MAT 210
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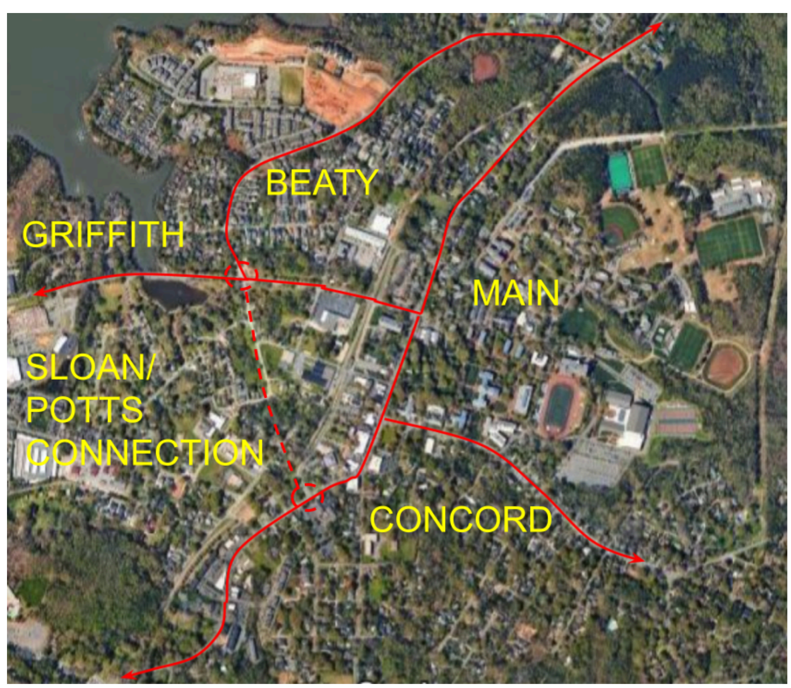
Predicted Effects of Roundabouts and Road Connections on Main Street Traffic in Davidson, NC

Abstract:

The Town of Davidson is implementing 3 new traffic features in the downtown area: a roundabout at Griffith St, Beaty St. and Sloan St., a roundabout at Potts St. and South Main St., and a connection of Potts St. and Sloan St. They would like to predict the effects that these features will have on Main St. traffic during rush hour. A model that simulates individual cars moving through the Main St. area is used in a fashion similar to a 'game board'. A Poisson distribution is also used to predict the time cars enter the system. According to our model, the average car on Main Street will have its commute decreased by around **10%**, with the most improvement found with people getting off or on the highway from the south of Davidson.

Problem at Hand:

The Town of Davidson was once much smaller than it is now, and the roads in the downtown area were not originally meant for such heavy traffic, especially Main Street itself. Traffic is not a significant problem for most of the day, but during rush hour (5-6 PM), traffic is often significantly backed up on Main St. going both directions. A trip that normally takes five minutes can be extended to as long as twenty minutes due to congestion. To ameliorate the slow-moving traffic on Main, the Town of Davidson decided to implement three intertwined changes: A roundabout at Griffith St. and Beaty St. (which turns into Sloan St.), a



roundabout at Potts St. and South Main St., and an extension of Potts St. into Sloan St. Both the roundabouts and the new road connection are indicated by the red-dashed line on the map. Construction of the roundabout at Potts St. and South Main St. has already begun.

Goal: The Town of Davidson has asked us to determine the **effects that these changes will have on Main Street traffic during rush hour.**

Intuitively, roundabouts are more efficient than stoplights or stop signs because traffic does not have to stop, but rather yield to oncoming traffic, creating a continuous flow. Roundabouts should also be more efficient because there is less waiting for factors that are not other cars. It's much easier to judge if one can proceed through the intersection than if they are turning left on a yellow flashing arrow or turning right on a red light.

The connection between Potts St. and Sloan St. should also reduce the backing-up of Main St. traffic. It would provide an alternative route for those whose destination is not somewhere on Main St. Traffic can be routed to this new connection instead of being forced into taking Main St. Cars can take Potts/Sloan and end up in the same spot, covering less distance and without stoplights.

Given that these changes *should* reduce traffic, the question became how we would measure the traffic on Main St. We decided that the best way to represent this was the **average time it takes for a car to make its way through the Main St. system**.

To summarize, our goal was to find the change in the average time it takes for a car to make its way through the Main St. system from before the implementations to after.

Simplifications + Assumptions:

Given the time constraints and limited access to relevant data, we had to make several simplifications and assumptions to make our problem solvable. However, these simplifications should not significantly impact our solution, which is why we decided to make them.

1. We assume that cars traveling to the same destination will all take the same route. This simplification was made since it would be difficult to calculate the decision-making of each individual driver. In practice, it may take some time for drivers to take the alternative Sloan/Potts route once it is made. There's no way of knowing how long it will take for the driver's habits to change, but if proven to

be faster (and more importantly, less congested), more cars should begin to use it.

2. We assume no pedestrians at the following intersections: Griffith/Beaty, Griffith/Jackson St., and South Main/Potts. The number of pedestrians at any of these intersections is random and infrequent enough that it would be nearly impossible to model their relatively small impact.

3. We assume a constant speed for each car, not accounting for acceleration or speeding. We mark this speed at 1 car length every second, or around 10 miles per hour. To make it through a stoplight or stop sign, we will assume it would take the time of one car length. Roundabouts take longer to get through for each individual car, but have less waiting time. This slow speed should help to account for traffic stop/starting and other small impacts to traffic that would otherwise be difficult to model.

4. We found it difficult to simulate smart traffic lights, which would change directions to account for traffic. Instead, we have a static light cycle for each light obtained from field data. This leads to times when a light waits for traffic that is not there, while other traffic waits. With more time and data, we could improve on this implementation, but it is currently unattainable.

5. We assume that smaller road traffic is negligible, and focused on the roads Beaty, Griffith east of Jettson Street, Main Street from Mccall to Beaty, and Concord Road going west. Sloan, Potts, and the road connection will be accounted for after the construction. We do this because it would be difficult for individual cars in the model to find the quickest route to their destination, given several extra roads.

6. We assume that each car is looking to go through our road system from one of the four entrances to another. Any cars stopping along the loop are likely accounted for by cars leaving from inside the loop. This assumption is made because finding data on cars that engage in this behavior is difficult.

7. We assume rush hour traffic trends are the same Monday through Friday. We didn’t have the means to collect data and verify it for each day of the week. Whatever differences we found may also not have been accurate, so we decided that each simulation will have a variable amount of cars enter and exit the system according to a Poisson distribution.

8. We assume that the current traffic resulting from Potts construction has no effect on Main St. Traffic. This was necessary because there was no time to collect data from before construction.

9. We assume that a car turning left at a yellow flashing arrow needs 2 “car lengths” of room from cars they would cross in front of. We also assume that cars turning right on a red light need 1 car length of room from the cars they would pull in front of. We made this decision because cars turning left need more room from oncoming traffic than cars turning right, given the low speeds.

10. We assume a constant rate of cars entering the system from each of the 4 entrances. Realistically, cars will enter the system in bunches due to stoplights, but coding somewhat random “bunches” of cars is very difficult.

11. Due to there not being a rush hour, we eliminate weekend traffic from our problem.

Data Collection:

Due to a lack of available information, we manually collected most of the data used in our code. Our method for collecting overall traffic data on Main was to count the total number of cars that pass through Main heading North and the total number of cars that pass through Main heading south in a given hour. Over multiple days, these numbers were nearly identical, with averages of 772 cars going North/hour and 550 cars going South/hour.

From there, we had to determine the rate of cars entering from each entrance to the system. The method for collecting this was to count the number of cars coming onto Main St. at each entrance point to the system. On average, we found the following rates of entrance:

Heading North from South Main St:	0.185 cars/second
Turning from Concord onto Main St:	0.17 cars/second
From Griffith St. onto Main St:	0.071 cars/second
Heading South from North Main St:	0.100 cars/second

The last data that we needed to collect were stoplight times, which were also collected by manually timing the stoplights. We found that at each intersection, the stoplight times were dependent on whether or not cars were waiting. In a high-traffic situation like rush hour on Main St., there will be cars waiting in every direction, so stoplight times are relatively constant. On average, we found the following times for green lights:

South Main St/South St (Ben and Jerry's)
Green light straight on Main: 20 seconds to 1 min (if no cars in 1 min)
Coming from Chairman Blake Ln: 10 seconds
Coming from South St: 8 seconds

Concord/Main St.:
Straight on main: 76 seconds
Green arrow turn onto main: 16 seconds
Turn Left onto Concord: 20 seconds of green arrow, yellow flashing arrow for the rest of the 55 second green light
Time for Pedestrians: 20 seconds

Griffith/Main St:
Straight on Main: 47 seconds
Turn onto Main: 20 seconds
Turn onto Griffith: 8 second arrow, remaining 39 seconds of yellow flashing arrow

Griffith/Beaty:
Straight on Griffith: 48 seconds
Straight on Sloan/Beaty: 8 seconds
Both ways turning left onto Sloan/Beaty: 8 seconds (green arrow, yellow flashing after)

Our Model:

To analyze traffic behavior around Main Street, we modeled the road network as a discrete-time system in which each car moves through a "gameboard," entering from one point on Main Street and coming out the other.

Structure: The town's road network is represented as a gameboard, where:

- Different spots on the gameboard represent intersections, which may be controlled by stop signs, roundabouts, or traffic lights.

- Road segments are modeled as one-dimensional arrays of fixed length, each slot holding either a car or remaining empty.

- Cars are discrete agents (Car objects) with the following attributes:

    - roadFrom: the entrance the car originated from (Griffith, Concord, North Main, South Main).

    - roadTo: the exit the car is trying to reach (North Main St past where Main St. intersects Beaty St or South Main St past the Potts/South Main intersection).

    - spawn: the simulation timestamp when the car entered the system

Entrances spawn new cars according to a **Poisson process** with empirically estimated arrival rates (λ, in cars per second). The probability of a car spawning in a given second is:

$P(arrival) = 1 - e\text{^}(-\lambda)$

Our model assigns each car an entrance time calculated with a variation of the formula:

$car[i].entranceTime = car[0{:}i-1].entranceTime + (1/\lambda * log(r)$

Where r is a random number between [0, 1]

Each car is randomly assigned a destination that is not the one it came from, weighted by ratios from annual traffic data (NCDOT).

Percentages are as follows:

Cars to Griffith	Cars to Concord	Cars to North Main	Cars to South Main
28%	28%	18.7%	25.2%

Traffic Routes

Once a car enters, it will go on a set route to its destination regardless of any current traffic.

- Before the new connection, all cars traveled on Main Street in order to reach their destination (apart from connections between Griffith and North Main Street, for which we assume traffic to go along Beaty Road)

- After the change, we assume that traffic between Griffith and South Main Street will use this new connection instead of going on Main Street. We also have the North Main Street and South Main Street connection flow through Beaty and the new connection. This causes these cars to take a slightly longer time, but suffer less congestion and make the average time faster.

The road connection lengths are listed as follows:

Road Segment	**Average car lengths**
Main from Beaty to Griffith	178
Main from Griffith to Concord	51
Main from Concord to South St.	25
Main from South St. to Potts	224
Main from Potts to McCall	117
Beaty from Griffith to Main	264
Griffith from Jettson to Beaty	147
Griffith from Beaty to Main	88
Sloan-Potts Road from Griffith to Main	224

Traffic Flow Rules

At each simulation tick (1 second), we perform the following updates:

- **Car Movement**: Cars move forward one space in their respective road arrays if that space is unoccupied.

- **Intersections**: Cars at intersections are either granted permission to proceed (depending on signal logic, priority rules, or roundabout conditions) or held back if movement is blocked.

- **Exit Processing**: Cars reaching the end of exit roads are removed and their commute times logged.

The main variables at each time are:

- The list of cars occupying each road segment
- The state (position, destination) of each car
- The Poisson queue at each entrance, generating arrivals based on our cars/second data collected from each entrance
- The current time impacting stoplight cycles

Solution to Math Model:

While we used some methods learned in class, such as the Poisson queue, the main function used for the problem was a custom algorithm. By running our simulation for one hour and calculating the average time for a car to make it through the Main St. system, we find out how intense the Main St. traffic is.

Then, we average the times taken to and from each road as well as the total. The times in seconds without stoplights for each road connection can be found in the appendix. The total average times based on the proportion of cars going to and from are **7.26 minutes** without the new construction, and **6.85 minutes** with the new construction, a 5% difference.

Our Algorithm + Pseudocode

Our algorithm loops through each second of simulated time, performing updates to road states, intersections, and car queues.

Pseudocode

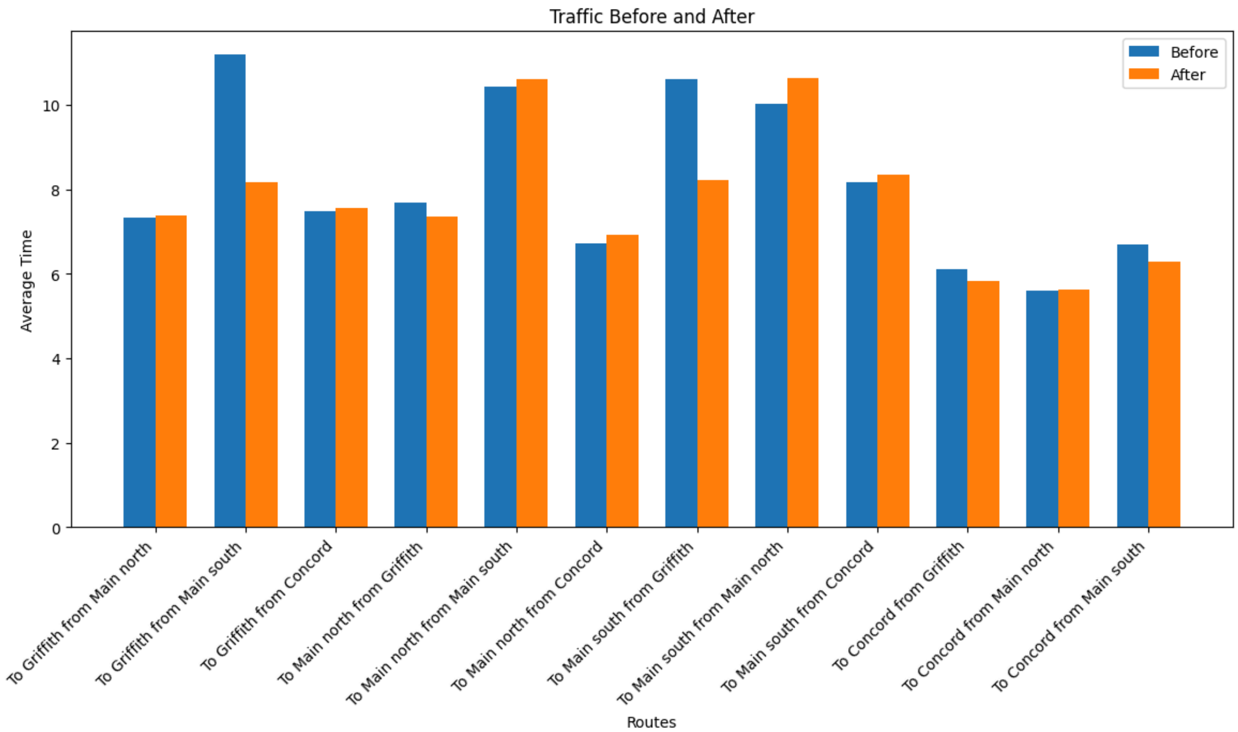
```
initialize road network arrays, intersections, and Poisson queues

for time from 0 to total_simulation_time:
    for each exit_road:
        if car at end of road:
            record commute time and remove car
        move cars forward if space ahead is empty

    for each intersection:
        detect cars at front of incoming roads
        determine which cars can move based on intersection type:
            if stop_light: use timed light cycle and special rules (left on yellow flashing arrow,
turn right on red) to permit movement
            if round_about: use conflict-free entry/exit rules
            if stop_sign: use right-of-way and priority rules
        move accepted cars into next road segments

    for each Poisson queue at entrances:
        check if it is time to spawn a car
        if road is not blocked, insert new car into road

    record data: commute times, car counts, state of each road
```

Example

- Suppose at time 2000 seconds (33 minutes into the simulation), a car enters from Concord headed to Main Street North
- The Poisson process determines its arrival, and it is placed at the start of the Concord array
- The car first goes to the stoplight at Concord and Main, before being placed on the Main-Griffith-Concord road array
- It then proceeds to the stoplight at Main and Griffith
- Once the code gives permission to go (green light), the car proceeds to the north main array and is removed from the main-griffith-concord array
- Upon reaching the end of the north main road, it is removed from the array, and its total time in the system is logged as its commute time.

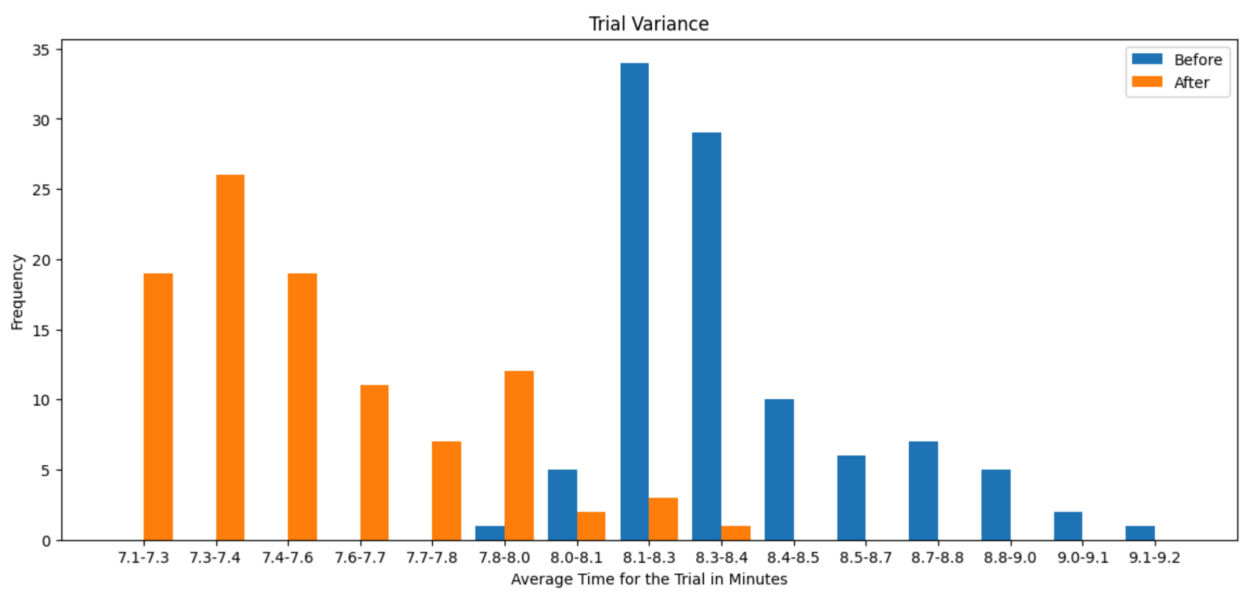
Results:

(1)



Traffic Before and After
Before
After
Average Time
0
2
4
6
8
10
To Griffith from Main north
To Griffith from Main south
To Griffith from Concord
To Main north from Griffith
To Main north from Main south
To Main north from Concord
To Main south from Griffith
To Main south from Main north
To Main south from Concord
To Concord from Griffith
To Concord from Main north
To Concord from Main south
Routes

(2)



Trial Variance
Before
After
Frequency
0
5
10
15
20
25
30
35
7.1-7.3
7.3-7.4
7.4-7.6
7.6-7.7
7.7-7.8
7.8-8.0
8.0-8.1
8.1-8.3
8.3-8.4
8.4-8.5
8.5-8.7
8.7-8.8
8.8-9.0
9.0-9.1
9.1-9.2
Average Time for the Trial in Minutes

Overall, the mean of the model's averages was **8.38 minutes** pre-construction. Post-construction, the mean time for cars' commute times was **7.53 minutes.** This indicates that on average, the construction will speed up commute times by **10.1%**. As shown on graph 1, the average commute times were similar pre and post construction except for two exceptions:

- From Main South St. to Griffith St.
- From Griffith St. to Main South St.

Overall, this shows that the Potts-Sloan connection reduces traffic on Main. Instead of being forced to take Main St, cars coming from Griffith will take Potts/Sloan to get to the other side of Main, and cars coming from South Main will also take the Potts/Sloan connection, leading to a 3.5 minute reduction on time coming from Griffith and a 2.5 minute reduction coming from South Main.

We believe that our results are reasonable, yet slightly conservative. We believe this because an increase in traffic on Potts/Sloan leads to a decrease in traffic on Main. Stoplight times will change in response to this, which our model doesn't take into account. This will lead to a further reduction in traffic on Main, which would lower average commute times even more.

To validate our model, we used Google Maps to see the time from one side of Main to the other in rush hour, and got 9 minutes. This is similar to our model, given our pre-construction average commute time is 8.38 minutes, which is reasonable given that traffic can vary. Another way to validate our results was to take the times with no stoplights on Main St. Total average times based on the proportion of cars going to and from were **7.26 minutes** without the new construction, and **6.85 minutes** with the new construction, a 5% difference (times for each road connection can be found in the appendix). This validates our model as it shows that stop lights do make a difference (but not too much), and that times with no stoplights are reasonable as well. Also, we observed this traffic in person and noticed that our model accurately showed what was happening on Main St.

Potential Improvements:

While we have confidence in our model, we acknowledge that it isn't 100% realistic compared to real-life Main Street Traffic. Here are some potential improvements we would've liked to make but didn't have the time/access for:

1. Modeling acceleration + deceleration – in our current model, cars are either stopped or going 10 mph. If we could have modeled cars speeding up and slowing down at intersections, our system would be more realistic and could yield slightly more accurate results. However, acquiring data for this would be challenging as every driver accelerates and decelerates slightly differently, and it is entirely dependent on how backed up the traffic is. Even if accurate data could be collected, coding it into our model would take more time than was available.

2. Accounting for pedestrians – in our current model, pedestrians are accounted for 18.5 seconds/min at the Concord/Main intersection and 15 seconds/min at the Griffith/Main intersection. Through observation, Concord/Main and Griffith/Main were the only intersections becoming backed up due to pedestrian stoppages. It wouldn't be difficult to implement some "dead time" for pedestrians at other intersections, but the number of pedestrian stoppages is very variable so they become difficult to account for.

3. Rate of incoming traffic – our current model assumes a constant flow of traffic from each of the four system entrances. This does not accurately describe how traffic enters the system, as oftentimes cars enter in bunches because of previous intersection/stoplight patterns. However, collecting data on and modeling the "bunches" would be nearly impossible given our time, resources, and how complicated our code already is.

4. Drivers' decision making – in our current model, cars decide whether or not they can proceed based on whether they have 1 "car length" of room to the car in front of them. They decide the same at intersections, except cars turning left on a yellow flashing arrow need 2 car lengths of room. This simplification may not be realistic because of individual driving habits; the "bunching up" of traffic when it is slow-moving, and the ability of cars to turn onto an intersection when the oncoming traffic is backed up (i.e. when traffic is so backed up, cars with a green light to go straight have to wait at the intersection which allows cars going the opposite direction to turn left in front of them).

5. 'Smart Lights,' or traffic lights that change based on the cars waiting on them, greatly help to reduce traffic. Currently, stoplights in our system wait for their entire cycle, even if no one is using them. These lights could be implemented with more time and data on how these smart lights are actually implemented on the road.

Conclusion:

The results of this paper come with many asterisks since so many details were simplified and not accounted for. Most of these issues could be slightly improved given more time to work on the project. However, our original model agrees with the estimated Google Maps time, so our model is at least accurate in modeling current traffic. The final number of around a 10% improvement in traffic time will ultimately be decided by driver behavior, but the estimate should still be considered conservative since the decrease in traffic will increase efficiency on the real road with smart lights and the stop start nature of traffic, which are not accounted for.

Additionally, if a 10% improvement is deemed insufficient by the Town of Davidson, field work noticed, and the model later confirmed, that a large backup is caused by the lack of a left turn lane from Main Street onto Concord. Adding a turn lane would also help to cut down on congestion north of Main.

Acknowledgements:

We would like to thank the Town of Davidson for trusting us with this project. In particular, we thank Andrew Golden, Transportation Planner for the Town of Davidson, for providing traffic volume data and offering insight into the most important times of day to model. His input helped us align our analysis with the town's priorities.

We are also grateful to Dr. Tim Chartier for connecting us with this project and for suggesting the "gameboard" modeling approach, which played a central role in the development of our model.

References:

Femke Kessels. *Traffic Flow Modeling : Introduction to Traffic Flow Theory through a Genealogy of Models*. Cham, Switzerland, Springer, 2019.

North Carolina Department of Transportation. *NCDOT Traffic Volume Map.* ArcGIS Web App, https://ncdot.maps.arcgis.com/apps/webappviewer/index.html?id=964881960f0549de8c3583bf46ef5ed4. Accessed 5 May 2025.

Appendix:

No traffic lights time in seconds for a car to reach the other side of the loop

		Exits			
		Griffith	Concord	North Main	South Main
	Griffith	–	336	441	604
Entrances	North Main	336	–	309	368
	Concord	441	309	–	557

	South Main	604	368	557	–

No traffic lights time in seconds for a car to reach the other side of the loop with roundabouts

		Exits			
		Griffith	Concord	North Main	South Main
Entrances	Griffith	–	336	441	488
	Concord	336	–	309	368
	North Main	441	309	–	635
	South Main	488	368	635	–