to run your code to reproduce your results. You may zip the Jupyter notebook if that helps with submitting your code.