# CS166 First Project

Waiting for the Bus

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## Overview

In this project, you complete the implementation of a bus route simulation that we start in class during the first two weeks of the course. You will experiment with different strategies for setting departure times on the bus route and measure how well the different strategies work.

**The purpose** of this assignment is to go through the entire modeling, simulation, and analysis process but with a lot of support provided by the instructor and your peers. We will repeat this modeling-simulation-analysis process a few times during the course. Use this project as an opportunity to learn how to do it right.

The main goals of this first project are

- to learn and practice object-oriented programming in Python,
- to learn and use basic NumPy functionality – using arrays, basic mathematical and statistical functions, generating random values – and Matplotlib functionality for generating figures,
- to learn how to document your project well and produce a readable and beautiful report.

## 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 (yes, all of them!) 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.

## Basic model (required)

A circular bus route operates 24 hours per day. The buses on the route allow passengers to embark and disembark at 15 different stops before looping back to the start of the route. At each bus stop, passengers wait until the next bus arrives, get on the bus, and finally get off the bus at their chosen destination. The rate at which passengers join the queue at a bus stop is constant and does not depend on the time of day. (This is unrealistic – see the optional Extension model section below for a more realistic model.)

**Figure 1.** Commuters queue at a bus stop in London. [source]

The time (in minutes) between consecutive passengers joining a queue at each bus stop is assumed to come from an exponential distribution with rate parameter $\lambda = 1$. Each passenger chooses uniformly at random a destination that is at most 7 stops away from where they start.

When a bus stops, the time (in minutes) it takes passengers to disembark is normally distributed with mean $\mu_1 = 0.03n$ and standard deviation $\sigma_1 = 0.01\sqrt{n}$ where $n$ is the number of passengers who want to disembark. The time it takes passengers in the queue to get on the bus is also normally distributed with mean $\mu_2 = 0.05n$ and standard deviation $\sigma_2 = 0.01\sqrt{n}$. No passengers can embark while other passengers are still disembarking.

The maximum capacity of each bus is 130 passengers. If the bus is full, no more passengers can embark and they have to wait for the next bus to arrive.

The travel time of the bus between consecutive bus stops follows a normal distribution with parameters $\mu_3 = 2$ minutes and $\sigma_3 = 0.5$ minutes.

**Main question** How many buses should be on the route? Address this question by implementing the simulation described above and analyzing the following metrics.

1. The expected value and a 95% confidence interval of the average passenger waiting time given the number of buses on the route. Waiting time is defined as the duration between a passenger joining a queue at a bus stop and when the passenger gets on the bus.
2. The expected value and a 95% confidence interval of the maximum queue length at all bus stops during a day given the number of buses on the route.
3. The expected value and a 95% confidence interval of another quantity that you have to propose. Explain what your chosen quantity is and why it helps address the main question.

## Extension model (optional)

You may complete this part of the project to improve your grades but it is not required and you may also omit it.

The rate at which passengers arrive at each bus stop now depends on the time of day. The interarrival distribution is still exponential but now with rate parameter

$$\lambda = 1.2 + \cos(\pi\,(t - 7)\,/\,6)$$

where $t$ is the time of day in hours on a 24-hour clock. (If you don't like this expression for $\lambda$, you may do some research and find a more accurate function to describe how the passenger interarrival rate depends on the time of day.)

Finally, passengers might get annoyed if the bus takes too long to arrive and choose to walk to their destination instead. If a passenger has been waiting for at least 10 minutes and if, at that time, there are still at least 20 passengers in front of them in the queue, they will give up on the bus and walk to their destination instead. A passenger who decides to walk is removed from the simulation but you should track how many passengers give up on the bus since this negatively affects their opinion of the city bus service.

**Main questions**

1. How many buses should be on the route for each hour of the day? Address this question by simulating the route during different hours of the day, using the rate parameter provided above.
2. When is it in the interest of an individual passenger to walk rather than ride the bus? How should a passenger decide whether it would be faster to take the bus or to walk?

## How to submit your deliverables

Follow all these formatting requirements or get a lower grade on the #Professionalism LO.

- 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. Do not simply upload a PDF version of your Python notebook as your project report.
- The purpose of the project report is to present your simulation model and to summarize your results.
    - Format your report appropriately using headings to organize your work.
    - Proofread and spell-check your report before submitting it.
    - Do not zip your PDF report. If you do, your instructor can't anchor feedback to the relevant part of the report.
    - Word limit: between 1500 and 3000 words.
- The purpose of the Python notebook is to show how your simulation generated your results and to ensure your instructor can reproduce your results.
    - The Python notebook must include all output (text and plots) generated by running the code.
    - Your instructor will rerun your notebook from start to finish and it has to reproduce all your results without any bugs/errors. (It's okay if the notebook takes a long time to run – simulations are slow sometimes.)
    - You may zip the Jupyter notebook if that helps with submitting your code.

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