TEAM RESEARCH PROJECT REPORT

Project # 5: Simulation-Based Impact Analysis of Signalized Intersections

Submitted To

The RET Site
For
"Sustainable Engineering for Urban Needs:
Research Experiences for Middle and High School Teachers"

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Prepared By

Todd Bonds, Pre-service Teacher Student, Northern Kentucky University, KY
Kelli Lee, Grant County Middle, Middle School, Dry Ridge, KY

Approved By

Dr. Heng Wei
School of Advanced Structures
College of Engineering and Applied Science
University of Cincinnati

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ABSTRACT

The signalized intersection of Clifton Ave and Martin Luther King Dr is a busy intersection in Cincinnati, OH. Like any other signalized intersections, the intersection delay and the large amount of CO emission from idling vehicles at the intersection are two major problems caused by improper configurations of traffic signal and intersection geometry. Through field data collection and microscopic simulation based analysis, it is proved that the intersection is not operating at the optimal condition. The existing level of service is unbalanced for different movements and the southbound left turn is rated "F" in its existing condition, which is unacceptable. The conducted analysis on the correlation between delay and CO concentration identifies that longer stopped delay will cause higher CO concentration in the air. Finally, the teachers propose two alternative solutions to the intersection that would decrease both the overall delay and the CO emission into the air under the simulation environment. The first alternative solution optimizes the timing and phasing of the traffic signal. It would result in a decrease in the overall delay by 2.9 seconds per vehicle and in turn decrease the amount of overall CO emission by 1.92 grams per hour. The second alternative solution optimizes the storage lengths of two left turning lanes. It would result in a decrease in overall delay of 4.87 seconds per vehicle and also reduce the CO emission by 4.35 grams per hour. In other words, implementing the alternatives would improve the amount of clean air, which is a health benefit. In addition, implementing the alternatives would reduce the amount of workforce lost caused by vehicle delay. That is a savings of as high as $126 an hour, or $138,648 annually.

1. INTRODUCTION

Many different issues contribute to the decreasing amount of clean air. One problem is CO emissions from cars idling at signalized intersections for long periods of time. The limiting of CO emissions is crucial clean air everywhere. It is especially important in major cities – here and abroad.

A pair of teachers – Todd Bonds and Kelli Lee – were selected to examine a signalized intersection in its existing condition and make recommendations for alternative solutions if it was determined that the intersection was not being used optimally. The intersection/study site is located at the crossing of Clifton Avenue and Martin Luther King, Jr. Drive in Cincinnati, OH.

A similar study was done by several Chinese engineering students here in the United States and a Chinese professor in Shanghai, China. The study was about the problems with CO emissions in their native land's urbanized areas, and suggests the issue is getting worse. They found that concentrations of CO and nitrogen oxide (NO) routinely violate the nation's Air Quality Standards. The violations often occur at signalized intersections during peak hours where cars are often idling, accelerating and decelerating. The issue is similar at the intersection the teachers researched.

Additionally, the intersection delay problem also commonly exists due to the improper configuration of signal phasing/timing and geometry of the intersection. The United States Bureau of Labor and Statistics stated that the average hourly wage in the country is $20.32. That means that if five people car pool and get stuck in traffic for an hour, the country loses more than $100 in production for that hour.

These are the problems the teachers tried to propose solutions for through their research efforts. The teachers wanted to find a way to contribute to decreasing the intersection delay and to cleaner air.

2. LITERATURE REVIEW

The teachers were presented with literature from research done on similar studies and problems. The research is was as recent as this year, and went back as far as 2002. The different pieces of literature allowed the teachers to gain insight on the different aspects of their project and some of the methods they would use while working on the project.

The Canadian Web site Canada.com (Harris, 2010) reported research done at the University of Cincinnati in the story "Amber lights a grey zone for many drivers" about driver's stopping at yellow lights. The report mentioned that "For each additional second a yellow light persists, drivers are more than three times as likely to pass through an intersection."

A study titled "Signal timing of intersections using integrated optimization of traffic quality, emissions and fuel consumption" (Li et al., 2004). Although the study dealt with China, the researchers concluded that the signal timing model proposed optimizes signal cycle length and green time by using integrated optimization of traffic quality, fuel consumption and emission pollution, and that when the traffic flow rate is larger, the optimal signal cycle length corresponding to the performance index function increases.

Another report, "The Traffic Impact Forecast of a Proposed Constructive Project and Simulation Analysis" (Wang et al., 2007) mentioned how precise the data collection must be in order to simulate the traffic of the study site in order to make accurate and viable alternative solutions. The researchers stated that, **"**The data must be exact before they are used to calibrate the model and to simulate the traffic situation, otherwise the precision of the forecast result will decrease."

A study done on limiting CO emissions titled "Microscopic Traffic-Emission Simulation and Case Study for Evaluation of Traffic Control Strategies" (Chen and Yu, 2007) found that a bus only lane would reduce the CO emissions from buses but might increase the CO emissions from cars. The study also suggested that the implementation of traffic control and management strategies should consider not only mitigating the traffic congestions, but also reducing the traffic emissions.

Further proof that the research had to be accurately and precisely done is evidenced from more literature the teachers read. In the report about emissions titled “Evaluating effects of traffic and vehicle characteristics on vehicular emissions near traffic intersections” (Pandian et al., 2008), the researchers ran simulation models for vehicle emissions as well. They surmised that the lack of proper methodology in estimating emissions at traffic intersections, which incorporates all dynamic parameters, has slowed down the advancement in emission modeling for such locations.

The problem with emissions was also studied Francois Dion, et al (2002). The researchers found that in particular, the consistency of delay models should be evaluated for multi-lane approaches, intersections controlled by actuated controllers, and intersections where non-random vehicle arrivals occurs as a result of signal coordination with upstream intersections.

3. GOALS AND OBJECTIVES

The goal of the research is to improve the delay at the signalized intersection and to limit emissions of CO, and to improve the delay and overall level of service of the intersection.

There were three objectives for the project.

- Identify whether or not there is a relationship and CO emissions.
- Identify the existing condition of the study site in terms of delay and CO emissions.
- Propose alternative solutions to minimize the delay and CO emissions through the aid of simulation-based analysis.

4. STUDY SITE

The study site is located at the signalized intersection of Clifton Ave and Martin Luther King Dr in Cincinnati, OH. **Figure 1** illustrates the aerial map of the study intersection. The study site is one of Cincinnati’s busiest signalized intersections. It is near the University of Cincinnati, and receives traffic from many different healthcare employers, businesses and city and county offices, students and university employees. It has 12 turning movements, with each approach having two through lanes, a left turn only lane and a right turn only lane.

5. METHODOLOGY

The heuristic framework shown in **Figure 2** illustrates the entire procedure of conducting this research project.

First, a substantial amount data collection is required. The data collected includes geometric data, signal timing and phasing of the study site, counting the number of vehicles for each turning movement, counting the delay of stopped vehicles, and collecting the CO data as well.

Figure 1. Map of Study Site

Figure 2. Heuristic Framework Showing the Methodology of the Research

A study analyzing the correlation between stopped delay and CO concentration is to be conducted in order to identify the potential relationship between the two variables. Once this correlation is confirmed, the existing EPA exhaust models can be used as a knowledge base to estimate the CO emissions from the delay of stopped vehicles.

A simulated network of the study site is to be built based on the collected data by using the VISSIM software program. The teachers are then able to make scenario analyses of the overall performance of the study site, which includes delay, level of service, and CO emission using the simulation.

Finally, what-if analyses are to be conducted under the simulation environment to propose alternative solutions that can improve the delay and CO emission. Each proposed alternative will be evaluated and modified until that delay and emission are minimized in the simulation.

The final alternative solutions reflect the optimal conditions for the study site in terms of delay and CO emission.

6. DATA COLLECTION

The teachers acquired the geometric data from the intersection of Clifton Ave. and MLK Dr. Amongst the data collected by the teachers were the lane lengths and widths of the four approaches. The teachers gathered the information for all traffic and pedestrian lanes. Each direction of the intersection has four lanes: two thru lanes; one lane for an unprotected right turn and one lane for a protected left turn. The protected left turn lane has a sensor embedded in the pavement that is actuated when a vehicle drives over it. Thus, the left turn signal is only given when there is at least one car waiting, and it is that approach's time for access.

Each traffic lane from the various approaches was determined to be 10 feet wide. The storage areas – where the cars idle waiting to proceed - were measured at 452' for the left and thru lanes on the North approach on Clifton Ave. with just 115' for the right turn lane; the left lane turn lane of the West approach on MLK Dr. has a storage area of 57' while the right and thru lanes can store up to 118'; the South approach of Clifton Ave. has storage lane measurements of 178' and 107' for the thru/right turn lanes and the left turn lane, respectively. Lastly, the storage areas for East approach of MLK Dr. were measured at 132' for the left turn lane and 259' for the thru and right turn lanes. The teachers used a measuring wheel to collect this data.

The measuring wheel was also used to find the lane measurements for pedestrian crossing lanes. It should be noted that the crosswalks have a smaller crosswalk that connects to an island in the intersection. The pedestrian crossing lanes primarily measured at 10 feet wide in all directions. The only exception is the south side of Clifton Ave and the East side of MLK Dr. That pedestrian crosswalk measured at 9' in width. The pedestrians have 20' to walk to reach the island. From there, pedestrians have 57' to walk to the island, before walking another 22' feet to reach Clifton Ave. If the person turned left and headed West across MLK Dr., the pedestrian would have to walk 52' feet to the island, then another 20' to the street. Continuing left, the pedestrian would have to walk 55' to reach the island connecting the West side of MLK with the South end of Clifton Ave., then another 17' to reach Clifton Ave. If a pedestrian turned left yet again and wanted to complete the intersection, they must walk 54' to the island, then the 20' they started to walk to get to the sidewalk.

A map of the intersection with lane measurements, storage lane lengths is illustrated by **Figure 3**.

Figure 3. Map Showing the Existing Geometric Conditions of the Study Site

The next piece of data the teachers had to collect was the turning movements of the vehicles. The teachers had to stand at opposite ends of the intersection and count cars making movements in each direction. This was done for an hour from 4:30-5:30 and with the help of a device known as a Petra Pro machine. The teachers held the devices in their hands and pushed a button on the machine to count a car. The teachers had to differentiate between normal automobiles and heavy vehicles such as buses and emergency vehicles while counting. This is because a heavy vehicle is figured to emit twice as much CO than would a regular sized vehicle. Pedestrians were also figured into the count for the purposes of the research. The teachers found difficulty in keeping up with the right turn movements as the multitude of through cars were crossing the intersection. Also, the teachers had to manually count and remember each bicycle that crossed the intersection, as well as someone parking a vehicle.

The actual number of vehicles that entered the intersection on the day was 3,531. This included the following turning movements: 73 vehicles traveling southbound on Clifton Ave and making a right turn while 371 vehicles continued south as 227 vehicles made left turns. This approach had 51 pedestrians enter the intersection and about 1.2 percent of all vehicles were considered heavy vehicles. A total of 274 vehicles made right turns while heading west and 903 vehicles continued east as 221 vehicles made a left turn while heading east. There were 103 pedestrians in this approach and about 0.4 percent of motor traffic was from heavy vehicles. The northbound traffic had 197 drivers make right turns while 384 continued north and 178 motorists made left turns. There were 11 pedestrians in this approach with 3.0 percent of the vehicles being defined as heavy vehicles for the purposes of the study. Lastly, there were 156 drivers that made a right turn while driving east and 494 continued eastbound and 53 vehicles turned left. There were 16 pedestrians to enter the intersection from this approach and 0.4 percent of all vehicles in this approach were considered heavy during the hour.

Finally, the numbers of vehicles and pedestrians were multiplied by a factor of 1.3. This was to account for the multitude of UC's 36,000 students not attending classes during the summer sessions, as well as families on vacations, etc. The counting data is summarized in **Table 1**.

Table 1. Counting of Turning Movements

	From North (SB)				From East (WB)				From South (NB)				From West (EB)			
	R	T	L	P	R	T	L	P	R	T	L	P	R	T	L	P
Veh	73	371	227	51	274	903	221	103	197	384	178	11	156	494	53	16
Veh x 1.3	95	482	295	66	356	1174	287	134	256	499	231	14	203	642	69	21
PHF	0.63	0.88	0.85	n/a	0.84	0.91	0.85	n/a	0.91	0.96	0.86	n/a	0.93	0.92	0.88	n/a

The phasing and timing information of the traffic signal of the study site is obtained from the engineering department of the City of Cincinnati.

The last part of the data collection includes collecting CO concentration at the road side. This was done by setting up a CO monitor on utility pole on the road site of south approach of Clifton Ave. The teachers also recorded the delay of the stopped vehicles. While one teacher would count the number of cars stopped at the approach, the other teacher would notify their partner of the time intervals. The time intervals were in15 second increments. At each interval, the teacher watching the time would say either: 0, 15, 30 or 45 and the other teacher would record the number of cars at the light.

7. ANALYSIS OF THE CORRELATION BETWEEN DELAY AND CO EMISSION

To analyze the potential relationship between delay and CO emission, we plotted the total delayed vehicle-seconds of the stopped vehicles in one minute and the average measured CO concentration against time on a coordinate system, as shown by **Figure 4**. Note that, the CO concentration is magnified by 100 times in order to match the magnitude of the delay. According to **Figure 4**, it indicates an obvious effect that delay of stopped vehicles has on CO concentration. There are correlated patterns on the peaks (highlighted by circles in **Figure 4**) and valleys (highlighted by squares in **Figure 4**) of Delay and CO Concentration. It is mainly because the longer a vehicle idles at the intersection, or the higher volume of vehicles that are idling at the intersection, will result in a higher concentration of CO. In summary, the analysis proves that there is a direct correlation between delay and CO emission. Longer vehicle delay increases the CO concentration in the air.

Figure 4. Correlation Analysis between Stopped Delay and CO Concentration

8. ANALYSIS OF EXISTING CONDITION

The evaluation results from the multiple simulation runs showed an average intersection delay as 33.19 seconds per vehicle, which reflects a level of service (LOS) of C. LOS is a measure of the easiness of maneuvers for drivers, which is typically used as the performance measure to evaluate the operational efficiency of an intersection. For signalized intersections, LOS is determined by the average controlled delay. The criteria are illustrated by **Figure 5**.

Figure 5. LOS of Signalized Intersection

Each approach and traffic movement is given a LOS of either (in descending order): A, B, C, D, E or F. Being rated as an "E" or "F" means the intersection is not operating efficiently. A LOS of D is usually regarded as the minimal goal for signal design.

The existing LOS condition of the intersection is summarized in **Table 2**.

Table 2. Existing Condition of the Study Site (LOS)

Movement	Existing Conditions	
	LOS	Delay (s)
WB LT	D	42.43
WB T	C	29.23
WB RT	B	15.42
EB LT	C	29.52
EB T	B	17.42
EB RT	A	9.47
NB LT	D	41.81
NB T	D	39.69
NB RT	B	17.31
SB LT	F	101.80
SB T	D	39.15
SB RT	B	16.83
Overall Average	C	33.19

Table 2 indicates the intersection provides a good LOS - of C. However, the intersection is not operating optimally because one traffic movement – the eastbound through is rated as a "B", while the southbound left turn is rated as an "F". This means the LOS of the different movements is unbalanced, which is a violation against the convention of traffic signal design. For the CO emission, the CO emitted from the idling vehicles at the intersection is estimated to be 44.97 grams per hour due to the stopped delay.

9. ALTERNATIVE SOLUTIONS

By conducting the what-if analysis under the VISSIM simulation environment, the teachers finally proposed two alternative solutions to improve the existing condition of the study site. The alternatives reflect the minimized intersection delay and CO emission from idling vehicles. According to EPA (2009), idling vehicles emit CO almost 3.5 times as compared to the running vehicles, which is a major contributing factor to the intersection CO concentration. Also, the study conducted on the relationship between CO concentration and delay also proved longer vehicle delay increases the CO concentration in the air. Therefore, the goal for the final alternatives is to minimize the delay.

First Alternative Solution

The first alternative solution is trying to improving the phasing and timing of the traffic signal without making any changes on the geometry of the intersection. A phase is a compilation of the traffic signals given at a signalized intersection, such as a protected turns, permissive turns, through lights, etc. given at the intersection. The alternative solution one is designed to be the most economic one, because the implement of it only needs two-hour labor work for adjusting phasing and timing configurations in the traffic controller. The existing phasing design of the study site is a typical 4-phase design, which is illustrated by **Figure 6**.

Figure 6. Existing Phasing and Timing

According to **Figure 6**, the green time for the EB and WB left turns are the same, ditto for the EB and WB through movements. However, according to **Table 1**, the actual volume of the WB left turn movement is almost 2 times as much as the volume of the EB left turn movement. Moreover, the actual volume of the WB through movement is more than 4 times as much as the volume of the EB through movement. It indicates that the demands from EB and WB are unbalanced. However, in the existing phasing and timing design, the green times for EB and WB are equal. That is reason why the existing LOS of the different movements is unbalanced. To

account for this problem, the phasing design of the first alternative uses 6-phase design instead of the 4-phase design, which is shown by **Figure 7**.

Figure 7. Phasing and Timing Design for Alternative Solution One

According to **Figure 7**, the movements that have larger volume have longer green time, while the movements that has smaller volume have shorter green time. For example, the green time for the EB protected left turn is now 4 seconds, while the green time for the WB protected left turn is now 4+3+1+9, which is 17 seconds. The green times of different movements now match with their actual traffic volumes. The timing of the new phase design is optimized and obtained through multiple trials of simulation runs until a minimized overall delay and a minimized hourly CO emission is obtained. Note that, the cycle length for the intersection still remains at 90 seconds compared with the existing timing. **Table 3** and **Table 4** summarize the evaluation results of the first alternative solution.

Table 3. Evaluation of Operational Performance of Alternative Solution One

Movement	Existing Conditions		Alternative Solution One	
	LOS	Delay (s)	LOS	Delay (s)
WB LT	D	42.43	D	38.62
WB T	C	29.23	C	29.68
WB RT	B	15.42	B	15.04
EB LT	C	29.52	D	43.60
EB T	B	17.42	C	30.71
EB RT	A	9.47	B	13.96
NB LT	D	41.81	D	40.37
NB T	D	39.69	D	43.32
NB RT	B	17.31	B	19.30
SB LT	F	101.80	D	35.45
SB T	D	39.15	C	32.39
SB RT	B	16.83	B	13.00
Overall Average	C	33.19	C	30.60

Table 4. Comprehensive Evaluation of Alternative Solution One

	In 1 Hour		
	Average Delay (sec/veh)	Overall Delay (vehxSec)	Overall Emitted CO (g)
Existing Condition	33.19	152295.10	44.97
Alternative 1	30.60	140444.52	43.05
Decreased by %	7.78%	7.78%	4.26%
Money Saved per Hour	N/A	$67.15	N/A

Table 3 indicates that after the implementation of the first alternative solution, the level of service for different movements are more balanced as no approach has an LOS below a "D". Moreover, the southbound left turn is improved to have a LOS "D" from an "F" in its existing condition. According to **Table 4,** the overall intersection delay becomes 30.60 seconds per vehicle, which is improved by 2.59 seconds compared with the existing condition. Reducing the delay also reduces the amount of CO emission at the intersection from 44.97 grams/hour to 43.05 grams/hour under the alternative solution one. In terms of money, this alternative solution would save the U.S. economy $67.15 per hour as drivers would spend less time waiting at the stop line. Note that, the calculations in **Table 4** are based on the following facts: Average hourly salary in US is $20.32/hr (US Bureau of Labor Statistics, 2010); Total number of vehicles traveling through the study intersection in 1 hour is 4589; The average exhaust emission factor for light vehicle is 1.23g/hr/veh (EPA, 2009); The average exhaust emission factor for heavy vehicle is 33.60g/hr/veh (EPA, 2009).

Second Alternative Solution

A second alternative is designed to involve further geometric changes on the lane storage lengths at the intersection in addition to the first alternative solution. In other word, the second alternative solution is to combine all the components of the first alternative solution with optimizing the storage lengths of two left turn lanes. This solution is obtained through numbers of simulation trials on testing changing the lengths of left turn lanes. Finally, the lowest intersection overall delay is obtained by increasing the storage length of the left turn lane on westbound MLK Dr. from 132' to 291'; along with decreasing the length of the left turn lane on southbound Clifton Ave. from 452' to 201'. This alternative solution would require a block of left turn from eastbound MLK Dr into the Brooklyn Ave. The modification of the storage lengths are illustrated by **Figure 8**.

Table 5 and **Table 6** summarize the evaluation results of the second alternative solution. **Table 5** indicates that after the implementation of the second alternative solution, the level of service for different movements are more balanced compared with the existing condition. Moreover, the southbound left turn is improved to have a LOS "C" from an "F" in its existing vehicle, which is improved by 4.87 seconds compared with the existing condition. Reducing the delay also reduces the amount of CO emission at the intersection from 44.97 grams/hour to 40.62

Figure 8. Geometric Changes Proposed in Alternative Solution Two

Table 5. Evaluation of Operational Performance of Alternative Solution Two

Movement	Existing Conditions		Alternative Solution Two	
	LOS	Delay (s)	LOS	Delay (s)
WB LT	D	42.43	C	26.69
WB T	C	29.23	C	25.18
WB RT	B	15.42	B	12.04
EB LT	C	29.52	D	42.71
EB T	B	17.42	C	29.91
EB RT	A	9.47	B	12.65
NB LT	D	41.81	D	43.41
NB T	D	39.69	D	41.88
NB RT	B	17.31	B	19.66
SB LT	F	101.80	C	34.17
SB T	D	39.15	C	33.58
SB RT	B	16.83	B	13.90
Overall Average	C	33.19	C	28.32

Table 6. Comprehensive Evaluation of Alternative Solution Two

	In 1 Hour		
	Average Delay (sec/veh)	Overall Delay (vehxSec)	Overall Emitted CO (g)
Existing Condition	33.19	152295.10	44.97
Alternative 2	28.32	129950.69	40.62
Decreased by %	14.67%	14.67%	9.68%
Money Saved per Hour	N/A	$126.62	N/A

grams/hour under the alternative solution two. In terms of money, this alternative solution would save the U.S. economy $126.62 per hour as drivers would spend less time waiting at the stop line. Note that, the calculations in Table 6 are based on the following facts: Average hourly salary in US is $20.32/hr (US Bureau of Labor Statistics, 2010); Total number of vehicles traveling through the study intersection in 1 hour is 4589; The average exhaust emission factor for light vehicle is 1.23g/hr/veh (EPA, 2009); The average exhaust emission factor for heavy vehicle is 33.60g/hr/veh (EPA, 2009).

10. CONCLUSIONS

The signalized intersection of Clifton Ave and Martin Luther King Dr is a busy intersection in Cincinnati, OH. Like any other signalized intersections, the intersection delay and the large amount of CO emission from idling vehicles at the intersection are two major problems caused by improper configurations of traffic signal and intersection geometry.

The analysis of the relationship between delay and emission finds correlated patterns on the peaks and valleys of Delay and CO Concentration. It reveals the fact that there is a direct correlation between delay and CO emission. Longer vehicle delay increases the CO concentration in the air.

Through simulation-based analysis on the existing condition of the study site, it reveals the intersection is not operating at the optimal condition. The LOS of the different movements is unbalanced, which is a violation against the convention of traffic signal design. For example, the eastbound through has a LOS of B, while the southbound left turn has an unacceptable LOS of F. The average intersection delay is 33.19 seconds per vehicle, while the CO emitted from the idling vehicles at the intersection is estimated to be 44.97 grams per hour due to the stopped delay. By conducting what-if analysis under the VISSIM simulation environment, two alternative solutions are proposed to improve the existing condition of the study site. The alternatives reflect the minimized intersection delay and CO emission from idling vehicles.

The first alternative solution optimizes the phasing and timing of the traffic signal without making any changes on the geometry of the intersection, which is regarded as the most economic and most easy-to-implement way to improve the existing condition. It uses 6-phase signal design instead of the existing 4-phase design. The timing of the new phase design is optimized and obtained through multiple trials of simulation runs until a minimized overall delay and a minimized hourly CO emission is obtained. The evaluation of the first alternative indicates that the LOS of the different movements is more balanced, and the “F” LOS is eliminated. It reduces the amount of CO emissions by 4.26 percent and the delay by 7.78 percent, when compared with the existing condition. The decrease in delay saves the U.S. economy $67.15 per hour in lost production caused, or $73,529.25 annually.

The second alternative solution involves further geometric changes on the lane storage lengths in addition to all the components of the first alternative solution. Through numbers of

simulation trials on testing changing the lengths of left turn lanes, the optimal storage lengths of the southbound and the westbound left turn lanes are obtained. The evaluation of the second alternative indicates that the amount of CO emissions is reduced by 9.68 percent and the delay is reduced by 14.67 percent, when compared with the existing condition. The decrease in delay saves the U.S. economy $126.62 per hour in lost production caused, or $138,648 annually.

Finally, the first alternative solution is recommended as a short-term solution because it is easy to implement and cost-effective. It would take only two hours for engineers and local traffic employees to change the intersection's signal phasing/timing. The second alternative solution is recommended as a long-term solution because it involves road surface work, and it requires blocking the left turn from eastbound MLK Dr to Brooklyn Ave. Workers would have to do groundwork to decrease the storage lengths of the southbound Clifton Ave. left turn lane, while increase the westbound MLK Dr. left turn storage lane. A "No Left Turn" sign is required to be installed on the East approach of MLK Dr for a left turn blockage into Brooklyn Ave. Although the change might upset some early, but everyone would benefit in the long run from cleaner air and shorter delay at the signalized intersection.

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APPENDIX I: NOMENCLATURE USED

‘ = feet (measurement)

EB = eastbound

NB = northbound

SB= southbound

WB = westbound

P = pedestrian

L = left turn

R = right turn

T = thru or straight

LOS = level of service

PHF = Peak Hour Factor

CO = carbon monoxide

NO = nitrogen oxide

PPM = parts per million

C = count of vehicles

Circles = peaks

Squares = valleys

veh = vehicle

“A” = acceptable level of service

“B” = acceptable level of service

“C” = acceptable level of service

“D” = acceptable level of service

“E” = unacceptable level of service

“F” = unacceptable level of service

APPENDIX II: RESEARCH SCHEDULE

Week 1: Introduction to the project and the problem

Week 2: Reading of literature and data collection

Week 3: Learning how to use the VISSIM software

Week 4: Building a simulation-based model of the study site and testing the theories

Week 5: Finalizing the simulation to propose alternative solutions to the study site's existing conditions

Week 6: Wrap up research work and prepare for presentations