CS166 Location-Based Project

Traffic Intersections

https://colab.research.google.com/drive/1SyTHmyC3j19PcqNVsYe2tki8oSwlFgyJ?usp=sharing (https://colab.research.google.com/drive/1SyTHmyC3j19PcqNVsYe2tki8oSwlFgyJ?usp=sharing)

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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, I am acting as a traffic engineer in my city. The mission is to find and compare different strategies to optimize traffic flow in a particular section of the city.

For this project report, I think of the city as my client. By considering what the needs of the city are, I can provide the best possible solutions to address those needs. In this report, I make the modeling assumptions clear, how the results were calculated, the process of modeling and simulation, the interpretations of the results, and the conclusions. Creating a cohesive and thorough report will show professionalism in this task.

Feedback and Grading

In this project report I would like to receive feedback on my analysis of the modeling and simulation process of the traffic problem. I am interested in the similarities between the results of a simulation compared to the results compared to the expected theoretical concepts in the real world scenario. So, feedback should address these components of my work. In this assignment I aim to address the following Learning Outcomes from CS166: #cs166-Modeling (https://forum.minerva.edu/app/outcome-index/learning-outcomes/cs166-Modeling), #cs166-PythonImplementation (https://forum.minerva.edu/app/outcome-index/learning-outcomes/cs166-PythonImplementation), #cs166-CodeReadability (https://forum.minerva.edu/app/outcome-index/learning-outcomes/cs166-CodeReadability), #cs166-TheoreticalAnalysis (https://forum.minerva.edu/app/outcome-index/learning-outcomes/cs166-TheoreticalAnalysis), #cs166-EmpiricalAnalysis (https://forum.minerva.edu/app/outcome-index/learning-outcomes/cs166-EmpiricalAnalysis), and #cs166-Professionalism (https://forum.minerva.edu/app/outcome-index/learning-outcomes/cs166-Professionalism). As well as the foregrounded Habits of Mind and Foundational Concepts such as #modeling (https://forum.minerva.edu/app/outcome-index/hcs/modeling), #professionalism (https://forum.minerva.edu/app/outcome-index/hcs/professionalism), #variables (https://forum.minerva.edu/app/outcome-index/hcs/variables), #composition (https://forum.minerva.edu/app/outcome-index/hcs/composition), #organization (https://forum.minerva.edu/app/outcome-index/hcs/organization), #audience (https://forum.minerva.edu/app/outcome-index/hcs/audience), #confidenceintervals (https://forum.minerva.edu/app/outcome-index/hcs/confidenceintervals), #dataviz (https://forum.minerva.edu/app/outcome-index/hcs/dataviz), and #descriptivestats (https://forum.minerva.edu/app/outcome-index/hcs/descriptivestats).

Collecting Data

To account for COVID-19 regulations and precautions, the location-based portion of this assignment can be completed outside or inside. I have chosen to complete most of the portion inside rather than outside.

Option 1: Outside

In terms of data collection, the traffic problem observes different traffic data such as street configuration and vehicle density among other things. An interesting section of the city I live in with multiple intersecting streets is located in the Tenderloin. I decided to observe a section delimited by O'Farrel Street in the North which is a one way street that goes from West to East, Mason Street in the East which is a one way street that goes from North to South, Ellis Street in the South which is a one way street that goes from East to West, and Taylor Street in the West which is a one way street that goes from South to North. Using Google Maps, I am able to get a bird's eye view of the streets in my chosen section of the city.

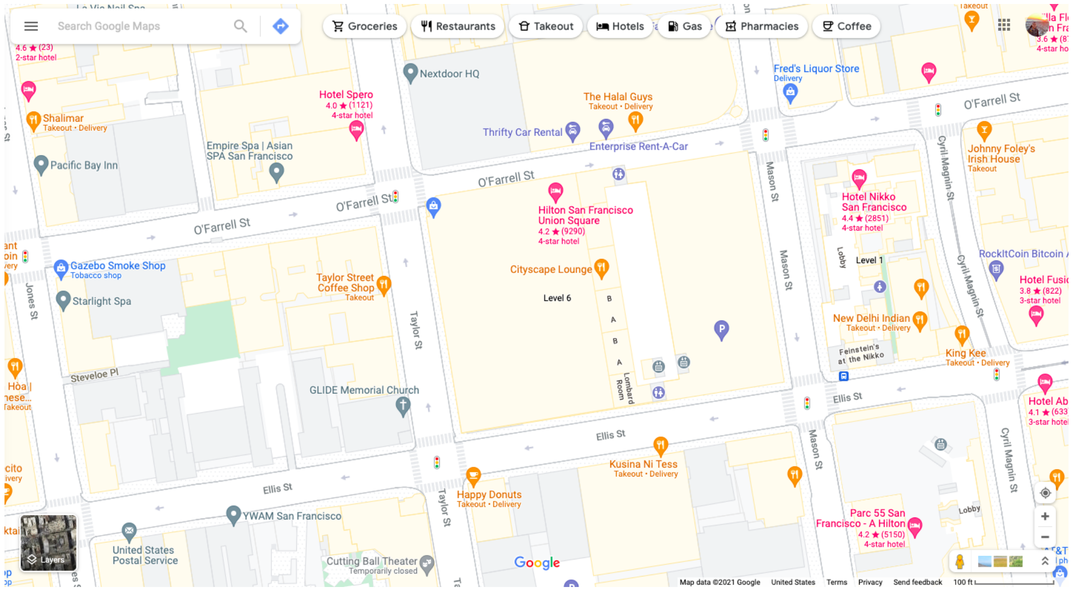


Figure 1. San Francisco streets in a grid layout. One-way streets are labeled with arrows.

Modeling Streets One of the measurements that is important for modeling these streets correctly is traffic density in each street. One way to do this can be by counting the total number of cars that pass in each direction, or counting the number of cars that enter the street for a predetermined amount of time, or measuring the time between consecutive cars that enter the street. A few different methods include counting the numbers that pass through a line at the beginning of the street and then computing the average or estimating an average.

Modeling Intersections One of the measurements that is important for modeling the intersections and traffic lights would be the conditions when they change. One way to do this is to observe the traffic lights at the intersections in the city region and figure out what strategy was used by the traffic engineers who installed them initially. It is important to make observations about the conditions during which traffic lights change from green to red and back and whether traffic lights at different intersections are independent or synchronized in some way.

However, all measurements described above require to be outside, and for this particular part of the project I have decided that I am not willing to go outside and rather do the majority inside.

Option 2: Inside

Given that I preferred to do the work inside, I use the tools available online to collect traffic data for the area chosen. As established above, the chosen section of the city is in the Tenderloin area and have noted the street names and the allowed directions of travel in each street. To estimate the traffic density/flow rate along each street, Google Maps offer a traffic layer.

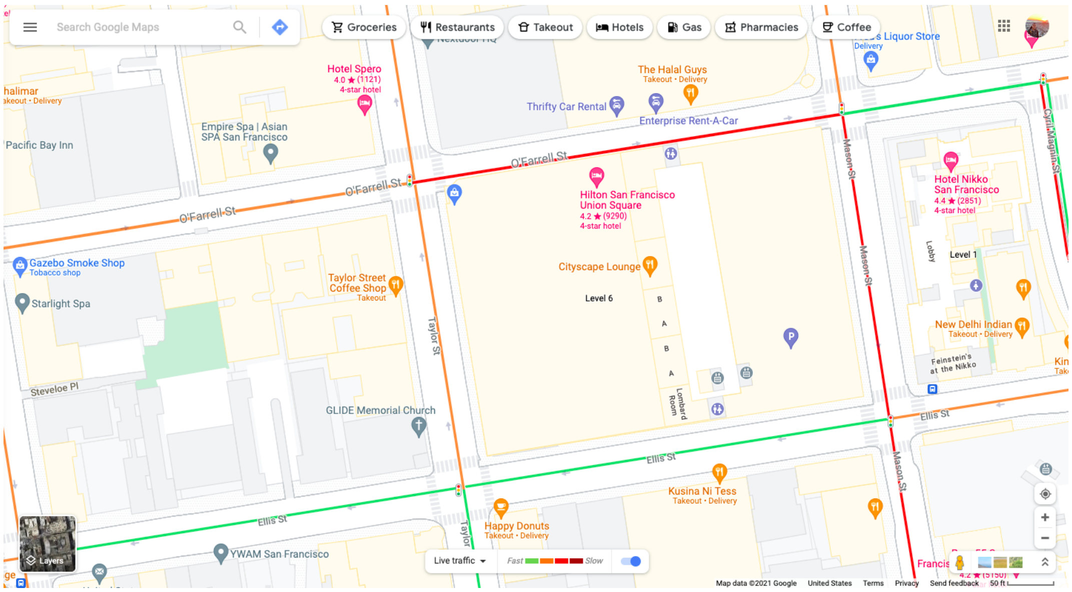


Figure 2. Google Maps with the traffic layer enabled.

The traffic signal map in the resources provided little to no information about the traffic signals at the intersections of the chosen area. The most useful article about how traffic lights work in San Francisco is from 2018, where the author describes a plan to make traffic lights smarter. The evidence provided in this source seems more anecdotal than driven by actual data but it suggests that traffic lights used to be out of sync or in other words not synchronized. However, the plan to make traffic lights smarter would implement adaptive traffic signal operations which would adjust the signal timing of the red, yellow, and green lights. This change would accommodate changing road conditions and continuously distribute green light for optimum traffic signal options and improve travel time and reduce congestion. Based on traffic data from the Traffic layer in Google Maps, there is no clear suggestion of a strategy in place, but we can assume that there might be a strategy that uses adaptive traffic signal operations. Perhaps, with the implementation of that system, traffic lights would be synchronized by that strategy. Also, the traffic in the map might not be representative of what the chosen area usually looks like.

Model and Simulation

Using the data collected through the online tools, the model of the traffic is simulated in the section of the city chosen. The implementation is a grid-based simulation that makes a few simplifying assumptions about the system. The initial starting point for the rules that govern this agent-based model come from the cellular automaton model for freeway traffic (https://course-resources.minerva.kgi.edu/uploaded_files/mke/YpqvNV/nagel-schreckenberg.pdf). Further rules and initial values are needed for creating a model that takes into account all the possible interactions in a grid system. As a traffic engineer, I notice and I am thankful for previous urban designers and traffic engineers to have created this real world scenario as close as possible to the grid-based design rather than curved streets or three-way intersections. This not only allows for better transit and traffic accross the model but also in real life too. Some of the assumptions, rules, and parameters of the model include considerations for the length of the road, the density of cars on the road, the speed limit, the probability of a car slowing down, the number of lanes in a road, the time between different colors of traffic lights, and the average traffic flow among other measurements and metrics.

The TrafficSimulation (https://nbviewer.org/urls/course-resources.minerva.kgi.edu/uploaded_files/mke/00212840-6806/traffic-simulation-examples.ipynb) code from Nagel & Schreckenberg was used in an attempt to design similar specifications that follow the ground rules already provided. For example, rules that govern the update of the position and speed of the car as observed in Session 9 - Synthesis: Connecting theory and simulation. This opportunity served as a chance to go back to look at the problem for traffic simulation and iterate on previous work to provide better modeling, simulation, and approximations using the tools available. The traffic simulation observes an initial spike and increase in traffic flow as the car density increases which represents free flowing traffic, then the number of cars that can go at maximum speed decreases so there is a slow down of traffic leading to less traffic flow and increased car density. The assumptions about the acceleration and deceleration of cars allows for a similar analysis which works for single road as well as extending it to multiple roads that intersect. Traffic ligths represent a mechanism through which cars follow rules that determine whether they can turn at an intersection or not.

In [6]:

```
plt.figure(figsize=(8, 6))
plt.title('Expected Average Traffic Flow at Different Car Densities')
plt.xlabel('Car Density')
plt.ylabel('Average Traffic Flow')
plt.legend()
plt.show()
```

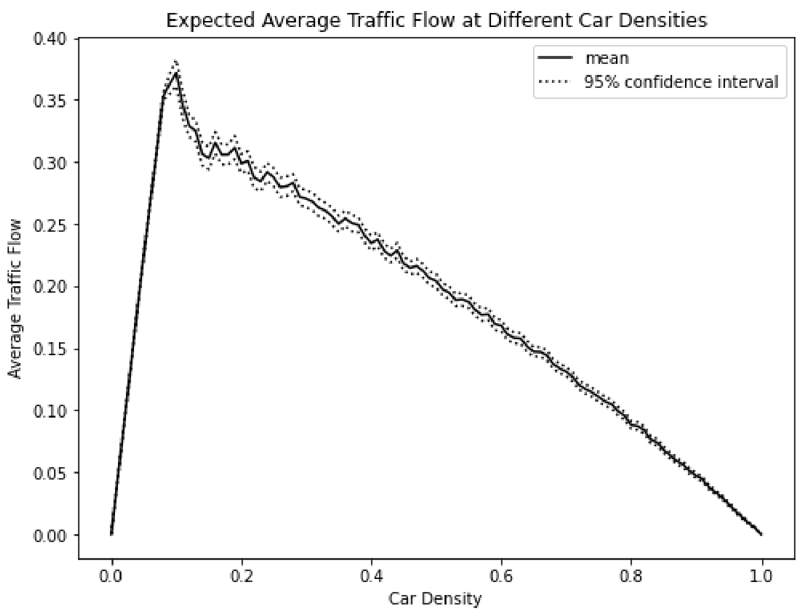


Figure 3. Average traffic flow varies with car density

In [ ]:

```
plt.figure(figsize=(8, 6))
    plt.title('Expected average traffic flow at different car densities')
    plt.xlabel('Car density')
    plt.ylabel('Average traffic flow')
    plt.xlim(0, 1)
    plt.ylim(0, 1)
    plt.legend()
    plt.show()
```

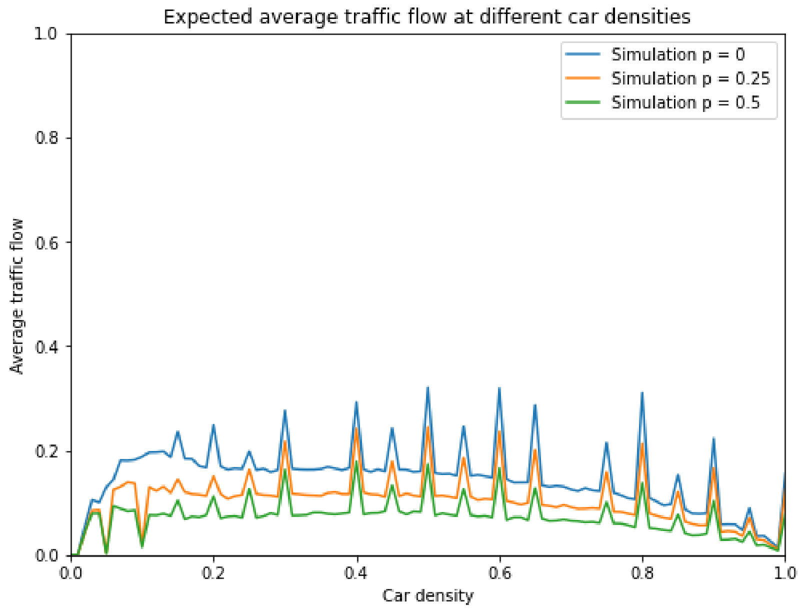


Figure 4. Average traffic flow varies with car density and probability of slow down

The results of the simulation provide insight into the traffic system in the chosen area of the city with the parameters of the model closely resembling the data collected from the traffic density and traffic light behavior. The simulation also implements different strategies in term of traffic lights by applying them to the city section where the main streets intersect. For example, the difference in strategy between updating the state of the traffic light without regard to the current density of cars vs updating the state of traffic lights given some aspect about the system such as high density of cars.

The Traffic Grid provides a good generalization for modeling traffic in real world scenarios. It allowed to implement four one-way streets (O'Farrel, Mason, Ellis, and Taylor) which meet at 4 intersections with traffic lights that govern traffic flow. As shown in the Google Maps image, the cars travel uni-directionally and can go straight or turn right; aditionally cars enter the system from different sources which might increase car density.

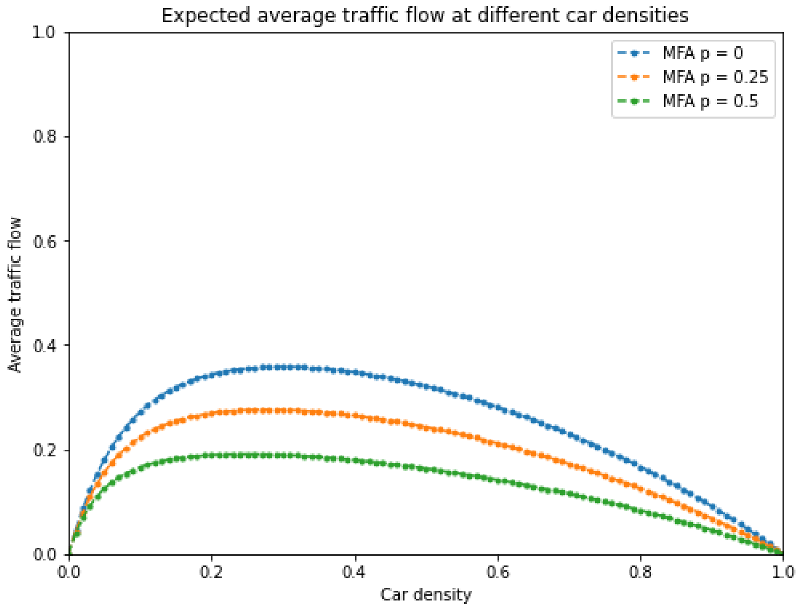
Analysis

The empirical results from the simulation provides a system that varies accross different iterations of the simulation since it is based on a limited set of assumptions. It can still further be improved and accuracy can increase by introducing other elements such as time of day or other assumptions that might change the traffic flow system. As a traffic engineer, I can consider whether the features such as probability of slow down and car density in the road are sufficient to determine a best strategy to implement in the city. For example, an improved system for traffic lights such as different time delays between lights or perhaps a different speed limit on certain streets.

Empirical vs Theoretical results provide an opportunity to double check that general assumptions follow the theories that govern the interactions of the different agents in the system. Using a mathematical model as a traffic engineer I can make sure that I compare predictions with the simulation results. The mean-field approximation of the traffic model can be extended from single lane models to increased complexity with streets, intersections, and traffic lights. Using the mean-field approximation, we can look at the car density as it relates to the average traffic flow, a similar observation with the empirical results. Then, see the differences and similarities in behavior. One of the difference can be that the mean-field approximation considers the system at the equilibrium state which can be different from the results of simulating the system and iterating again and again.

In [ ]:

```
plt.figure(figsize=(8, 6))
plt.title('Expected average traffic flow at different car densities')
plt.xlabel('Car density')
plt.ylabel('Average traffic flow')
plt.xlim(0, 1)
plt.ylim(0, 1)
plt.legend()
plt.show()
```



Resources

[Traffic Simulation (https://nbviewer.org/urls/course-resources.minerva.kgi.edu/uploaded_files/mke/00212840-6806/traffic-simulation-examples.ipynb)](https://nbviewer.org/urls/course-resources.minerva.kgi.edu/uploaded_files/mke/00212840-6806/traffic-simulation-examples.ipynb)

[Cellular Automaton Model (https://course-resources.minerva.kgi.edu/uploaded_files/mke/YpqvNV/nagel-schreckenberg.pdf)](https://course-resources.minerva.kgi.edu/uploaded_files/mke/YpqvNV/nagel-schreckenberg.pdf)

[Runtime Warning Solution (https://codesource.io/solved-runtimewarning-invalid-value-encountered-in-double_scalars/)](https://codesource.io/solved-runtimewarning-invalid-value-encountered-in-double_scalars/)

In [1]:

```
from IPython.core.display import HTML
HTML("""
<style>

div.cell { /* Tunes the space between cells */
margin-top:1em;
margin-bottom:1em;
}

div.text_cell_render h1 { /* Main titles bigger, centered */
font-size: 2.2em;
line-height:1.4em;
text-align:center;
}

div.text_cell_render h2 { /*  Parts names nearer from text */
margin-bottom: -0.4em;
text-align:center;
}


div.text_cell_render { /* Customize text cells */
font-family: 'Times New Roman';
font-size:1.5em;
line-height:1.4em;
padding-left:3em;
padding-right:3em;
}
</style>
""")
```

Out[1]:

In [ ]: