A SERVICE LIFE ANALYSIS OF ROUNDABOUTS RETROFITS FOR SIGNALIZED INTERSECTIONS

by

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A SERVICE LIFE ANALYSIS OF ROUNDABOUTS RETRIFITS FOR SIGNALIZED INTERSECTIONS

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Roundabouts have long been regarded as an effective traffic control method. While this method is quite popular in some foreign countries like Australia, there are not as many existing roundabout sites in the U.S. According to foreign experiences and limited experience in the U.S., roundabouts can be good replacement alternatives where signalized intersections no longer function well.

This thesis examined and monetized the potential benefits of converting signalized intersections to roundabouts under three different circumstances. To be specific, the potential benefits included crash reduction, delay time reduction, fuel efficiency improvement and air pollutant reduction. Then a benefit-cost analysis (BCA) was conducted. The monetization of environmental benefits was used to improve the BCA methodology that has been used by others. Three different intersections, that are currently signalized, were studied to determine the BCA. After a systematic evaluation, it was found that a five-way intersection with moderate traffic volume had the best benefit-cost ratio among all three intersections studied.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

This section introduces the background, hypothesis, objectives and methodologies of this research.

1.1 BACKGROUND

Conventional signalized intersections and stop-controlled intersections are common throughout the country. The public accepts them well and is familiar with them. So when agencies are making decisions to control a junction or improve traffic conditions, signalization of conventional intersections is usually a preferred alternative.

However, safety for both pedestrians and vehicles can be an issue in these intersections. There are 32 potential conflict points in a signalized intersection with one lane per approach. Some of the typical crash types are severe. Traffic signals can also be inefficient from an economic or environmental standpoint. Equipment often lacks periodic maintenance, technology changes, there are reoccurring maintenance costs, and traffic patterns may change over time. Moreover, when a traffic signal is not as efficient as it used to be, owners of the traffic signal don't always have the funding for upgrading of the equipment. Mostly, they only do updates of the timing plan, which may not bring significant savings for operating costs or environmental impacts.

Also, traffic signals require replacement at the end of their useful life, which is a major construction cost.

An alternative to updating or replacing a traffic signal to other more efficient and safer control methods for those intersections should be considered.

Roundabouts have been regarded as an effective traffic control method under specific conditions for decades. Single lane roundabouts, the most common type, have only 8 potential conflict points. This is a significant reduction when compared to a signalized intersection. Vehicles are forced to reduce speeds as a result of the geometric design of roundabouts. These factors contribute to the safety advantages of roundabouts. So they can be applied to improve safety and calm traffic in most cases while sometimes applied in new intersections that have complex geometric features. However, the conversion of an existing signalized intersection to a modern roundabout is also worth considering in terms of economic and environmental benefit aspects in some urban areas with certain traffic volumes.

Since roundabouts can be an environmentally friendly, low construction and operating costs and a good traffic performance method of intersection control, they can be a competitive alternative as a replacement for a traffic signal when some existing signalized intersections are no longer operated efficiently.

Based on the consideration of exploring an alternative control method both to the user and the operator, such a conversion is worth conducting research on to determine the service life benefits of the conversion.

1.2 HYPOTHESIS

The hypothesis to be considered is whether this type of traffic control conversion is beneficial in terms of construction replacement costs, annual operating costs and environmental impacts. In addition, a corollary to be explored will be under what circumstances such as traffic volumes, number of approaches to the intersection and number of approach lanes are these benefits realized. To evaluate this hypothesis three existing signalized intersections were selected to be studied.

Three potential roundabout locations are selected on the basis of differing conditions related to traffic volumes, number of approaches to the intersection and the complexity of existing signal phasing. Two of these potential roundabouts are located in the Oakland section of the City of Pittsburgh, Pennsylvania, which has many congested signalized intersections. Another intersection located in Squirrel Hill, the City of Pittsburgh, was selected because it has five approaches, which are currently signalized. All three of the intersections have varying geometric conditions and existing timing plans as shown in Figure 1-1 through Figure 1-6.

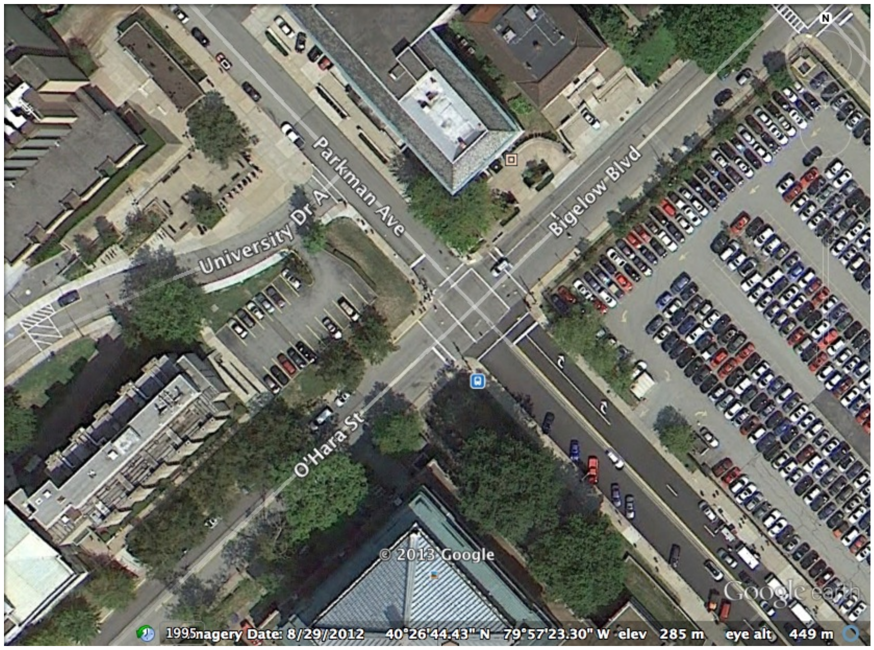
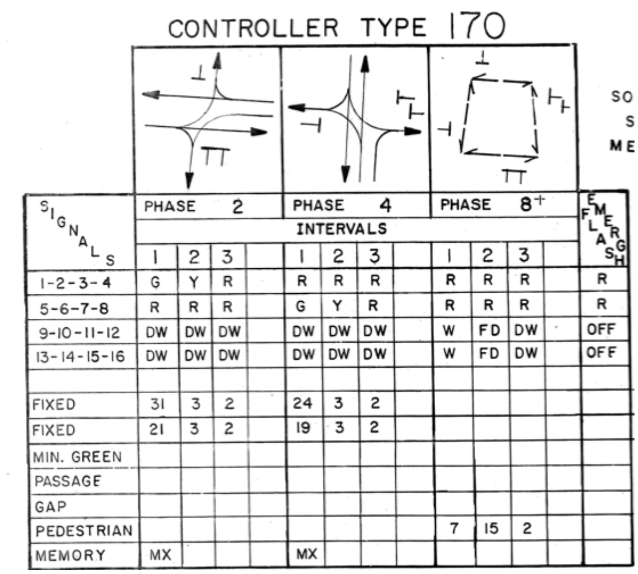


Figure 1-1 Intersection of Bigelow Blvd-O'Hara ST-Parkman Ave



SIGNALS	PHASE 2				PHASE 4				PHASE 8+				EMER FLASH
	INTERVALS												
	1	2	3		1	2	3		1	2	3		
1-2-3-4	G	Y	R		R	R	R		R	R	R		R
5-6-7-8	R	R	R		G	Y	R		R	R	R		R
9-10-11-12	DW	DW	DW		DW	DW	DW		W	FD	DW		OFF
13-14-15-16	DW	DW	DW		DW	DW	DW		W	FD	DW		OFF
FIXED	31	3	2		24	3	2						
FIXED	21	3	2		19	3	2						
MIN. GREEN													
PASSAGE													
GAP													
PEDESTRIAN									7	15	2		
MEMORY	MX				MX								

Figure 1-2 Timing Plan for Intersection of Bigelow Blvd-O'Hara ST-Parkman Ave

Figure 1-3 Intersection of Fifth Ave-Morewood Ave

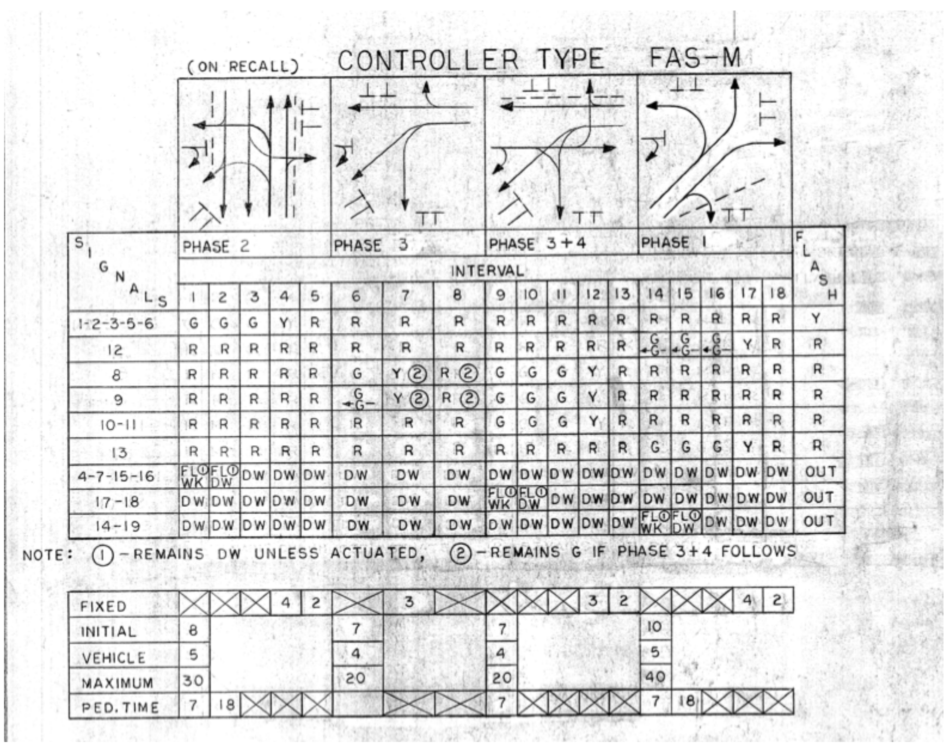
PITTSBURGH PA DPW
ACTUATED TIMING REPORT FOR INTERSECTION #187:
FIFTH @ MOREWOOD

DATE: 10-01-2013 TIME: 13:06:45

(0 + key) FUNCTION	PHASES 12345678	key FUNCTION	(phase + key) 1	2	3	4	5	6	7	8
VEH. RECALL	12 4 6	0 MAX I	7	25	0	21	0	25	0	0
PED RECALL	2 4	1 MAX II/HFDW	9	31	0	23	0	31	0	0
RED LOCK	0	2 WALK	0	10	0	9	0	0	0	0
YELLOW LOCK	0	3 FLASH DW	0	15	0	12	0	0	0	0
PERMIT	12 4 6	4 MAX INITIAL	0	0	0	0	0	0	0	0
PED PHASES	0	5 MIN GREEN	5	15	0	7	0	15	0	0
LEAD PHASES	1 3 5 7	6 T B R	0	0	0	0	0	0	0	0
DOUBLE ENTRY	0	7 T T R	0	0	0	0	0	0	0	0
SEQ. TIMING	0	8 OBSERVE GAP								
START UP GRN	2 6	9 PASSAGE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OVERLAP A	0	A MIN GAP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OVERLAP B	0	B ADDED/ACT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OVERLAP C	0	C YELLOW	3.0	4.0	0.0	4.0	0.0	4.0	0.0	0.0
OVERLAP D	0	D RED CLEAR	2.0	2.0	0.0	2.0	0.0	2.0	0.0	0.0
EXCLUSIVE	0	E RED REVERT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SIM. GAP	0	F WALK II	0	0	0	0	0	0	0	0

Figure 1-4 Timing Plan for Intersection of Morewood &Fifth Avenue

Figure 1-5. Intersection of Forward Ave.-Murray Ave.-Pocusset ST.



SIGNALS	PHASE 2					PHASE 3			PHASE 3+4					PHASE 1					FLASH
	INTERVAL																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
1-2-3-5-6	G	G	G	Y	R	R	R	R	R	R	R	R	R	R	R	R	R	R	Y
12	R	R	R	R	R	R	R	R	R	R	R	R	R	G ←G	G ←G	G ←G	Y	R	R
8	R	R	R	R	R	G	Y ②	R ②	G	G	G	Y	R	R	R	R	R	R	R
9	R	R	R	R	R	G ←G	Y ②	R ②	G	G	G	Y	R	R	R	R	R	R	R
10-11	R	R	R	R	R	R	R	R	G	G	G	Y	R	R	R	R	R	R	R
13	R	R	R	R	R	R	R	R	R	R	R	R	R	G	G	G	Y	R	R
4-7-15-16	FL① WK	FL① DW	DW	DW	DW	DW	DW	DW	DW	DW	DW	DW	DW	DW	DW	DW	DW	DW	OUT
17-18	DW	DW	DW	DW	DW	DW	DW	DW	FL① WK	FL① DW	DW	DW	DW	DW	DW	DW	DW	DW	OUT
14-19	DW	DW	DW	DW	DW	DW	DW	DW	DW	DW	DW	DW	DW	FL① WK	FL① DW	DW	DW	DW	OUT

NOTE: ① - REMAINS DW UNLESS ACTUATED, ② - REMAINS G IF PHASE 3+4 FOLLOWS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
FIXED				4	2		3					3	2				4	2
INITIAL	8					7			7					10				
VEHICLE	5					4			4					5				
MAXIMUM	30					20			20					40				
PED. TIME	7	18							7					7	18			

Figure 1-6 Timing Plan for Forward Ave-Murray Ave-Pocusset ST

1.3 RESEARCH OBJECTIVES

Potential benefits of the conversion from traffic signal operations to a roundabout installation include safety, operational, environmental and service life costs benefits were explored in this research study. It was hypothesized that traffic and safety conditions will improve after the conversion in the three intersections selected, but benefits may vary due to the specific conditions. Based on this hypothesis the service life of the roundabouts was evaluated through a benefit-cost analysis in this research. It is expected then when the service life costs of maintaining and replacing a traffic signal are compared to the same costs for a roundabout, and the operational safety and environmental benefits are quantified, an overall benefit will result.

1.4 METHODOLOGY

1.4.1 Data Collection

Traffic and pedestrian peak hour volume including turning movement were collected manually for each of the three intersections, 7:00 to 9:00 in the morning and 4:00 to 6:00 in the afternoon time periods were selected for analysis because they represent the peak traffic periods on a typical weekday. Peak hours vary slightly at the three intersections as determined by the traffic counts. The 2013 peak hour traffic volumes are presented in Table 1-1 for the selected intersections.

Table 1-1 2013 Peak Hour and Traffic Volume

	Bigelow & O'Hara	Morewood & Fifth Ave	Murray & Forward
AM Peak Hour	7:45 - 8:45	7:15 - 8:15	7:30 - 8:30
AM Peak Hour Volume (veh/hour)	1025	2108	1894
PM Peak Hour	4:45 - 5:45	5:00 - 6:00	4:45 - 4:45
PM Peak Hour Volume (veh/hour)	1278	2427	1763

1.4.2 Traffic Analysis

There are few service life economic analyze tools available currently to perform the analysis. . In this research, a benefit-cost analysis (BCA) methodology, specific to this traffic control change, was developed as the final task to test the hypothesis. Service life cost of such a conversion, and also monetized benefits were all factors that were evaluated to calculate a benefit-cost ratio.

Benefit-cost analysis is a proven method of comparing transportation alternatives to achieve a specific goal. A traffic capacity analysis was the first step in the analysis to compare the operating characteristics of each method of traffic control. Operational performance is the first and most important criteria when considering a conversion from signalization to a roundabout. If operational benefits cannot be demonstrated then the service life comparison would not be needed. Such an analysis can confirm that if the conversion of the signalized intersections to a roundabout is completed, it will improve the level of service (LOS) and safety conditions.

These operational benefits can be calculated using the Highway Capacity Manual (HCM) 2010 published by the Transportation Research Board. The Synchro version 8.0.804.795 software modeling package, which replicates the HCM method, was applied on all the three signalized intersections for existing LOS analysis under signalized conditions. The LOS for existing conditions was reported based upon an optimized timing plan, developed by Synchro version 8.0.804.795, and was used for the comparison. However, only control delay for roundabouts is included in the Highway Control Manual (HCM) currently. For the reason that SIDRA method, which is the most popular roundabout analyze tool in U.S, and it is used by various state agencies, was used to determine the appropriate design, performance characteristics and overall delay of roundabouts, in addition to the FHWA procedure in this research. Then level of service per the HCM method, after using SIDRA to calculate delays for the roundabouts, was applied to the HCM level of service definitions. Roundabout design criteria were input to Synchro version 8.0.804.795 and generated reports for comparison.

1.4.3 Conceptual Roundabout Design

In order to conduct a benefit cost analysis, a conceptual design of potential roundabouts is important. In the NCHRP Report 672,[1] a summary of fundamental design factors to identify a roundabout's preliminary configuration as depicted in Figure 1-7. Initial design criteria, such as inscribed circle diameter and design speed, were input to SIDRA software based on the recommendation. Adjustment was need based on the SIDRA report. After confirming design elements, SIDRA method can provide the roundabout alignments and then be used to estimate the cost.

Design Element	Mini-Roundabout	Single-Lane Roundabout	Multilane Roundabout
Desirable maximum entry design speed	15 to 20 mph (25 to 30 km/h)	20 to 25 mph (30 to 40 km/h)	25 to 30 mph (40 to 50 km/h)
Maximum number of entering lanes per approach	1	1	2-3
Typical inscribed circle diameter	45 to 90 ft (13 to 27 m)	90 to 180 ft (27 to 55 m)	150 to 300 ft (46 to 91 m)

Figure 1-7 Roundabout Category Comparison [1]

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

This literature review evaluated the current research in this area to determine guidelines for the conversion of signalized intersections to roundabouts while considering traffic capacity and safety. Also methodologies used to evaluate intersection improvement alternatives were identified to determine the service life costs of this traffic control conversion. The goal of the literature review was to determine if all of the conversion guideline research evaluated the service life costs of the conversion as part of the benefits and costs.

2.2 POTENTIAL BENEFIT

Both operators and users of intersections have concerns about safety. It is important to let users feel they are safe when passing through an intersection and agencies would seek control changes which result in safer operation methods, when there has to be a change. So the potential safety benefits from replacing signalized intersections with roundabouts were considered in this research. As rapid development happens around urban areas, there are many methodologies developed to achieve traffic mitigation. Roundabouts are considered as one of them. For this reason, potential improvement of level of service and fuel consumption benefit derived from this was examined. Transportation activities play a role in achieving better air quality. So another key benefit identified in this research was environmental benefits in terms of reducing air pollutants emission.

2.2.1 Safety

Much published research on roundabouts focuses on crash reduction of roundabout implementations. As noted by FHWA in *Information Guide* to roundabouts, one potential benefit of installing roundabouts is the overall safety performance improvement. [1] The guide also noted that in terms of safety, roundabouts could perform even better than other intersection forms such as signalization.

A similar conclusion was drawn that converting signalized intersections to roundabouts can efficiently reduce crashes in some conditions.[2] There is frequently cited data that indicates this conclusion well. Based on research in Britain and Australia, about 35% reduction of total crashes and 65% reduction of injury crashes happen after such a conversion. [3]

In the United States of America, a study of 8 one-lane roundabouts converted from signalized intersections was conducted in the State of Maryland. The results reveals that in the first year after installation, a 64% reduction in total crashes and 83% reduction in injury crashes resulted because of the roundabouts.[4] The State of Maryland has built more than 25 modern roundabouts. [5] Another study into 24 conventional intersections converted to roundabouts in the United States revealed a 39% reduction of total collisions, 76% of injury collisions and 90%of fatal and incapacitating injury crashes. [6] Frank Gross and Craig Lyon conducted a study to determine safety effectiveness of converting signalized intersections to roundabouts in 2012. This systematic study examined 29 conversions in the United States and developed Crash

Mitigation Factors (CMFs), in addition to CMFs used for conventional intersections. [2] The Highway safety manual (HSM) provides a commonly used evaluation factors to calculate crash frequency after such a conversion.[7]

2.2.2 Traffic Performance

To analyze the traffic performance including delay, level of service (LOS), capacity and congestion is the first step to compare intersection control alternatives. Many studies came to a similar conclusion, that converting signalized intersections to roundabouts can significantly reduce delay time, although different simulation methods were used in the studies. [8] There is a 24% average delay reduction identified in a study conducted in Mississippi that indicates the delay time reduced by 1/3 after such a conversion. [9]

2.2.3 Environment

Transportation related pollution is not only harmful to the environment, but also has a directly impact on human beings. It is vital to identify how much reduction will result through such a conversion. Total annual emissions including CO_2, CO, NO_x, PM_{10} and SO_2 were reduced by 179,440Kg in the impact study conducted in Clearwater, Florida. [10] This data is the total of three studied intersections. There was a 77% reduction of vehicle emission examined for the roundabouts converted from stop-controlled intersections in Mississippi. [9] Although this indicates the conversion from stop-control to roundabouts can efficiently reduce traffic emission by reducing overall delay, it is not applicable for a conversion from signal control. Moreover, deceleration or acceleration by vehicles is reduced when vehicles are forced to drive through roundabouts. It can be concluded that there is significant environment benefits for such a conversion.

2.3 BENEFIT COST ANALYSIS

As mentioned in Roundabouts: An Informational Guide US Department of Transportation, benefit-cost analysis is recommended by FHWA as the most appropriate method to compare the alternatives of an intersection improvement. [1]Benefits include environment benefits, safety benefits and economic benefits should be considered in the analysis. Since transportation projects can impact an area for a long time, a service life cost should also be considered. The literature research has revealed that, BCA was done in several different ways to evaluate the conversion from conventional intersections to roundabouts in former studies. Most of the studies focused on crash reduction only. There are many benefits that are not considered when a BCA only includes safety benefits. Bruce Corben did a relative net present value (NPV) calculation to evaluate the safety economic benefits of such a conversion. [11] NPV is “the present amount that is equivalent to specified amounts of money or time in different time periods, at a given discount rate” as defined by the September 2010 AASHTO publication “User and Non-user Benefit Analysis for Highways”. A comprehensive BCA was conducted in an impact study in Florida. But the author regarded environment impacts as a non-monetary impact. [10]

2.4 SUMMARY

In summary, there are very few published research articles relating to such a conversion. Though service life cost was considered in some studies, environment benefits were never considered as monetary impacts and added into service life cost category. Furthermore, in this research the cost-benefit ratio was calculated and then used as an indicator to evaluate whether those benefits realized in different circumstances.

Based on this review it was concluded that an improved method of service life analysis for the conversion was needed because previous research did not address all of the benefits. This research developed such a method.

3.0 BENEFITS ANALYSIS

To confirm the hypothesis that the conversion of the signalized intersections will improve traffic, safety condition, improve air quality, and result in a positive service life cost, a systematic traffic analysis was conducted. The analysis includes a comparison of the existing levels of service and current safety conditions to conditions with the potential improvement in place. Emission benefits were also analyzed in this section. The following is a description of this analysis for the three intersections selected for study. The existing and design drawings for each of the three studied intersections were shown in Appendix A.

3.1 INTERSECTION OF BIGELOW BLVD- O'HARA ST-PARKMAN AVE

3.1.1 Existing Condition

The intersection of Bigelow Blvd, O'Hara St and Parkman Ave is located in the Oakland area. It serves as a main route to the UPMC hospitals as well as the University of Pittsburgh campus. Each approach of the intersection provides one lane of travel except there is an exclusive right turn lane on the northbound Bigelow Blvd and an exclusive left turn lane for the westbound traffic. Street parking is available along Bigelow Blvd and O'Hara Street.

Due to the high pedestrian volume in the intersection, there is a scramble phase in this signalized intersection. This phase increases pedestrian safety by simply eliminating pedestrian-vehicle conflicts. Meanwhile, it increases the overall delay for this intersection when the cycle time is longer. Though the pedestrian phase was designed for the users' safety, many pedestrians ignore the "Don't Walk" signal and cross the street during the entire cycle length in this intersection. This makes the scramble phase less useful than it was intended to be.

The Synchro version 8.0.804.795 analysis, which was run for this intersection, shows that there is an overall delay of 80.3s and 42.8s for A.M peak and P.M peak respectively under current operations with optimized signal timings. The intersection operated at level of service F for the AM peak and D for the PM peak. Contributing to the poor LOS at the intersection is the inefficiency of the pedestrian phase and a 9% heavy vehicle factor in this four-leg intersection. The pedestrian phase is an exclusive phase and all traffic stops when it is actuated, which is used during many cycles in the peak periods. For analysis purposes the phase was assumed to be actuated for all cycles. The majority of heavy vehicles using this intersection are school buses. Since there are parking lanes along O'Hara Street and east of Bigelow, there is not enough space for heavy vehicles to make a smooth turning. During the observation, whenever there was one school bus turning, it took a long time and the other vehicles queued behind the truck.

3.1.2 Initial Roundabout Elements

Based on the space constraint and the current traffic volume in this intersection, the roundabout was designed as a single-lane roundabout. Since *Guide to Roundabouts* suggests that the inscribed circle diameter for an urban single-lane roundabout to be 90-150ft,[1] the diameter was assumed to be 100ft. The 100ft inscribed circle includes one circling lane with a 12ft width, one

12ft truck apron and a center island with a 52ft diameter. These trial design elements were determined to be acceptable per the Sidra analysis, due to resultant levels of service, therefore the design was used and is shown in Figure 3-1.

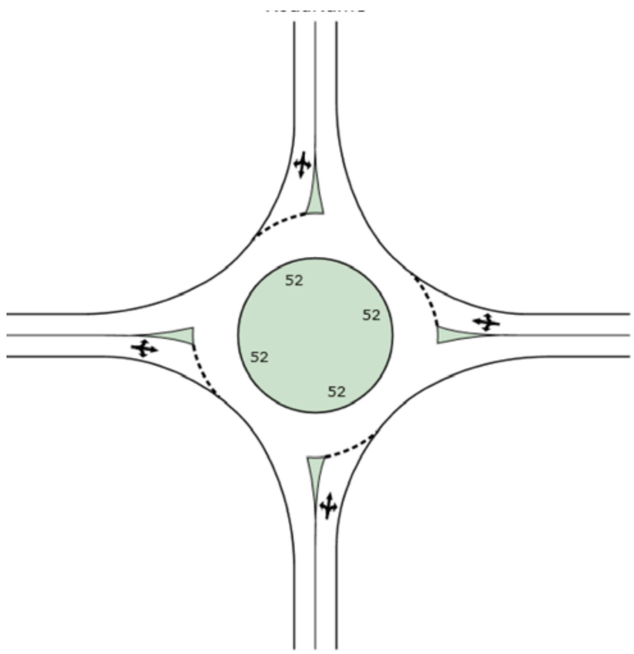


Figure 3-1 Conceptual Roundabout Design for Intersection of Bigelow & O'Hara

Approach levels of service are estimated by the SIDRA method. But to compare the two options equally, signalized and with the roundabout, both designs were analyzed through the Synchro version 8.0.804.795 method and then compared.

3.1.3 Comparison of Signal Control and Roundabout

As summarized in Table 3-1 and Table 3-2, there is a significant reduction of delay time after converting to a roundabout for this intersection during both AM and PM peak hour. The proposed roundabout is forecast to operate at an overall intersection LOS B during both the AM peak and PM peak in weekdays. The poorest performance of the existing traffic signal control occurs in the westbound traffic approach in the morning and eastbound traffic approach in the afternoon.

Table 3-1 A.M Peak Hour LOS and Delay for Intersection of Bigelow & O'Hara

	Signal Control		Roundabout	
	Delay(s)	LOS	Delay(s)	LOS
East Bound	31.8	C	7.8	A
West Bound	124.3	F	16.6	C
North Bound	29.5	C	7.7	A
South Bound	23.8	C	7.8	A
Overall	80.3	F	12.5	B

Table 3-2 P.M Peak Hour LOS and Delay for Intersection of Bigelow & O'Hara

	Signal Control		Roundabout	
	Delay	LOS	Delay	LOS
East Bound	55.1	E	14.7	B
West Bound	41.5	D	10	A
North Bound	34.3	C	15.2	C
South Bound	38.2	D	8.3	A
Overall	42.8	D	12.7	B

3.2 INTERSECTION OF FIFITH AVE-MOREWOOD AVE

3.2.1 Existing Condition

The challenge for moving traffic in Oakland is particularly vital on Fifth Avenue and Forbes Avenue because these are the two main arterials serving the area. Fifth Avenue is the main route for both inbound and outbound vehicles for major destinations in Oakland. Morewood Avenue is a connecting cross street that serves vehicles, pedestrians and bicycles accessing the Carnegie Mellon University (CMU) main campus. There are two lanes in each direction on Fifth Avenue. Morewood Avenue has one lane in each direction with an exclusive right turn lane for northbound traffic flow and an exclusive left turn lane for southbound traffic. There is no exclusive pedestrian phase control in this intersection but there is an additional phase for westbound movement. Pedestrian are controlled by traffic control devices without countdown lights at this intersection.

The overall level of service at this intersection is C and the northbound approach traffic is the worst approach with a LOS D in both A.M and P.M peak hour. This is due to the high right turn traffic volume which exceeds the volume of the through movement traffic.

3.2.2 Initial Roundabout Elements

At first, it was assumed that a one-lane roundabout with a large diameter of 150ft could handle the traffic volume in this intersection for the research analysis. This assumption was based on the consideration that a multi-lane roundabout would theoretically have more conflict points. But the analysis result of delay time from SIDRA showed a much worse LOS than the existing situation.

According to the design manual, a two-lane roundabout should be considered at intersections with such a high traffic volume. Given that the intersection area space is limited in this intersection, and after some adjustment of the diameter of the roundabout, the roundabout in this intersection was finally designed as shown in Figure 3-2. There are two 12ft circling lanes and one 12ft truck apron. The diameter of the center island is 98ft.

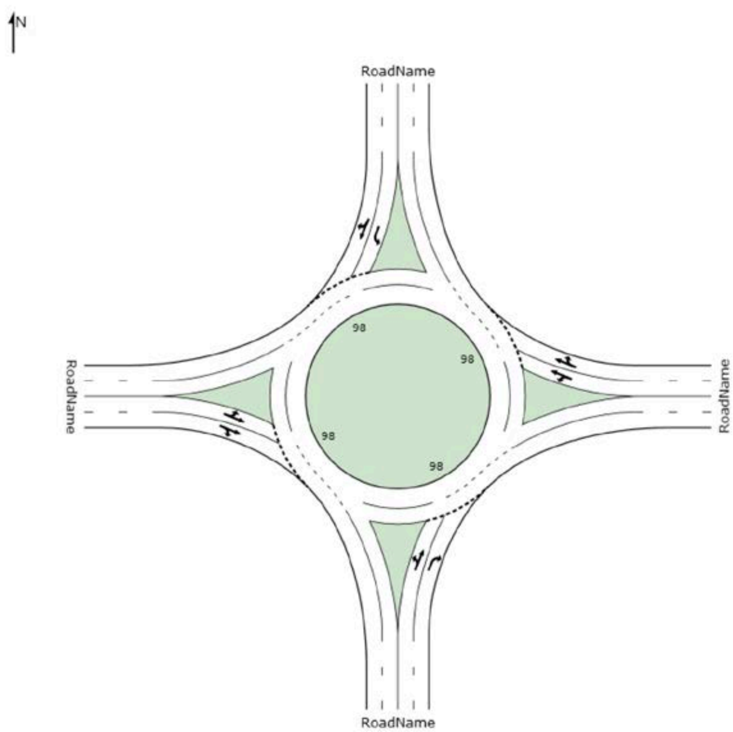


Figure 3-2 Conceptual Roundabout Design for Intersection of Morewood & Fifth Ave

3.2.3 Comparison of Signalized Control and Roundabout

The analyze result showed that after converting the signalized intersection to a two-lane roundabout, the A.M. peak hour would have a lower LOS than the signal control. It can be deduced the high volume in westbound direction and the high right turn movement causes the increased delay with the roundabout in place. During the P.M peak hour, a reduction of delay occurs in each approach with the roundabout in place. The conversion improves LOS one level. The LOS details are summarized in Table 3-3 and Table 3-4.

Table 3-3 A.M Peak Hour LOS and Delay for Intersection of Morewood & Fifth Ave

	Signal Control		Roundabout	
	Delay	LOS	Delay	LOS
East Bound	26.8	C	7.9	A
West Bound	21.4	C	48.7	E
North Bound	42.2	D	9.4	A
South Bound	31.3	C	20.3	C
Overall	26.6	C	32.8	D

Table 3-4 P.M Peak Hour LOS and Delay for Intersection of Morewood & Fifth Ave

	Signal Control		Roundabout	
	Delay	LOS	Delay	LOS
East Bound	33	C	16.2	C
West Bound	14.3	B	10.9	B
North Bound	46.9	D	18	C
South Bound	29.9	C	11.5	B
Overall	30.8	C	14.6	B

Although the LOS was degraded in the AM peak but improved in the PM peak, the intersection was still included in the research to determine if this type of intersection conversion would result in a positive service life comparison.

3.3 INTERSECTION OF FORWARD-MURRAY AVE-POCUSSETT ST

3.3.1 Existing Condition

This is a five-approach lane intersection located in the Squirrel Hill neighborhood of the City of Pittsburgh, and is in a busy commercial district that serves Chatham University campus. Two lanes in major directions are provided, while the minor road Pocusset Street has one lane in each direction. Street parking is available along Forward Ave and Pocusset Street.

It is recommended that wherever practical, multi-leg intersections should not be constructed. However, when they are present and traffic control is needed a roundabout may be a better alternative to the traffic signal control. The existing signalized intersection causes longer cycle length and confuses the traveling public by its awkward configuration. This intersection suffers from a poor LOS E during morning peak hour as well as the afternoon peak hour.

Moreover, there are too many potential conflict points in a five-leg signalized intersection, and this can be eliminated by reconfiguration or redesign to a roundabout. Such a five-leg intersection also is not pedestrian- friendly. Pedestrians can feel unsafe when they have to cross multi lanes of traffic. A drawing of conflict points for a five-leg roundabout is shown in Figure 3-3.

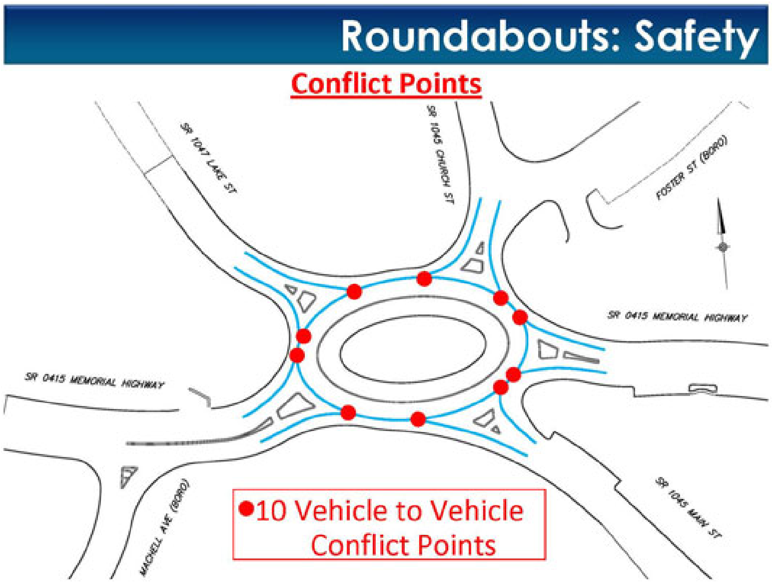


Figure 3-3 Conflict Points of a Five-leg Roundabout [12]

This type of configuration is a good candidate for conversion to a roundabout because of the multiple lane approaches and complex traffic signal phasing.

3.3.2 Initial roundabout Elements

As shown in Figure 3-4, this was analyzed for conversion to a one-lane roundabout with a 102ft diameter of the center island. Based upon a review of the intersection area, it was concluded that this intersection has sufficient space for a large diameter roundabout. The total diameter was designed as 160ft including a 12ft truck apron. There was no change made to the lane groups from the signalized intersection design. The result from SIDRA showed good performance of such a design. The roundabout design resulted in a LOS C and B for A.M and P.M. peak hours respectively.

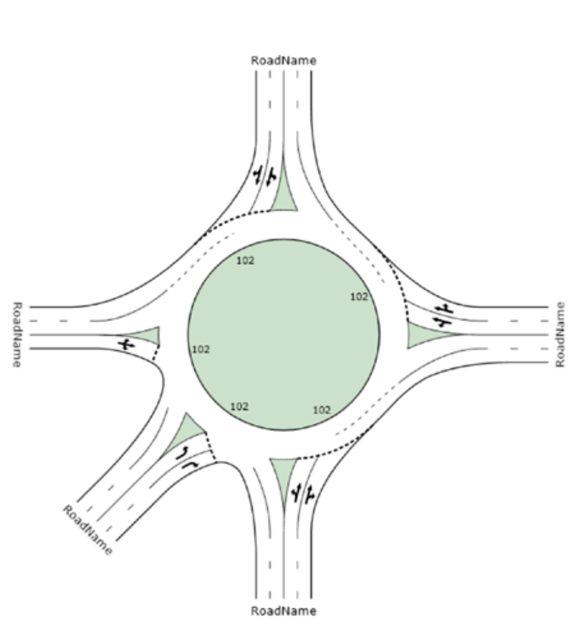


Figure 3-4 Conceptual Roundabout Design for Intersection of Murray & Forward

3.3.3 Comparison of Signalized Control and Roundabout

According to the LOS comparison results, this intersection will experience a significant improvement after conversion to a roundabout. All the approaches perform well in terms of reduced delay time. The results are summarized in Table 3-5 and Table 3-6.

Table 3-5 A.M Peak Hour LOS and Delay for Intersection of Murray & Forward

	Signal Control		Roundabout	
	Delay	LOS	Delay	LOS
East Bound	42.1	D	21.1	C
West Bound	29.3	C	22	C
North Bound	74	E	8.2	A
South Bound	64.4	E	43.2	E
North-East	72.5	E	6.2	A
Overall	56.4	E	22.9	C

Table 3-6 P.M Peak Hour LOS and Delay for Intersection of Murray & Forward

	Signal Control		Roundabout	
	Delay	LOS	Delay	LOS
East Bound	95.8	F	31.7	D
West Bound	31.4	C	10.5	B
North Bound	38.9	D	11.8	B
South Bound	64.4	E	10	B
North-East	61	E	10.6	B
Overall	60.5	E	14.8	B

3.4 SAFETY ANALYSIS

To estimate the crash reduction benefit after conversion of signalized intersections to roundabouts, the AASHTO Highway Safety Manual (HSM) was used as a reference. In the manual, Crash Modification Factors (CMFs) are provided to estimate the expected average crash frequency reduction. These are used when a particular treatment to the existing condition for a Safety Performance Function (SPF) is not available. The SPF for the conversion of a signalized intersection to a roundabout, is not provided in the HSM, therefore the CMF was used. CMF is defined as

$$CMF = \frac{\text{Expected Average Crash Frequency with Site Condition b}}{\text{Expected Average Crash Frequency with Site Condition a}}$$

When CMF value is 1.0, it means there is no expected change in safety conditions after a treatment is implemented at an intersection. When a value greater than 1.0 is reported it indicates that a potential reduction of crash frequency can be expected and when a CMF less than 1.0 is reported the potential crash frequency increases when compared to the base condition.[7]

CMFs from the HSM for all conditions, such as rural, suburban or urban locations for converting a signalized intersection into a modern roundabout are presented in Figure 3-5. Since all the three intersections that were studied fall into the category of one or two lanes urban intersections, a CMF value of 0.40 was selected to determine the safety benefits.

Treatment	Setting (Intersection Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
Convert signalized intersection to modern roundabout	Urban (One or two lanes)	Unspecified	All types (All severities)	**0.99***	**0.1**
			All types (Injury)	**0.40**	**0.1**
	Suburban (Two lanes)		All types (All severities)	**0.33**	**0.05**
	All settings (One or two lanes)		All types (All severities)	**0.52**	**0.06**
			All types (Injury)	**0.22**	**0.07**
Base Condition: Signalized intersection.					

Figure 3-5 Crash Effects of Converting Signalized Intersections into Modern Roundabouts [7]

When calculating safety benefits the reduction in both injury and property damage only accidents needs to be estimated. The HSM provides a CMF of 0.40 for injury accidents only. There is no CMF value provided in the HSM to evaluate the change of “property damage only” (PDO) crashes. [7]However, PDO crash is a vital element when estimate the potential benefits. This is because PDO crashes occur more frequently than injury crashes. To determine the percent change of PDO crashes for such a conversion, data from several before-after studies was examined. A 32% reduction of PDO is frequently cited in many studies. This reduction rate is recommended by U.S Department of Transportation for roundabouts converted from all conventional intersection and therefore was used in lieu of a CMF provided by the HSM. The data was based upon conversion of both signalized and unsignalized intersections to roundabouts. Although the actual rate for the conversion from signalized intersections may differ, 32% was used in this research for the reason that this data was concluded from a sample size of 8 sites. It cannot be denied that the overall effect of such a conversion is positive.[1]

Crash data was obtained from PennDOT for the years 2009, 2010, 2011 and 2012 for the three intersections studied. Injury, fatal and property damage only crash data was used in the calculations. The data was averaged for the four years for the 3 intersections studied.

Table 3-7 to Table 3-9 shows the existing crash data and the projected crash frequency after converting to a roundabout for each of the three intersections.

Table 3-7 Existing and Projected Crash Data for Intersection of Bigelow & O'Hara

	Injury Crashes	PDO
2009 Crashes	1	0
2010 Crashes	1	1
2011 Crashes	2	1
2012 Crashes	1	1
Total	5	3
Signalized Intersection	1.25	0.75
Reduction in Crash (%)	60.00%	32.00%
Roundabout	0.5	0.51

Table 3-8 Existing and Projected Crash Data for Intersection of Morewood & Fifth Ave

	Injury Crashes	PDO
2009 Crashes	1	1
2010 Crashes	7	6
2011 Crashes	5	7
2012 Crashes	3	3
Total	16	17
Signalized Intersection	4	4.25
Reduction in Crash (%)	60.00%	32.00%
Roundabout	1.6	2.89

Table 3-9 Existing and Projected Crash Data for Intersection of Murray & Forward

	Injury Crashes	PDO
2009 Crashes	0	0
2010 Crashes	1	2
2011 Crashes	1	1
2012 Crashes	0	1
Total	2	4
Signalized Intersection	0.5	1
Reduction in Crash (%)	60.00%	32.00%
Roundabout	0.2	0.68

As shown a significant reduction factor is expected at the three intersections for all types of crashes. However, there is no significant safety benefit, in terms of the number of crashes eliminated, due to such a conversion because the number of crashes is very small. But the historic data from PennDOT only include reportable crashes. The definition of a reportable crash in Pennsylvania is one in which an injury or a fatality occurs or if at least one of the vehicles involved required towing from the scene. If non-reportable data were available, the reduction would be more significant. However this data was not available. The resultant data was still used in the benefit analysis.

3.5 ENVIRONMENTAL BENEFITS

It was hypothesized that by converting the three signalized intersections to roundabouts, some environmental benefits would be achieved. The environmental benefits were expected to include the reduction of fuel consumption and emission from vehicles due to reduced delays at the intersections.

3.5.1 Increasing Fuel Efficiency

When a signalized intersection is converted to a roundabout, unnecessary stops and traveler delay are expected to be reduced. Vehicles only have to yield to the circling traffic and traffic flow should increase. When this occurs fuel consumption is reduced. The Synchro version 8.0.804.795 model was used to estimate this reduction in fuel consumption. The model estimates fuel consumption based on delay time.

The “measure of effectiveness” reports generated by the Synchro version 8.0.804.795 model describe fuel consumption for each approach. The comparison results in the reduction in fuel consumption for signal control when compared to the roundabout control in each of the three studied intersection. The results are presented in the following Table 3-10.

Table 3-10 Fuel Consumption and Savings per Hour for Three Intersections

AM Peak	Signal Control (gal/h)	Roundabout (gal/h)	Change in Fuel Used (gal/h)	Reduction Rate
Bigelow & O'Hara	22	7	15	68.18%
Morewood & Fifth	32	23	9	28.13%
Murray & Forward	33	15	18	54.55%
PM Peak				
Bigelow & O'Hara	17	8	9	52.94%
Morewood & Fifth	37	25	12	32.43%
Murray & Forward	32	14	19	59.38%

The results revealed that roundabouts are a more environmental friendly way of traffic control than traffic signal in these three studied intersections. Such a conversion not only saves nature resource, but also saves operating costs for drivers.

3.5.2 Reducing Emissions

Traffic emissions include tailpipe emissions and service life emissions. Service life emissions are more global impacts as compared to tailpipe emissions which occur at the intersection. Tailpipe emissions are pollutants that are released directly from vehicle exhaust pipes while service life emissions include indirect emissions such as emissions from fuel extraction and refining as well. In this research, only tailpipe emissions reduction is considered as potential benefits since their impacts can be local and regional.

As summarized by the US Environment Protection Agency (USEPA), the scale of impact of carbon monoxide (CO) emission is "very local" while nitrogen oxides (NOx) emissions and volatile organic compounds (VOC) emissions are regarded as both local and regional in their impact. All these three emissions can be harmful to human health. CO has harmful effects on climate change while the other two emissions can be ozone precursors. NOx can also have some ecological damage. [13]USEPA also identifies that highway vehicles emissions are a significant share of overall transportation pollution as shown in Figure 3-6.

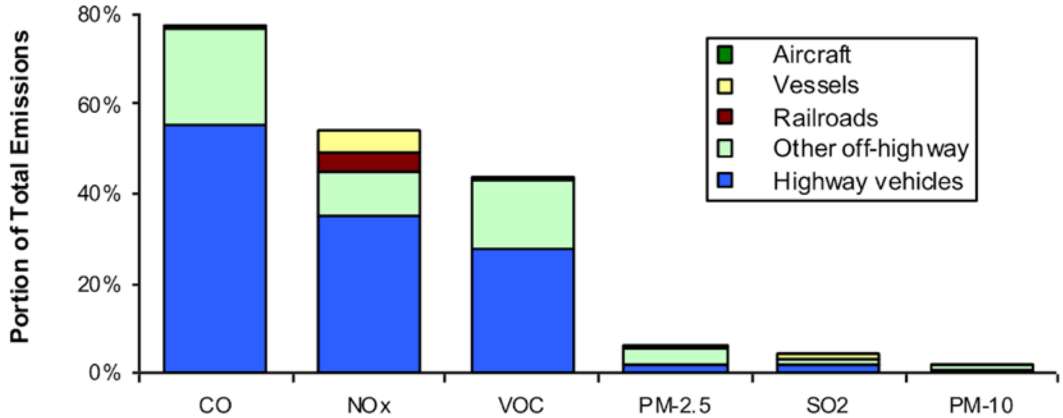


Figure 3-6 Transport Air Pollutant Shares (2002) [13]

Although CO2 is one fuel combustion by product of vehicles, it was not considered into the calculation of service life benefits. Because CO2 is a major component of greenhouse gases (GHG) and its harmful impacts are on a global scale. The impact of such a conversion can be difficult to evaluate on a small scale such as a single intersection and therefore were not considered.

The Synchro version 8.0.804.795 model generates emissions data for CO, NO_x and VOC based on the fuel consumption.

Table 3-11 to Table 3-13 depicts the comparison of vehicle emissions for signalized intersections and roundabouts at the three studied intersections.

Table 3-11 Emission Comparison for Intersection of Bigelow & O'Hara

AM Peak	CO	NOx	VOC
Signalized Control	1.52	0.3	0.35
Roundabout	0.46	0.09	0.11
Reduction Rates	69.74%	70.00%	68.57%
PM Peak			
Signalized Control	1.21	0.24	0.28
Roundabout	0.56	0.11	0.13
Reduction Rates	53.72%	54.17%	53.57%

Table 3-12 Emission Comparison of Emission for Intersection of Morewood & Fifth Ave

AM Peak	CO	NOx	VOC
Signalized Control	2.25	0.44	0.52
Roundabout	1.62	0.31	0.38
Reduction Rates	28.00%	29.55%	26.92%
PM Peak			
Signalized Control	2.57	0.5	0.6
Roundabout	1.74	0.34	0.4
Reduction Rates	32.30%	32.00%	33.33%

Table 3-13 Emission Comparison of Emission for Intersection of Murray & Forward

AM Peak	CO	NOx	VOC
Signalized Control	2.33	0.45	0.54
Roundabout	1.05	0.2	0.24
Reduction Rates	54.94%	55.56%	55.56%
PM Peak			
Signalized Control	2.22	0.43	0.51
Roundabout	0.97	0.19	0.22
Reduction Rates	56.31%	55.81%	56.86%

There are significant reductions of all the three air pollutants at the studied intersections. These benefits were monetized for the benefit-cost analysis.

3.6 SUMMARY AND CONCLUSIONS

In summary, for all the three intersections studied, there is an improvement in level of service, except for the intersection of Morewood Avenue & Fifth Avenue during A.M peak hour. The crash data obtained revealed that the existing safety conditions are not that significant. However, a reduction of all kinds of crashes is expected with the conversion of the intersections per the safety analysis performed. Since safety is always a priority, this benefit should be considered. A reduction of fuel consumption and air pollutant emission can also be expected after the conversion. Even though CO_2 emission reductions were not included in this benefit analysis, it is apparent that this kind of conversion would have a positive impact on the environment.

There is no doubt that all of these benefits would make a difference to the environment, the travelling public and society in general throughout the roundabout's service life. After the analysis for this portion of the research confirmed that there would be expected benefits in terms of safety, environment and level of service, a benefit-cost analysis was conducted as the next step in the research.

4.0 BENEFIT-COST ANALYSIS

Modern roundabouts have long been suffering by myths perceived by the public. These myths include assumptions that roundabouts can cause longer commutes, more accidents, difficult for larger vehicles to maneuver and even cost more than traditional intersections.[14] After examining the potential benefits of the conversion from signalization to roundabouts in this research, these myths were proven to be wrong for three intersections studied. In fact, roundabouts can reduce delays and stops, reduce many types of serious crashes at signalized intersections and improve the environment.

In this portion of the research, all the benefits of the conversion from signalized intersections to roundabouts were monetized. Although the construction cost of roundabouts can be much higher than upgrading an existing signalized intersection, the maintenance cost are lower. This is because there is no electricity costs or equipment repair fees occur at an intersection controlled by roundabout. The service life of a roundabout is also longer than signalized intersections. [14]

Based on these generalized conclusions it was hypothesized that the monetized benefits of the conversion would be positive when evaluated over the service life of operating an intersection with a traffic signal versus a roundabout. It is then expected that the roundabout method of operation would have a positive benefit-cost ratio when compared to the traffic signal operation.

There are two typically methods of conducting a benefit-cost analysis for transportation projects. One method is to compare each of the alternatives to a no-build alternative; the other method is to calculate the relative benefit-cost ratio of alternative A and alternative B. Because it can be assumed that some type of traffic control is warranted at an intersection when considering such a conversion, the second type of benefit-cost analysis is more appropriate. This analysis determines if the conversion results in the benefits outweighing the costs for the life of the intersection during a typical replacement cycle for a traffic signal. The equation of the second method is shown below. [1]

$$B/C_{BA} = \frac{Benefits_B - Benefits_B}{Cost_B - Cost_B}$$

This ratio can express how roundabout would benefits both users and operators during the whole service life in a more directly way.

4.1 COST SAVINGS

Conceptual design plans for the 3 proposed roundabouts were shown in the previous section. Since the designs are in a conceptual level, the construction and maintenance cost were derived by obtaining cost data from recent similar project costs. The data used had similar design and operating characteristics to the 3 intersections studied. Also reported cost ranges from other state agencies were considered. Since state agencies in Pennsylvania, where the intersections are located, lacks much data for these costs because of the limited number of conversions, the higher end of the range was assumed.

4.1.1 Construction Cost

Construction cost of such a conversion includes utility relocations, maintenance and protection of traffic during construction and many other items. Construction cost of all the previous projects, used as examples, were converted to year 2013 values by applying National Highway Construction Cost Index (NHCCI) to different construction years.[15]

The proposed roundabout at intersection of Bigelow and O'Hara was designed as a one-lane roundabout with four legs. According to the data from three roundabouts converted from signalized intersections studied on Cleveland Street in Clearwater, Florida in 2004,[10] the construction cost in this intersection was shown in Table 4-1.

Table 4-1 2013 Roundabout Construction Cost for Intersection of Bigelow & O'Hara

		Construction Cost
	2004	$1,740,398
	2013	$1,795,519
NHCCI		1.03

Due to the high peak hour volume and existing alignment on intersection of Morewood & Fifth Avenue, this intersection was designed as a two-lane roundabout with a larger diameter. The construction cost of this intersection was estimated by calculating the average cost of two similar projects. The first one is an intersection study conducted in 2010 in Minnesota.[16] Another one is located in Georgia.[17] Original costs of both two lane roundabouts were converted to 2013 values. The calculation is shown as below.

Table 4-2 2013 Roundabout Construction Cost for Intersection of Morewood & Fifth

	Construction Cost	NHCCI	2013
2012	$2,170,000	0.98	$2,119,526
2011	$3,500,000	1.03	$3,589,392
		Average	$2,854,459

To build a one-lane roundabout in a five-leg intersection can be as expensive as a two-lane roundabout in a high volume intersection. A feasibility study of a five-leg roundabout converted from signalized intersection in New York State in 2011 shows a construction cost of nearly 2 million dollars. [18]By calculating the average construction cost of this study and another one in the City of Oviedo,[19]conceptual construction cost of the five-leg intersection in Squirrel Hill is presented as below.

Table 4-3 2013 Roundabout Construction Cost for Intersection of Murray & Forward

	Construction Cost	NHCCI	2013
2005	$2,500,000	0.93	$2,333,305
2011	$1,909,000	1.03	$1,957,757
		Average	$2,145,531

4.1.2 Maintenance Cost

Roundabouts have many advantages over signalized intersection in terms of maintenance. One major reason is that there are no electric cost or bulb replacement cost which is a major portion of a traffic signal maintenance cost.

Institute of Transportation Engineers recommends for budgeting purposes a range of $2,000 to $5,000 for the annual maintenance cost of a typical signalized intersection should be considered.[20] Agencies from different states assume various ranges but barely for a particular intersection. However, due to the different size of each of the 3 intersections, the maintenance cost for both the roundabout control and signal control option in each of these intersections would be different.

The methodology of estimating the maintenance cost used in this research was to utilize the relative proportional ratio of the size of the three intersections. The first step was to select one intersection, which has available historical data to be the base condition. The next step in the process was to calculate the cost of another two intersections by multiply the relative proportional ratio to the base intersection. Because maintenance costs can be directly related to the original cost for construction, the relative proportional ratio was derived from the construction cost of each three intersections. Construction costs are $1,795,518.56, $2,854459.08 and $2,145531.07 for intersection of Bigelow & O'Hara, intersection of Morewood & Fifth Ave and intersection of Murray & Forward respectively. The ratio is shown in Table 4-4.

Table 4-4 Construction Ratio for the Three Studied Intersections

Construction Cost	$1,795,518.56	$2,854,459.08	$2,145,531.07
Ratio	1 :	1.59 :	1.19

A recent study conducted by Scott Alisoglu emphasized the economic advantage of roundabouts. [21] The author used data from engineering division of City of Topeka, Kansas.

That revealed a annual maintenance cost of $2,000 for a roundabout and $5,000 for a signalized intersection.

This data was selected to be the base condition for the following reasons. The configuration and size of the intersection in City of Topeka is very similar to the intersection of Morewood & Fifth Ave. Secondly, data from Kansas State is more comparable to the conditions in Pittsburgh than other data that was found from the Florida Department of Transportation. The maintenance costs for both signalized intersections and roundabouts are highly relevant to climate, therefore the Kansas data was used.[10]

The $2,000 and $5,000 annual maintenance cost were converted to year 2013 values using an NHCCI of 1.04 since the Kansas intersection was analyzed in 2010. A comparison result of signal control and roundabout are shown in Table 4-5.

Table 4-5 Maintenance Cost Comparison for Three Studied Intersections

	Signalized Intersection	Roundabout	Annual Savings
O'Hara & Bigelow	$3,259.08	$1,308.37	$1,950.72
Morewood & Fifth	$5,181.19	$2,080.00	$3,101.19
Murray & Forward	$3,894.40	$1,563.42	$2,330.99

For all the three intersections, annual maintenance cost savings of converting the signalized intersections to roundabouts fall into the range of $2,000 to $3,500 annually.

4.1.3 Replacement Cost

A service life benefit-cost analysis of this conversion considers not only the annual maintenance costs but also replacement costs when the life of the traffic control has reached the end of its service life. Both signalized intersections and roundabouts need to be replaced to remain functional. To replace an existing traffic signal at the end of its service life typically requires installation of a new one. This is because of the advancement in technologies for traffic control and changing design and safety standards.

An ITE publication cites a range of $50,000 to more than $200,000 for installation a new traffic signal.[22] Similar to the method used to calculate the maintenance costs, the 1:1.59 and 1.19 ratio of three intersections were used to estimate replacement construction costs. The intersection of O'Hara Street & Bigelow Boulevard was selected as the baseline condition when calculating replacement costs of the signalized intersections. In the impact study conducted by Sides, Ken and Wallwork, Michael [10], a replacement cost was estimated and used as a reference for four-leg intersection with one lane in each direction. An NHCCI of 1.03 was applied to the $80,000 replacement cost in order to estimate a present value for application to the intersections studied. After calculating the replacement cost in the intersection of O'Hara & Bigelow, cost of the other two intersections was determined by the relative ratio.

Because roundabouts are not a widely used type of intersection control method in the USA currently, there is little data about the cost of replacing existing roundabouts at the end of their service life. But replacement costs do have a direct relationship to the construction cost. It was important to determine this relationship for the research. The study conducted in Kansas for a four-leg roundabout with two circling lanes estimated a roundabout replacement cost of $735,855. This intersection is similar to intersection of Morewood & Fifth Avenue and the data was used. When comparing the present value of the replacement cost to the estimated construction cost of intersection for Morewood & Fifth Avenue, the roundabout replacement cost was estimated to be 26.71% of its construction cost. Then this percentage was applied to another two intersections to evaluate a conceptual replacement cost. The result is shown in the following table.

Because traffic signals involve equipment replacement costs and roundabouts have no traffic equipment to replace, the method of equipment costs comparison could be viewed differently. When comparing these two types of costs for this research it was assumed that replacement of the roadway components, such as curbs and pavement for the roundabout, would be equivalent to the replacement of the traffic signal equipment. However, an alternative method of comparing replacement savings could be conducted by bringing the replacement cost of roundabouts to $ 0 while using the replacement cost of signal control for comparison. Because the other factors of the replacement at signalized intersections are similar to roundabout replacement.

Table 4-6 Replacement Cost Comparison for Three Studied Intersections

	Signalized Intersection	Roundabout	Replacement Savings
O'Hara & Bigelow	$82,533.70	$479,642.79	-$397,109.09
Morewood & Fifth	$131,209.49	$762,521.06	-$631,311.57
Murray & Forward	$98,622.55	$573,142.78	-$474,520.23

The result shows that signal control have advantage over roundabouts in the replacement cost. This happens mainly because the method used in the calculation and high initial construction cost of roundabouts.

4.1.4 Summary and Conclusions

Construction costs occur when the method of traffic control is initially constructed while replacement cost occurs at the end of the service life of a particular facility. Maintenance cost occurs throughout the life of the traffic control. These costs cannot be analyzed separately. In order to determine a benefit-cost ratio, these costs must be annualized for comparison purposes.

4.2 MONETIZED BENEFITS

To calculate a benefit-cost ratio, all the benefits quantified in the previous research needed to be converted to a monetary value. This part of the research followed the September 2010 (3^{rd} edition) AASHTO publication "User and Non-User Benefit Analysis for Highways" methodology to calculate annualized benefit and costs for each of the three intersections.

Three primary benefits were included in the analysis. They are the crash costs, fuel costs and emission damage costs. All the unit values used in the manual were quantified in year 2000 US dollars. For this reason, an inflation rate of 36%, derived from latest US government CPI data was applied to bring the year 2000 value up to a year 2013 value.

4.2.1 Delay Reduction Benefits

Cost savings, due to reductions in delays, during both A.M and P.M peak hours were determined by using the "value of time saved due to change in delay" equation.[23] According to the Census data (2005-2009 average), there are about 12% people commute to work in a carpool. Using the peak hour traffic volume to calibrate and assume the average number of people per carpool is 3, and then the average vehicle occupancy is determined to be 1.24. According to table 5-1 and 5-2 in the manual, value of time per hour for users was determined as $12.62 and $26.84 for vehicles and trucks respectively. Total value of time savings per peak hour is summarized in Table 4-7.

Table 4-7 Total value of Time Savings per Peak Hour

	Cars	Trucks	Total
Bigelow & O'Hara AM	$268.05	$56.38	$324.43
Bigelow & O'Hara PM	$148.55	$16.63	$165.18
Morewood & Fifth AM	-$44.39	-$7.11	-$51.49
Morewood & Fifth PM	$174.26	$11.46	$185.72
Murray & Forward AM	$300.05	$26.59	$326.64
Murray & Forward PM	$245.72	$16.16	$261.89

4.2.2 Crashes & Fuel Consumption

The analysis in crash research showed a predicted crash frequency after converting existing signalized intersections to roundabouts. The AASHTO manual provides an equation to calculate annual savings in crash costs. The equation sums up crash cost savings for each crash type. Since there were no fatal crashes reported from year 2009 to 2012, the "Vd*D" value is 0. Crash costs in this modal only includes direct cost associated with a crash. Insurance reimbursements are subtracted in the unit crash value. Unit crash value was obtained from table 5-17 in the manual and converted to 2013 value. The results of annual savings for the three intersections are shown in Table 4-8 to Table 4-10.

Table 4-8 Annual Crash Saving for Intersection of Bigelow & O'Hara

	Injury Crashes	PDO
Change in crashes	0.75	0.24
Cost in 2013 per Crash	$147,696.00	$272.00
Changes in Crash Costs	$110,772.00	$65.28
Total	$110,837.28	

Table 4-9 Annual Crash Saving for Intersection of Morewood & Fifth

	Injury Crashes	PDO
Change in Crashes	2.4	1.36
Cost in 2013 per Crash	$147,696.00	$272.00
Changes in Crash Costs	$354,470.40	$369.92
Total	$354,840.32	

Table 4-10 Annual Crash Saving for Intersection of Murray & Forward

	Injury Crashes	PDO
Change in crashes	0.3	0.32
Cost in 2013 per Crash	$147,696.00	$272.00
Changes in Crash Costs	$44,308.80	$87.04
Total	$44,395.84	

Cost savings of fuel consumption for the studied intersections are based on the fuel consumption modal used in Sychro 8. Fuel price was determined by the average price in the City of Pittsburgh in October 2013. By multiplying the reduction of fuel consumption per hour to the average fuel price, a peak hour cost saving would be obtained. The results include both A.M peak hour and P.M. peak hour are shown in the following Table 4-11.

Table 4-11 Peak Hour Fuel Savings

AM Peak	Signal Control (gal/h)	Roundabout (gal/h)	Change in Fuel Used (gal/h)	Reduction Rate	Total savings ($/hour)
Bigelow & O'Hara	22	7	15	68.18%	52.31
Morewood & Fifth	32	23	9	28.13%	31.38
Murray & Forward	33	15	18	54.55%	62.77
PM Peak					
Bigelow & O'Hara	17	8	9	52.94%	31.38
Morewood & Fifth	37	25	12	32.43%	41.84
Murray & Forward	32	14	19	59.38%	66.25

4.2.3 Emission Reduction Benefits

The emission unit costs in this research were derived from the procedure used in FHWA'S HERS model. [24] Costs in this model include cost of human health and property damage per ton of each pollutant. Since the costs in the model represent average damage costs at a national level, the model also provides adjustment factors to bring the damage costs up to reflect a local urban situation. The damage cost for CO, NOx and VOC are 0.136 dollar/kg, 5.61dollar/kg and 7.395 dollar/kg respectively in 2013 value for each type of emission. The cost savings of CO_2 emissions were not calculated in this research because it is difficult to put a value on this kind of emission. By inputting the emission data from Synchro version 8.0.804.795 model analysis to this cost rate, peak hour cost savings for emissions are shown in Table 4-12.

Table 4-12 Peak Hour Air Pollutant Damage Cost Savings ($/hour)

AM Peak	CO	NOx	VOC
Bigelow & O'Hara	0.14	1.18	1.77
Morewood & Fifth	0.09	0.73	1.04
Murray & Forward	0.17	1.40	2.22
PM Peak			
Bigelow & O'Hara	0.09	0.73	1.11
Morewood & Fifth	0.11	0.90	1.48
Murray & Forward	0.18	1.46	2.37

4.2.4 Summary and Conclusions

In this section, peak hour cost savings for fuel consumption, value of time and traffic emissions are determined based on the data from Synchro version 8.0.804.795 model traffic analysis reports. The results show that these factors have considerable economic benefits to the society when the three signalized intersections are converted to roundabouts. In the following section, peak hour savings were converted to annual savings and combine with the annual crash saving to determine an annual monetized benefit to each of the three intersections.

4.3 SERVICE LIFE BENEFIT COST ANALYSIS

A net service life benefit cost ratio was calculated based on the user and non-user benefit analysis methodology.

4.3.1 Total Annual Benefits

To convert the benefits of the peak hours on weekdays to a yearly saving, the following procedures were followed. The first step was to determine total value of savings per day. Based on hourly percentage data from SPC[25], volume for each hour in a day has a relationship to the peak hour as depicted in Figure 4-1. Assuming normal traffic conditions for five days a week, 52 weeks a year and minus 10 assumed federal holidays, the yearly savings for emission, delay and fuel can be estimated. Total yearly cost savings are summarized in Table 4-13.

Hourly Percentages: Total Vehicles							
TPG 5				TPG 6			
HOUR	DIR 1	DIR 2	TOTAL	HOUR	DIR 1	DIR 2	TOTAL
1	0.71%	0.93%	0.68%	1	0.74%	0.80%	0.69%
2	0.44%	0.59%	0.39%	2	0.53%	0.49%	0.43%
3	0.40%	0.49%	0.32%	3	0.50%	0.45%	0.40%
4	0.49%	0.54%	0.35%	4	0.61%	0.58%	0.49%
5	0.90%	0.83%	0.66%	5	1.08%	1.11%	0.96%
6	2.41%	1.83%	1.87%	6	2.64%	2.18%	2.34%
7	5.31%	3.75%	4.39%	7	5.42%	4.11%	4.56%
8	7.47%	5.34%	6.51%	8	7.03%	5.14%	5.93%
9	6.79%	5.14%	5.97%	9	6.19%	5.37%	5.60%
10	5.42%	4.69%	5.07%	10	5.47%	4.73%	5.38%
11	5.06%	4.68%	5.01%	11	5.28%	4.80%	5.57%
12	5.36%	5.18%	5.44%	12	5.63%	5.36%	5.83%
13	5.75%	5.68%	5.86%	13	5.83%	5.62%	6.05%
14	5.70%	5.73%	5.77%	14	5.99%	5.84%	6.16%
15	6.10%	6.39%	6.37%	15	6.44%	6.84%	6.86%
16	6.97%	7.99%	7.53%	16	7.17%	8.30%	7.86%
17	7.43%	9.04%	8.18%	17	7.35%	8.55%	8.10%
18	7.23%	8.82%	8.07%	18	7.10%	8.50%	7.39%
19	5.80%	6.43%	6.24%	19	5.61%	6.03%	5.61%
20	4.43%	4.84%	4.86%	20	4.18%	4.79%	4.37%
21	3.62%	3.99%	3.99%	21	3.19%	3.89%	3.51%
22	2.88%	3.24%	3.06%	22	2.60%	2.95%	2.71%
23	2.03%	2.27%	2.08%	23	2.02%	2.05%	1.91%
24	1.30%	1.61%	1.34%	24	1.36%	1.50%	1.28%
TOTAL	100.00%	100.00%	100.00%	TOTAL	100.00%	100.00%	100.00%

Figure 4-1 2012 Hourly Percentage for Total Vehicles in Pennsylvania [25]

Table 4-13 Total Annual Cost Savings of All Kinds of Benefits

	Bigelow & O'Hara	Morewood & Fifth	Murray & Forward
Fuel	$130,105.66	$126,144.03	$215,863.33
Delay	$745,414.51	$324,466.66	$950,182.81
Crash	$110,837.28	$354,840.32	$44,395.84
CO	$362.57	$341.55	$601.22
NOx	$2,977.34	$2,775.15	$4,777.87
VOC	$4,507.41	$4,367.38	$7,681.31
Total	$994,204.76	$812,935.09	$1,223,502.38

4.3.2 Benefit-Cost Ratio

To calculate a service life benefit-cost ratio, the following assumptions were made in this research. The analysis period selected was 40 years from year 2013. Based on the literature review that roundabouts can have a much longer service life than traffic signals, it was assumed that traffic signals would need a replacement after 20 years and 40 years while roundabouts only need a replacement after 40 years. A time line describes this is shown in Figure 4-2.

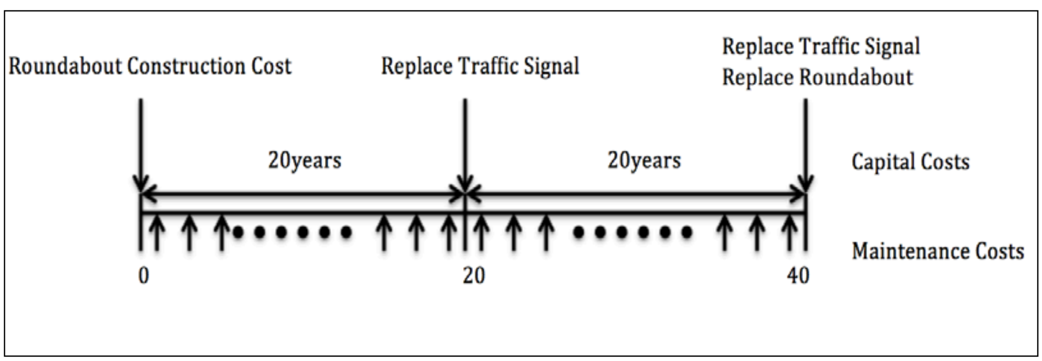


Figure 4-2 Timeline for Service life Analysis

Traffic volumes in the future were assumed to remain the same and no growth rate was applied to calculate the future traffic volume. While traffic volume increases are normally applied to predict future conditions it was assumed for this research that any increases in volumes would result in the same proportional delays for both types of traffic control.

A basic present value formula was applied to user benefit cost, construction cost and maintenance cost for each year to bring their values to present day, which is 2013 dollars. The user and non-user benefit analysis manual provides the present value formula. Since the net benefit calculations were in real terms, a risk-free real discount rate was used in the formula and assumed to be 3.5%. A 3% risk premia was used as a risk-adjusted discount rate. [23]

Table 4-14 demonstrates the net present value of evaluation year 2013 and benefit/cost ratios to the three studied intersections. The detailed calculations are shown in Appendix B.

Table 4-14 Net Present Value (2013) and Benefit-Cost Ratio

	Bigelow & O'Hara		Morewood & Fifth		Murray & Forward	
	Benefit	Cost	Benefit	Cost	Benefit	Cost
2013 Dollar	$14,063,550	$1,813,841	$11,499,395	$2,883,588	$17,307,086	$2,167,425
Ratio	7.75 : 1		3.99 : 1		7.99 : 1	

4.3.3 Analysis

The following results can be concluded from the research analysis in this portion:

- A 47% reduction of annual air pollutant emissions
- A 47% reduction of annual fuel consumption
- A 61.4% reduction of annual delay time

- A 32% reduction of PDO crashes and 60% reduction of injury crashes

The three pie charts below show the percentage of four benefits among annual savings at each intersection.

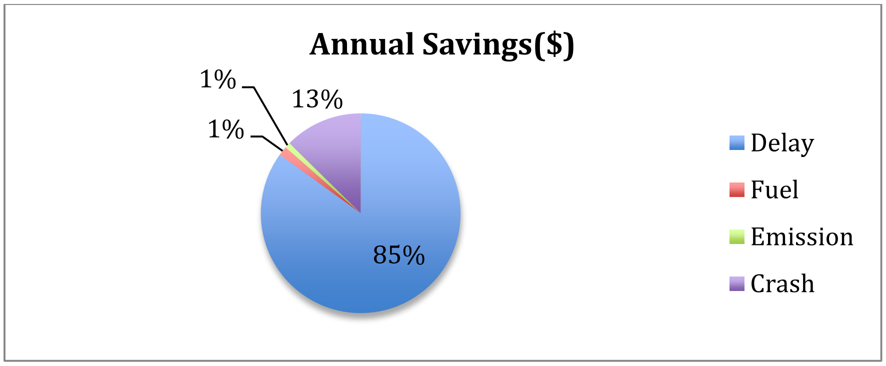


Figure 4-3 Intersection of Bigelow & O'Hara Annual Benefit Savings Pie Chart

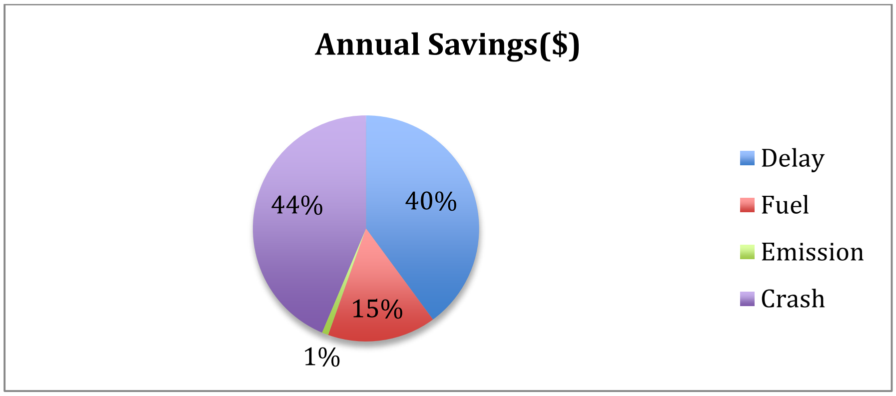


Figure 4-4 Intersection of Morewood Ave & Fifth Ave Annual Benefit Savings Pie Chart

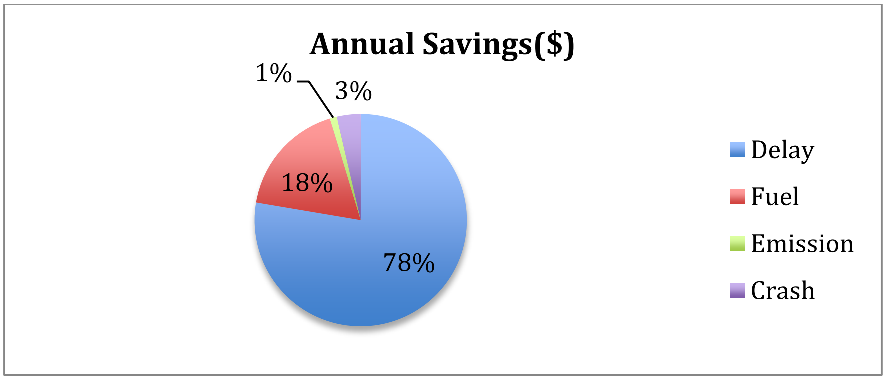


Figure 4-5 Intersection of Forward & Murray Annual Benefits Savings Pie Chart

The research results also showed that all the three intersections have a positive net benefit-cost ratio. The benefits of roundabouts were compared to traffic signals with optimized signal timing, instead of to the existing operation. Although the intersection of Morewood & Fifth Avenue would suffer a level of service reduction during the A.M. peak after converting to a roundabout, the final benefit cost ratio indicates the conversion can still be an effective way to improve the existing situation in this intersection. Intersection of Bigelow & O'Hara ranks in the 2^{nd} place, even though it costs the least to convert the existing traffic signal control to a roundabout. The five-leg intersection turns out to have the highest ratio of all the three intersections for its high annual benefit savings.

5.0 SUMMARY AND CONCLUSIONS

This section summarized the analysis results. The improved method of service life analysis, which includes an environment benefit analysis, was included in this section. The evaluation of the performances of those benefits in different circumstances, which is another main purpose of this thesis, was presented in this section. Research limitations and suggestions for further research were concluded at the end of this section.

5.1 SUMMARY OF ANALYSIS RESULT

According to the analysis in previous sections, average potential benefits for the three intersections after such a conversion can be concluded as following:

- An average saving in air pollutant damage cost by $10,530.36 annually
- An average saving in crash cost by $170,024.48 annually
- An average saving in value of time by $673,354.66 annually
- An average saving in fuel cost by $472,113.02 annually

The hypothesis made first, that converting signalized intersections to roundabouts in the examined circumstances is a considerable option to improve existing conditions was confirmed.

This kind of conversion can be a good alternative when agencies consider making some improvements.

5.2 ENVIRONMENTAL BENEFITS

Evaluating the monetized environmental benefits is the key improvement of service life analysis conducted in this research. The emission of CO, NOx and VOC were examined. The following table shows a total annual emissions reduction for each of the three pollutants at the three intersections.

Table 5-1 Total Annual Emissions Reduction (kg/year)

	CO	NOx	VOC	Total
Bigelow & O'Hara	2665.94	530.72	609.52	3806.18
Morewood & Fifth	2511.39	494.68	590.59	3596.66
Murray & Forward	4420.72	851.67	1038.72	6311.10
Total	9598.05	1877.07	2238.83	13713.94

There was a significantly reduction of these air pollutants after converted from signalized intersections. The exposure time when pedestrians crossing an intersection are relative long, also the public have awareness and concern about air quality in their neighborhood. For these reasons, adding this portion to the service life analysis can be useful for the public to realize the benefits that roundabouts can bring. On the other hand, this makes the impact evaluation more complete since the air quality issue cannot be ignored.

5.3 DIFFERENT CIRCUMSTANCES

The three intersections examined in this research stand for different circumstances. The intersection of Bigelow & O'Hara is a four-leg intersection with one lane in each direction while the intersection of Morewood & Fifth Avenue represents two lane four-leg intersections. The alignment of the five-leg intersection in Squirrel Hill is one that recommended as a good candidate in AASHTO publication. [1]

The results revealed that such a conversion may not be so applicable at intersections have high traffic volume and are located on a main arterial. The capacity of roundabouts can be limited and not suitable for this kind of intersections.

The conclusion can be drawn as that converting a signalized intersection with moderate traffic volume or awkward existing alignment to a roundabout can be a good solution to improve safety, level of service, air quality and fuel effectiveness.

5.4 FUTURE RESEARCH

There were some limitations in this research that can be addressed in future researches. First of all, the selection of emission model and pollutant damage model in this research had impacts over the benefit cost result. SIDRA method ran out different results of emissions and fuel consumptions when compared to Synchro version 8.0.804.795 method. Since SIDRA can analyze conventional intersections as well, analyze derived from this method can be conducted and have a comparison to the one used in this research. Only damage cost was included in the HERS model while control costs, which reflect the mitigation costs of reducing emissions, were not included. Factors such as the value of human health, the number of people exposed or even the range of additional costs and damages to the environment can be determined in differently in various models. Since there is no universal manual for this cost evaluation, the result can also be compared among different models and then to determine a more reasonable one for such a regional research. Secondly, for the limitation of completed projects of this kind of conversion, the construction cost, maintenance cost and replacement cost were not so accurate for the analysis. If possible, a detail calculate of these costs can be conducted and applied in the benefit-cost analysis. At last, the sample size in this research was small, although the selected intersections were representative. So the method developed in this research can be applied to more intersections to make a common conclusion.

5.5 SUMMARY AND CONCLUSIONS

This research developed an improved methodology to conduct service life cost analysis to roundabouts. To be specific, it was confirmed that the environmental benefits could play a role when conducting economic analysis to the conversion from signalized intersection to roundabouts. So they shouldn’t be excluded in this kind of traffic analysis.

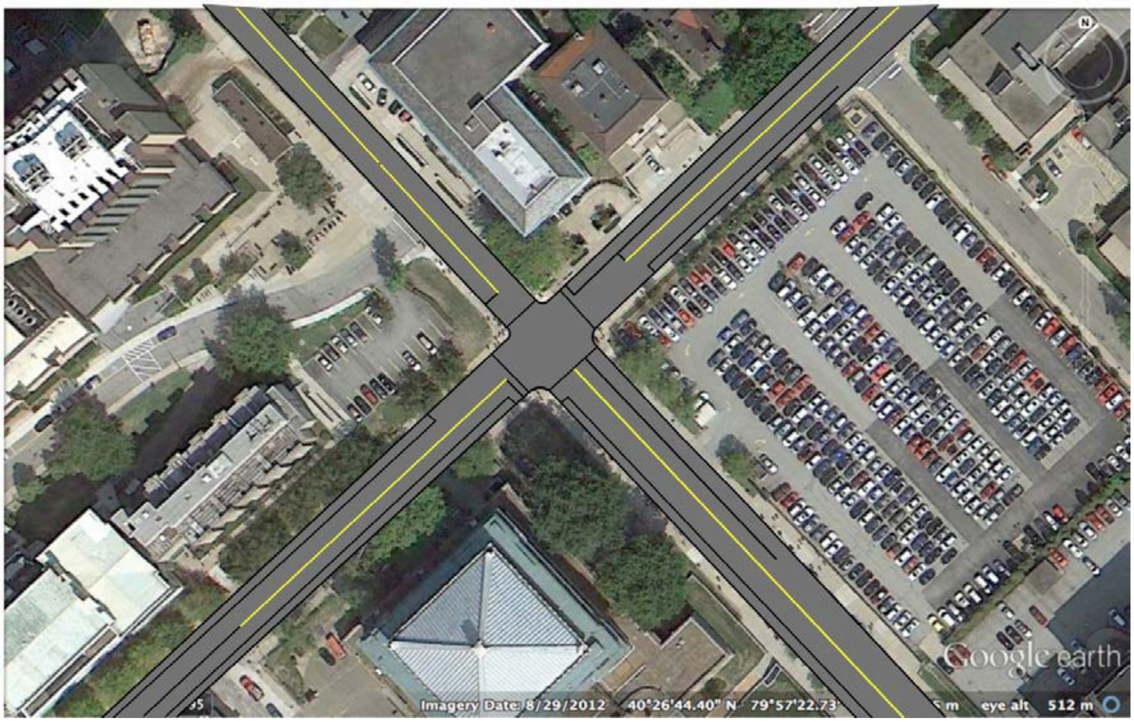
All those benefits were realized in different circumstances in this research, except the level of service experiences a level down after the conversion at intersection of Morewood & Fifth Avenue. So such a conversion can be considered under circumstances like intersection of Forward Ave, Murray Ave & Pocusset St or intersection of Bigelow Blve, O’Hara St & Parkman Ave.

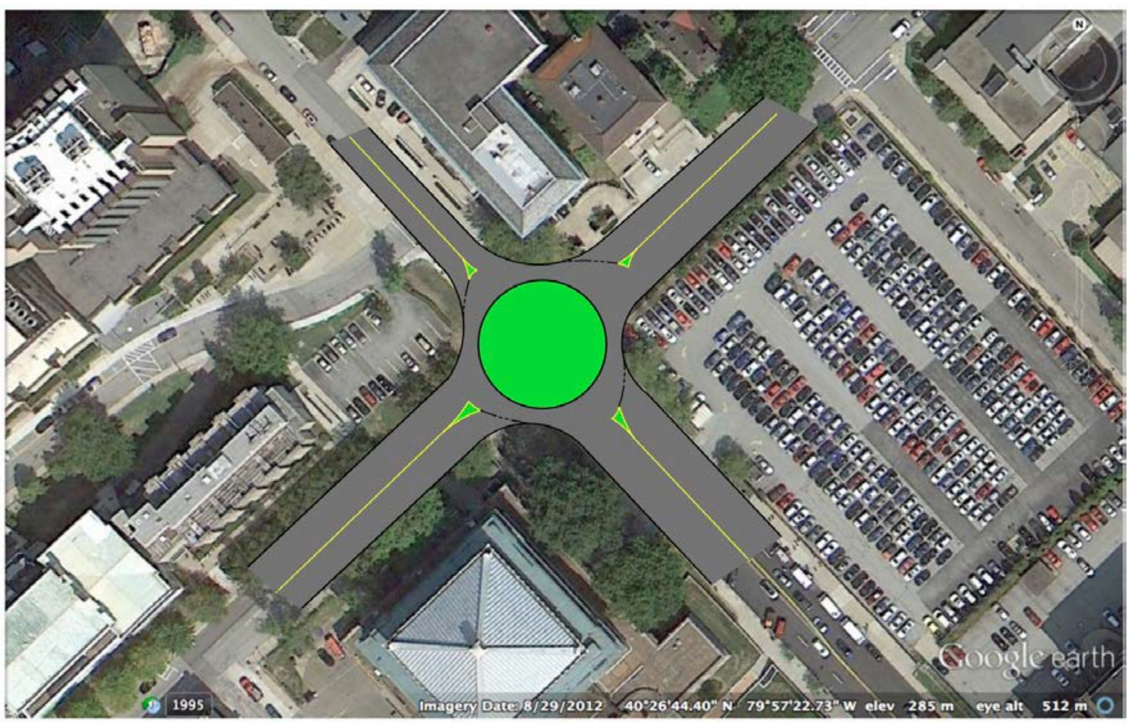
APPENDIX A

INTERSECTION ALIGNMENT DRAWINGS

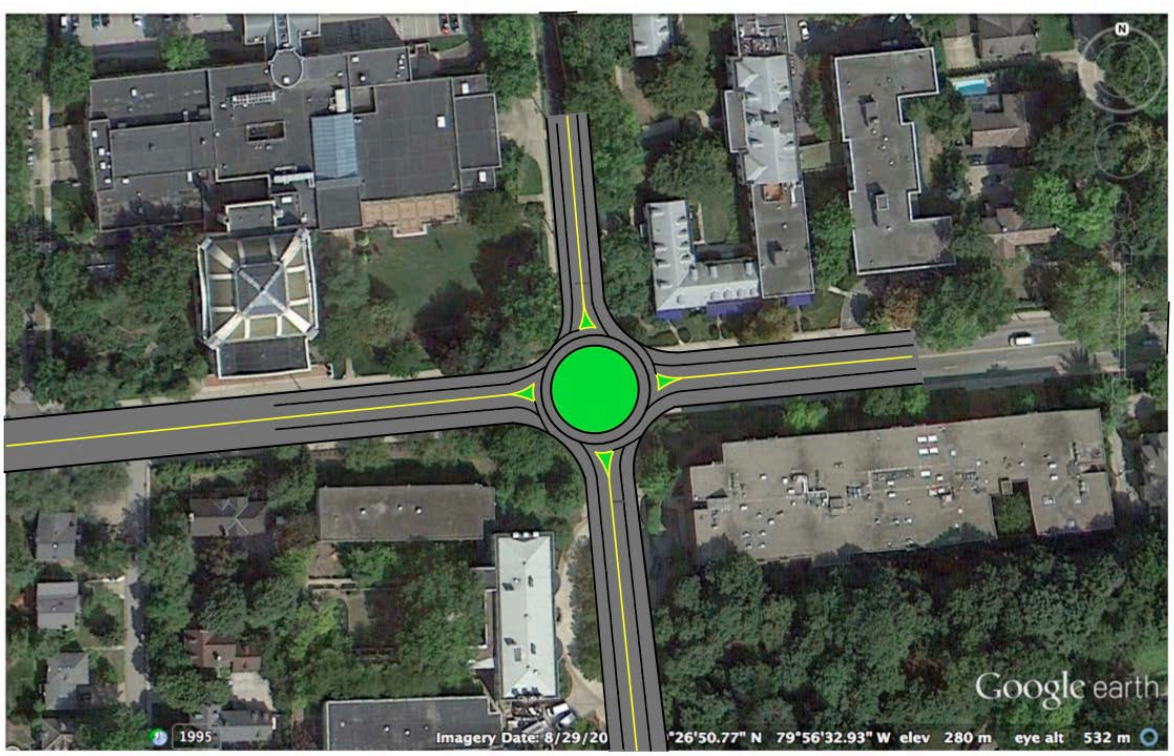
In this section, both existing alignment and conceptual alignment drawings are presented for each of the three intersections.

Intersection of Bigelow & O’Hara





Intersection of Morewood & Fifth



Intersection of Murray & Forward

APPENDIX B

BENEFIT COST ANALYSIS WORKSHEETS

This section shows the detail calculation of benefit cost analysis.

Intersection of Bigelow & O'Hara

	Year	Construction Cost	O&M cost	Replacement	Benefit ($)	B-C	PV	PV of Benefits	PV of Costs
Construction year	0	$1,795,518.56	$0.00	$0.00	$0.00	-$1,795,519	-1,795,519	0	1,795,519
Service Year1	1	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	931,694	933,526	1,832
Service Year2	2	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	874,830	876,550	1,720
Service Year3	3	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	821,437	823,052	1,615
Service Year4	4	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	771,302	772,818	1,516
Service Year5	5	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	724,227	725,651	1,424
Service Year6	6	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	680,026	681,362	1,337
Service Year7	7	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	638,522	639,777	1,255
Service Year8	8	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	599,551	600,730	1,179
Service Year9	9	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	562,959	564,065	1,107
Service Year10	10	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	528,600	529,639	1,039
Service Year11	11	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	496,338	497,313	976
Service Year12	12	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	466,045	466,961	916
Service Year13	13	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	437,601	438,461	860
Service Year14	14	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	410,893	411,700	808
Service Year15	15	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	385,815	386,573	758
Service Year16	16	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	362,267	362,980	712
Service Year17	17	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	340,157	340,826	669
Service Year18	18	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	319,396	320,024	628
Service Year19	19	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	299,903	300,492	590
Service Year20	20	$0.00	$0.00	$82,533.70	$994,204.76	$911,671	258,730	282,152	23,423
Service Year21	21	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	264,412	264,932	520
Service Year22	22	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	248,274	248,762	488
Service Year23	23	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	233,121	233,580	458
Service Year24	24	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	218,893	219,324	430
Service Year25	25	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	205,534	205,938	404
Service Year26	26	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	192,989	193,369	379
Service Year27	27	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	181,211	181,567	356
Service Year28	28	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	170,151	170,485	335
Service Year29	29	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	159,766	160,080	314
Service Year30	30	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	150,015	150,310	295
Service Year31	31	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	140,859	141,136	277
Service Year32	32	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	132,262	132,522	260
Service Year33	33	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	124,190	124,434	244
Service Year34	34	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	116,610	116,839	229
Service Year35	35	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	109,493	109,708	215
Service Year36	36	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	102,810	103,013	202
Service Year37	37	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	96,536	96,725	190
Service Year38	38	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	90,644	90,822	178
Service Year39	39	$0.00	$1,950.72	$0.00	$994,204.76	$992,254	85,111	85,279	167
Service Year40	40	$0.00	$0.00	-$397,109.09	$994,204.76	$1,391,314	112,057	80,074	-31,983
						Net Present Value=	12,249,709		
							Total:	14,063,550	1,813,841
						Benefit Cost Ratio		7.75 : 1	

Intersection of Morewood & Fifth Ave

	Year	Construction Cost	O&M cost	Replacement	Benefits ($)	B-C	PV	PV of Benefits	PV of Costs
Construction year	0	$2,854,459.08	$0.00	$0.00	$0.00	-$2,854,459	-2,854,459	0	2,854,459
Service Year1	1	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	760,407	763,319	2,912
Service Year2	2	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	713,998	716,732	2,734
Service Year3	3	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	670,420	672,988	2,567
Service Year4	4	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	629,503	631,913	2,411
Service Year5	5	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	591,082	593,346	2,263
Service Year6	6	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	555,007	557,132	2,125
Service Year7	7	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	521,133	523,129	1,996
Service Year8	8	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	489,327	491,201	1,874
Service Year9	9	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	459,462	461,221	1,759
Service Year10	10	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	431,420	433,072	1,652
Service Year11	11	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	405,089	406,640	1,551
Service Year12	12	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	380,365	381,822	1,457
Service Year13	13	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	357,150	358,518	1,368
Service Year14	14	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	335,352	336,637	1,284
Service Year15	15	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	314,885	316,091	1,206
Service Year16	16	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	295,667	296,799	1,132
Service Year17	17	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	277,621	278,684	1,063
Service Year18	18	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	260,677	261,675	998
Service Year19	19	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	244,767	245,705	937
Service Year20	20	$0.00	$0.00	$131,209.49	$812,935.09	$681,726	193,472	230,709	37,237
Service Year21	21	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	215,801	216,628	826
Service Year22	22	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	202,630	203,406	776
Service Year23	23	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	190,263	190,992	729
Service Year24	24	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	178,651	179,335	684
Service Year25	25	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	167,747	168,390	642
Service Year26	26	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	157,509	158,112	603
Service Year27	27	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	147,896	148,462	566
Service Year28	28	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	138,870	139,401	532
Service Year29	29	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	130,394	130,893	499
Service Year30	30	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	122,436	122,904	469
Service Year31	31	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	114,963	115,403	440
Service Year32	32	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	107,946	108,360	413
Service Year33	33	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	101,358	101,746	388
Service Year34	34	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	95,172	95,536	364
Service Year35	35	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	89,363	89,706	342
Service Year36	36	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	83,909	84,231	321
Service Year37	37	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	78,788	79,090	302
Service Year38	38	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	73,979	74,263	283
Service Year39	39	$0.00	$3,101.19	$0.00	$812,935.09	$809,834	69,464	69,730	266
Service Year40	40	$0.00	$0.00	-$631,311.57	$812,935.09	$1,444,247	116,321	65,474	-50,846
						Net Present Value=	$8,615,807		
							Total:	11,499,395	2,883,588
						Benefit Cost Ratio		3.99 : 1	

Intersection of Murray & Forward

	Year	Construction Cost	O&M cost	Replacement	Benefits ($)	B-C	PV	PV of Benefits	PV of Costs
Construction year	0	$2,145,531.07	$0.00	$0.00	$0.00	-$2,145,531	-2,145,531	0	2,145,531
Service Year1	1	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	1,146,640	1,148,829	2,189
Service Year2	2	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	1,076,657	1,078,712	2,055
Service Year3	3	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	1,010,946	1,012,875	1,930
Service Year4	4	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	949,245	951,057	1,812
Service Year5	5	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	891,310	893,011	1,701
Service Year6	6	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	836,910	838,508	1,598
Service Year7	7	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	785,831	787,331	1,500
Service Year8	8	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	737,870	739,278	1,408
Service Year9	9	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	692,836	694,158	1,322
Service Year10	10	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	650,550	651,792	1,242
Service Year11	11	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	610,845	612,011	1,166
Service Year12	12	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	573,563	574,658	1,095
Service Year13	13	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	538,557	539,585	1,028
Service Year14	14	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	505,687	506,653	965
Service Year15	15	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	474,824	475,730	906
Service Year16	16	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	445,844	446,695	851
Service Year17	17	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	418,633	419,432	799
Service Year18	18	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	393,082	393,833	750
Service Year19	19	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	369,092	369,796	705
Service Year20	20	$0.00	$0.00	$98,622.55	$1,223,502.38	$1,124,880	319,238	347,226	27,989
Service Year21	21	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	325,413	326,034	621
Service Year22	22	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	305,552	306,135	583
Service Year23	23	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	286,903	287,451	548
Service Year24	24	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	269,393	269,907	514
Service Year25	25	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	252,951	253,434	483
Service Year26	26	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	237,513	237,966	453
Service Year27	27	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	223,017	223,442	426
Service Year28	28	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	209,405	209,805	400
Service Year29	29	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	196,625	197,000	375
Service Year30	30	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	184,624	184,977	352
Service Year31	31	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	173,356	173,687	331
Service Year32	32	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	162,776	163,086	311
Service Year33	33	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	152,841	153,133	292
Service Year34	34	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	143,513	143,787	274
Service Year35	35	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	134,754	135,011	257
Service Year36	36	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	126,529	126,771	242
Service Year37	37	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	118,807	119,034	227
Service Year38	38	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	111,556	111,769	213
Service Year39	39	$0.00	$2,330.99	$0.00	$1,223,502.38	$1,221,171	104,747	104,947	200
Service Year40	40	$0.00	$0.00	-$474,520.23	$1,223,502.38	$1,698,023	136,760	98,542	-38,218
						Net Present Value=	$15,139,660		
							Total:	17,307,086	2,167,425
						Benefit Cost Ratio		7.99 : 1	

APPENDIX C

ANALYSIS INPUT DETAIL

This section shows the input report generated by Synchro version 8.0.804.795 software package for each of the three studied intersections.

Intersection of Bigelow & O'Hara Signal Control A.M Peak

Lanes, Volumes, Timings
3: BIGELOW & O'HARA & PARKMAN 12/1/2013

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	9	139	37	208	267	72	42	119	82	6	37	7
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width (ft)	12	12	12	10	10	12	12	13	14	12	15	12
Grade (%)		-4%			-1%			3%			-12%	
Storage Length (ft)	0		0	0		0	0		0	0		0
Storage Lanes	0		0	1		0	0		1	0		0
Taper Length (ft)	25			25			25			25		
Right Turn on Red			Yes			Yes			Yes			Yes
Link Speed (mph)		25			25			25			25	
Link Distance (ft)		279			295			324			241	
Travel Time (s)		7.6			8.0			8.8			6.6	
Confl. Peds. (#/hr)	150		138	138		150	128		54	54		128
Confl. Bikes (#/hr)												
Peak Hour Factor	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)		0										
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)				10%					10%			
Turn Type	Perm	NA		Perm	NA		Perm	NA	Perm	Perm	NA	
Protected Phases		2			6			4			8	
Permitted Phases	2			6			4		4	8		
Detector Phase	2	2		6	6		4	4	4	8	8	
Switch Phase												
Minimum Initial (s)	4.0	4.0		8.0	8.0		8.0	8.0	8.0	4.0	4.0	
Minimum Split (s)	21.0	21.0		28.0	28.0		28.0	28.0	28.0	21.0	21.0	
Total Split (s)	29.0	29.0		29.0	29.0		28.0	28.0	28.0	28.0	28.0	
Total Split (%)	34.1%	34.1%		34.1%	34.1%		32.9%	32.9%	32.9%	32.9%	32.9%	
Maximum Green (s)	24.0	24.0		24.0	24.0		23.0	23.0	23.0	23.0	23.0	
Yellow Time (s)	3.0	3.0		3.0	3.0		3.0	3.0	3.0	3.0	3.0	
All-Red Time (s)	2.0	2.0		2.0	2.0		2.0	2.0	2.0	2.0	2.0	
Lost Time Adjust (s)		0.0		0.0	0.0			0.0	0.0		0.0	
Total Lost Time (s)		5.0		5.0	5.0			5.0	5.0		5.0	
Lead/Lag												
Lead-Lag Optimize?												
Vehicle Extension (s)	3.0	3.0		3.0	3.0		3.0	3.0	3.0	3.0	3.0	
Minimum Gap (s)	3.0	3.0		3.0	3.0		3.0	3.0	3.0	3.0	3.0	
Time Before Reduce (s)	0.0	0.0		0.0	0.0		0.0	0.0	0.0	0.0	0.0	
Time To Reduce (s)	0.0	0.0		0.0	0.0		0.0	0.0	0.0	0.0	0.0	
Recall Mode	Max	Max		Max	Max		Max	Max	Max	Max	Max	
Walk Time (s)	5.0	5.0		5.0	5.0		5.0	5.0	5.0	5.0	5.0	
Flash Dont Walk (s)	11.0	11.0		11.0	11.0		11.0	11.0	11.0	11.0	11.0	
Pedestrian Calls (#/hr)	0	0		0	0		0	0	0	0	0	

Intersection Summary

Area Type: CBD

Cycle Length: 86

Lane Group	ø10
Lane Configurations	
Volume (vph)	
Ideal Flow (vphpl)	
Lane Width (ft)	
Grade (%)	
Storage Length (ft)	
Storage Lanes	
Taper Length (ft)	
Right Turn on Red	
Link Speed (mph)	
Link Distance (ft)	
Travel Time (s)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	10
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	7.0
Minimum Split (s)	28.0
Total Split (s)	28.0
Total Split (%)	33%
Maximum Green (s)	16.0
Yellow Time (s)	10.0
All-Red Time (s)	2.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Vehicle Extension (s)	3.0
Minimum Gap (s)	3.0
Time Before Reduce (s)	0.0
Time To Reduce (s)	0.0
Recall Mode	Max
Walk Time (s)	5.0
Flash Dont Walk (s)	11.0
Pedestrian Calls (#/hr)	0

Intersection Summary

Actuated Cycle Length: 85
Offset: 0 (0%), Referenced to phase 2:EBTL, Start of Green, Master Intersection
Natural Cycle: 85
Control Type: Pretimed

Splits and Phases: 3: BIGELOW & O'HARA & PARKMAN

Intersection of Bigelow & O'Hara Signal Control P.M Peak

Lanes, Volumes, Timings
3: BIGELOW & O'HARA & PARKMAN 12/1/2013

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	19	292	65	124	161	26	55	115	210	60	137	14
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width (ft)	12	12	12	10	10	12	12	13	14	12	15	12
Grade (%)		-4%			-1%			3%			-12%	
Storage Length (ft)	0		0	0		0	0		0	0		0
Storage Lanes	0		0	1		0	0		1	0		0
Taper Length (ft)	25			25			25			25		
Right Turn on Red			Yes			Yes			Yes			Yes
Link Speed (mph)		25			25			25			25	
Link Distance (ft)		279			295			324			241	
Travel Time (s)		7.6			8.0			8.8			6.6	
Confl. Peds. (#/hr)	102		234	234		102	312		53	312		53
Confl. Bikes (#/hr)												
Peak Hour Factor	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)		0										
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)				10%					13%			
Turn Type	Perm	NA		Perm	NA		Perm	NA	Perm	Perm	NA	
Protected Phases		2			6			4			8	
Permitted Phases	2			6			4		4	8		
Detector Phase	2	2		6	6		4	4	4	8	8	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		4.0	4.0	4.0	8.0	8.0	
Minimum Split (s)	21.0	21.0		21.0	21.0		21.0	21.0	21.0	28.0	28.0	
Total Split (s)	34.0	34.0		34.0	34.0		28.0	28.0	28.0	28.0	28.0	
Total Split (%)	37.8%	37.8%		37.8%	37.8%		31.1%	31.1%	31.1%	31.1%	31.1%	
Maximum Green (s)	29.0	29.0		29.0	29.0		23.0	23.0	23.0	23.0	23.0	
Yellow Time (s)	3.0	3.0		3.0	3.0		3.0	3.0	3.0	3.0	3.0	
All-Red Time (s)	2.0	2.0		2.0	2.0		2.0	2.0	2.0	2.0	2.0	
Lost Time Adjust (s)		0.0		0.0	0.0			0.0	0.0		0.0	
Total Lost Time (s)		5.0		5.0	5.0			5.0	5.0		5.0	
Lead/Lag												
Lead-Lag Optimize?												
Vehicle Extension (s)	3.0	3.0		3.0	3.0		3.0	3.0	3.0	3.0	3.0	
Minimum Gap (s)	3.0	3.0		3.0	3.0		3.0	3.0	3.0	3.0	3.0	
Time Before Reduce (s)	0.0	0.0		0.0	0.0		0.0	0.0	0.0	0.0	0.0	
Time To Reduce (s)	0.0	0.0		0.0	0.0		0.0	0.0	0.0	0.0	0.0	
Recall Mode	Max	Max		Max	Max		Max	Max	Max	Max	Max	
Walk Time (s)	5.0	5.0		5.0	5.0		5.0	5.0	5.0	5.0	5.0	
Flash Dont Walk (s)	11.0	11.0		11.0	11.0		11.0	11.0	11.0	11.0	11.0	
Pedestrian Calls (#/hr)	0	0		0	0		0	0	0	0	0	

Intersection Summary

Area Type: CBD

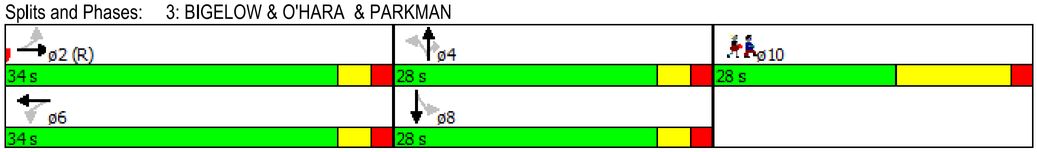
Cycle Length: 90

Lane Group	ø10
Lane Configurations	
Volume (vph)	
Ideal Flow (vphpl)	
Lane Width (ft)	
Grade (%)	
Storage Length (ft)	
Storage Lanes	
Taper Length (ft)	
Right Turn on Red	
Link Speed (mph)	
Link Distance (ft)	
Travel Time (s)	
Confl. Peds. (#/hr)	
Confl. Bikes (#/hr)	
Peak Hour Factor	
Growth Factor	
Heavy Vehicles (%)	
Bus Blockages (#/hr)	
Parking (#/hr)	
Mid-Block Traffic (%)	
Shared Lane Traffic (%)	
Turn Type	
Protected Phases	10
Permitted Phases	
Detector Phase	
Switch Phase	
Minimum Initial (s)	4.0
Minimum Split (s)	28.0
Total Split (s)	28.0
Total Split (%)	31%
Maximum Green (s)	16.0
Yellow Time (s)	10.0
All-Red Time (s)	2.0
Lost Time Adjust (s)	
Total Lost Time (s)	
Lead/Lag	
Lead-Lag Optimize?	
Vehicle Extension (s)	3.0
Minimum Gap (s)	3.0
Time Before Reduce (s)	0.0
Time To Reduce (s)	0.0
Recall Mode	Max
Walk Time (s)	5.0
Flash Dont Walk (s)	11.0
Pedestrian Calls (#/hr)	0

Intersection Summary

Actuated Cycle Length: 90
Offset: 0 (0%), Referenced to phase 2:EBTL, Start of Green
Natural Cycle: 90
Control Type: Pretimed

Splits and Phases: 3: BIGELOW & O'HARA & PARKMAN



Intersection of Bigelow & O’Hara Roundabout A.M Peak

Lanes, Volumes, Timings

3: BIGELOW & O'HARA & PARKMAN (Roundabout AM) 12/1/2013

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	9	139	37	208	267	72	42	119	82	6	37	7
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width (ft)	12	12	12	10	12	12	12	12	14	12	12	12
Grade (%)		-4%			-1%			3%			-12%	
Storage Length (ft)	0		0	0		0	0		0	0		0
Storage Lanes	0		0	0		0	0		0	0		0
Taper Length (ft)	25			25			25			25		
Link Speed (mph)		25			25			25			25	
Link Distance (ft)		279			295			324			241	
Travel Time (s)		7.6			8.0			8.8			6.6	
Confl. Peds. (#/hr)	150		138	138		150	128		54	54		128
Confl. Bikes (#/hr)												
Peak Hour Factor	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Sign Control		Yield			Yield			Yield			Yield	

Intersection Summary	
Area Type:	CBD
Control Type: Roundabout	

Educational Use Only

Intersection of Bigelow & O’Hara Roundabout P.M Peak

Lanes, Volumes, Timings

3: BIGELOW & O'HARA & PARKMAN (Roundabout PM) 12/1/2013

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	19	292	65	124	161	26	55	115	210	60	137	14
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width (ft)	12	12	12	10	12	12	12	12	14	12	12	12
Grade (%)		-4%			-1%			3%			-12%	
Storage Length (ft)	0		0	0		0	0		0	0		0
Storage Lanes	0		0	0		0	0		0	0		0
Taper Length (ft)	25			25			25			25		
Link Speed (mph)		25			25			25			25	
Link Distance (ft)		279			295			324			241	
Travel Time (s)		7.6			8.0			8.8			6.6	
Confl. Peds. (#/hr)	102		234	234		102	312		53	312		53
Confl. Bikes (#/hr)												
Peak Hour Factor	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)		0										
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Sign Control		Yield			Yield			Yield			Yield	

Intersection Summary	
Area Type:	CBD
Control Type: Roundabout	

Educational Use Only

Intersection of Morewood & Fifth Signal Control A.M Peak

Lanes, Volumes, Timings

3: MOREWOOD ST & FIFTH AVE

12/1/2013

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	12	300	41	103	973	139	15	198	135	46	131	15
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width (ft)	11	11	11	11	11	11	10	10	10	10	10	10
Grade (%)		2%			-2%			-2%			4%	
Storage Length (ft)	0		0	0		0	0		0	0		0
Storage Lanes	0		0	0		0	0		1	1		0
Taper Length (ft)	25			25			25			25		
Right Turn on Red			Yes			Yes			No			No
Link Speed (mph)		35			35			25			25	
Link Distance (ft)		501			649			532			438	
Travel Time (s)		9.8			12.6			14.5			11.9	
Confl. Peds. (#/hr)	55		61	61		55	19		39	39		19
Confl. Bikes (#/hr)												
Peak Hour Factor	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	7%	7%	7%	7%	7%	7%	7%	7%	7%	7%	7%	7%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm	NA		pm+pt	NA		Perm	NA	Perm	Perm	NA	
Protected Phases		2		1	6			4			8	
Permitted Phases	2			6	1		4		4	8		
Detector Phase	2	2		1	6		4	4	4	8	8	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		4.0	4.0	4.0	4.0	4.0	
Minimum Split (s)	22.0	22.0		22.0	22.0		22.0	22.0	22.0	22.0	22.0	
Total Split (s)	26.0	26.0		22.0	48.0		22.0	22.0	22.0	22.0	22.0	
Total Split (%)	37.1%	37.1%		31.4%	68.6%		31.4%	31.4%	31.4%	31.4%	31.4%	
Maximum Green (s)	20.0	20.0		17.0	42.0		16.0	16.0	16.0	16.0	16.0	
Yellow Time (s)	4.0	4.0		3.0	4.0		4.0	4.0	4.0	4.0	4.0	
All-Red Time (s)	2.0	2.0		2.0	2.0		2.0	2.0	2.0	2.0	2.0	
Lost Time Adjust (s)		0.0			0.0			0.0	0.0	0.0	0.0	
Total Lost Time (s)		6.0			6.0			6.0	6.0	6.0	6.0	
Lead/Lag	Lag	Lag		Lead								
Lead-Lag Optimize?	Yes	Yes		Yes								
Vehicle Extension (s)	3.0	3.0		3.0	3.0		3.0	3.0	3.0	3.0	3.0	
Minimum Gap (s)	3.0	3.0		3.0	3.0		3.0	3.0	3.0	3.0	3.0	
Time Before Reduce (s)	0.0	0.0		0.0	0.0		0.0	0.0	0.0	0.0	0.0	
Time To Reduce (s)	0.0	0.0		0.0	0.0		0.0	0.0	0.0	0.0	0.0	
Recall Mode	Max	Max		Max	Max		Max	Max	Max	Max	Max	
Walk Time (s)	5.0	5.0		5.0	5.0		5.0	5.0	5.0	5.0	5.0	
Flash Dont Walk (s)	11.0	11.0		11.0	11.0		11.0	11.0	11.0	11.0	11.0	
Pedestrian Calls (#/hr)	0	0		0	0		0	0	0	0	0	

Intersection Summary

Area Type: CBD

Cycle Length: 70

Actuated Cycle Length: 70
Offset: 0 (0%), Referenced to phase 2:EBTL, Start of Green
Natural Cycle: 70
Control Type: Pretimed

Splits and Phases: 3: MOREWOOD ST & FIFTH AVE

Intersection of Morewood & Fifth Signal Control P.M Peak

Lanes, Volumes, Timings
3: MOREWOOD ST & FIFTH AVE 12/1/2013

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	32	719	121	66	524	46	77	232	271	73	231	35
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width (ft)	11	11	11	11	11	11	10	10	10	10	10	10
Grade (%)		2%			-2%			-2%			4%	
Storage Length (ft)	0		0	0		0	0		0	0		0
Storage Lanes	0		0	0		0	0		1	1		0
Taper Length (ft)	25			25			25			25		
Right Turn on Red			Yes			Yes			No			No
Link Speed (mph)		35			35			25			25	
Link Distance (ft)		501			649			532			438	
Travel Time (s)		9.8			12.6			14.5			11.9	
Confl. Peds. (#/hr)	42		74	74		42	100		98	98		100
Confl. Bikes (#/hr)												
Peak Hour Factor	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Turn Type	Perm	NA		pm+pt	NA		Perm	NA	Perm	Perm	NA	
Protected Phases		2		1	6			4			8	
Permitted Phases	2			6	1		4		4	8		
Detector Phase	2	2		1	6		4	4	4	8	8	
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0		4.0	4.0	4.0	4.0	4.0	
Minimum Split (s)	22.0	22.0		9.0	22.0		22.0	22.0	22.0	22.0	22.0	
Total Split (s)	44.0	44.0		9.0	53.0		37.0	37.0	37.0	37.0	37.0	
Total Split (%)	48.9%	48.9%		10.0%	58.9%		41.1%	41.1%	41.1%	41.1%	41.1%	
Maximum Green (s)	38.0	38.0		4.0	47.0		31.0	31.0	31.0	31.0	31.0	
Yellow Time (s)	4.0	4.0		3.0	4.0		4.0	4.0	4.0	4.0	4.0	
All-Red Time (s)	2.0	2.0		2.0	2.0		2.0	2.0	2.0	2.0	2.0	
Lost Time Adjust (s)		0.0			0.0			0.0	0.0	0.0	0.0	
Total Lost Time (s)		6.0			6.0			6.0	6.0	6.0	6.0	
Lead/Lag	Lag	Lag		Lead								
Lead-Lag Optimize?	Yes	Yes		Yes								
Vehicle Extension (s)	3.0	3.0		3.0	3.0		3.0	3.0	3.0	3.0	3.0	
Minimum Gap (s)	3.0	3.0		3.0	3.0		3.0	3.0	3.0	3.0	3.0	
Time Before Reduce (s)	0.0	0.0		0.0	0.0		0.0	0.0	0.0	0.0	0.0	
Time To Reduce (s)	0.0	0.0		0.0	0.0		0.0	0.0	0.0	0.0	0.0	
Recall Mode	Max	Max		Max	Max		Max	Max	Max	Max	Max	
Walk Time (s)	5.0	5.0			5.0		5.0	5.0	5.0	5.0	5.0	
Flash Dont Walk (s)	11.0	11.0			11.0		11.0	11.0	11.0	11.0	11.0	
Pedestrian Calls (#/hr)	0	0			0		0	0	0	0	0	

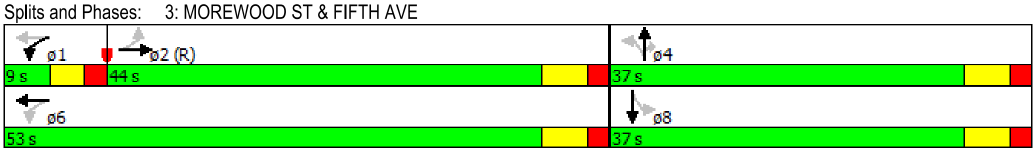
Intersection Summary

Area Type: CBD

Cycle Length: 90

Actuated Cycle Length: 90
Offset: 0 (0%), Referenced to phase 2:EBTL, Start of Green
Natural Cycle: 90
Control Type: Pretimed

Splits and Phases: 3: MOREWOOD ST & FIFTH AVE



Intersection of Morewood & Fifth Roundabout A.M Peak

Lanes, Volumes, Timings
3: MOREWOOD ST & FIFTH AVE(Roundabout AM) 12/1/2013

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	12	300	41	103	973	139	15	198	135	46	131	15
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width (ft)	11	12	11	11	12	11	10	12	10	10	12	10
Grade (%)		2%			-2%			-2%			4%	
Storage Length (ft)	0		0	0		0	0		0	0		0
Storage Lanes	0		0	0		0	0		1	1		0
Taper Length (ft)	25			25			25			25		
Link Speed (mph)		35			35			25			25	
Link Distance (ft)		501			649			532			438	
Travel Time (s)		9.8			12.6			14.5			11.9	
Confl. Peds. (#/hr)	55		61	61		55	19		39	39		19
Confl. Bikes (#/hr)												
Peak Hour Factor	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	7%	7%	7%	7%	7%	7%	7%	7%	7%	7%	7%	7%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Sign Control		Yield			Yield			Yield			Yield	

Intersection Summary	
Area Type:	CBD
Control Type: Roundabout	

Intersection of Morewood & Fifth Roundabout P.M Peak

Lanes, Volumes, Timings
3: MOREWOOD ST & FIFTH AVE(Roundabout PM) 12/1/2013

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (vph)	32	719	121	66	524	46	77	232	271	73	231	35
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width (ft)	11	12	11	11	12	11	10	12	12	12	12	10
Grade (%)		2%			-2%			-2%			4%	
Storage Length (ft)	0		0	0		0	0		0	0		0
Storage Lanes	0		0	0		0	0		1	1		0
Taper Length (ft)	25			25			25			25		
Link Speed (mph)		35			35			25			25	
Link Distance (ft)		501			649			532			438	
Travel Time (s)		9.8			12.6			14.5			11.9	
Confl. Peds. (#/hr)	42		74	74		42	100		98	98		100
Confl. Bikes (#/hr)												
Peak Hour Factor	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%			0%	
Shared Lane Traffic (%)												
Sign Control		Yield			Yield			Yield			Yield	

Intersection Summary	
Area Type:	CBD
Control Type: Roundabout	

Educational Use Only

2 10/7/2013 Baseline

Intersection of Murray & Forward Signal Control A.M Peak

Lanes, Volumes, Timings
3: 12/1/2013

Lane Group	EBL	EBT	EBR	EBR2	WBL2	WBL	WBT	WBR	NBL2	NBL	NBT	NBR
Lane Configurations												
Volume (vph)	27	24	9	91	11	412	70	25	91	29	178	5
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width (ft)	16	10	12	12	12	11	11	12	10	10	10	12
Grade (%)		-4%					-5%				-5%	
Storage Length (ft)	0		0			0		0		0		0
Storage Lanes	0		0			1		0		1		0
Taper Length (ft)	25					25				25		
Right Turn on Red				Yes				Yes				Yes
Link Speed (mph)		25					25				25	
Link Distance (ft)		460					450				605	
Travel Time (s)		12.5					12.3				16.5	
Confl. Peds. (#/hr)	34		10	5	10	5		34	5	2		33
Confl. Bikes (#/hr)												
Peak Hour Factor	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)	0	0					0					
Mid-Block Traffic (%)		0%					0%				0%	
Shared Lane Traffic (%)						40%				10%		
Turn Type	Perm	NA			pm+pt	pm+pt	NA		Perm	Perm	NA	
Protected Phases		4			3	3	8				2	
Permitted Phases	4				8	8			2	2		
Detector Phase	4	4			3	3	8		2	2	2	
Switch Phase												
Minimum Initial (s)	4.0	4.0			4.0	4.0	4.0		4.0	4.0	4.0	
Minimum Split (s)	21.0	21.0			8.0	8.0	21.0		22.0	22.0	22.0	
Total Split (s)	21.0	21.0			20.0	20.0	41.0		27.0	27.0	27.0	
Total Split (%)	23.3%	23.3%			22.2%	22.2%	45.6%		30.0%	30.0%	30.0%	
Maximum Green (s)	16.0	16.0			16.0	16.0	36.0		21.0	21.0	21.0	
Yellow Time (s)	3.0	3.0			3.5	3.5	3.0		4.0	4.0	4.0	
All-Red Time (s)	2.0	2.0			0.5	0.5	2.0		2.0	2.0	2.0	
Lost Time Adjust (s)		0.0				0.0	0.0			0.0	0.0	
Total Lost Time (s)		5.0				4.0	5.0			6.0	6.0	
Lead/Lag	Lag	Lag			Lead	Lead						
Lead-Lag Optimize?					Yes	Yes						
Vehicle Extension (s)	3.0	3.0			3.0	3.0	3.0		3.0	3.0	3.0	
Minimum Gap (s)	3.0	3.0			3.0	3.0	3.0		3.0	3.0	3.0	
Time Before Reduce (s)	0.0	0.0			0.0	0.0	0.0		0.0	0.0	0.0	
Time To Reduce (s)	0.0	0.0			0.0	0.0	0.0		0.0	0.0	0.0	
Recall Mode	Max	Max			Max	Max	Max		Max	Max	Max	
Walk Time (s)	5.0	5.0					5.0		5.0	5.0	5.0	
Flash Dont Walk (s)	11.0	11.0					11.0		11.0	11.0	11.0	
Pedestrian Calls (#/hr)	0	0					0		0	0	0	

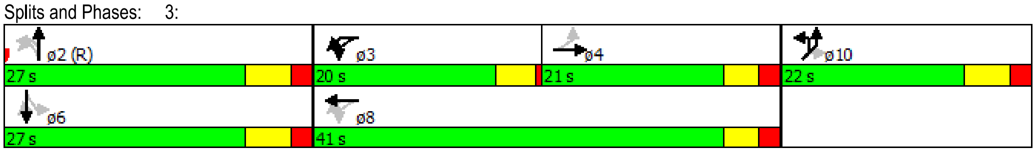
Intersection Summary	
Area Type:	CBD
Cycle Length: 90	

Lane Group	SBL	SBT	SBR	SBR2	NEL2	NEL	NER	NER2
Lane Configurations								
Volume (vph)	11	75	475	8	27	203	144	9
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width (ft)	12	10	10	12	12	10	10	12
Grade (%)		-5%				4%		
Storage Length (ft)	0		0			0	0	
Storage Lanes	0		1			1	1	
Taper Length (ft)	25					25		
Right Turn on Red				Yes				Yes
Link Speed (mph)		25				25		
Link Distance (ft)		343				578		
Travel Time (s)		9.4				15.8		
Confl. Peds. (#/hr)	33		5	2	2	34	33	10
Confl. Bikes (#/hr)								
Peak Hour Factor	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	4%	4%	4%	4%	4%	4%	4%	4%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0
Parking (#/hr)							0	
Mid-Block Traffic (%)		0%				0%		
Shared Lane Traffic (%)			43%				10%	
Turn Type	Perm	NA	Perm		Split	NA	Perm	
Protected Phases		6			10	10		
Permitted Phases	6		6				10	
Detector Phase	6	6	6		10	10	10	
Switch Phase								
Minimum Initial (s)	4.0	4.0	4.0		4.0	4.0	4.0	
Minimum Split (s)	22.0	22.0	22.0		22.0	22.0	22.0	
Total Split (s)	27.0	27.0	27.0		22.0	22.0	22.0	
Total Split (%)	30.0%	30.0%	30.0%		24.4%	24.4%	24.4%	
Maximum Green (s)	21.0	21.0	21.0		16.0	16.0	16.0	
Yellow Time (s)	4.0	4.0	4.0		4.0	4.0	4.0	
All-Red Time (s)	2.0	2.0	2.0		2.0	2.0	2.0	
Lost Time Adjust (s)		0.0	0.0			0.0	0.0	
Total Lost Time (s)		6.0	6.0			6.0	6.0	
Lead/Lag								
Lead-Lag Optimize?								
Vehicle Extension (s)	3.0	3.0	3.0		3.0	3.0	3.0	
Minimum Gap (s)	3.0	3.0	3.0		3.0	3.0	3.0	
Time Before Reduce (s)	0.0	0.0	0.0		0.0	0.0	0.0	
Time To Reduce (s)	0.0	0.0	0.0		0.0	0.0	0.0	
Recall Mode	Max	Max	Max		Max	Max	Max	
Walk Time (s)	5.0	5.0	5.0		5.0	5.0	5.0	
Flash Dont Walk (s)	11.0	11.0	11.0		11.0	11.0	11.0	
Pedestrian Calls (#/hr)	0	0	0		0	0	0	

Intersection Summary

Actuated Cycle Length: 90	
Offset: 0 (0%), Referenced to phase 2:NBTL, Start of Green	
Natural Cycle: 90	
Control Type: Pretimed	

Splits and Phases: 3:



Intersection of Murray & Forward Signal Control P.M Peak

Lanes, Volumes, Timings

3: 12/1/2013

Lane Group	EBL	EBT	EBR	EBR2	WBL2	WBL	WBT	WBR	NBL2	NBL	NBT	NBR
Lane Configurations												
Volume (vph)	95	156	4	101	30	197	42	38	22	38	172	31
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width (ft)	16	10	12	12	12	11	11	12	10	10	10	12
Grade (%)		-4%					-5%				0%	
Storage Length (ft)	0		0			0		0		0		0
Storage Lanes	0		0			1		0		1		0
Taper Length (ft)	25					25				25		
Right Turn on Red				Yes				Yes				Yes
Link Speed (mph)		25					25				25	
Link Distance (ft)		460					450				605	
Travel Time (s)		12.5					12.3				16.5	
Confl. Peds. (#/hr)	42		5	2	5	2		42	2	10		76
Confl. Bikes (#/hr)												
Peak Hour Factor	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)		0					0					
Mid-Block Traffic (%)		0%					0%				0%	
Shared Lane Traffic (%)						39%				10%		
Turn Type	Perm	NA			pm+pt	pm+pt	NA		Perm	Perm	NA	
Protected Phases		4			3	3	8				2	
Permitted Phases	4				8	8			2	2		
Detector Phase	4	4			3	3	8		2	2	2	
Switch Phase												
Minimum Initial (s)	4.0	4.0			4.0	4.0	4.0		4.0	4.0	4.0	
Minimum Split (s)	21.0	21.0			9.0	9.0	21.0		22.0	22.0	22.0	
Total Split (s)	36.0	36.0			9.0	9.0	45.0		33.0	33.0	33.0	
Total Split (%)	36.0%	36.0%			9.0%	9.0%	45.0%		33.0%	33.0%	33.0%	
Maximum Green (s)	31.0	31.0			4.0	4.0	40.0		27.0	27.0	27.0	
Yellow Time (s)	3.0	3.0			3.0	3.0	3.0		4.0	4.0	4.0	
All-Red Time (s)	2.0	2.0			2.0	2.0	2.0		2.0	2.0	2.0	
Lost Time Adjust (s)		0.0				0.0	0.0			0.0	0.0	
Total Lost Time (s)		5.0				5.0	5.0			6.0	6.0	
Lead/Lag	Lag	Lag			Lead	Lead						
Lead-Lag Optimize?	Yes	Yes			Yes	Yes						
Vehicle Extension (s)	3.0	3.0			3.0	3.0	3.0		3.0	3.0	3.0	
Minimum Gap (s)	3.0	3.0			3.0	3.0	3.0		3.0	3.0	3.0	
Time Before Reduce (s)	0.0	0.0			0.0	0.0	0.0		0.0	0.0	0.0	
Time To Reduce (s)	0.0	0.0			0.0	0.0	0.0		0.0	0.0	0.0	
Recall Mode	Max	Max			Max	Max	Max		Max	Max	Max	
Walk Time (s)	5.0	5.0					5.0		5.0	5.0	5.0	
Flash Dont Walk (s)	11.0	11.0					11.0		11.0	11.0	11.0	
Pedestrian Calls (#/hr)	0	0					0		0	0	0	

Intersection Summary

Area Type: CBD

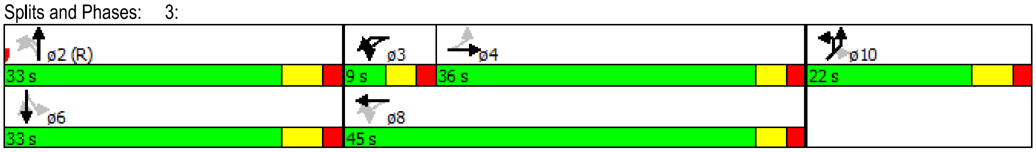
Cycle Length: 100

Lane Group	SBL	SBT	SBR	SBR2	NEL2	NEL	NER	NER2
Lane Configurations								
Volume (vph)	51	237	196	8	34	126	177	8
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width (ft)	12	10	10	12	12	10	10	12
Grade (%)		-5%				4%		
Storage Length (ft)	0		0			0	0	
Storage Lanes	0		1			1	1	
Taper Length (ft)	25					25		
Right Turn on Red				Yes				Yes
Link Speed (mph)		25				25		
Link Distance (ft)		343				578		
Travel Time (s)		9.4				15.8		
Confl. Peds. (#/hr)	76		2	10	10	42	76	5
Confl. Bikes (#/hr)								
Peak Hour Factor	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	3%	3%	3%	3%	3%	3%	3%	3%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0
Parking (#/hr)							0	
Mid-Block Traffic (%)		0%				0%		
Shared Lane Traffic (%)			10%				12%	
Turn Type	Perm	NA	Perm		Split	NA	Perm	
Protected Phases		6			10	10		
Permitted Phases	6		6				10	
Detector Phase	6	6	6		10	10	10	
Switch Phase								
Minimum Initial (s)	4.0	4.0	4.0		4.0	4.0	4.0	
Minimum Split (s)	22.0	22.0	22.0		22.0	22.0	22.0	
Total Split (s)	33.0	33.0	33.0		22.0	22.0	22.0	
Total Split (%)	33.0%	33.0%	33.0%		22.0%	22.0%	22.0%	
Maximum Green (s)	27.0	27.0	27.0		16.0	16.0	16.0	
Yellow Time (s)	4.0	4.0	4.0		4.0	4.0	4.0	
All-Red Time (s)	2.0	2.0	2.0		2.0	2.0	2.0	
Lost Time Adjust (s)		0.0	0.0			0.0	0.0	
Total Lost Time (s)		6.0	6.0			6.0	6.0	
Lead/Lag								
Lead-Lag Optimize?								
Vehicle Extension (s)	3.0	3.0	3.0		3.0	3.0	3.0	
Minimum Gap (s)	3.0	3.0	3.0		3.0	3.0	3.0	
Time Before Reduce (s)	0.0	0.0	0.0		0.0	0.0	0.0	
Time To Reduce (s)	0.0	0.0	0.0		0.0	0.0	0.0	
Recall Mode	Max	Max	Max		Max	Max	Max	
Walk Time (s)	5.0	5.0	5.0		5.0	5.0	5.0	
Flash Dont Walk (s)	11.0	11.0	11.0		11.0	11.0	11.0	
Pedestrian Calls (#/hr)	0	0	0		0	0	0	

Intersection Summary

Actuated Cycle Length: 100
Offset: 0 (0%), Referenced to phase 2:NBTL, Start of Green
Natural Cycle: 100
Control Type: Pretimed

Splits and Phases: 3:



Intersection of Murray & Forward Roundabout A.M Peak

Lanes, Volumes, Timings
3: 12/1/2013

Lane Group	EBL	EBT	EBR	EBR2	WBL2	WBL	WBT	WBR	NBL2	NBL	NBT	NBR
Lane Configurations												
Volume (vph)	27	24	9	91	11	412	70	25	91	29	178	5
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width (ft)	16	12	12	12	12	12	12	12	10	12	12	12
Grade (%)		-4%					-5%				-5%	
Storage Length (ft)	0		0			0		0		0		0
Storage Lanes	0		0			1		0		1		0
Taper Length (ft)	25					25				25		
Link Speed (mph)		25					25				25	
Link Distance (ft)		460					450				605	
Travel Time (s)		12.5					12.3				16.5	
Confl. Peds. (#/hr)	34		10	5	10	5		34	5	2		33
Confl. Bikes (#/hr)												
Peak Hour Factor	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%					0%				0%	
Shared Lane Traffic (%)						40%				10%		
Sign Control		Yield					Yield				Yield	

Intersection Summary

Area Type: CBD

Control Type: Roundabout

Educational Use Only

Lane Group	SBL	SBT	SBR	SBR2	NEL2	NEL	NER	NER2
Lane Configurations								
Volume (vph)	11	75	475	8	27	203	144	9
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width (ft)	12	12	12	12	12	12	12	12
Grade (%)		-5%				4%		
Storage Length (ft)	0		0			0	0	
Storage Lanes	0		1			1	1	
Taper Length (ft)	25					25		
Link Speed (mph)		25				25		
Link Distance (ft)		343				578		
Travel Time (s)		9.4				15.8		
Confl. Peds. (#/hr)	33		5	2	2	34	33	10
Confl. Bikes (#/hr)								
Peak Hour Factor	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	4%	4%	4%	4%	4%	4%	4%	4%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0
Parking (#/hr)								
Mid-Block Traffic (%)		0%				0%		
Shared Lane Traffic (%)			43%				10%	
Sign Control		Yield				Yield		

Intersection Summary

Intersection of Murray & Forward Roundabout P.M Peak

Lanes, Volumes, Timings
3: 12/1/2013

Lane Group	EBL	EBT	EBR	EBR2	WBL2	WBL	WBT	WBR	NBL2	NBL	NBT	NBR
Lane Configurations												
Volume (vph)	95	156	4	101	30	197	42	38	22	38	172	31
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width (ft)	16	12	12	12	12	12	12	12	10	12	12	12
Grade (%)		-4%					-5%				0%	
Storage Length (ft)	0		0			0		0		0		0
Storage Lanes	0		0			1		0		1		0
Taper Length (ft)	25					25				25		
Link Speed (mph)		25					25				25	
Link Distance (ft)		460					450				605	
Travel Time (s)		12.5					12.3				16.5	
Confl. Peds. (#/hr)	42		5	2	5	2		42	2	10		76
Confl. Bikes (#/hr)												
Peak Hour Factor	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%					0%				0%	
Shared Lane Traffic (%)						37%				10%		
Sign Control		Yield					Yield				Yield	

Intersection Summary	
Area Type:	CBD
Control Type: Roundabout	

Educational Use Only

Lane Group	SBL	SBT	SBR	SBR2	NEL2	NEL	NER	NER2
Lane Configurations								
Volume (vph)	51	237	196	8	34	126	177	8
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width (ft)	12	12	12	12	12	12	12	12
Grade (%)		-5%				4%		
Storage Length (ft)	0		0			0	0	
Storage Lanes	0		1			1	1	
Taper Length (ft)	25					25		
Link Speed (mph)		25				25		
Link Distance (ft)		343				578		
Travel Time (s)		9.4				15.8		
Confl. Peds. (#/hr)	76		2	10	10	42	76	5
Confl. Bikes (#/hr)								
Peak Hour Factor	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	3%	3%	3%	3%	3%	3%	3%	3%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0
Parking (#/hr)							0	
Mid-Block Traffic (%)		0%				0%		
Shared Lane Traffic (%)			10%				12%	
Sign Control		Yield				Yield		

Intersection Summary

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