Effects of Articulated versus Actuated Signaling on Traffic Congestion

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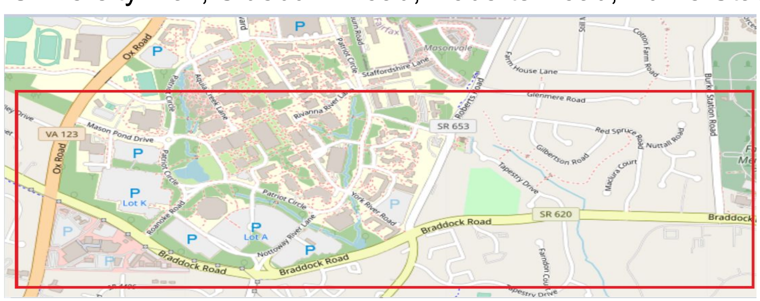
Introduction

Traffic congestion plays a large role in human life as each year there are more and more drivers on the roads, as well as more places to go. Some common downsides to high traffic congestion include wasted time (“opportunity cost”), late arrivals, motorist frustration, inaccuracy of GPS predictions, wasted fossil fuels accelerating air pollution, wear and tear on vehicles, inefficient emergency response, and higher chances of collision. The list goes on. All of these inconveniences, with their varying degrees of negativity, can be eased as traffic congestion is also eased and vehicles are flowing more efficiently. This is why finding the best way to improve vehicle flows (ease traffic congestion) is a very important question.

Traffic congestion is the result of multiple factors, including volumes of traffic relative to road capacity, obstacles (i.e. road work), pedestrians, and the functionality of traffic signals. Each one of these factors is capable of having a large impact on congestion, which is why studying ideal settings and methods can aid in lessening the impact of traffic.

In this study, we look specifically at traffic signals. Our main goal is to determine whether signal articulation increases or decreases congestion. To do this, we compare metrics between signals using fixed cycle times and actuated signals. Actuated signals are based on real time detection of vehicles with no predefined signal phase timing. Conclusions are made based on the comparison of three key metrics: average flow rate, average inter-vehicular distance, and vehicular densities. We observe these metrics for both timed signals and actuated signals in the morning (peak), evening (peak), and midday (non-peak). Five Braddock Road intersections are used in this case study along with their associated flow rates going in each direction, given by the Virginia Department of Transportation.

Ox Road, University Mall, Sideburn Road, Roberts Road, Burke Station Road

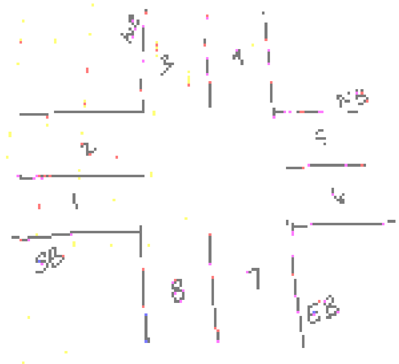


Experimental Process

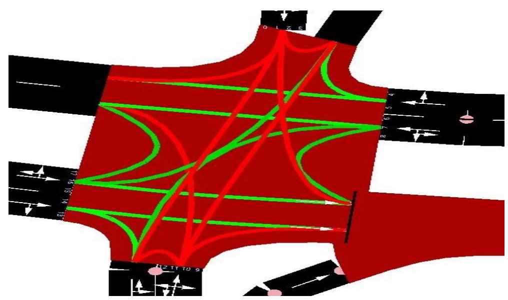
This experiment / set of simulations, was run using SUMO (Simulation of Urban MObility). SUMO allows for the simulation of large road networks and traffic systems which can include multiple variables such as pedestrians, public transportation, and regular automobile traffic.

To begin, the preliminary map including our intersections was downloaded from OpenStreetMap (OSM), which is an open source map edited by volunteers. Then, since maps from OSM are often imperfect, the map was edited to ensure close correspondence with our real-life intersections. This editing process included modifying the number of lanes, and ensuring each necessary road in our simulation was connected to another.

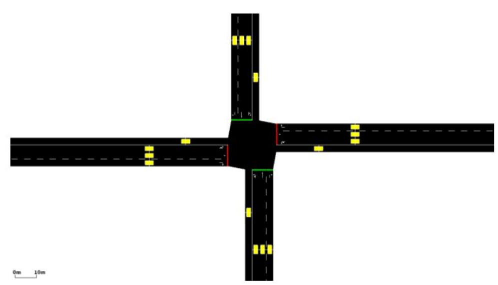
Next, flow information was added in the form of an Origin-Destination Matrix (OD Matrix) from VDOT flow information for each intersection at each period from the day (i.e. am, pm, and midday flows). Three different OD matrices were created for each time period. To create the OD matrices, we begin by creating the TAZ file containing all of the relevant edges in our maps and giving them new and simplified ids for use in the OD file. Each 4-way intersection is made of 8 edges total, having two edges (one going each direction) in each of the northbound, southbound, eastbound, and westbound directions. The image to the right represents the intersection of Braddock and Ox Rd. The TAZ file takes the edge id numbers and assigns them to simplified ids. The edges comprising each intersection in this experiment are given unique identifiers continuing on from the identifier of the previous intersection. To assign the flows, we determine which origin and destination edges make up a given direction. For example, using this layout, SBT (south bound through) would begin at edge 1 and end at edge 6, SBR (southbound right) would be edge 1 to 8, and SBL (southbound left) would be edge 1 to 4. Once the information from VDOT is filled in for each OD point for each intersection, the route file is created to generate the proper routes for the given flow.



Signal phase timings and phases were taken from the provided traffic flow data and they were implemented in sumo. Signal phase timings for each of the intersections were provided by an additional tls file. Along with the cycle length, different phases provided by VDOT were implemented for all the intersections for AM, PM, and MD. Both the static and actuated signal phase timings were implemented. While the signal phase timing for static signals remained fixed, actuated signals phase timing varied between a given minimum and maximum durations.



Finally metrics were collected from the network in order to compare the different settings. To collect data on flow rate, E1 detectors were attached to each lane of our 5 intersections, allowing us to get the flow rate of each simulation respectively. An example of E1 detectors associated with an intersection can be seen to the right. To collect information on traffic density, an edge-based state dump is defined in an additional file. To collect intervehicular distance, we equip a vehicle with an SSM device which logs the conflicts of the vehicle with other vehicles and corresponding safety surrogate measures. Attaching this device to each vehicle required the standard procedure for device attachment, but with the <device name> = ssm. From SSM, SGAP measures the spacing bumper to bumper from the vehicle’s leader minus the vehicle’s minGap.



Experimental Results

In order to address the main research question proposed during this experiment (whether signal articulation affected congestion in any way), three separate mathematical calculations were performed to aid in the solution. The average flow rate, inter-vehicular distance, and vehicular densities are the metrics that are going to be analyzed in the following section.

Inserted below are two tables that display the information. Table 1 shows the flow, inter-vehicular, and density for the default fixed cycle time of 170 seconds for peak hours (i.e. AM and PM) and a default fixed cycle time of 150 seconds for non-peak hours (i.e. MD). Table 2 displays the same calculations; however, it is calculated for actuated signals.

Preset Signals Phase	AM	MD	PM
Avg. Flow Rate	418.85	375.98	360.79
Avg. Inter-Vehicular Distance	100.53	67.01	60.57
Vehicular Densities	43.86	43.86	47.85

Table 1

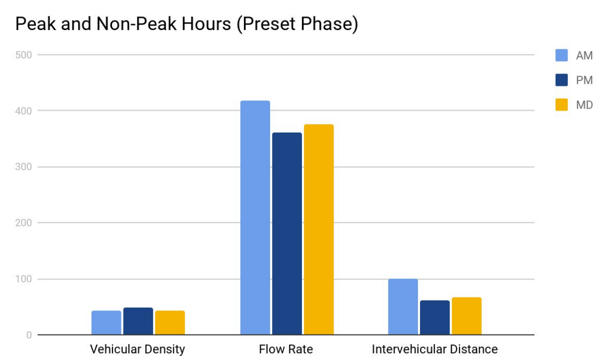
Actuated Signals Phase	AM	MD	PM
Avg. Flow Rate	379.01	318.83	380.81
Avg. Inter-Vehicular Distance	53.45	102.76	72.51
Vehicular Densities	28.74	21.21	35.56

Table 2

Peak vs Non-Peak Results

This section takes a deeper look into the results and compares the results of the fixed signal timings and actuated signal timing with peak and non peak hours.

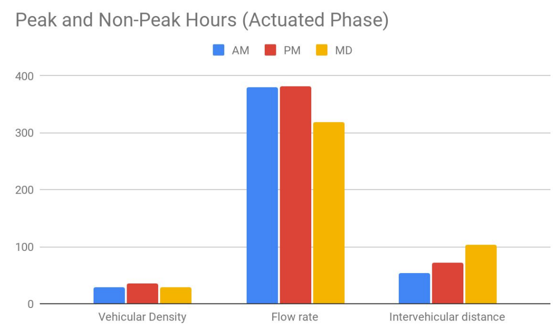
The initial comparison below between the peak and non-peak hours during the preset phase and actuated phase is to conclude upon a concept that is already clear: there is an expectation of increased traffic congestion during the AM and PM hours as they are considered to be peak hours and a decrease in traffic congestion during the midday (as it is non peak). The results shared below justify that statement.



- Vehicular density remains the same in case of AM and Midday, while it increases by 9% by PM.
- Flow rate during peak values at AM is really high compared to peak PM by 16%, while the non peak value remains 4% higher than PM peak.
- Inter-vehicular distance during AM is 65.97% higher than PM peak, and non-peak value is 10.63% higher than PM peak.

Observation

From the above observations, we can conclude that the vehicular traffic is high during PM and hence flow rate and inter-vehicular distance remains the lowest.
Even though the vehicular density is the same for AM and midday, the flow rate is slightly higher in case of midday and hence the inter-vehicular distance is also much larger when compared to AM.



- Vehicular Density remains the same in case of AM and Midday , white it gets increases PM by 6.83.
- Flow rate remains almost the same in case of AM and PM but compared with MD it has decreased to around 61.98 .
- InterVehicular distance has different values for each timing , as for AM it's 53.45 , PM 72.51 and with MD slightly higher to 102.76.

Observation

From the above observations we can conclude that the vehicular traffic density is high during PM but the flow rate is highest and intervehicular distance is moderately higher than during peak values at AM. Even though the vehicular density is the same for AM and midday, the flow rate is higher in case of midday but hence the intervehicular distance is also much smaller when compared to AM.

Peak Metric Comparison (Preset Phase and Actuated Phase)

AM

- Comparing the density for both AM Preset and actuated phase, there is sudden **decrease** in density from Preset phase AM density to actuated phase AM density which from 43.86 to 28.73.
- Comparing the flow rate for both AM Preset and actuated phase, there is sudden **decrease** in flow rate from Preset phase AM density to actuated phase AM density which from 418.85 to 379.01.
- Comparing the intervehicular for both AM Preset and actuated phase there is sudden **decrease** in intervehicular from Preset phase AM density to actuated phase AM density which from 100.53 to 53.45

PM

- Comparing the density for both PM Prest and actuated phase there is sudden **decrease** in density from Preset phase PM density to actuated phase AM density which from 47.85 to 35.56.
- Comparing the flow rate for both PM Prest and actuated phase there is sudden **increased** in flow rate from Preset phase PM density to actuated phase PM density which from 360.79 to 380.81

- Comparing the intervehicular for both PM Prest and actuated phase there is sudden **increased** in intervehicular from Preset phase PM density to actuated phase PM density which from 60.57 to 72.51

Non-Peak Metric Comparison (Preset Phase and Actuated Phase)

- Comparing the density for both AM Prest and actuated phase there is sudden **decrease** in density from Preset phase AM density to actuated phase AM density which from 43.86 to 28.73.
- Comparing the flow rate for both AM Prest and actuated phase there is sudden **decrease** in flow rate from Preset phase AM density to actuated phase AM density which from 375.98 to 318.83
- Comparing the intervehicular for both AM Prest and actuated phase there is sudden **increased** in intervehicular from Preset phase AM density to actuated phase AM density which from 67.01 to 102.76

Research Question Discussion

From our experimental results, this signal articulation **decreased** the congestion. We can see that intervehicular distance has been increased while the vehicular density has been decreased. While we might've expected differently, the results from this experiment may have come from using signal phase timings given by VDOT and for the actuated signals using sumo's default phases with modified cycle length.

Conclusion

In this experiment, we looked at the intersections of Braddock Road starting with Ox Road (VA- 123) and ending with Burke Station Road. As Braddock Road is host to many different types of vehicles and supports a wide range of traffic -commercial, institutional, commuter and residential, just to name a few, this artery is a good contender to analyze when it comes to traffic congestion. Congestion is only expected to continue to grow as more and more drivers are on the road. As the main objective of this experiment was to conclude whether signal articulation has an effect in traffic congestion, using traffic signals as the chosen variable to change was one way to address that question. After running the simulation using SUMO in conjunction with OpenStreetMap, three main calculations were taken. Flow, density and inter vehicular distance are all metrics that would help answer the question.

Looking at the results, it can be concluded that traffic congestion does in fact decrease with signal articulation. When comparing the results from the fixed signal timings and actuated signals, there is a clear decrease in density as well as a clear increase in inter-vehicular distance, especially during the peak hours of PM and non-peak hours of MD. One thing to note is that this experiment was based solely on the use of the intersections and the main artery of Braddock Rd by road vehicles. An area of further research could include the usage of these intersections by pedestrians as that may cause further delay between each traffic signal and would affect flow, inter-vehicular, and density. Determining if signal articulation then still contributes to a decrease in congestion would be an interesting experiment.