Culver Road and East Main Street Intersection

Traffic Analysis Report

March 20, 2015

Introduction

There has been intense study in the area of traffic management since the mid-1990s. The ability to quantify and discern underlying patterns with a simple loop detector is a useful tool in understanding the complex nature of transportation systems. We were tasked with identifying unique trends present in data from a magnetic loop sensor and to provide sound recommendations to improve traffic conditions for the intersection of Culver Road and East Main Street in Rochester, New York. The data, obtained from a loop detector approximately 200 feet away from intersection in the southbound lane, has nearly eight months of data stretching from October of 2013 to June of 2014. The loop detector transmits data in five minute intervals, and calculates pertinent metrics such as estimated hourly volume, number of vehicles approaching a red light, delay, and the speed of the vehicles as they approach the intersection.

The intersection, pictured in Figure 1, is part of an important byway between Bay Street and East Main Street. Zoning data provided by the city of Rochester shows us that the area surrounding this portion of Culver Road is mainly residential. However, there are designated commercial zones at both the intersections of Bay and East Main, and additional commercial lots in between both of these locations [1]. These are mainly smaller business and not large scale commercial plazas similar to those in Henrietta or elsewhere in the city of Rochester. It is important to consider this information in conjunction with the results of our analyses when providing meaningful suggestions.

We also used the Traffic Volume Map that is provided by the Monroe County and the City of Rochester. Culver Road normally experiences a large amount of traffic that is comparable to East Main [2]. Furthermore, it appears as though the traffic continues down Culver and that there is no noticeable amount of traffic turning onto East Main that would contribute to any possible congestion.

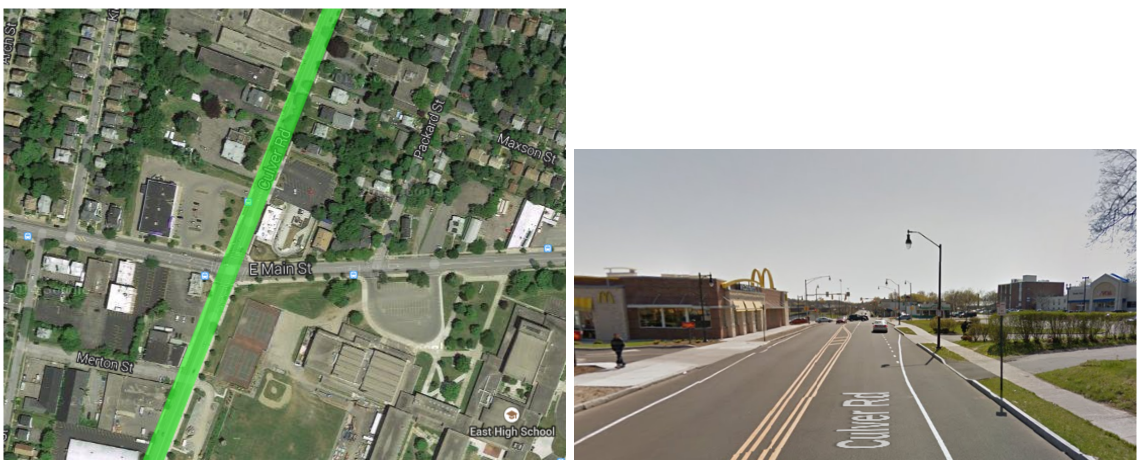

Figure 1: Pictured Left: satellite image of the intersection of Culver and East Main. Culver Road is highlighted in a light green. To the bottom right is East High School of the Rochester School District. Pictured Right: A streetview of Culver Road as it approaches East Main. Several businesses are located on both sides of the street. Location is approximate to where the loop detector is installed. Both images courtesy of Google Maps.

Data Analysis

To assess the traffic conditions at the Culver Road and East Main Street intersection, we determined the current state of the intersection in terms of federal DOT guidelines for this class of intersection, as well as analyses to examine trends and patterns in the traffic recorded, and the calculation of the probability of traffic congestion based on the time of day and day of the week.

Traffic Analysis

There are a few common characteristics to examine when determining the traffic flow for a particular intersection. Namely, it is important to determine the amount of delay experienced by drivers as they enter the intersection, the density of the vehicles as they pass through the intersection, and the velocity at which traffic flows through the intersection. With these three variables, it is possible to determine the conditions that result in congestion at this intersection.

The amount of time that vehicles wait at an intersection is referred to as the Level of Service (LOS). Ranked in letter grades from A to F, the LOS is an identifier for the overall health of the intersection. Ideally, an intersection should be classified as being either A, B, or C, denoting free flow, reasonably free flow, and stable flow, respectively. The 2010 Highway Capacity Manual classifications for LOS can be seen in Table 1, in which grade A intersections have less then 10 seconds of vehicle control delay, whereas grade F intersections have more than 80 of vehicle control delay.

Table 1: Level of Service classifications published in the 2010 Highway Capacity Manual.

LOS	**Vehicle Control Delay (Sec.)**
A	≤ 10
B	$10 - 20$
C	$20 - 35$
D	$35 - 55$
E	$55 - 80$
F	≥ 80

Using these classifications, we examined the average vehicle control delay for each five minute observation period. As shown in Figure 2, the majority of observations have a Grade F Level of Service (58.38%). Each of the other levels of service occurred in between 7.45% and 8.63% of observations. This suggests that the Culver Road and East Main Street intersections is experiencing traffic congestion, in which each vehicle move in lock step with the vehicle in front of it [3].

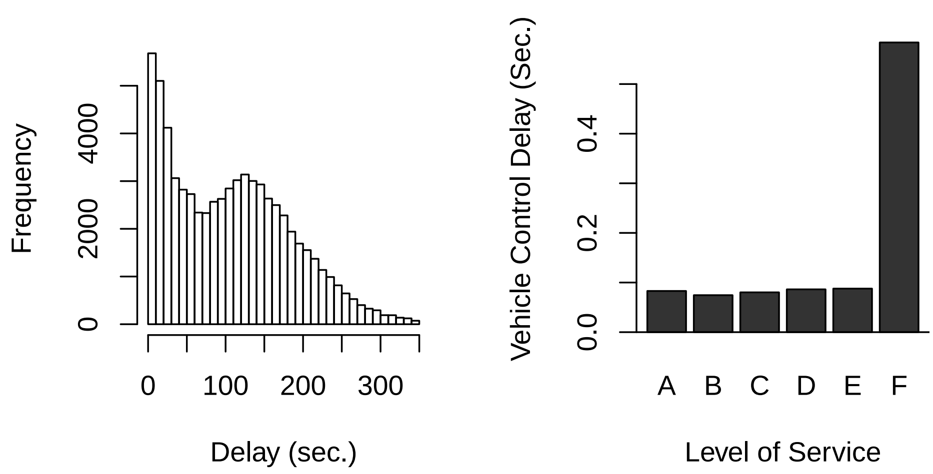

Figure 2: The Culver Road/East Main Street intersection has a poor Level of Service. The histogram on the left shows the distribution of the average vehicle control delay for each observation. The distribution is bimodal with peaks at zero seconds and 140 seconds. The median delay was 103 seconds with a IQR of 123 seconds. The bar plot on the right shows the distribution of each LOS grade for each observation in our data set. Observations were given a letter grade based on the average vehicle control delay for each 5 minute interval. The majority of all observations had a delay of greater than 80 seconds, suggesting that the intersection is predominantly grade F.

We also examined the relationship between the traffic density and traffic volume, also known as flux.

When plotted, the relationship between the traffic density and the traffic volume creates the fundamental diagram of traffic flow [3], as shown in Figure 3. Using linear regression techniques, we were able to estimate the free flow velocity to be 19.5 miles per hour and the traffic wave velocity to be 2.43 miles per hour against the direction of traffic. We also determined the critical traffic density to be 42.8 vehicles per mile. As the vehicle density passes the critical density, the traffic flow becomes more unstable leading to traffic waves and congestion. To maximize the traffic flow, the vehicle density must remain below the critical density.

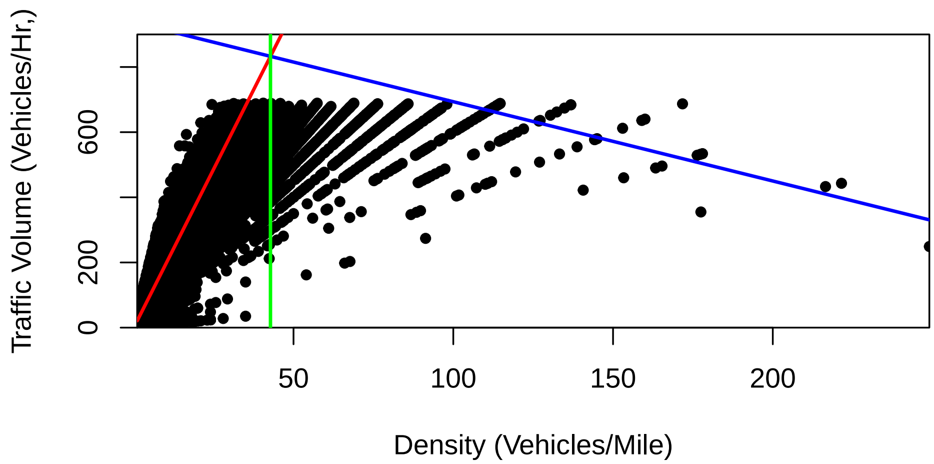

Figure 3: Fundamental diagram of traffic flow provides free flow and traffic wave velocities. Traffic density was calculated by dividing the traffic volume by the traffic speed. Using linear regression, we found the free flow velocity (19.5 mph) as depicted in red, the traffic wave velocity (2.43 mph) as depicted in blue, and the critical density (42.8 vehicles per mile) as depicted in green.

Trend Analysis

To examine general trends from the metrics we were provided, we performed linear regression on the traffic delay and the traffic volume. This techniques allows us to approximate the traffic volume and delay over multiple observations. Figure 4 shows the median delay for each week and the median traffic volume for each week with the linear regression for each data set. Our data suggest that the median amount of time that vehicles wait at the intersection may be increasing by 0.24 seconds per week. Our data also suggest that the median number of vehicles utilizing the intersection may be increasing by approximately 11 vehicles per week. Although the correlation coefficients are rather low, we are confident that the traffic congestions will worsen as more vehicles utilize the intersection.

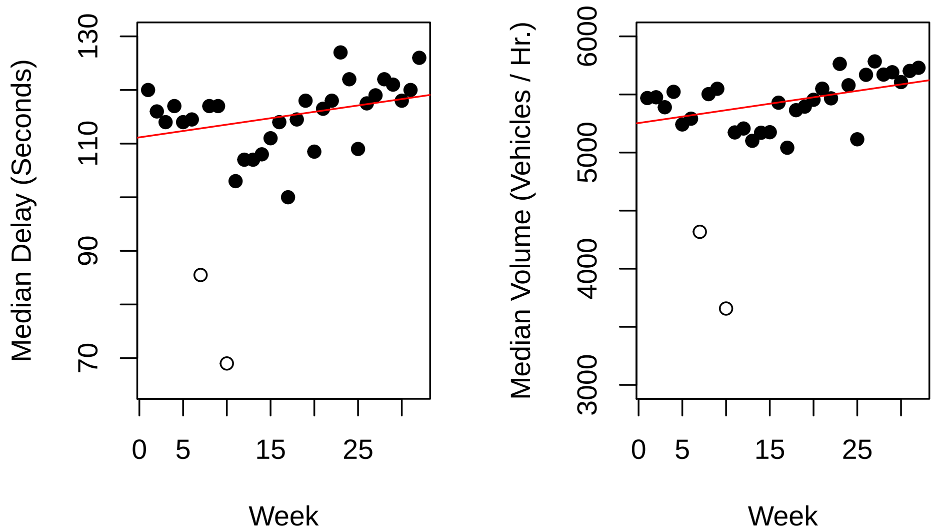

Figure 4: The median traffic delay and median weekly traffic volume are increasing over time. A linear regression of the median traffic delay for each week suggests that the traffic delay may be increasing 0.24 seconds per week ($R^2 = 0.13$). Similarly, a linear regression of the median number of vehicles to pass through the intersection per week suggests that the number of vehicles utilizing the intersection may be increasing at a rate of 11.08 vehicles per week ($R^2 = 0.24$).

Pattern Analyses

A secondary way of understanding the traffic passing though the Culver Road and East Main Street intersection is to assess the prevailing patterns of traffic. Two methods of analyzing traffic patterns are clustering and correlation analysis. Clustering algorithms give us an opportunity to treat each day's traffic like a single data point. By comparing the distance between each day's traffic, we can group similar traffic patterns together. Correlation analyses, on the other hand, examine how similar each individual pairing of days is by comparing each traffic 5-minute observation. These two different techniques provide different ways of finding patterns: clustering allows us to find similar large-scale similarities between days, whereas correlations gives a more granular measure of similarity between a day and the expected traffic.

Using a CLARA clustering algorithm, we clustered the daily traffic volume for each day of data using 10-minute intervals. We found that there are three primary types of traffic: weekday traffic, Saturday traffic, and Sunday traffic. Each of these types is named after the days in which they are most likely to occur. Figure 5A, shows a cluster plot of the three clusters of traffic measured along their principle components. The gray circles represent traffic classified as Sunday traffic, the orange triangles are weekday traffic, and the blue pluses are Saturday traffic. It should be noted that the most variable traffic type is the Sunday classification, suggesting that there may be incidences of highly irregular traffic that are more similar to Sundays than any other day of the week. A notable example of this is Thanksgiving Thursday on November 28, 2013. Thanksgiving experiences drastically lower traffic than both the typical Sunday and the typical Thursday, but the low traffic volume is more similar to a Sunday so it was clustered accordingly, as shown in Figure 5B.

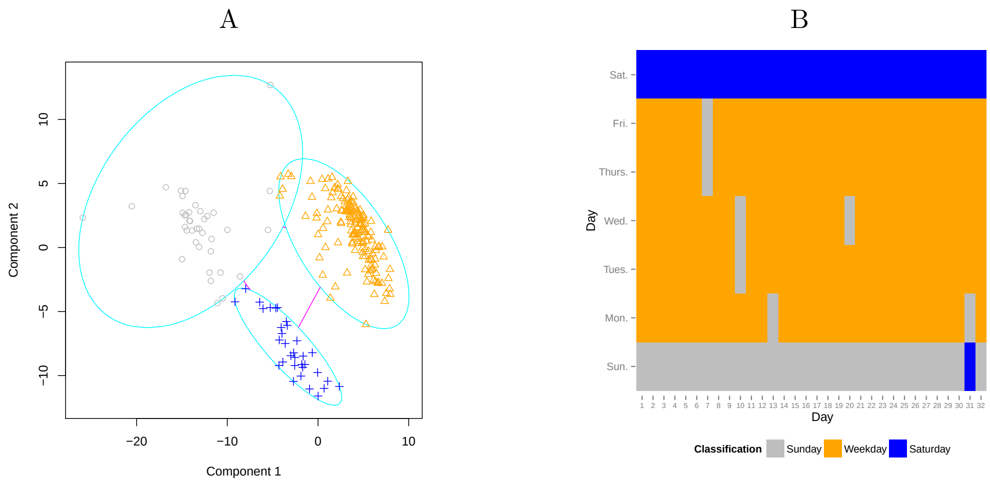

Figure 5: CLARA clustering suggests three primary traffic types. Each day's traffic volume was aligned in a matrix and clustered using a CLARA clustering algorithm. Subfigure A shows a plot of the principle components of the days clustered. Similar traffic types are grouped spatially together in a manner that allows them to be clustered easily. Figure B shows a calendar view of each day as classified by the CLARA clustering algorithm. This plot clearly shows the weekly relationship between the traffic types, and highlights traffic abnormalities.

For our correlation analysis we compared each day's traffic volume to the median traffic for that day of the week. For example, we examined the correlation between the traffic volume for Thanksgiving to the median traffic volume at each 5-minute interval for all Thursdays. A plot of each day's correlation, as shown in Figure 6, outlines the variability in each day's traffic patterns. It should be noted that the days of abnormally low correlation relate to weekdays clustered as Sunday traffic in Figure 5B. In this figure, high correlation suggests that the day's traffic is very similar to the expected traffic for that day of the week, whereas a low correlation is indicative of an abnormality in traffic volume. One interesting case of abnormal traffic is the seventh Thursday of the data set, which corresponds to Thanksgiving. The 2013 Thanksgiving traffic was abnormally low for a Thursday. Similarly, the 10th and 20th Wednesdays of the data set exhibit similar patterns of minimal traffic. Interestingly, weekdays have a higher median correlation (0.946) and a lower variance in correlation (0.003) than the weekends. This suggests that weekdays have a relatively stable or predictable traffic pattern with a few dramatic exceptions.

Bayesian Analysis

In order to determine how the probability of congestion relates to the time of day we adapted Bayes' Theorem for use with the data provided. Because the traffic on the weekend is not as intense as the traffic during the weekdays, the decision was made to evaluate each day independently of one another so as not to induce any sort of bias into the results. Congestion was determined simply by using the critical density of the intersection, identified as 42.8 Vehicles per Mile. Any situation where the density is equal to or greater than this measure is determined to be 'congested.' Any situation below this measure is simply 'not congested.'

This is then sorted for each time step, and a proportion is generated about how many times (on a specific day of the week) that particular time is considered congested. For example, this means that if 2 out of the 10 observations at 2:10am on Wednesdays is considered to be congested, equal or exceeding the critical density, the proportion is calculated to be 0.2. This is then multiplied by the probability of congestion at any time amongst all the observations, and is then divided by the probability of randomly selecting that time from the dataset.

Figure **??** provides a way of seeing the probability of congestion occurring given the day of the week and the time of day. As expected the probability of congestion increases dramatically between 4 and 6 PM, which correspond with the traditional rush hour period. Interestingly, there is a non-trivial probability of traffic congestion occurring between 2 and 6 AM. This may correspond with people who work during the evening.

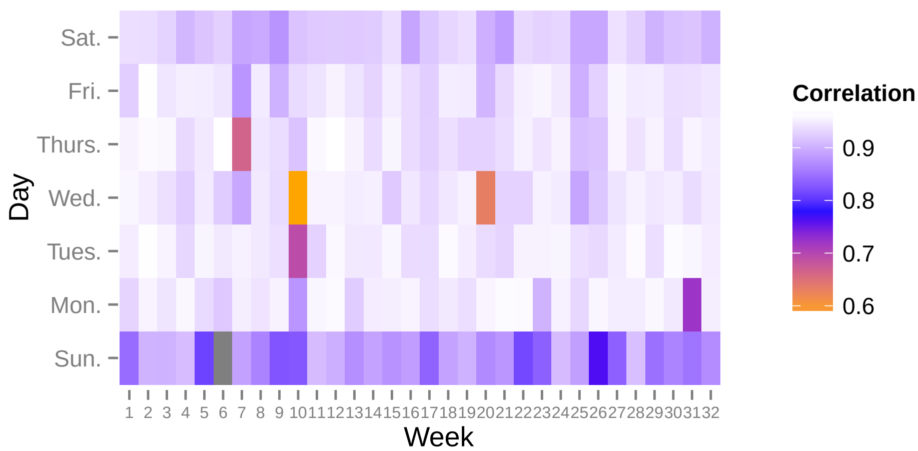

Figure 6: Correlation analysis shows holidays, data collection errors, and small-scale traffic patterns. In this color scale, white indicates high correlation, purple indicates moderate correlation, and orange indicates low correlation. Some days of interest include the seventh Thursday, which corresponds with Thanksgiving, the 10th Tuesday and Wednesday, and the 20th Wednesday.

Additionally, there is a slight spike at 7 AM, which may correspond with school traffic or people leaving for jobs with 7:20 or 8 AM starting times.

Table presents times that have he highest probability of observing traffic congestion. For the purposes of this table Saturday and Sunday were omitted from the table due to the fact that their relative probabilities were approximately zero. A point of interest is that congested periods start earlier on Fridays, suggesting that people may be leaving work early on Fridays.

Table 2: Selected results from Bayesian analysis of traffic data.

Time	Mon	Tues	Wed	Thur	Fri
17:05	0.500	0.471	0.529	0.588	0.500
17:10	0.765	0.824	0.677	0.824	0.853
17:15	0.824	0.853	0.882	0.824	0.912
17:20	0.853	0.882	0.765	0.882	0.677
17:25	0.588	0.794	0.647	0.677	0.529

Recommendations

Culver Road is an important byway for the citizens of Rochester, and it's ability to function properly is critical in order to avoid unnecessary congestion whenever possible. Considering that the intersection has a Grade F LOS approximately sixty percent of the time, appropriate action must be taken in order to reduce the amount of time vehicles are waiting at this intersection. Since both East Main and Culver are high volume roads, an alteration of the intersection signal light to allow more traffic to flow through the intersection via Culver would most most likely cause more harm than good. Similarly, the speed at which cars enter the intersection is a function of the traffic at the intersection it self, so altering the speed of Culver Road will not relieve traffic.

Instead, we offer four potential solutions that could reduce the incidence of traffic congestion. Based on the published traffic volume maps and the recorded data, Culver experiences more north-south traffic than turning traffic, we suggest that Culver be widened into a two lane avenue so that it can accommodate the higher amount of traffic moving from north to south. Widening Culver would have a dramatic effect on reducing the amount of time vehicles are waiting at the intersection and thereby increasing the LOS.A

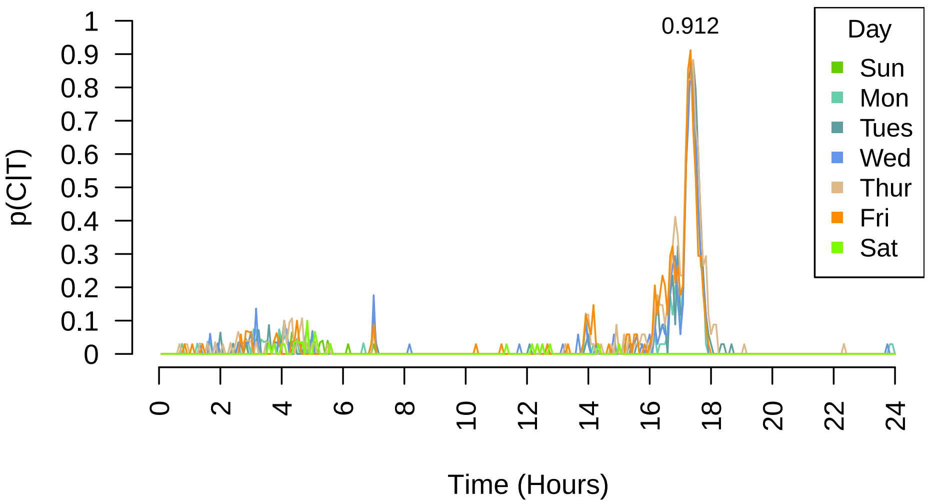

Figure 7: Probability of observing congestion based on specific times throughout the day (represented as p(C|T)). All days are represented as separate lines. A maximum probability of 91.2% is shown on the graph and occurs at 5:15pm on Friday. Most weekdays have the highest probability of congestion between 5:00pm and 5:25pm, or during evening rush hour.

second infrastructure change that could reduce traffic congestion is the lengthening of turn lanes. In the case that there is an up tick in turning traffic, turning vehicles can extend past the designated lane and disrupt the south-bound majority.

A non-infrastructure suggestion is to limit the number of commercial permits and to rezone available lots to be residential-only. Our data suggest that there is a surge in volume during the typical ”end of the work day.” This is also supported by our Bayesian analysis of congestion probability. Should we have access to data for the north bound lane of Culver at this intersection it would be likely that we would see high volume in the morning. These vehicles could simply be representative of individuals commuting to work, and by reducing the number of businesses in the area, you could thereby reduce traffic and eliminate the need to increase the capacity of the road itself.

Our last recommendation is the formation of an automated system to classify traffic on-the-fly. Such a system would be able to diagnose abnormal traffic patterns and predict whether a given day is experiencing abnormally high or low traffic. This would provide the Monroe County Department of Transportation an early warning about traffic collisions, signal timing malfunctions, or other issues that may affect drivers.

In conclusion, we have shown that the current traffic conditions at the intersection of Culver Road and East Main Steet are untenable and require remediation. While this report is by no means comprehensive, it does present a stark image of increasing traffic congestion as the traffic volume and delay times increase week by week. Regardless of the solutions implemented, it is important that the traffic density at this intersection be reduced and the traffic congestion relieved while it is still feasible to do so.

Bibliography

[1] City of Rochester, *Property Information Application*. HTTP://maps.cityofrochester.gov/propinfo/.

[2] City of Rochester, *Traffic Volume Map*. 2014. http://www2.monroecounty.gov/files/dot/pdfs/City-adt-map-through-2014.pdf.

[3] Transportation Research Board of the National Academies, *Highway Capacity Manual 2010*. 5th edition, 2010.