CUY-90-9.09 SAFETY STUDY

INTERSTATE 90 AT WARREN ROAD (CR 66)

INTERSTATE 90 AT W. 140TH STREET (CR 232)

ODOT DISTRICT 12
PID # 103796/105414
JUNE 30, 2018

PREPARED FOR:

OHIO DEPARTMENT OF TRANSPORTATION
DISTRICT 12
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INTRODUCTION

The purpose of this study is to evaluate the existing safety performance and to identify potential countermeasures to reduce crashes at two interchanges on I-90 west of downtown Cleveland in Cuyahoga, County. **Figure 1** is an aerial photo of the study area.

- Warren Road (CR 66) – SLM 9.09.
- W. 140th Street (CR 232/ Bunts Road – SLM 9.48

ODOT uses AASHTOWare's Safety Analyst software to prioritize safety locations across Ohio. The software system prioritizes locations that have higher-than-predicted crash frequencies and crash severity. A CAM tool consisting of 156 crashes (2014-2016) was furnished by ODOT District 12 to evaluate the crash patterns that resulted in a statewide ranking of #335 for an Urban Freeway (SLM 9.05-9.15). This segment of I-90 has appeared on the ODOT Highway Safety Improvement Plan (HSIP) regularly fluctuating between #160 and #300 on alternate years. The expectation is that the study area will increase in the ranking in the #160 - #170 range.

Year 2012: #293

Year 2013: #161

Year 2014: #300

Year 2015: #166

Year 2016: #335

The following crash types and condition are over-represented on the study corridor compared to statewide averages (shown in parenthesis). Note the statewide crash averages and the project data encompasses 2010 to 2014 for roadways on the non-state system (i.e., not numbered state routes nor interstates).

- Fatal crashes: 1 fatal crash or 0.6% (0.3 percent)
- Injury crashes: 55 crashes or 28.9 percent (26.1 percent)
- Angle crashes: 53 crashes or 34.0 percent (17.6 percent)
- Rear end crashes: 45 crashes or 28.8 percent (20.7 percent)
- Sideswipe passing crashes: 30 crashes or 19.2 percent (6.9 percent)
- Left Turn crashes: 5 crashes or 3.2 percent (3.9 percent)

The safety analysis contained in this current study is based on crash data from 2014 through 2016. The 2014-2016 crash data shows that the total number of crashes (228 crashes) is comparable to historical crash data. Two safety studies have been completed at the Airport Highway (State Route 2) and Byrne Road intersection since 2012.

No studies have been completed at this location since 2012.

FIGURE 1: STUDY AREA

EXISTING CONDITIONS

General Conditions

Lakewood Heights Boulevard (north side property line) is the boundary between the City of Lakewood (north) and the City of Cleveland (south). Warren Road is functionally classified as an Urban Minor Arterial. Warren Road is a north-south roadway that connects State Route 2 in the City of Lakewood to I-71 and to I-480 in the City of Cleveland. Warren Road is a 5/6 lane section at the I-90 interchange. Warren Road transitions to a 4-lane section south and to a 2/3 lane section north of the study area. Warren Road in the City of Cleveland was resurfaced in 2017.

W. 140 Street, Lakewood Heights Boulevard, and the S. Marginal Drive are functionally classified as Urban Major Collector roadways. W. 140th Street changes name to Bunts Road in the City of Lakewood. The W. 140th Street interchange is a partial interchange that is connected via the S. Marginal Drive (eastbound traffic) and Lakewood Heights Boulevard (westbound traffic) Two-way traffic is accommodated on Lakewood Heights Boulevard from Brown Road to points east of the study area.

Lakewood Heights Boulevard and S. Marginal Drive are one-way, 3-lane roadways within the study area.

Existing roadway conditions are summarized in **Table 1** and shown graphically in **Figure 1**.

TABLE 1: VOLUMES AND POSTED SPEEDS

Street	Posted Speed	AADT	Truck %
Warren Road (south)	25 MPH	18,465 (2016)	--%
W. 140th Street (south)	35 MPH	17,455 (2016)	--%
Lakewood Heights Blvd (east of Warren Rd)	35 MPH	12,781 (2016)	--%
S. Marginal Drive (east of Warren Rd)	35 MPH	12,063 (2016)	2%
I-90 (west of Warren Rd)	60 MPH	92,638 (2016)	5%

A speed limit transition on W. 140th Street occurs at the Lakewood Heights Boulevard intersection. Bunts Road is posted as 25 MPH.

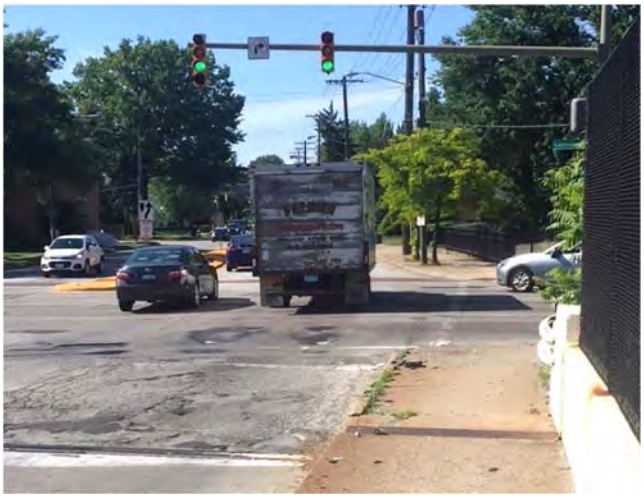
The Greater Cleveland Regional Transit Authority (GCRTA) operates a bus line (Route 83) on Warren Road that connects Cuyahoga Community College (Western Campus) in Parma and the Lakewood Park. Destinations served by this route include Southland Shopping Center, John Marshall High School, and Warren Village Shopping Center. A park and ride facility exists near the W. 140th Street interchange (Triskett Station).

Traffic Signal Operations (Warren Road at Lakewood Heights Blvd). The Warren Road and Lakewood Heights Boulevard intersection is signalized. The following operations were confirmed as part of the field observations:

- Right turns on red are permitted on all approaches. The sight distance of westbound right turning vehicles is restricted due to vandal fencing on the bridge over I-90 and vegetation The sight line shown in **Photo 1A** requires vehicles to block the pedestrian crossing in order to maximum intersection sight distance. Photo 1B shows the visibility of side street traffic from NB Warren Road.
- A pedestrian crosswalk is painted on the south leg of the intersection. The crosswalk does not have pedestrian signal heads which are needed to provide positive guidance for pedestrians on the SW quadrant of the intersection – signal heads are not provided since Lakewood Heights Blvd is a one-way street.
- The northbound approach has a lagging left turn phase from a shared left-through lane (L-TH).
- Pedestrian phases are recalled although pedestrian buttons exist for all crossings. The pedestrian crossing signs are illegible.
- The lane configuration on the westbound approach is L-T, T, T-R. Three (3) signal heads are provided for the multi-lane approach. Overhead lane use signs with sign lighting is located 180 feet from the stop line. Vegetation blocks visibility of the signs.

PHOTO 1A: WB LAKEWOOD HEIGHTS BLVD AT WARREN RD – SIGHT DISTANCE

PHOTO 1B: NB WARREN ROAD AT LAKEWOOD HEIGHTS BLVD – SIGHT DISTANCE



A signal retiming project is currently being sponsored by NOACA for traffic signals on Warren Road.

Traffic Signal Operations (Warren Road at S. Marginal Drive). The Warren Road and S. Marginal Road intersection is signalized. The following operations were confirmed as part of the field observations:

- The southbound approach has a lagging left turn phase from a shared lane. Unlike the Warren Road/Lakewood Heights Blvd intersection, the lagging left turn phase is one an approach permitting dual left turn lanes (L, L-TH, TH). A permissive left turn movement operates as a dual left turn movement.
- **Right turns on red is prohibited on the eastbound approach**. The sight distance of eastbound right turning vehicles is restricted due to vandal fencing on the bridge over I-90 and vegetation The sight line shown in **Photo 2A** requires vehicles to block the pedestrian crossing in order to maximum intersection sight distance.
- The lane configuration on the eastbound approach is L-T, T, T-R. **Only (2) signal heads are provided for the multi-lane approach**. Overhead lane use signs with sign lighting is located 330 feet from the stop line. Overhead lane use signs with sign lighting is located 180 feet from the stop line.
- The pedestrian crossing on the south leg of the intersection is setback 30 feet from the intersection. The visibility of pedestrians in the crosswalk by eastbound right turning traffic is reduced since pedestrians are setback from the intersection. **Photo 2B** also shows NB right turning vehicles (red circle) blocking the crosswalk during the red phase (right turn on red).
- Vegetation blocks visibility of destination signs on the eastbound approach (220 ft in advance of stop line). Vegetation also blocks visibility of the overhead guide sign for the EB I-90 entrance ramp downstream of the intersection.

PHOTO 2A: EB MARGINAL DRIVE AT WARREN ROAD – SIGHT DISTANCE

PHOTO 2B: EB MARGINAL DRIVE AT WARREN ROAD – PED CROSSING

A signal retiming project is currently being sponsored by NOACA for traffic signals on Warren Road.

Traffic Signal Operations (W. 140th Street at WB I-90 Exit Ramp). The W. 140th Street and WB I-90 Exit Ramp intersection is signalized. The partial interchange does not provide for a direct route to re-enter I-90 in the westbound direction. The following operations were confirmed as part of the field observations:

- Concrete barrier is installed along the west curb of W. 140th Street. The concrete barrier is located on the opposite side of the WB I-90 exit ramp. A large arrow sign (W1-7-48) with reflectorized posts exists at the end of the exit ramp (behind the concrete barrier).
- The SB W. 140th Street stop line is setback 35 feet from the end of the concrete median between the Lakewood Heights Blvd and the WB I-90 Exit Ramp intersections.
- Destination signs on the westbound approach is located 450 feet in advance of stop line. Ground mounted lane use signs (dual) are located 200 feet in advance of the stop line. Vegetation also blocks visibility of the overhead guide sign for the EB I-90 entrance ramp downstream of the intersection.
- No wayfinding signs exist for re-entry to WB I-90.
- Northbound queues extended from the Lakewood Heights Blvd intersection through the WB I-90 Exit Ramp intersection during the PM peak period. Vehicles destine to the NB left turn lane were restricted by the concrete median on W. 140th Street.
- A lane imbalance occurs on the northbound approach due to the percentage of vehicles destine to Bunts Road (north). The curb lane through the interchange area becomes an exclusive right turn lane at Lakewood Heights Boulevard and W. 140th Street/ Bunts Road.

FIGURE 2: W. 140TH STREET AT WB I-90 EXIT RAMP INTERSECTION

Traffic Signal Operations (W. 140th Street at S. Marginal Drive). The W. 140th Street and S. Marginal Drive intersection is signalized. The following operations were confirmed as part of the field observations:

- The southbound left turn phase is lagging phase.
- Eastbound left turning vehicles conflict with NB left turning vehicles on the W. 140th Street approach. The turning radius for the dual left turn movement from the S. Marginal Drive approach is about 15 feet if a vehicle is positioned at the stop line on W. 140th Street. The receiving lanes on W. 140th Street are 11.5 feet measured to the face of curb resulting in an effective width of 10.5 feet each.
- The offsets during the PM peak period at Lakewood Heights Blvd and at the WB I-90 Exit Ramp were within 3 seconds. Signal indications of the 2 closely spaced intersections 225 feet were different at the critical period of the phase – onset of yellow clearance interval.
- The eastbound approach has an exclusive left turn lane (L, L-TH-R) that differs from other intersections on the S. Marginal Road and on Lakewood Heights Boulevard corridors. The left most curb lane is a shared lane at the previous 2 signalized intersections on S. Marginal Road. The eastbound S. Marginal Drive approach at W. 140th Street does not have overhead lane use signs to communicate this change of lane use. One ground mounted lane use sign exists 350 feet in advance of the intersection on the right side of the roadway. See **Photo 3**.

PHOTO 3: EB S. MARGINAL DRIVE APPROACH TO W. 140TH STREET

DATA COLLECTION

Manual turning movement counts (TMC) at the Warren Road intersections were provided by NOACA. Traffic data was collected on May 17 and 19, 2018. The raw data suggests the AM peak period (7:00 – 8:00 AM) may be truncated – 15 minutes volumes do not exhibit a typical bell curve which is representative of the begin and end of a peak period. The 2018 traffic data for the 1-hour peak periods are summarized in **Appendix A in addition to** .

CRASH ANALYSIS

Crash data was furnished by ODOT District 12 for the study area. The OH-1 crash report for each documented crash of 3-year period between 2014 and 2016 was reviewed to confirm accuracy and to locate crashes properly within the study limits. The crash data was focus at two interchanges on I-90 west of downtown Cleveland in Cuyahoga, County:

- Warren Road (CR 66) – SLM 9.09.
- W. 140th Street (CR 232/ Bunts Road – SLM 9.48

A total of 156 crashes within the study area resulted in a statewide ranking of #335 for an Urban Freeway (SLM 9.05-9.15) at the Warren Road interchange. This segment of I-90 has appeared on the ODOT Highway Safety Improvement Plan (HSIP) regularly fluctuating between #160 and #300 on alternate years. The expectation is that the study area will increase in the ranking in the #160 - #170 range.

Year 2012: #293

Year 2013: #161

Year 2014: #300

Year 2015: #166

Year 2016: #335

The following crash types and condition are over-represented on the study corridor compared to statewide averages (shown in parenthesis). Note the statewide crash averages and the project data encompasses 2010 to 2014 data for roadways on the non-state system – roadways that are not numbered state routes and are not interstates. While the priority ranking using AASHTOWare's Safety Analyst software identified crashes between SLM 9.05 and 9.15, the majority of crashes were coded to Warren Road and to W. 140th Street.

- Fatal crashes: 1 fatal crash or 0.6% (0.3 percent)
- Injury crashes: 55 crashes or 28.9 percent (26.1 percent)
- Angle crashes: 53 crashes or 34.0 percent (17.6 percent)
- Rear end crashes: 45 crashes or 28.8 percent (20.7 percent)
- Sideswipe passing crashes: 30 crashes or 19.2 percent (6.9 percent)
- Left Turn crashes: 5 crashes or 3.2 percent (3.9 percent)

The fatal crash occurred on westbound I-90 approximately 500 feet west of the Agler Road overpass. An Ohio Highway Patrol officer was conducting enforcement on I-90 from the inside shoulder adjacent to the concrete barrier. A vehicle swerved onto the inside shoulder to avoid slowing traffic and struck the patrol office who was outside his vehicle. The crash was coded as a pedestrian fatality on I-90. Crash patterns of the current safety study are not related to the fatality west of the study area.

Figures 3A and 3B show crash diagrams of the Warren Road and of W. 140th Street corridors. Appendix B contains the crash diagrams for the entire study area as well as the crash statistics in tabular format.

FIGURE 3A: CRASH DIAGRAM OF WARREN ROAD

LEGEND

TYPES OF CRASHES	SYMBOLS
Rear End	Moving Vehicle
Right Angle	Stopped Vehicle
Side Swipe	Bicycle
Left Turn	Pedestrian
Head On	Vehicle at Fault
Fixed Object	

ROAD CONDITION		WEATHER CONDITION	
X	Not Stated	X	Not Stated
D	Dry	C	Clear
W	Wet	R	Rain
S	Snow	S	Snow
I	Ice	F	Fog
M	Mud/Sand	L	Cloudy

SEVERITY
PDO - Property Damage Only
INJ - Injury
FAT - Fatal

CRASH DIAGRAM

LOG POINT 8.86 AND 9.15

PERIOD 3 Years FROM 2014 TO 2016

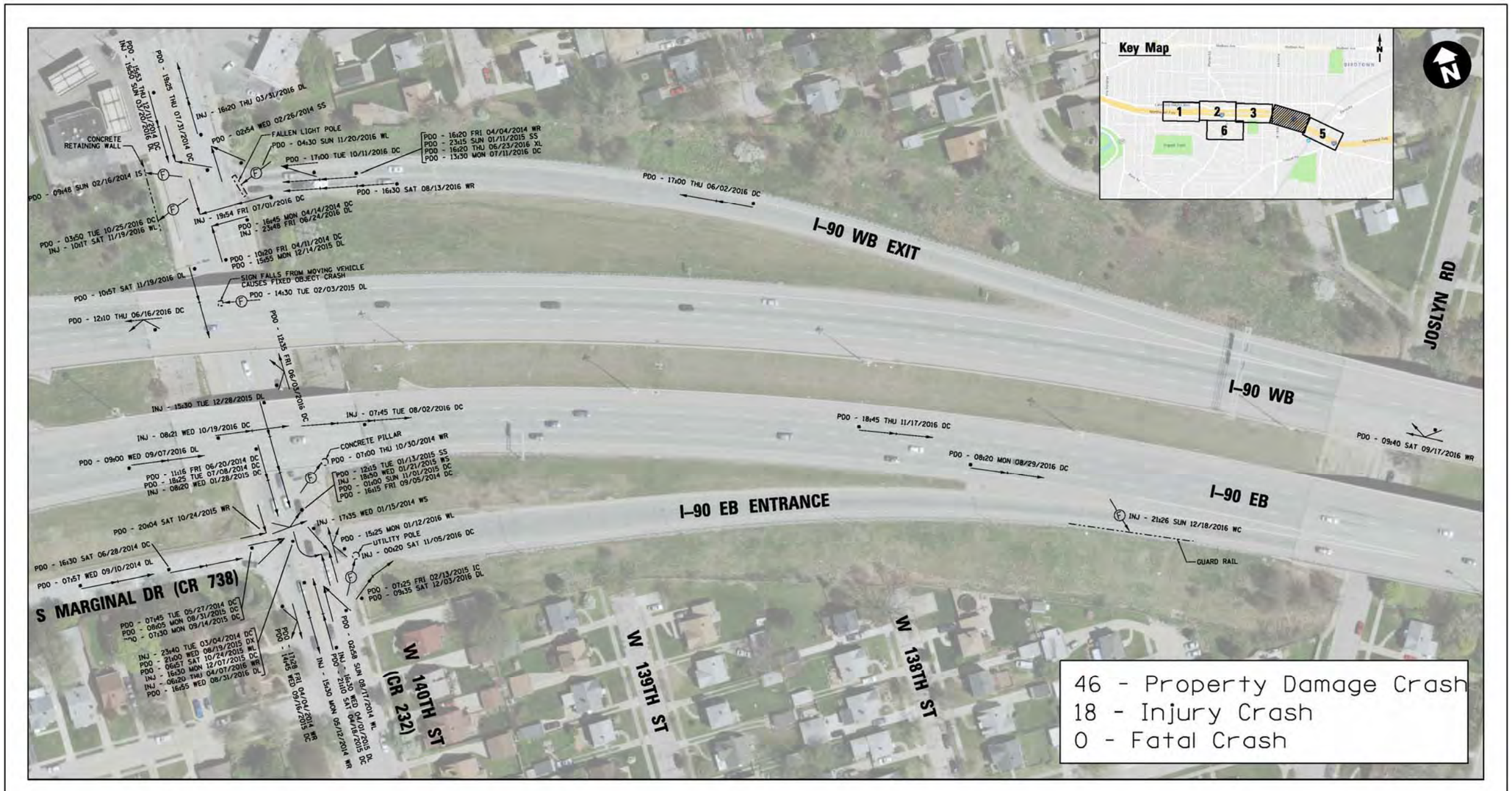
JURISDICTION City of Cleveland

ROUTE NAME / NUMBER Interstate 90

CMT
Crawford, Murphy & Tilly | Engineers & Consultants
8101 North High Street, Suite 150 | Columbus, OH | 43235

DATE: June 5, 2018 PAGE: 2 of 6

FIGURE 3B: CRASH DIAGRAM OF W. 140TH STREET



LEGEND

TYPES OF CRASHES	SYMBOLS
Rear End	Moving Vehicle
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ROAD CONDITION	
X	Not Stated
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W	Wet
S	Snow
I	Ice
M	Mud/Sand

WEATHER CONDITION	
X	Not Stated
C	Clear
R	Rain
S	Snow
F	Fog
L	Cloudy

SEVERITY
PDO - Property Damage Only
INJ - Injury
FAT - Fatal

CRASH DIAGRAM

LOG POINT 9.44 AND 9.74

PERIOD 3 Years FROM 2014 TO 2016

JURISDICTION City of Cleveland

ROUTE NAME / NUMBER Interstate 90

CMT
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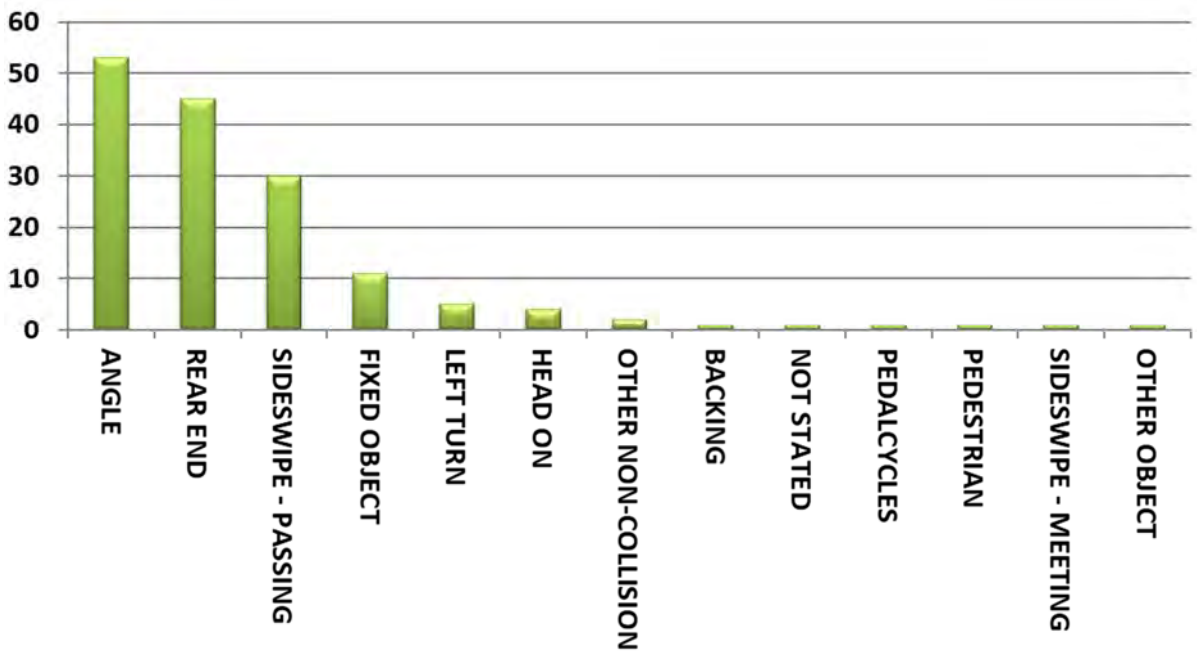
Figure 4 shows the frequency of crashes by type. Angle crashes are over represented by a factor of 2 whereas sideswipe passing crashes are over represented by a factor of 3.

FIGURE 4: FREQUENCY OF CRASHES BY TYPE



Intersection and intersection-related crashes represent 80% of all crashes. The statewide crash average for similar locations on the non-state system is 39.2%. The focus of the safety analysis is the signalized intersections within the study area.

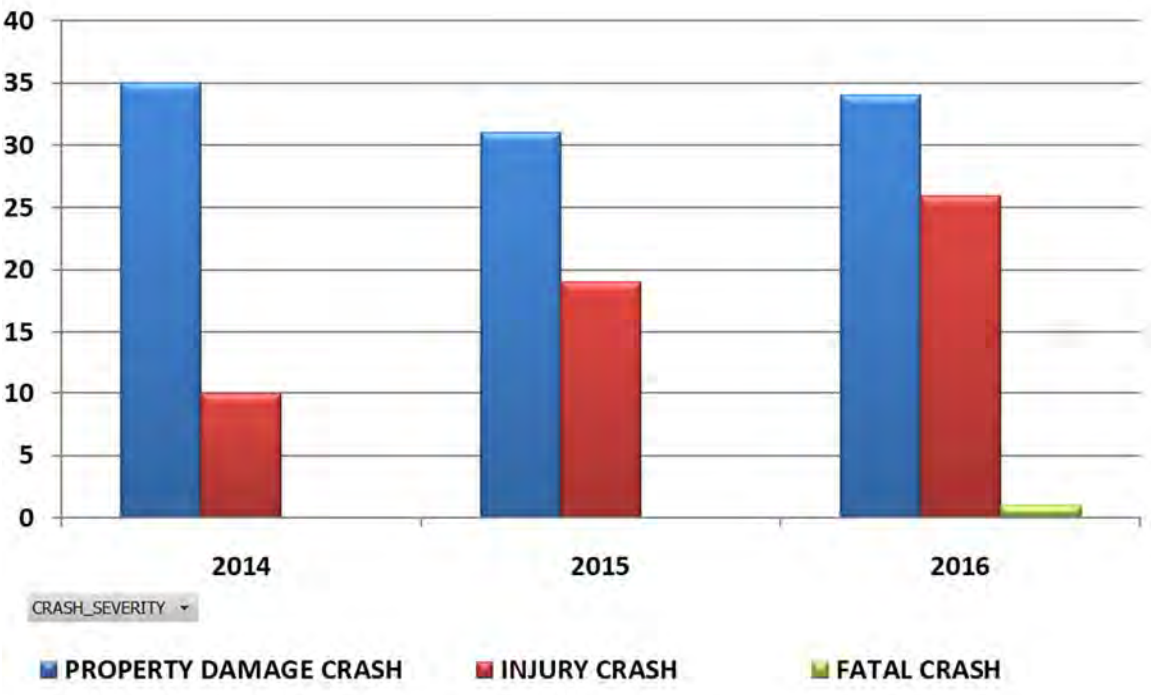
The majority of angle crashes are right angle crashes having 2 contributing factors:

- Stop lines of the side street are a minimum distance of 16 feet from the cross street. The one-way operation of exit ramps and of marginal roads enable small radii to discourage right turn movements (wrong way travel). Since the small radius enables pedestrian crosswalks to be positioned at the radius return, the stop line is unusually close to cross traffic. The start up time on the onset of green is short thus increasing the potential for crashes of vehicles that enter the intersection after the onset of the all red clearance interval.
- The small radius near the end of a bridge parapet obstructs the visibility of opposing traffic. Research conducted by Wayne State Universtiy suggested that drivers are more inclined to run red lights when intersection sight distance is restricted. Not seeing opposing traffic due to sight line obstructions such as bridge parapets, vandal fencing, and vegetation may increase the potential for red light running.

Increasing the all-red clearance time and moving stop lines away from an intersection to increase start up time of opposing are countermeasures that will mitigate right angle crashes. Increasing intersection sight distance

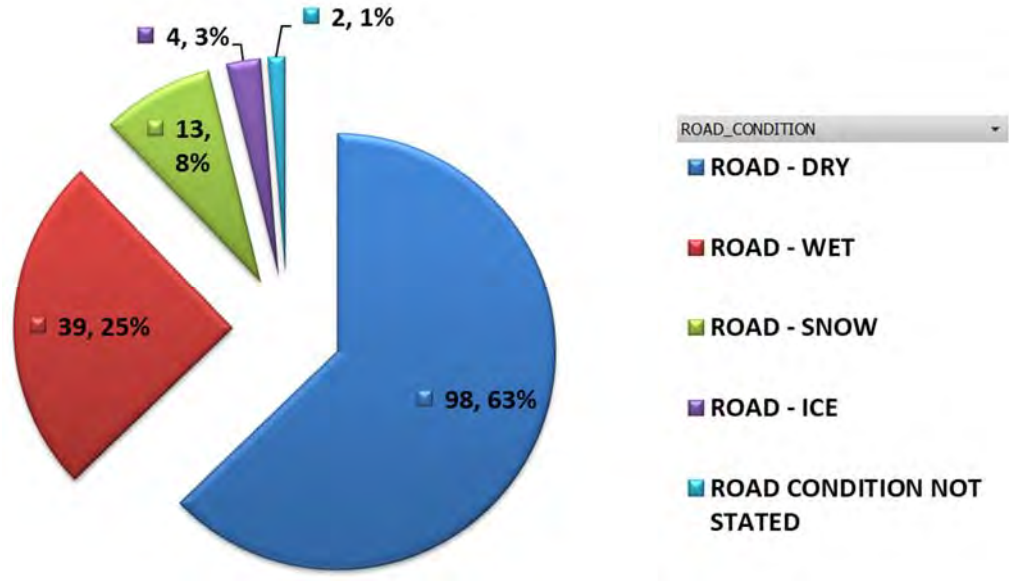
Angle crashes typically correlate to higher injury rates. While the injury rate for the 3-year period in slightly above statewide averages, the injury rate continues to increase each year as shown in **Figure 5**. Injury crashes comprise 43% of all crashes in 2016.

FIGURE 5: FREQUENCY OF CRASHES BY YEAR AND SEVERITY



Wet crashes (39 crashes or 25%) and snow crashes (13 crashes or 8%) are above statewide average crash rates of 19.4% and 6.1%, respectively as shown in **Figure 6**. Countermeasures should also improve existing pavement conditions.

FIGURE 6: FREQUENCY OF CRASHES BY ROAD CONDITION



CAPACITY ANALYSIS

The peak hour factor (PHF) for critical movements during the PM peak period is equal to 0.94. The Highway Capacity Manual (HCM) assumes roadways are congested when PHFs are 0.95 or higher.

Traffic signal operation was evaluated to determine what capacity improvements are needed to mitigate congestion related safety factors. Intersection capacity was evaluated using HCS software. The AM and PM peak periods of existing conditions were evaluated using the 2018 traffic volumes contained in **Appendix A**.

Table 2 summarizes the levels of service (LOS), delay, and lane configuration of existing conditions. Despite the Peak Hour Factors (PHF)suggesting some movements are near capacity, levels of service are acceptable (LOS C). Since HCS does not analyze shared lanes, the following lane configuration was assumed for

TABLE 2: HCS SUMMARY

	Warren Road Northbound		Warren Road Southbound		Lakewood Heights Blvd Westbound		
Inter-section	Left	Through	Through	Right	Left	Through	Right
LOS/ delay (sec/veh)	LOS/ delay (sec/veh)	LOS/ delay (sec/veh)	LOS/ delay (sec/veh)	LOS/ delay (sec/veh)	LOS/ delay (sec/veh)	LOS/ delay (sec/veh)	LOS/ delay (sec/veh)
AM PEAK							
	L	TH	TH	R	L	TH	R
C/24.7	C/30.2	B/11.0	C/29.2	C/29.3	C/24.3	C/23.8	C/23.9
PM PEAK							
C/28.8	D/41.0	B/15.0	C/32.7	C/32.8	C/30.6	C/26.8	C/27.3

	Warren Road Northbound		Warren Road Southbound		S. Marginal Drive Eastbound		
Inter-section	Through	Right	Left	Through	Left	Through	Right
LOS/ delay (sec/veh)	LOS/ delay (sec/veh)	LOS/ delay (sec/veh)	LOS/ delay (sec/veh)	LOS/ delay (sec/veh)	LOS/ delay (sec/veh)	LOS/ delay (sec/veh)	LOS/ delay (sec/veh)
AM PEAK							
	TH	R	L	TH	L	TH	R
C/24.1	C/26.0	C/32.0	C/21.8	B/11.2	C/27.6	C/26.6	C/26.7
PM PEAK							
B/19.3	C/24.5	C/22.1	C/26.0	B/19.8	B/14.1	B/13.7	B/13.8

Detailed reports for the AM and PM peak periods are contained in **Appendix C.**

COUNTERMEASURES

Countermeasures are identified that improve safety performance by focusing on the crash types having the greatest potential for mitigation. Additional countermeasures may be suggested to minimize potential safety issues that may not be directly linked to historical crash patterns. These countermeasures are low cost and focus on signing and pavement markings not consistent with the Ohio Manual of Uniform Traffic Control Devices (OMUTCD). Compliance with the OMUTCD will reduce driver workload thus improve safety performance.

WARREN ROAD COUNTERMEASURES

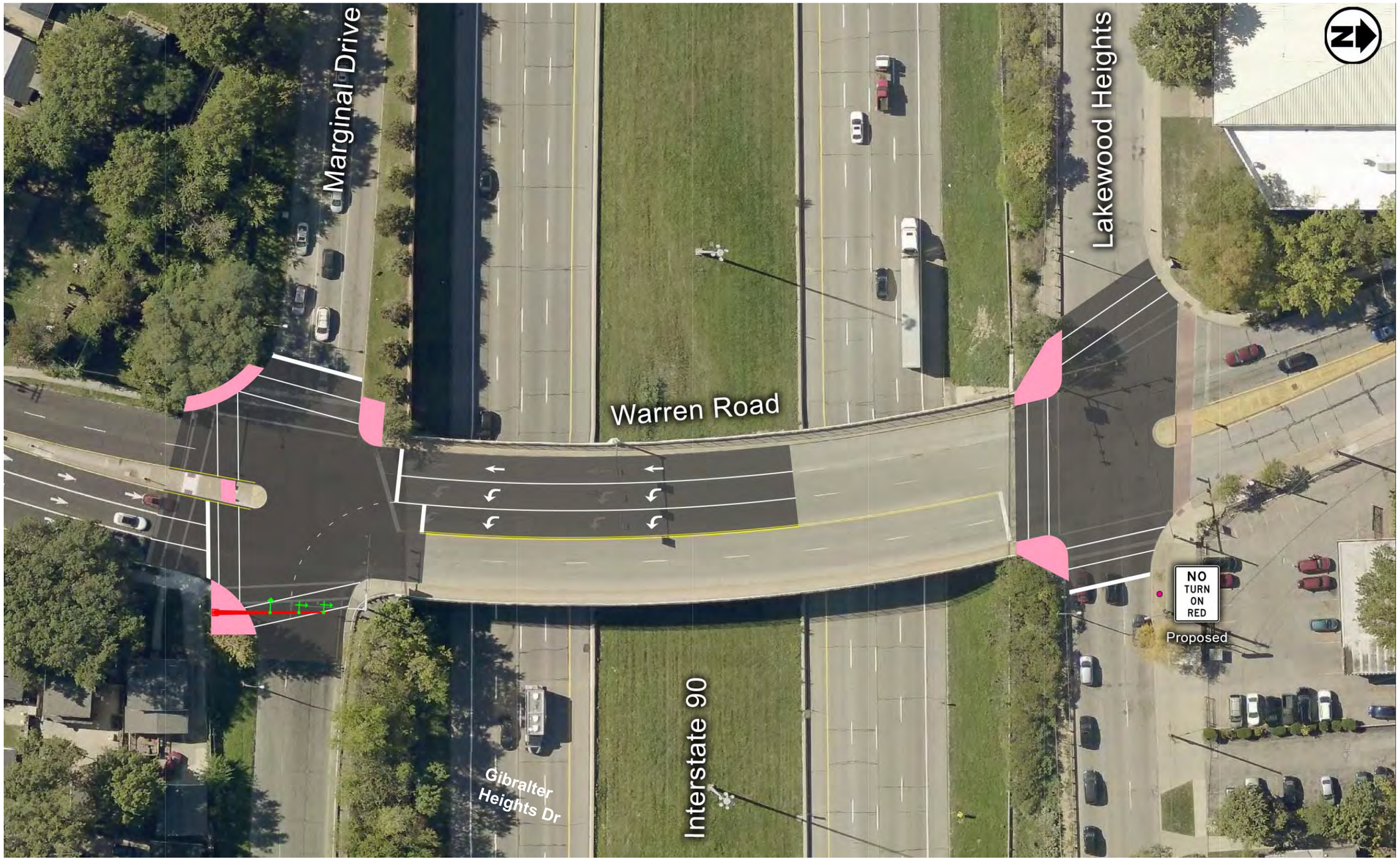
Figure 7A is a conceptual plan of the proposed improvements at the 2 signalized intersections on Warren Road. The following countermeasures are proposed at the Warren Road and Lakewood Heights Boulevard signalized intersection:

1. Setback stop line on the westbound Lakewood Heights Boulevard approach. The sidewalk on the SE quadrant will require extending the bridge parapet and additional sidewalk. This countermeasure is to increase the time required for vehicles to leave the stop line at the onset of green and enter the signalized intersection (curb line extended).
2. Add pedestrian signal heads for the crossing of the south leg.
3. Add No Turn Lane on Red sign (R-10-11b) sign for the westbound right turn movement.
4. Revise crosswalk location of west leg. The sidewalk on the SW quadrant will require extending the bridge parapet and additional sidewalk. This countermeasure is to increase the all-red clearance time and better align pedestrian crosswalks (directional ramps).
5. Relocate the overhead lane use signs for the westbound approach from 180 feet to 325 feet from the intersection. Replace signs and remove sign lighting.
6. Remove vegetation at SW quadrant, SE quadrant, and near proposed sign support location to increase visibility of signs and pedestrians.

The following countermeasures are proposed at the Warren Road and S. Marginal Drive signalized intersection:

7. Setback stop line on the eastbound S. Marginal Drive approach. The sidewalk on the NW quadrant will require extending the bridge parapet and additional sidewalk. The sidewalk on the SW quadrant will need to be constructed, too. This countermeasure is to increase the time required for vehicles to leave the stop line at the onset of green and enter the signalized intersection (curb line extended).
8. Reconstruct the pedestrian crossing on the south leg of the intersection. This countermeasure is to improve pedestrian visibility within the crosswalk, to minimize NB vehicles from blocking the pedestrian crosswalk when turning right on red, and to increase visibility of cross street vehicles.
9. Convert southbound approach from L, L-TH, TH to a more conventional L, L, TH lane configuration. The permissive dual left turn movement may contribute to the left turn crash pattern at this intersection. The City may consider using a Flashing Yellow Arrow (FYA) sequence in conjunction with a variable lane use control by time of day to accommodate the variable traffic volumes by time of day. **Appendix D** contains a sample implementation plan for the FYA sequence.

FIGURE 7A: CONCEPTUAL PLAN (WARREN ROAD)



10. Add signal support on the eastbound approach to enable 3 signal heads to be erected for the 3-lane approach.
11. Install new destination signs at a distance 550 feet from the intersection on the eastbound approach. Remove and dispose of existing sign.
12. Replace overhead lane use signs and remove sign lighting. Remove vegetation from blocking visibility of existing overhead lane use sign support.
13. Add dotted lines between dual left turn lanes on the southbound approach.

W. 140TH STREET COUNTERMEASURES

Figure 7B is a conceptual plan of the proposed improvements at the 2 signalized intersections on W. 140th Street. The following countermeasures are proposed at the W. 140th Street and WB I-90 Exit Ramp intersection:

1. Reconstruct traffic signal on new signal supports to enable southbound stop line to be moved further south. Signal reconstruction will also enable signal head indications on the westbound approach to have left and right turn arrows. This countermeasure is to reduce the frequency of vehicles from striking the concrete barrier on the west side of the intersection.
2. Increase size of the large arrow sign (W1-7-60) to increase visibility.
3. Setback stop line on the westbound I-90 Exit Ramp approach. The sidewalk on the NE and SE quadrants will need to be extended to reach the setback crosswalk. This countermeasure is to increase the time required for vehicles to leave the stop line at the onset of green and enter the signalized intersection (curb line extended).
4. Add No Turn Lane on Red sign (R-10-11b) sign for the westbound right turn movement.
5. Add ground mounted guide sign on the westbound approach to direct traffic to the WB I-90 entrance ramp via Lakewood Heights Boulevard.
6. Extend channelizing lines from the NB approach of Lakewood Heights Blvd to provide positive guidance across the intersection.
7. Replace ground mounted lane use signs on the westbound approach with overhead lane use signs 250 feet in advance of the intersection.

The following countermeasures are proposed at the W. 140th Street and WB I-90 Exit Ramp intersection:

8. Remove raised median on W. 140th Street between the WB I-90 Exit Ramp and the S. Marginal Road intersection. Removal of the median will improve the lane widths of the receiving lanes of eastbound left turning traffic.
9. Add dotted line having a 60 ft radius to improve the turning radius of the eastbound dual left turn movement. Setback stop lines on the southbound W. 140th Street approach. Vehicles already stop in advance of the stop lines on the W. 140th Street approach to avoid crashes with eastbound left turning vehicles.

FIGURE 7B: CONCEPTUAL PLAN (W. 140TH STREET)

10. Install sign support for overhead lane use signs on the eastbound approach 400 feet from the intersection.
11. Remove raised median south of the intersection.
12. Add Right Lane Ends sign to SW quadrant of the intersection to provide advance warning of the lane merge 125 feet south of the intersection.
13. Consider the use of the Flashing Yellow Arrow (FYA) sequence for the lagging left turn phase (southbound approach). See **Appendix D** for more information.

COST ESTIMATES

Construction costs were estimated for the short-term safety countermeasures outlined above. No property impacts are anticipated with the proposed improvements. Signal retiming costs were not estimated as part of the construction cost estimate.

Construction costs for the Warren Road improvements were estimated to cost $750,00 including a 35% contingency factor.

Construction costs for the W. 140th Street improvements were estimated to cost $750,000 including a 35% contingency factor.

A summary of costs are contained in **Appendix E**.

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APPENDIX A: TRAFFIC DATA

CMT

Start Time	Warren Road Southbound				Lakewood Heights Blvd Westbound				Warren Road Northbound				Subtotal
	Right	Thru	Left	Peds	Right	Thru	Left	Peds	Right	Thru	Left	Peds	
07:00 AM	5	167	0	0	33	51	31	0	0	53	27	0	367
07:15 AM	5	188	0	0	32	86	39	0	0	92	32	0	474
07:30 AM	8	167	0	0	48	135	53	0	0	84	53	0	548
07:45 AM	7	172	0	1	41	139	46	0	0	105	38	0	548
04:30 PM	12	147	0	0	82	187	84	0	0	134	52	0	698
04:45 PM	9	117	0	0	82	136	86	0	0	136	60	0	626
05:00 PM	11	171	0	0	78	159	91	1	0	138	71	0	719
05:15 PM	9	124	0	1	97	159	72	0	0	139	56	0	656
AM Peak (7:00-8:00)	**25**	**694**	**0**	**1**	**154**	**411**	**169**	**0**	**0**	**334**	**150**	**0**	**1937**
PM Peak (4:30-5:30)	**41**	**559**	**0**	**1**	**339**	**641**	**333**	**1**	**0**	**547**	**239**	**0**	**2699**

Start Time	Warren Road Southbound				S. Marginal Drive Eastbound				Warren Road Northbound				Subtotal
	Right	Thru	Left	Peds	Right	Thru	Left	Peds	Right	Thru	Left	Peds	
07:00 AM	0	80	108	0	31	127	12	0	64	59	0	0	481
07:15 AM	0	125	108	0	34	201	29	0	87	101	0	0	685
07:30 AM	0	116	106	0	42	245	24	1	104	120	0	0	757
07:45 AM	0	111	98	0	35	268	26		88	119	0	0	745
04:30 PM	0	170	55	0	61	121	48	0	45	134	0	0	634
04:45 PM	0	149	59	0	62	117	42	1	31	158	0	0	618
05:00 PM	0	193	63	0	68	108	50	4	44	157	0	0	683
05:15 PM	0	140	56	0	69	172	57	0	40	141	0	2	675
AM Peak (7:00-8:00)	**0**	**432**	**420**	**0**	**142**	**841**	**91**	**1**	**343**	**399**	**0**	**0**	**2668**
PM Peak (4:30-5:30)	**0**	**652**	**233**	**0**	**260**	**518**	**197**	**5**	**160**	**590**	**0**	**2**	**2610**

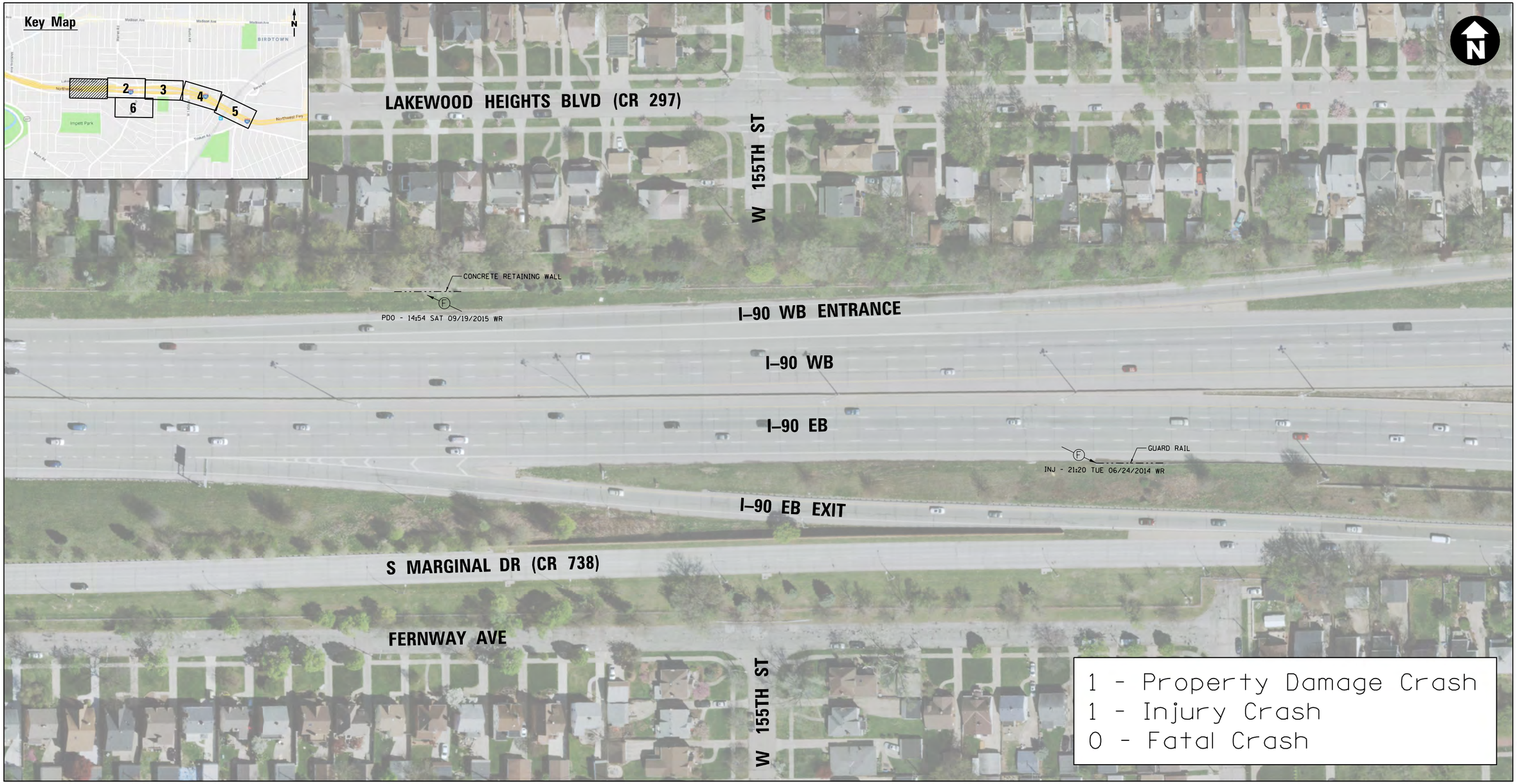
Leg	Warren Rd.							Lakewood Hts. Blvd.							Warren Rd.							Lakewood Hts. Blvd.							
Direction	Southbound							Westbound							Northbound							Eastbound							
Start Time	Right	Thru	Left	U-Turn	App Total	Peds CW	Peds CCW	Right	Thru	Left	U-Turn	App Total	Peds CW	Peds CCW	Right	Thru	Left	U-Turn	App Total	Peds CW	Peds CCW	Right	Thru	Left	U-Turn	App Total	Peds CW	Peds CCW	Int Total
2018-05-17 06:00:00	1	59	0	0	**60**	0	0	9	36	9	0	**54**	0	1	0	19	16	0	**35**	0	0	0	0	0	0	**0**	0	0	**149**
2018-05-17 06:15:00	2	75	0	0	**77**	0	0	13	32	14	0	**59**	0	0	0	23	16	0	**39**	0	0	0	0	0	0	**0**	0	0	**175**
2018-05-17 06:30:00	7	113	0	0	**120**	0	0	19	63	17	0	**99**	0	0	0	43	18	0	**61**	0	0	0	0	0	0	**0**	1	0	**280**
2018-05-17 06:45:00	0	131	0	0	**131**	0	0	28	50	30	0	**108**	0	0	0	54	33	0	**87**	0	0	0	0	0	0	**0**	0	0	**326**
2018-05-17 07:00:00	5	167	0	0	**172**	0	0	33	51	31	0	**115**	0	0	0	53	27	0	**80**	0	0	0	0	0	0	**0**	0	0	**367**
2018-05-17 07:15:00	5	188	0	0	**193**	1	0	32	86	39	0	**157**	0	0	0	92	32	0	**124**	0	0	0	0	0	0	**0**	0	0	**474**
2018-05-17 07:30:00	8	167	0	0	**175**	0	0	48	135	53	0	**236**	0	0	0	84	53	0	**137**	0	0	0	0	0	0	**0**	0	0	**548**
2018-05-17 07:45:00	7	172	0	0	**179**	0	1	41	139	46	0	**226**	0	0	0	105	38	0	**143**	0	0	0	0	0	0	**0**	0	0	**548**
2018-05-17 12:00:00	6	94	0	0	**100**	0	0	48	67	39	0	**154**	0	0	0	81	39	0	**120**	0	0	0	0	0	0	**0**	1	0	**374**
2018-05-17 12:15:00	3	102	0	0	**105**	0	0	39	76	36	0	**151**	0	0	0	77	28	0	**105**	0	0	0	0	0	0	**0**	0	0	**361**
2018-05-17 12:30:00	7	99	0	0	**106**	0	0	41	82	54	0	**177**	0	1	0	79	28	0	**107**	0	0	0	0	0	0	**0**	0	0	**390**
2018-05-17 12:45:00	8	115	0	0	**123**	0	0	41	79	47	0	**167**	0	0	0	71	33	0	**104**	0	0	0	0	0	0	**0**	0	0	**394**
2018-05-17 13:00:00	10	90	0	0	**100**	0	0	44	65	39	0	**148**	0	0	0	80	42	0	**122**	0	0	0	0	0	0	**0**	0	0	**370**
2018-05-17 13:15:00	8	107	0	0	**115**	0	0	37	82	37	0	**156**	0	0	0	68	41	0	**109**	0	0	0	0	0	0	**0**	0	0	**380**
2018-05-17 13:30:00	5	113	0	0	**118**	0	0	53	68	53	0	**174**	0	0	0	84	28	0	**112**	0	0	0	0	0	0	**0**	0	0	**404**
2018-05-17 13:45:00	6	101	0	0	**107**	0	1	53	80	38	0	**171**	0	0	0	70	34	0	**104**	0	0	0	0	0	0	**0**	0	1	**382**
2018-05-17 14:00:00	8	104	0	0	**112**	0	0	58	96	46	0	**200**	1	0	0	79	43	0	**122**	0	0	0	0	0	0	**0**	0	0	**434**
2018-05-17 14:15:00	10	109	0	0	**119**	1	0	48	90	44	0	**182**	0	0	0	103	42	0	**145**	0	0	0	0	0	0	**0**	0	0	**446**
2018-05-17 15:00:00	2	131	0	0	**133**	0	0	67	135	68	0	**270**	0	1	0	77	47	0	**124**	0	0	0	0	0	0	**0**	0	0	**527**
2018-05-17 15:15:00	7	152	0	0	**159**	0	0	59	148	71	0	**278**	0	1	0	79	36	0	**115**	0	0	0	0	0	0	**0**	0	2	**552**
2018-05-17 15:30:00	8	144	0	0	**152**	0	0	61	160	81	0	**302**	0	0	0	98	52	0	**150**	0	0	0	0	0	0	**0**	2	0	**604**
2018-05-17 15:45:00	12	106	0	0	**118**	0	0	91	164	88	0	**343**	0	0	0	113	46	0	**159**	0	0	0	0	0	0	**0**	0	1	**620**
2018-05-17 16:00:00	9	135	0	0	**144**	1	1	88	134	91	0	**313**	0	0	0	95	65	0	**160**	0	0	0	0	0	0	**0**	0	0	**617**
2018-05-17 16:15:00	7	126	0	0	**133**	0	0	67	163	87	0	**317**	0	0	0	127	46	0	**173**	0	0	0	0	0	0	**0**	0	0	**623**
2018-05-17 16:30:00	12	147	0	0	**159**	0	0	82	187	84	0	**353**	0	0	0	134	52	0	**186**	0	0	0	0	0	0	**0**	0	0	**698**
2018-05-17 16:45:00	9	117	0	0	**126**	0	2	82	136	86	0	**304**	0	0	0	136	60	0	**196**	0	0	0	0	0	0	**0**	0	0	**626**
2018-05-17 17:00:00	11	171	0	0	**182**	0	0	78	159	91	0	**328**	1	0	0	138	71	0	**209**	0	0	0	0	0	0	**0**	1	2	**719**
2018-05-17 17:15:00	9	124	0	0	**133**	1	0	97	159	72	0	**328**	0	3	0	139	56	0	**195**	0	0	0	0	0	0	**0**	0	0	**656**
2018-05-17 18:15:00	8	111	0	0	**119**	0	3	118	131	93	0	**342**	0	0	0	106	40	0	**146**	0	0	0	0	0	0	**0**	0	0	**607**
2018-05-17 18:30:00	4	111	0	0	**115**	0	0	67	115	67	0	**249**	0	1	0	122	42	0	**164**	0	0	0	0	0	0	**0**	0	0	**528**
2018-05-17 18:45:00	11	90	0	0	**101**	1	0	77	124	60	0	**261**	0	0	0	111	38	0	**149**	0	0	0	0	0	0	**0**	0	0	**511**
2018-05-17 19:00:00	9	96	0	0	**105**	3	1	83	98	55	0	**236**	0	0	0	86	38	0	**124**	0	0	0	0	0	0	**0**	0	0	**465**
2018-05-19 08:30:00	4	81	0	0	**85**	0	0	37	84	36	0	**157**	0	0	0	55	26	0	**81**	0	0	0	0	0	0	**0**	1	0	**323**
2018-05-19 08:45:00	6	83	0	0	**89**	0	0	42	100	31	0	**173**	0	0	0	57	33	0	**90**	0	0	0	0	0	0	**0**	0	0	**352**
2018-05-19 09:00:00	8	92	0	0	**100**	0	1	30	74	34	0	**138**	0	0	0	66	33	0	**99**	0	0	0	0	0	0	**0**	0	0	**337**
2018-05-19 09:15:00	9	110	0	0	**119**	0	0	33	74	38	0	**145**	1	1	0	55	28	0	**83**	0	0	0	0	0	0	**0**	0	0	**347**
2018-05-19 09:30:00	7	122	0	0	**129**	1	0	33	95	46	0	**174**	1	0	0	64	34	0	**98**	0	0	0	0	0	0	**0**	1	0	**401**
2018-05-19 09:45:00	9	88	0	0	**97**	0	0	48	91	48	0	**187**	0	0	0	80	32	0	**112**	0	0	0	0	0	0	**0**	0	0	**396**
2018-05-19 10:00:00	6	114	0	0	**120**	0	0	45	74	42	0	**161**	0	0	0	88	34	0	**122**	0	0	0	0	0	0	**0**	0	0	**403**
2018-05-19 10:15:00	6	113	0	0	**119**	0	0	41	85	48	0	**174**	0	0	0	78	36	0	**114**	0	0	0	0	0	0	**0**	0	0	**407**
2018-05-19 10:30:00	12	120	0	0	**132**	0	1	58	92	43	0	**193**	0	0	0	79	36	0	**115**	0	0	0	0	0	0	**0**	0	0	**440**
2018-05-19 10:45:00	8	112	0	1	**121**	0	0	46	72	48	0	**166**	0	0	0	87	47	0	**134**	0	0	0	0	0	0	**0**	0	0	**421**
2018-05-19 11:00:00	8	116	0	0	**124**	0	0	59	103	61	0	**223**	0	0	0	73	35	0	**108**	0	0	0	0	0	0	**0**	0	0	**455**
2018-05-19 11:15:00	7	134	0	0	**141**	0	0	43	97	39	0	**179**	0	0	0	76	45	0	**121**	0	0	0	0	0	0	**0**	0	0	**441**
2018-05-19 11:30:00	9	113	0	0	**122**	0	1	70	104	42	0	**216**	0	0	0	75	40	0	**115**	0	0	0	0	0	0	**0**	0	1	**453**
2018-05-19 11:45:00	14	151	0	0	**165**	0	0	60	103	55	0	**218**	0	0	0	92	40	0	**132**	0	0	0	0	0	0	**0**	0	0	**515**
2018-05-19 12:00:00	20	157	0	0	**177**	1	0	44	103	58	0	**205**	0	0	0	109	39	0	**148**	0	0	0	0	0	0	**0**	0	0	**530**
2018-05-19 12:15:00	15	141	0	0	**156**	0	0	59	98	45	0	**202**	0	0	0	82	46	0	**128**	0	0	0	0	0	0	**0**	0	0	**486**
2018-05-19 12:30:00	14	140	0	0	**154**	0	0	57	125	47	0	**229**	0	0	0	114	54	0	**168**	0	0	0	0	0	0	**0**	0	0	**551**
2018-05-19 12:45:00	8	135	0	0	**143**	0	0	42	83	58	0	**183**	0	0	0	99	53	0	**152**	0	0	0	0	0	0	**0**	0	0	**478**
2018-05-19 13:00:00	11	130	0	0	**141**	1	0	44	67	44	0	**155**	2	0	0	110	40	0	**150**	0	0	0	0	0	0	**0**	0	0	**446**
2018-05-19 13:15:00	12	117	0	0	**129**	0	0	45	103	42	0	**190**	1	0	0	87	34	0	**121**	0	0	0	0	0	0	**0**	0	3	**440**
2018-05-19 13:30:00	6	133	0	0	**139**	0	1	55	102	53	0	**210**	0	0	0	95	45	0	**140**	0	0	0	0	0	0	**0**	0	0	**489**
2018-05-19 13:45:00	10	123	0	0	**133**	0	0	63	91	31	0	**185**	0	1	1	94	40	0	**135**	0	0	0	0	0	0	**0**	0	1	**453**
2018-05-19 14:00:00	14	135	0	0	**149**	0	0	53	95	52	0	**200**	0	0	0	89	46	0	**135**	0	0	0	0	0	0	**0**	0	2	**484**
2018-05-19 14:15:00	11	116	0	0	**127**	1	0	57	94	45	0	**196**	0	0	0	88	39	0	**127**	0	0	0	0	0	0	**0**	0	0	**450**
2018-05-19 14:30:00	5	122	0	0	**127**	0	1	57	92	57	0	**206**	0	0	0	113	40	0	**153**	0	0	0	0	0	0	**0**	0	0	**486**
2018-05-19 14:45:00	6	125	0	0	**131**	0	0	66	111	53	0	**230**	0	0	0	116	35	0	**151**	0	0	0	0	0	0	**0**	0	1	**512**
2018-05-19 15:00:00	6	133	0	0	**139**	0	0	65	76	35	0	**176**	0	0	0	103	29	0	**132**	0	0	0	0	0	0	**0**	0	0	**447**
2018-05-19 15:15:00	12	143	0	0	**155**	0	0	62	98	55	0	**215**	0	0	0	88	33	0	**121**	0	0	0	0	0	0	**0**	0	0	**491**
2018-05-19 18:00:00	7	105	0	0	**112**	0	0	53	76	43	0	**172**	0	0	0	89	29	0	**118**	0	0	0	0	0	0	**0**	0	0	**402**
2018-05-19 18:15:00	10	123	0	0	**133**	0	0	49	99	35	0	**183**	0	0	0	92	23	0	**115**	0	0	0	0	0	0	**0**	0	0	**431**
2018-05-19 18:30:00	7	78	0	0	**85**	0	0	51	72	52	0	**175**	0	0	0	80	23	0	**103**	0	0	0	0	0	0	**0**	0	0	**363**
2018-05-19 18:45:00	8	94	0	0	**102**	0	0	58	69	41	0	**168**	0	0	0	77	19	0	**96**	0	0	0	0	0	0	**0**	0	0	**366**
Grand Total	519	7666	0	1	**8186**	12	14	3427	6292	3223	0	**12942**	7	10	1	5576	2446	0	**8023**	0	0	0	0	0	0	**0**	7	14	**29151**
% Approach	6.3%	93.6%	0.0%	0.0%				26.5%	48.6%	24.9%	0.0%				0.0%	69.5%	30.5%	0.0%				0.0%	0.0%	0.0%	0.0%				
% Total	1.8%	26.3%	0.0%	0.0%	**28.1%**			11.8%	21.6%	11.1%	0.0%	**44.4%**			0.0%	19.1%	8.4%	0.0%	**27.5%**			0.0%	0.0%	0.0%	0.0%	**0.0%**			
Lights	505	7576	0	1	**8082**			3386	6233	3179	0	**12798**			1	5512	2406	0	**7919**			0	0	0	0	**0**			**28799**
% Lights	97.3%	98.8%	0.0%	100.0%	**98.7%**			98.8%	99.1%	98.6%	0.0%	**98.9%**			100.0%	98.9%	98.4%	0.0%	**98.7%**			0.0%	0.0%	0.0%	0.0%				**98.8%**
Single-Unit Trucks	12	57	0	0	**69**			32	27	23	0	**82**			0	38	33	0	**71**			0	0	0	0	**0**			**222**
% Single-Unit Trucks	2.3%	0.7%	0.0%	0.0%	**0.8%**			0.9%	0.4%	0.7%	0.0%	**0.6%**			0.0%	0.7%	1.3%	0.0%	**0.9%**			0.0%	0.0%	0.0%	0.0%				**0.8%**
Articulated Trucks	1	6	0	0	**7**			6	1	7	0	**14**			0	3	3	0	**6**			0	0	0	0	**0**			**27**
% Articulated Trucks	0.2%	0.1%	0.0%	0.0%	**0.1%**			0.2%	0.0%	0.2%	0.0%	**0.1%**			0.0%	0.1%	0.1%	0.0%	**0.1%**			0.0%	0.0%	0.0%	0.0%				**0.1%**
Buses	1	23	0	0	**24**			3	30	12	0	**45**			0	23	4	0	**27**			0	0	0	0	**0**			**96**
% Buses	0.2%	0.3%	0.0%	0.0%	**0.3%**			0.1%	0.5%	0.4%	0.0%	**0.3%**			0.0%	0.4%	0.2%	0.0%	**0.3%**			0.0%	0.0%	0.0%	0.0%				**0.3%**
Bicycles on Road	0	4	0	0	**4**			0	1	2	0	**3**			0	0	0	0	**0**			0	0	0	0	**0**			**7**
% Bicycles on Road	0.0%	0.1%	0.0%	0.0%	**0.0%**			0.0%	0.0%	0.1%	0.0%	**0.0%**			0.0%	0.0%	0.0%	0.0%	**0.0%**			0.0%	0.0%	0.0%	0.0%				**0.0%**
Pedestrians						12	14						7	10						0	0						7	14	
% Pedestrians						100.0%	100.0%						100.0%	100.0%						0.0%	0.0%						100.0%	100.0%	

Leg	Warren Rd.						S. Marginal Dr.			Warren Rd.						S. Marginal Dr.						
Direction	Southbound						Westbound			Northbound						Eastbound						
Start Time	Thru	Left	U-Turn	**App Total**	Peds CW	Peds CCW	**App Total**	Peds CW	Peds CCW	Right	Thru	U-Turn	**App Total**	Peds CW	Peds CCW	Right	Thru	Left	**App Total**	Peds CW	Peds CCW	**Int Total**
2018-05-17 06:00:00	30	29	0	**59**	0	0	**0**	0	1	42	30	0	**72**	0	0	12	36	5	**53**	0	0	**184**
2018-05-17 06:15:00	40	48	0	**88**	0	0	**0**	0	0	61	29	0	**90**	0	0	20	58	10	**88**	0	0	**266**
2018-05-17 06:30:00	56	74	0	**130**	0	0	**0**	0	0	61	48	0	**109**	0	0	13	61	11	**85**	1	0	**324**
2018-05-17 06:45:00	57	96	0	**153**	0	0	**0**	0	0	54	68	0	**122**	0	0	26	97	17	**140**	0	0	**415**
2018-05-17 07:00:00	80	108	0	**188**	0	0	**0**	0	0	64	59	0	**123**	0	0	31	127	12	**170**	0	0	**481**
2018-05-17 07:15:00	125	108	0	**233**	0	0	**0**	0	0	87	101	0	**188**	0	0	34	201	29	**264**	0	0	**685**
2018-05-17 07:30:00	116	106	0	**222**	0	0	**0**	1	0	104	120	0	**224**	0	0	42	245	24	**311**	0	0	**757**
2018-05-17 07:45:00	111	98	0	**209**	0	0	**0**	0	0	88	119	0	**207**	0	0	35	268	26	**329**	0	0	**745**
2018-05-17 12:00:00	89	42	0	**131**	0	0	**0**	0	0	47	86	0	**133**	0	0	41	79	33	**153**	1	0	**417**
2018-05-17 12:15:00	81	55	0	**136**	0	0	**0**	0	0	49	84	0	**133**	0	0	45	81	26	**152**	0	0	**421**
2018-05-17 12:30:00	101	50	0	**151**	0	0	**0**	0	0	42	83	0	**125**	0	0	33	64	24	**121**	0	0	**397**
2018-05-17 12:45:00	100	65	0	**165**	0	0	**0**	0	0	40	82	0	**122**	0	0	56	73	23	**152**	0	0	**439**
2018-05-17 13:00:00	87	39	0	**126**	0	0	**0**	0	0	51	96	0	**147**	0	0	30	87	24	**141**	0	0	**414**
2018-05-17 13:15:00	100	46	0	**146**	0	0	**0**	0	0	41	85	0	**126**	0	0	51	72	25	**148**	0	0	**420**
2018-05-17 13:30:00	113	53	0	**166**	0	0	**0**	0	0	51	93	0	**144**	0	0	43	82	18	**143**	0	0	**453**
2018-05-17 13:45:00	91	46	0	**137**	0	0	**0**	0	0	42	90	0	**132**	0	0	40	76	16	**132**	0	1	**401**
2018-05-17 14:00:00	97	53	0	**150**	0	0	**0**	1	0	40	94	0	**134**	0	0	43	87	23	**153**	0	0	**437**
2018-05-17 14:15:00	97	53	0	**150**	0	0	**0**	0	0	49	95	0	**144**	0	0	29	86	37	**152**	0	0	**446**
2018-05-17 15:00:00	138	71	0	**209**	0	0	**0**	0	1	38	101	0	**139**	0	0	42	126	23	**191**	0	0	**539**
2018-05-17 15:15:00	164	64	0	**228**	0	0	**0**	0	1	60	94	0	**154**	0	0	60	127	22	**209**	0	0	**591**
2018-05-17 15:30:00	141	65	0	**206**	0	0	**0**	0	0	40	113	0	**153**	0	0	50	102	37	**189**	0	0	**548**
2018-05-17 15:45:00	158	47	0	**205**	0	0	**0**	0	0	63	122	0	**185**	0	0	50	120	40	**210**	0	0	**600**
2018-05-17 16:00:00	167	53	0	**220**	0	0	**0**	0	0	46	117	0	**163**	0	0	38	90	35	**163**	0	0	**546**
2018-05-17 16:15:00	158	54	0	**212**	0	0	**0**	0	0	53	134	0	**187**	0	0	56	120	36	**212**	0	0	**611**
2018-05-17 16:30:00	170	55	0	**225**	0	0	**0**	0	0	45	134	0	**179**	0	0	61	121	48	**230**	0	0	**634**
2018-05-17 16:45:00	149	59	0	**208**	0	0	**0**	0	0	31	158	0	**189**	0	0	62	117	42	**221**	1	0	**618**
2018-05-17 17:00:00	193	63	0	**256**	0	0	**0**	1	1	44	157	0	**201**	0	0	68	108	50	**226**	1	1	**683**
2018-05-17 17:15:00	140	56	0	**196**	0	0	**0**	0	2	40	141	0	**181**	0	2	69	172	57	**298**	0	0	**675**
2018-05-17 18:15:00	151	56	0	**207**	0	0	**0**	0	0	38	124	0	**162**	0	0	49	108	25	**182**	0	0	**551**
2018-05-17 18:30:00	124	52	0	**176**	0	0	**0**	0	1	48	126	0	**174**	1	0	44	108	39	**191**	1	0	**541**
2018-05-17 18:45:00	100	55	0	**155**	0	0	**0**	0	0	36	122	0	**158**	0	0	36	105	26	**167**	0	0	**480**
2018-05-17 19:00:00	106	40	0	**146**	0	0	**0**	0	0	38	91	0	**129**	0	0	33	113	32	**178**	0	0	**453**
2018-05-19 08:30:00	62	47	0	**109**	0	0	**0**	0	0	36	66	0	**102**	0	0	24	46	14	**84**	0	0	**295**
2018-05-19 08:45:00	67	43	0	**110**	0	0	**0**	0	0	48	79	0	**127**	0	0	23	69	14	**106**	0	0	**343**
2018-05-19 09:00:00	69	50	0	**119**	0	0	**0**	0	0	34	85	0	**119**	0	0	20	75	16	**111**	0	0	**349**
2018-05-19 09:15:00	96	55	0	**151**	0	0	**0**	1	0	38	66	0	**104**	0	0	18	65	19	**102**	0	0	**357**
2018-05-19 09:30:00	91	69	0	**160**	0	0	**0**	0	0	43	79	0	**122**	0	0	28	79	18	**125**	1	0	**407**
2018-05-19 09:45:00	90	53	0	**143**	0	0	**0**	0	0	46	79	0	**125**	0	0	32	67	32	**131**	0	0	**399**
2018-05-19 10:00:00	83	65	0	**148**	0	0	**0**	0	0	24	95	0	**119**	0	0	38	91	24	**153**	0	0	**420**
2018-05-19 10:15:00	94	51	0	**145**	0	0	**0**	0	0	26	92	0	**118**	0	0	38	69	23	**130**	0	0	**393**
2018-05-19 10:30:00	113	58	0	**171**	0	0	**0**	0	0	41	104	0	**145**	0	1	39	77	23	**139**	0	0	**455**
2018-05-19 10:45:00	102	40	0	**142**	0	0	**0**	0	0	48	105	0	**153**	0	0	51	90	30	**171**	0	0	**466**
2018-05-19 11:00:00	119	65	0	**184**	0	0	**0**	0	0	47	88	0	**135**	0	0	60	86	23	**169**	0	0	**488**
2018-05-19 11:15:00	115	65	0	**180**	0	0	**0**	0	0	55	91	0	**146**	0	0	38	97	30	**165**	0	0	**491**
2018-05-19 11:30:00	96	60	0	**156**	0	0	**0**	0	0	33	80	0	**113**	0	0	32	76	27	**135**	0	1	**404**
2018-05-19 11:45:00	132	61	0	**193**	0	0	**0**	0	3	50	108	1	**159**	0	0	53	89	27	**169**	0	0	**521**
2018-05-19 12:00:00	147	61	0	**208**	0	0	**0**	1	0	52	116	0	**168**	0	0	70	84	28	**182**	0	0	**558**
2018-05-19 12:15:00	116	63	0	**179**	0	0	**0**	0	0	53	93	0	**146**	0	0	44	95	28	**167**	0	0	**492**
2018-05-19 12:30:00	124	72	0	**196**	0	0	**0**	0	0	50	135	0	**185**	0	0	62	100	34	**196**	0	0	**577**
2018-05-19 12:45:00	140	57	0	**197**	0	0	**0**	0	0	37	113	0	**150**	0	0	39	77	41	**157**	0	0	**504**
2018-05-19 13:00:00	106	57	0	**163**	0	0	**0**	1	0	49	115	0	**164**	0	0	49	88	35	**172**	0	0	**499**
2018-05-19 13:15:00	103	60	0	**163**	0	0	**0**	1	0	44	96	0	**140**	0	0	36	90	27	**153**	0	3	**456**
2018-05-19 13:30:00	104	59	0	**163**	0	0	**0**	0	0	39	106	0	**145**	0	0	61	99	34	**194**	0	0	**502**
2018-05-19 13:45:00	112	59	0	**171**	0	0	**0**	0	1	42	100	0	**142**	0	0	58	86	30	**174**	0	0	**487**
2018-05-19 14:00:00	110	76	0	**186**	0	0	**0**	0	0	42	116	0	**158**	0	0	51	95	19	**165**	0	0	**509**
2018-05-19 14:15:00	100	67	0	**167**	0	0	**0**	1	0	45	101	0	**146**	0	0	52	101	28	**181**	0	0	**494**
2018-05-19 14:30:00	126	47	0	**173**	0	0	**0**	0	0	36	114	0	**150**	0	0	67	107	30	**204**	0	0	**527**
2018-05-19 14:45:00	125	64	0	**189**	0	0	**0**	0	0	42	113	0	**155**	0	0	60	102	37	**199**	0	1	**543**
2018-05-19 15:00:00	96	56	0	**152**	0	1	**0**	0	0	45	101	0	**146**	0	0	49	97	34	**180**	0	0	**478**

2018-05-19 15:15:00	129	71	0	**200**	0	0	**0**	0	0	66	102	0	**168**	0	0	54	83	20	**157**	0	0	**525**
2018-05-19 18:00:00	85	64	0	**149**	0	0	**0**	0	0	48	91	0	**139**	0	0	41	84	27	**152**	0	0	**440**
2018-05-19 18:15:00	96	63	0	**159**	0	0	**0**	0	0	46	83	0	**129**	0	0	37	82	30	**149**	0	0	**437**
2018-05-19 18:30:00	83	40	0	**123**	0	0	**0**	0	0	40	81	0	**121**	0	0	24	73	23	**120**	0	0	**364**
2018-05-19 18:45:00	77	58	0	**135**	0	0	**0**	0	0	35	69	0	**104**	0	0	34	69	27	**130**	0	0	**369**
Grand Total	6938	3835	0	**10773**	0	1	**0**	8	11	3013	6258	1	**9272**	1	3	2724	6205	1747	**10676**	6	7	**30721**
% Approach	64.4%	35.6%	0.0%							32.5%	67.5%	0.0%				25.5%	58.1%	16.4%				
% Total	22.6%	12.5%	0.0%	**35.1%**			**0.0%**			9.8%	20.4%	0.0%	**30.2%**			8.9%	20.2%	5.7%	**34.8%**			
Lights	6840	3801	0	**10641**			**0**			2972	6168	1	**9141**			2683	6116	1732	**10531**			**30313**
% Lights	98.6%	99.1%	0.0%	**98.8%**						98.6%	98.6%	100.0%	**98.6%**			98.5%	98.6%	99.1%	**98.6%**			**98.7%**
Single-Unit Trucks	55	28	0	**83**			**0**			28	57	0	**85**			28	46	10	**84**			**252**
% Single-Unit Trucks	0.8%	0.7%	0.0%	**0.8%**						0.9%	0.9%	0.0%	**0.9%**			1.0%	0.7%	0.6%	**0.8%**			**0.8%**
Articulated Trucks	9	5	0	**14**			**0**			7	5	0	**12**			6	8	1	**15**			**41**
% Articulated Trucks	0.1%	0.1%	0.0%	**0.1%**						0.2%	0.1%	0.0%	**0.1%**			0.2%	0.1%	0.1%	**0.1%**			**0.1%**
Buses	31	1	0	**32**			**0**			6	27	0	**33**			7	33	4	**44**			**109**
% Buses	0.4%	0.0%	0.0%	**0.3%**						0.2%	0.4%	0.0%	**0.4%**			0.3%	0.5%	0.2%	**0.4%**			**0.4%**
Bicycles on Road	3	0	0	**3**			**0**			0	1	0	**1**			0	2	0	**2**			**6**
% Bicycles on Road	0.0%	0.0%	0.0%	**0.0%**						0.0%	0.0%	0.0%	**0.0%**			0.0%	0.0%	0.0%	**0.0%**			**0.0%**
Pedestrians					0	1		8	11					1	3					6	7	
% Pedestrians					0.0%	100.0%		100.0%	100.0%					100.0%	100.0%					100.0%	100.0%	

CUY-90-9.09 SAFETY STUDY

APPENDIX B: CRASH DIAGRAM/ DATA



LEGEND

TYPES OF CRASHES	SYMBOLS
Rear End	Moving Vehicle
Right Angle	Stopped Vehicle
Side Swipe	Bicycle
Left Turn	Pedestrian
Head On	Vehicle at Fault
Fixed Object	

ROAD CONDITION	
X	Not Stated
D	Dry
W	Wet
S	Snow
I	Ice
M	Mud/Sand

WEATHER CONDITION	
X	Not Stated
C	Clear
R	Rain
S	Snow
F	Fog
L	Cloudy

SEVERITY
PDO - Property Damage Only
INJ - Injury
FAT - Fatal

CRASH DIAGRAM

LOG POINT 8.56 AND 8.86

PERIOD 3 Years FROM 2014 TO 2016

JURISDICTION City of Cleveland

ROUTE NAME / NUMBER Interstate 90

CMT
Crawford, Murphy & Tilly | Engineers & Consultants
8101 North High Street, Suite 150 | Columbus, OH | 43235

DATE: June 5, 2018

LEGEND

TYPES OF CRASHES	SYMBOLS
Rear End	Moving Vehicle
Right Angle	Stopped Vehicle
Side Swipe	Bicycle
Left Turn	Pedestrian
Head On	Vehicle at Fault
Fixed Object	

ROAD CONDITION	
X	Not Stated
D	Dry
W	Wet
S	Snow
I	Ice
M	Mud/Sand

WEATHER CONDITION	
X	Not Stated
C	Clear
R	Rain
S	Snow
F	Fog
L	Cloudy

SEVERITY
PDO - Property Damage Only
INJ - Injury
FAT - Fatal

CRASH DIAGRAM

LOG POINT 8.86 AND 9.15

PERIOD 3 Years FROM 2014 TO 2016

JURISDICTION City of Cleveland

ROUTE NAME / NUMBER Interstate 90

Crawford, Murphy & Tilly | Engineers & Consultants
8101 North High Street, Suite 150 | Columbus, OH | 43235

DATE: June 5, 2018

LEGEND

TYPES OF CRASHES	SYMBOLS
Rear End	Moving Vehicle
Right Angle	Stopped Vehicle
Side Swipe	Bicycle
Left Turn	Pedestrian
Head On	Vehicle at Fault
Fixed Object	

ROAD CONDITION		WEATHER CONDITION	
X	Not Stated	X	Not Stated
D	Dry	C	Clear
W	Wet	R	Rain
S	Snow	S	Snow
I	Ice	F	Fog
M	Mud/Sand	L	Cloudy

SEVERITY
PDO - Property Damage Only
INJ - Injury
FAT - Fatal

CRASH DIAGRAM

LOG POINT 9.15 AND 9.44

PERIOD 3 Years FROM 2014 TO 2016

JURISDICTION City of Cleveland

ROUTE NAME / NUMBER Interstate 90

CMT
Crawford, Murphy & Tilly | Engineers & Consultants
8101 North High Street, Suite 150 | Columbus, OH | 43235

DATE: June 5, 2018

LEGEND

TYPES OF CRASHES	SYMBOLS
Rear End	Moving Vehicle
Right Angle	Stopped Vehicle
Side Swipe	Bicycle
Left Turn	Pedestrian
Head On	Vehicle at Fault
Fixed Object	

ROAD CONDITION	
X	Not Stated
D	Dry
W	Wet
S	Snow
I	Ice
M	Mud/Sand

WEATHER CONDITION	
X	Not Stated
C	Clear
R	Rain
S	Snow
F	Fog
L	Cloudy

SEVERITY
PDO - Property Damage Only
INJ - Injury
FAT - Fatal

CRASH DIAGRAM

LOG POINT 9.44 AND 9.74

PERIOD 3 Years FROM 2014 TO 2016

JURISDICTION City of Cleveland

ROUTE NAME / NUMBER Interstate 90

CMT
Crawford, Murphy & Tilly | Engineers & Consultants
8101 North High Street, Suite 150 | Columbus, OH | 43235

DATE: June 5, 2018

LEGEND

TYPES OF CRASHES	SYMBOLS
Rear End	Moving Vehicle
Right Angle	Stopped Vehicle
Side Swipe	Bicycle
Left Turn	Pedestrian
Head On	Vehicle at Fault
Fixed Object	

ROAD CONDITION	
X	Not Stated
D	Dry
W	Wet
S	Snow
I	Ice
M	Mud/Sand

WEATHER CONDITION	
X	Not Stated
C	Clear
R	Rain
S	Snow
F	Fog
L	Cloudy

SEVERITY
PDO - Property Damage Only
INJ - Injury
FAT - Fatal

CRASH DIAGRAM

LOG POINT 9.74 AND 10.03

PERIOD 3 Years FROM 2014 TO 2016

JURISDICTION City of Cleveland

ROUTE NAME / NUMBER Interstate 90

CMT
Crawford, Murphy & Tilly | Engineers & Consultants
8101 North High Street, Suite 150 | Columbus, OH | 43235

DATE: June 5, 2018

LEGEND

TYPES OF CRASHES	SYMBOLS
Rear End	Moving Vehicle
Right Angle	Stopped Vehicle
Side Swipe	Bicycle
Left Turn	Pedestrian
Head On	Vehicle at Fault
Fixed Object	

ROAD CONDITION	
X	Not Stated
D	Dry
W	Wet
S	Snow
I	Ice
M	Mud/Sand

WEATHER CONDITION	
X	Not Stated
C	Clear
R	Rain
S	Snow
F	Fog
L	Cloudy

SEVERITY
PDO - Property Damage Only
INJ - Injury
FAT - Fatal

CRASH DIAGRAM

LOG POINT 3.48 AND 3.65

PERIOD 3 Years FROM 2014 TO 2016

JURISDICTION City of Cleveland

ROUTE NAME / NUMBER Warren Road (CR 66)

CMT
Crawford, Murphy & Tilly | Engineers & Consultants
8101 North High Street, Suite 150 | Columbus, OH | 43235

DATE: June 5, 2018

2016-UrbFwy-069; CUY-90 (9.09)_156 Crashes

	Number
Total	**156**

CRASH_SEVERITY	Number	%
FATAL CRASH	**1**	0.6%
INJURY CRASH	**55**	35.3%
PROPERTY DAMAGE CRASH	**100**	64.1%
Grand Total	**156**	**100.0%**

TRAFFIC_CRASH_YEAR	Number	%
2014	**45**	28.8%
2015	**50**	32.1%
2016	**61**	39.1%
Grand Total	**156**	**100.0%**

DAY_OF_WEEK	Number	%
SATURDAY	**27**	17.3%
THURSDAY	**26**	16.7%
WEDNESDAY	**23**	14.7%
FRIDAY	**22**	14.1%
TUESDAY	**22**	14.1%
SUNDAY	**19**	12.2%
MONDAY	**17**	10.9%
Grand Total	**156**	**100.0%**

HOUR_OF_DAY	Number	%
00	**1**	0.6%
01	**1**	0.6%
02	**2**	1.3%
03	**2**	1.3%
04	**2**	1.3%
05	**1**	0.6%
06	**4**	2.6%
07	**10**	6.4%
08	**8**	5.1%
09	**9**	5.8%
10	**5**	3.2%
11	**4**	2.6%
12	**10**	6.4%
13	**6**	3.8%
14	**11**	7.1%
15	**8**	5.1%
16	**17**	10.9%
17	**10**	6.4%
18	**12**	7.7%
19	**11**	7.1%
20	**6**	3.8%
21	**8**	5.1%
22	**3**	1.9%
23	**5**	3.2%
Grand Total	**156**	**100.0%**

TYPE_OF_CRASH	Number	%
ANGLE	**53**	34.0%
REAR END	**45**	28.8%
SIDESWIPE - PASSING	**30**	19.2%
FIXED OBJECT	**11**	7.1%
LEFT TURN	**5**	3.2%
HEAD ON	**4**	2.6%
OTHER NON-COLLISION	**2**	1.3%
BACKING	**1**	0.6%
NOT STATED	**1**	0.6%
PEDALCYCLES	**1**	0.6%
PEDESTRIAN	**1**	0.6%
SIDESWIPE - MEETING	**1**	0.6%
OTHER OBJECT	**1**	0.6%
Grand Total	**156**	**100.0%**

2016-UrbFwy-069; CUY-90 (9.09)_156 Crashes

WEATHER_CONDITION	Number	%
NO ADVERSE WEATHER CONDITION	**119**	76.3%
RAIN	**22**	14.1%
SNOW	**12**	7.7%
OTHER WEATHER CONDITION	**3**	1.9%
Grand Total	**156**	**100.0%**

ROAD_CONDITION	Number	%
ROAD - DRY	**98**	62.8%
ROAD - WET	**39**	25.0%
ROAD - SNOW	**13**	8.3%
ROAD - ICE	**4**	2.6%
ROAD CONDITION NOT STATED	**2**	1.3%
Grand Total	**156**	**100.0%**

LIGHT_CONDITION	Number	%
DAYLIGHT	**102**	65.4%
DARK - LIGHTED	**42**	26.9%
LIGHT NOT STATED	**4**	2.6%
DUSK	**4**	2.6%
DAWN	**3**	1.9%
DARK - NO LIGHTS	**1**	0.6%
Grand Total	**156**	**100.0%**

NUMBER_OF_VEHICLES		Number	%
	1	**13**	8.3%
	2	**133**	85.3%
	3	**10**	6.4%
Grand Total		**156**	**100.0%**

LOCATION	Number	%
INTERSECTION	**109**	69.9%
NON-INTERSECTION	**30**	19.2%
INTERSECTION RELATED	**16**	10.3%
LOCATION NOT STATED	**1**	0.6%
Grand Total	**156**	**100.0%**

CRASH_MONTH_NBR		Number	%
	1	**18**	11.5%
	2	**8**	5.1%
	3	**12**	7.7%
	4	**12**	7.7%
	5	**6**	3.8%
	6	**10**	6.4%
	7	**11**	7.1%
	8	**12**	7.7%
	9	**19**	12.2%
	10	**18**	11.5%
	11	**14**	9.0%
	12	**16**	10.3%
Grand Total		**156**	**100.0%**

ROAD_CONTOUR	Number	%
STRAIGHT - LEVEL	**145**	92.9%
STRAIGHT - GRADE	**8**	5.1%
CURVE - GRADE	**2**	1.3%
CONTOUR NOT STATED	**1**	0.6%
Grand Total	**156**	**100.0%**

SPECIAL_AREA	Number	%
SPECIAL AREA - NOT STATED	**155**	99.4%
ROAD CONSTRUCTION/MAINTENANCE ARE	**1**	0.6%
Grand Total	**156**	**100.0%**

ANIMAL_TYPE	Number	%
ANIMAL NOT STATED	**156**	100.0%
Grand Total	**156**	**100.0%**

2016-UrbFwy-069; CUY-90 (9.09)_156 Crashes

ACTION1	Number	%
GOING STRAIGHT	76	48.7%
TURNING LEFT	24	15.4%
OTHER ACTION	18	11.5%
STOPPED IN TRAFFIC	12	7.7%
CHANGING LANES	11	7.1%
TURNING RIGHT	9	5.8%
ACTION NOT STATED	6	3.8%
Grand Total	**156**	**100.0%**

CONTRIBUTING_FACTOR1	Number	%
OTHER DRIVER ERROR	34	21.8%
FOLLOWING TOO CLOSE	28	17.9%
FAILURE TO CONTROL	27	17.3%
RAN RED LIGHT	23	14.7%
FAILURE TO YIELD	20	12.8%
NO DRIVER ERRORS	8	5.1%
IMPROPER LANE CHANGE	6	3.8%
IMPROPER TURNING	5	3.2%
DROVE OFF ROAD-REASON UNKNOWN	2	1.3%
VEHICLE DEFECT	1	0.6%
EXCESSIVE SPEED	1	0.6%
PAVEMENT DEFECT	1	0.6%
Grand Total	**156**	**100.0%**

	Number	%
Total	**156**	**100.0%**

TRAFFIC_CONTROL1	Number	%
TRAFFIC SIGNAL	102	65.4%
NO TRAFFIC CONTROL DRIVER	32	20.5%
PAVEMENT MARKINGS	16	10.3%
STOP SIGN	3	1.9%
TRAFFIC FLASHERS	2	1.3%
YIELD SIGN	1	0.6%
Grand Total	**156**	**100.0%**

DRIVER_ALCOHOL1	Number	%
NO ALCOHOL DETECTED	127	81.4%
ALCOHOL NOT STATED	18	11.5%
HBD - ABILITY UNKNOWN	7	4.5%
HBD - ABILITY IMPAIRED	4	2.6%
Grand Total	**156**	**100.0%**

DRIVER_DRUGS1	Number	%
NO DRUGS DETECTED	129	82.7%
DRUGS NOT STATED	25	16.0%
USING PRESCRIBED DRUG	2	1.3%
Grand Total	**156**	**100.0%**

2016-UrbFwy-069; CUY-90 (9.09)_156 Crashes

DIRECTION_FROM1	Number	%
NORTH	37	23.7%
WEST	37	23.7%
EAST	33	21.2%
SOUTH	29	18.6%
UNKNOWN	19	12.2%
NORTHWEST	1	0.6%
Grand Total	**156**	**100.0%**

DIRECTION_TO1	Number	%
UNKNOWN	37	23.7%
EAST	33	21.2%
NORTH	32	20.5%
WEST	31	19.9%
SOUTH	22	14.1%
SOUTHEAST	1	0.6%
Grand Total	**156**	**100.0%**

POSTED_SPEED1	Number	%
POSTED 35	70	44.9%
POSTED 25	51	32.7%
POSTED OVER 55	24	15.4%
POSTED SPEED NOT STATED	9	5.8%
POSTED 30	1	0.6%
POSTED 55	1	0.6%
Grand Total	**156**	**100.0%**

ESTIMATED_SPEED1	Number	%
SPEED 20 AND UNDER	62	39.7%
VEHICLE SPEED NOT STATED	23	14.7%
SPEED 21-25	23	14.7%
SPEED 26-35	20	12.8%
SPEED 46-55	9	5.8%
SPEED 56-65	7	4.5%
NO SPEED - VEHICLE STOPPED	5	3.2%
SPEED 36-45	5	3.2%
SPEED 66-75	1	0.6%
OVER 75	1	0.6%
Grand Total	**156**	**100.0%**

VEHICLE_TYPE1	Number	%
MID-SIZE	56	35.9%
OTHER VEHICLE	55	35.3%
COMPACT	17	10.9%
FULL-SIZE	14	9.0%
PICKUP TRUCK	6	3.8%
TRACTOR SEMI TRAILER	2	1.3%
STRAIGHT TRUCK	2	1.3%
SUB-COMPACT	1	0.6%
MOTORCYCLE - 351CC-750CC	1	0.6%
TAXI	1	0.6%
PANEL TRUCK	1	0.6%
Grand Total	**156**	**100.0%**

VEHICLE_TYPE2	Number	%
OTHER VEHICLE	52	33.3%
MID-SIZE	47	30.1%
COMPACT	19	12.2%
VEHICLE NOT STATED	13	8.3%
FULL-SIZE	7	4.5%
PICKUP TRUCK	7	4.5%
PANEL TRUCK	2	1.3%
POLICE VEHICLE	2	1.3%
STRAIGHT TRUCK	2	1.3%
STRAIGHT TRUCK TRAILER	1	0.6%
BICYCLE	1	0.6%
MOTORCYCLE - 351CC-750CC	1	0.6%
TRUCK TRACTOR	1	0.6%
FIRE TRUCK	1	0.6%
Grand Total	**156**	**100.0%**

2016-UrbFwy-069; CUY-90 (9.09)_156 Crashes

ACTION2	Number	%
GOING STRAIGHT	79	50.6%
STOPPED IN TRAFFIC	43	27.6%
TURNING LEFT	14	9.0%
ACTION NOT STATED	13	8.3%
OTHER ACTION	2	1.3%
CHANGING LANES	2	1.3%
BACKING	1	0.6%
TURNING RIGHT	1	0.6%
PARKED	1	0.6%
Grand Total	**156**	**100.0%**

CONTRIBUTING_FACTOR2	Number	%
NO DRIVER ERRORS	132	84.6%
(blank)	13	8.3%
OTHER DRIVER ERROR	9	5.8%
IMPROPER LANE CHANGE	1	0.6%
RAN RED LIGHT	1	0.6%
Grand Total	**156**	**100.0%**

DIRECTION_FROM2	Number	%
SOUTH	41	26.3%
WEST	36	23.1%
EAST	34	21.8%
NORTH	30	19.2%
(blank)	13	8.3%
UNKNOWN	1	0.6%
SOUTHEAST	1	0.6%
Grand Total	**156**	**100.0%**

DIRECTION_TO2	Number	%
NORTH	44	28.2%
EAST	32	20.5%
WEST	32	20.5%
SOUTH	28	17.9%
(blank)	13	8.3%
UNKNOWN	5	3.2%
SOUTHEAST	1	0.6%
NORTHWEST	1	0.6%
Grand Total	**156**	**100.0%**

DRIVER_ALCOHOL2	Number	%
NO ALCOHOL DETECTED	139	89.1%
ALCOHOL NOT STATED	16	10.3%
HBD - ABILITY UNKNOWN	1	0.6%
Grand Total	**156**	**100.0%**

DRIVER_DRUGS2	Number	%
NO DRUGS DETECTED	139	89.1%
DRUGS NOT STATED	17	10.9%
Grand Total	**156**	**100.0%**

2016-UrbFwy-069; CUY-90 (9.09)_156 Crashes

SEVERITY	CRASH_SEVERITY		
TRAFFIC_CRASH_YEAR	PROPERTY DAMAGE CRASH	INJURY CRASH	FATAL CRASH
2014	35	10	0
2015	31	19	0
2016	34	26	1
Grand Total	**100**	**55**	**1**

TRAFFIC_CRASH_YEAR	Fatalities	Incapacitating Injuries
2014	0	0
2015	0	0
2016	1	1
Grand Total	**1**	**1**

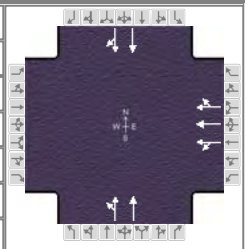
TRAFFIC_CRASH_YEAR	INJ_TYPE2_SERIOUS_VISIBLE	INJ_TYPE3_MINOR_VISIBLE	INJ_TYPE4_NO_VISIBLE
2014	0	6	9
2015	0	10	18
2016	1	6	31
Grand Total	**1**	**22**	**58**

CUY-90-9.09 SAFETY STUDY

APPENDIX C: CAPACITY ANALYSIS

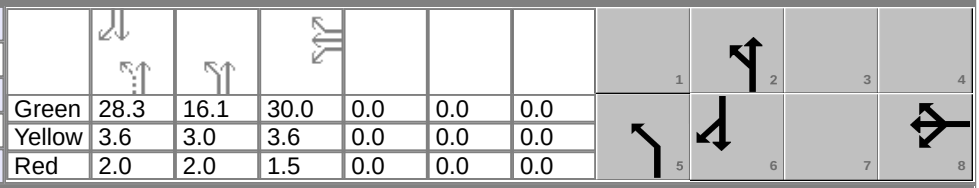
HCS 2010 Signalized Intersection Results Summary

General Information				Intersection Information	
Agency				Duration, h	0.25
Analyst		Analysis Date	6/29/2018	Area Type	CBD
Jurisdiction		Time Period		PHF	1.00
Urban Street	CUY-90 (Warren Road) at	Analysis Year	2018	Analysis Period	1> 7:00
Intersection	Lakewood Heights Blvd	File Name	HCS_AM_Warren at Lakewood Heights_2018062…		
Project Description	AM Peak				



Demand Information	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Demand (*v*), veh/h				169	411	154	150	334			694	25

Signal Information			
Cycle, s	90.1	Reference Phase	2
Offset, s	0	Reference Point	End
Uncoordinated	Yes	Simult. Gap E/W	On
Force Mode	Fixed	Simult. Gap N/S	On



Green	28.3	16.1	30.0	0.0	0.0	0.0			
Yellow	3.6	3.0	3.6	0.0	0.0	0.0			
Red	2.0	2.0	1.5	0.0	0.0	0.0			

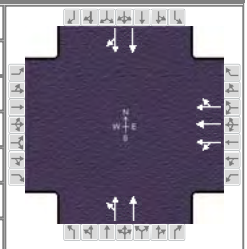
Timer Results	EBL	EBT	WBL	WBT	NBL	NBT	SBL	SBT
Assigned Phase				8	5	2		6
Case Number				12.0	0.0	14.0		8.3
Phase Duration, s				35.1	21.1	55.0		33.9
Change Period, ($Y+R_c$), s				5.1	5.0	5.0		5.6
Max Allow Headway (*MAH*), s				3.2	0.0	3.9		3.2
Queue Clearance Time (g_s), s				13.9		52.0		27.8
Green Extension Time (g_e), s				1.6	0.0	0.0		0.5
Phase Call Probability				1.00		1.00		1.00
Max Out Probability				0.00		1.00		1.00

Movement Group Results	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Assigned Movement				3	8	18	5	2			6	16
Adjusted Flow Rate (*v*), veh/h				264	246	225	198	286			362	357
Adjusted Saturation Flow Rate (*s*), veh/h/ln				1600	1651	1470	541	1552			1702	1680
Queue Service Time (g_s), s				11.9	10.5	10.8	6.0	9.1			25.8	16.7
Cycle Queue Clearance Time (g_c), s				11.9	10.5	10.8	50.0	9.1			25.8	16.7
Green Ratio (*g/C*)				0.33	0.33	0.33	0.55	0.55			0.31	0.31
Capacity (*c*), veh/h				533	550	489	370	861			534	528
Volume-to-Capacity Ratio (*X*)				0.495	0.447	0.459	0.534	0.332			0.677	0.677
Back of Queue (*Q*), ft/ln (50 th percentile)				111.7	102.1	94	95.7	75			175.4	173.5
Back of Queue (*Q*), veh/ln (50 th percentile)				4.5	4.1	3.8	3.8	3.0			7.0	6.9
Queue Storage Ratio (*RQ*) (50 th percentile)				0.32	0.30	0.27	0.33	0.26			0.44	0.44
Uniform Delay (d_1), s/veh				24.0	23.5	23.7	29.4	10.9			26.9	26.9
Incremental Delay (d_2), s/veh				0.3	0.2	0.3	0.8	0.1			2.3	2.4
Initial Queue Delay (d_3), s/veh				0.0	0.0	0.0	0.0	0.0			0.0	0.0
Control Delay (*d*), s/veh				24.3	23.8	23.9	30.2	11.0			29.2	29.3
Level of Service (LOS)				C	C	C	C	B			C	C
Approach Delay, s/veh / LOS	0.0			24.0		C	18.8		B	29.3		C
Intersection Delay, s/veh / LOS	24.7						C					

Multimodal Results	EB		WB		NB		SB	
Pedestrian LOS Score / LOS	2.7	B	2.7	B	1.9	A	2.8	C
Bicycle LOS Score / LOS			0.9	A	0.9	A	1.1	A

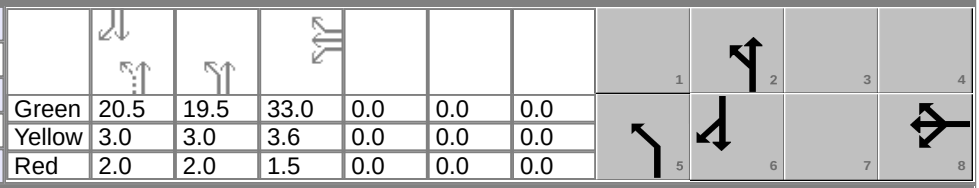
HCS 2010 Signalized Intersection Results Summary

General Information				Intersection Information	
Agency				Duration, h	0.25
Analyst		Analysis Date	6/29/2018	Area Type	CBD
Jurisdiction		Time Period		PHF	1.00
Urban Street	CUY-90 (Warren Road) at	Analysis Year	2018	Analysis Period	1> 7:00
Intersection	Lakewood Heights Blvd	File Name	HCS_PM_Warren at Lakewood Heights_2018062…		
Project Description	PM Peak				



Demand Information	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Demand (*v*), veh/h				333	641	339	239	547			559	41

Signal Information			
Cycle, s	88.1	Reference Phase	2
Offset, s	0	Reference Point	End
Uncoordinated	Yes	Simult. Gap E/W	On
Force Mode	Fixed	Simult. Gap N/S	On



Green	20.5	19.5	33.0	0.0	0.0	0.0			
Yellow	3.0	3.0	3.6	0.0	0.0	0.0			
Red	2.0	2.0	1.5	0.0	0.0	0.0			

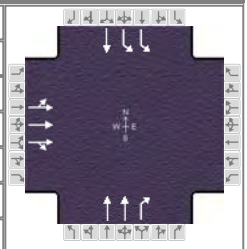
Timer Results	EBL	EBT	WBL	WBT	NBL	NBT	SBL	SBT
Assigned Phase				8	5	2		6
Case Number				12.0	0.0	14.0		8.3
Phase Duration, s				38.1	24.5	50.0		25.5
Change Period, ($Y+R_c$), s				5.1	5.0	5.0		5.0
Max Allow Headway (*MAH*), s				3.3	0.0	3.7		3.2
Queue Clearance Time (g_s), s				25.5		47.0		19.4
Green Extension Time (g_e), s				2.5	0.0	0.0		1.1
Phase Call Probability				1.00		1.00		1.00
Max Out Probability				0.24		1.00		0.00

Movement Group Results	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Assigned Movement				3	8	18	5	2			6	16
Adjusted Flow Rate (*v*), veh/h				476	449	388	353	433			303	297
Adjusted Saturation Flow Rate (*s*), veh/h/ln				1596	1651	1427	714	1568			1702	1660
Queue Service Time (g_s), s				23.5	20.5	20.6	6.0	16.5			17.4	14.7
Cycle Queue Clearance Time (g_c), s				23.5	20.5	20.6	45.0	16.5			17.4	14.7
Green Ratio (*g/C*)				0.37	0.37	0.37	0.51	0.51			0.23	0.23
Capacity (*c*), veh/h				598	619	535	434	801			396	387
Volume-to-Capacity Ratio (*X*)				0.797	0.725	0.726	0.813	0.541			0.765	0.768
Back of Queue (*Q*), ft/ln (50 th percentile)				240	208.4	182.2	203.4	142			151.7	148.8
Back of Queue (*Q*), veh/ln (50 th percentile)				9.6	8.3	7.3	8.1	5.7			6.1	6.0
Queue Storage Ratio (*RQ*) (50 th percentile)				0.70	0.61	0.53	0.70	0.49			0.38	0.37
Uniform Delay (d_1), s/veh				24.6	23.7	23.7	30.5	14.6			31.5	31.6
Incremental Delay (d_2), s/veh				6.0	3.1	3.6	10.5	0.4			1.2	1.2
Initial Queue Delay (d_3), s/veh				0.0	0.0	0.0	0.0	0.0			0.0	0.0
Control Delay (*d*), s/veh				30.6	26.8	27.3	41.0	15.0			32.7	32.8
Level of Service (LOS)				C	C	C	D	B			C	C
Approach Delay, s/veh / LOS	0.0			28.3		C	26.7		C	32.8		C
Intersection Delay, s/veh / LOS	28.8						C					

Multimodal Results	EB		WB		NB		SB	
Pedestrian LOS Score / LOS	2.7	B	2.7	B	1.9	A	2.8	C
Bicycle LOS Score / LOS			1.2	A	1.1	A	1.0	A

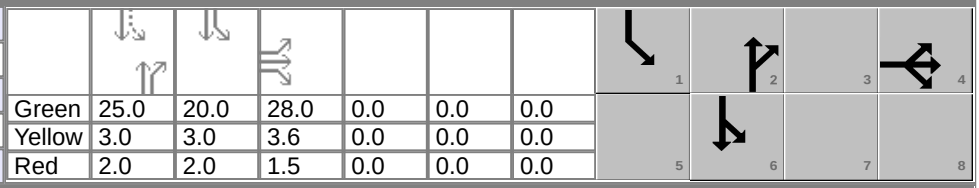
HCS 2010 Signalized Intersection Results Summary

General Information				Intersection Information	
Agency				Duration, h	0.25
Analyst		Analysis Date	6/29/2018	Area Type	CBD
Jurisdiction		Time Period		PHF	1.00
Urban Street	CUY-90 (Warren Road) at	Analysis Year	2018	Analysis Period	1> 7:00
Intersection	S. Marginal Drive	File Name	HCS_AM_Warren at S. Marginal Drive_20180629…		
Project Description	AM Peak				



Demand Information	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Demand (*v*), veh/h	91	841	142					399	343	420	432	

Signal Information			
Cycle, s	88.1	Reference Phase	2
Offset, s	0	Reference Point	End
Uncoordinated	Yes	Simult. Gap E/W	On
Force Mode	Fixed	Simult. Gap N/S	On



Green	25.0	20.0	28.0	0.0	0.0	0.0						
Yellow	3.0	3.0	3.6	0.0	0.0	0.0						
Red	2.0	2.0	1.5	0.0	0.0	0.0						

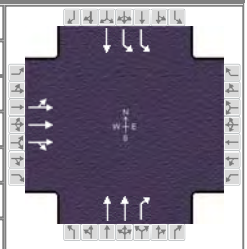
Timer Results	EBL	EBT	WBL	WBT	NBL	NBT	SBL	SBT
Assigned Phase		4				2	1	6
Case Number		12.0				7.3	1.0	4.0
Phase Duration, s		33.1				30.0	25.0	55.0
Change Period, ($Y+R_c$), s		5.1				5.0	5.0	5.0
Max Allow Headway (*MAH*), s		3.1				3.2	3.2	3.2
Queue Clearance Time (g_s), s		20.4				22.4	2.0	15.1
Green Extension Time (g_e), s		2.1				1.7	1.5	2.1
Phase Call Probability		1.00				1.00	1.00	1.00
Max Out Probability		0.00				0.00	0.00	0.00

Movement Group Results	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Assigned Movement	7	4	14					2	12	1	6	
Adjusted Flow Rate (*v*), veh/h	387	356	332					399	343	420	432	
Adjusted Saturation Flow Rate (*s*), veh/h/ln	1649	1668	1548					1580	1407	1550	1693	
Queue Service Time (g_s), s	18.4	16.3	16.4					9.1	20.4	0.0	13.1	
Cycle Queue Clearance Time (g_c), s	18.4	16.3	16.4					9.1	20.4	0.0	13.1	
Green Ratio (*g/C*)	0.32	0.32	0.32					0.28	0.28	0.49	0.57	
Capacity (*c*), veh/h	524	530	492					897	399	1146	961	
Volume-to-Capacity Ratio (*X*)	0.738	0.671	0.674					0.445	0.859	0.366	0.450	
Back of Queue (*Q*), ft/ln (50 th percentile)	174.6	158.2	145.6					84.2	169.6	85.6	117.6	
Back of Queue (*Q*), veh/ln (50 th percentile)	7.0	6.2	5.8					3.3	6.8	3.4	4.6	
Queue Storage Ratio (*RQ*) (50 th percentile)	0.22	0.20	0.18					0.08	0.98	0.29	0.39	
Uniform Delay (d_1), s/veh	26.8	26.1	26.1					25.9	29.9	21.7	11.1	
Incremental Delay (d_2), s/veh	0.8	0.6	0.6					0.1	2.1	0.1	0.1	
Initial Queue Delay (d_3), s/veh	0.0	0.0	0.0					0.0	0.0	0.0	0.0	
Control Delay (*d*), s/veh	27.6	26.6	26.7					26.0	32.0	21.8	11.2	
Level of Service (LOS)	C	C	C					C	C	C	B	
Approach Delay, s/veh / LOS	27.0	C		0.0			28.8	C		16.4	B	
Intersection Delay, s/veh / LOS	24.1						C					

Multimodal Results	EB		WB		NB		SB	
Pedestrian LOS Score / LOS	2.5	B	2.9	C	2.8	C	1.9	A
Bicycle LOS Score / LOS	1.1	A			1.1	A	1.9	A

HCS 2010 Signalized Intersection Results Summary

General Information				Intersection Information	
Agency				Duration, h	0.25
Analyst		Analysis Date	6/29/2018	Area Type	CBD
Jurisdiction		Time Period		PHF	1.00
Urban Street	CUY-90 (Warren Road) at	Analysis Year	2018	Analysis Period	1> 7:00
Intersection	S. Marginal Drive	File Name	HCS_PM_Warren at S. Marginal Drive_20180629…		
Project Description	AM Peak				



Demand Information	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Demand (*v*), veh/h	197	518	260					590	160	233	652	

Signal Information												
Cycle, s	65.7	Reference Phase	2									
Offset, s	0	Reference Point	End									
Uncoordinated	Yes	Simult. Gap E/W	On									
Force Mode	Fixed	Simult. Gap N/S	On									
				Green	15.4	7.3	28.0	0.0	0.0	0.0		
				Yellow	3.0	3.0	3.6	0.0	0.0	0.0		
				Red	2.0	2.0	1.5	0.0	0.0	0.0		

Timer Results	EBL	EBT	WBL	WBT	NBL	NBT	SBL	SBT
Assigned Phase		4				2	1	6
Case Number		12.0				7.3	1.0	4.0
Phase Duration, s		33.1				20.4	12.3	32.6
Change Period, ($Y+R_c$), s		5.1				5.0	5.0	5.0
Max Allow Headway (*MAH*), s		3.1				3.1	3.2	3.2
Queue Clearance Time (g_s), s		12.6				13.6	2.0	25.5
Green Extension Time (g_e), s		2.0				1.8	2.1	2.1
Phase Call Probability		1.00				1.00	0.99	1.00
Max Out Probability		0.00				0.00	0.00	0.00

Movement Group Results	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Assigned Movement	7	4	14					2	12	1	6	
Adjusted Flow Rate (*v*), veh/h	355	331	289					590	160	233	652	
Adjusted Saturation Flow Rate (*s*), veh/h/ln	1623	1668	1434					1580	1420	1566	1710	
Queue Service Time (g_s), s	10.6	9.3	9.5					11.6	6.4	0.0	23.5	
Cycle Queue Clearance Time (g_c), s	10.6	9.3	9.5					11.6	6.4	0.0	23.5	
Green Ratio (*g/C*)	0.43	0.43	0.43					0.23	0.23	0.31	0.42	
Capacity (*c*), veh/h	691	711	611					739	332	607	719	
Volume-to-Capacity Ratio (*X*)	0.513	0.466	0.473					0.799	0.482	0.384	0.907	
Back of Queue (*Q*), ft/ln (50 th percentile)	84.9	78.2	67.7					102.1	49.9	39.9	222.3	
Back of Queue (*Q*), veh/ln (50 th percentile)	3.4	3.1	2.7					4.0	2.0	1.6	8.8	
Queue Storage Ratio (*RQ*) (50 th percentile)	0.11	0.10	0.09					0.10	0.29	0.13	0.74	
Uniform Delay (d_1), s/veh	13.9	13.5	13.6					23.7	21.7	25.8	17.9	
Incremental Delay (d_2), s/veh	0.2	0.2	0.2					0.8	0.4	0.1	1.9	
Initial Queue Delay (d_3), s/veh	0.0	0.0	0.0					0.0	0.0	0.0	0.0	
Control Delay (*d*), s/veh	14.1	13.7	13.8					24.5	22.1	26.0	19.8	
Level of Service (LOS)	B	B	B					C	C	C	B	
Approach Delay, s/veh / LOS	13.9	B		0.0			24.0	C		21.4	C	
Intersection Delay, s/veh / LOS	19.3						B					

Multimodal Results	EB		WB		NB		SB	
Pedestrian LOS Score / LOS	2.5	B	2.9	C	2.8	C	1.9	A
Bicycle LOS Score / LOS	1.0	A			1.1	A	1.9	A

CUY-90-9.09 SAFETY STUDY

APPENDIX D: FYA IMPLEMENTATION PLAN

TECHNICAL PROJECT MEMORANDUM

VAR-D12/D03 Traffic Engineering Servs
ODOT D12 Flashing Yellow Arrow (FYA) Technical Memorandum

TO: **Brian Blayney, Ohio Department of Transportation**

CC: Consultant Team

FROM: John Albeck, Albeck Gerken, Inc.; Scott Knebel, Crawford, Murphy & Tilly

SUBJECT: VAR-D12 Traffic Engineering Services
FYA Technical Memorandum

DATE: January 3, 2017

I. Introduction

The purpose of this technical memorandum is to present the results of an investigation regarding the deployment and implementation of the Flashing Yellow Arrow (FYA) left-turn treatment in Ohio, specifically, ODOT District 12.

A FYA traffic signal head features a flashing yellow arrow indication in addition to red, yellow and green steady arrow indications. While the flashing yellow arrow indication is displayed, left turns are permitted, but the motorist must first yield to oncoming traffic and pedestrians. Though the signal display is different from five-section heads used for protected/permissive left turn phasing, the flow of vehicles and the left turn phasing at the intersection is the same as traditional protected/permissive signals.

The FYA was added as a configuration for protected/permissive and permissive left-turn signal heads in the Federal 2009 Manual on Uniform Traffic Control Devices (MUTCD) and is currently being used in a majority of states nationwide. As a result, there has been increased interest in applying the FYA signal head for left turn signal phasing within communities in Ohio, and this paper provides background on the safety and operational implications of its use.

With more widespread implementation of the FYA since its inclusion in the MUTCD, the term FYA has taken on a number of meanings and is used to describe many aspects of signal operation. Specifically it has been used in the context of the following terms:

- Phasing – refers to the sequence of right-of-way, yellow change and red clearance intervals for vehicular movements at the signalized intersection. When used in the context of FYA, it typically refers to the use of turning movement phases.
- Mode – refers to possible types of turning movement phases. When used in the context of FYA it typically refers to permissive and protected/permissive turn movements or those same movements in combination with a protected-only phase.

- Display – refers to the arrangement of indications in a signal head. When used in the context of FYA, it typically refers to the four-section or three-section heads described above.
- Indication – refers to the particular lens in a signal display. When used in the context of FYA, it typically refers to the flashing yellow arrow lens.
- Operation – refers to a sequence of events. In the context of FYA; when describing the operation of the signal display it typically refers to the progression of illumination of lenses in the signal face. When describing the operation of the signalized intersection, it typically refers to the selection of phases and modes and the progression of ROW assignment through those phases.

II. History and Current State of the Practice

Accommodating left-turning traffic at signalized intersections has long been an issue for traffic engineers. Traditionally, the driver was required to find a gap in the opposing traffic and yield to oncoming traffic prior to proceeding. As a result of this conflict of movements, successfully accommodating left-turn and opposing through movement vehicles is critical to the safe and efficient operation of signalized intersections. Since the first traffic signal, a circular green indication has allowed left turns to be permitted after yielding to oncoming traffic and conflicting pedestrians.

Protected/Prohibited Left-Turn Phasing

With protected/prohibited phasing, left-turn movements are "protected" and have the right-of-way when a green arrow is displayed, and are prohibited via the display of a red indication in the left-turn signal head at all other times. Protected/prohibited left-turn phasing was implemented using a three-section head with green arrow, circular yellow, and circular red indications prior to the 1971 MUTCD, and the use of a supplementary LEFT TURN SIGNAL sign was required. The 1971 MUTCD introduced the red and yellow arrows, although the red arrow was not mandatory until the 2009 MUTCD.

Protected/Permissive Left-Turn (PPLT) Phasing

In PPLT operation, the left turn has the advantages of both the protected phase (green arrow) and the permissive phase (circular green). Since the 1988 edition of the MUTCD, a yellow arrow is required to terminate a green arrow indication unless the adjacent circular green indication terminates at the same time (in which case the circular yellow can serve as the clearance for both the left-turn and adjacent through movements). Ohio has traditionally used a five-section cluster signal head, "doghouse," for protected/permissive left-turn movements since the 1980s.

Since the MUTCD didn't specify a standard display for protected/permissive left-turn phasing, various displays were implemented throughout the United States and these were investigated extensively in National Cooperative Highway Research program (NCHRP) Report 493 (2003), Evaluation of Traffic Signal Displays for Protected/Permissive Left-Turn Control. NCHRP Report 493 identified the FYA as the best overall alternative to the circular green as the permissive signal display for a left-turn movement.

In March of 2006, the FHWA issued Interim Approval for Optional Use of Flashing Yellow Arrow for Permissive Left Turns. Many states and local municipalities implemented the FYA based on this interim

approval. FYA operation was ultimately approved for optional use in the 2009 MUTCD using a four-section head for protected/permissive operation (red arrow, yellow arrow, flashing yellow arrow, and green arrow) and a three-section head for permissive left-turn operation (red arrow, yellow arrow, flashing yellow arrow). Since then a majority of states have implemented FYA use at some or all PPLT locations.

On August 12, 2014, the FHWA issued Interim Approval 17 to permit the optional use of a three-section flashing yellow arrow (FYA) signal face that uses the middle section to show both the FYA and the steady yellow arrow.

III. Background

Concerns with Current State of Practice

Investigation of the FYA signal head was undertaken on a national level because there were concerns with the understanding of existing signal head displays when conveying the intent of permissive and protected/permissive left turn phasing at intersections. Those concerns are described in more detail below.

Circular Green for Permissive Left Turns

Engineers have had concern that drivers turning left on a permissive circular green signal indication might inadvertently mistake that indication as implying the left turn has the right-of-way over the opposing traffic. National studies, such as NCHRP Report 493, have found that displaying a circular green signal indication in a separate signal face over or directly in line with an exclusive left-turn lane causes the largest amount of driver confusion and inappropriate behavior when turning left, and produces a higher left-turn crash rate than "shared" displays with a circular green that are placed over the lane line between the left-turn lane and the adjacent through lane, or to the right of that line. When a driver incorrectly interprets the circular green over the left-turn lane as meaning they have the right-of-way to turn without yielding, the resulting crash can be serious. This is why for decades some jurisdictions have been experimenting with alternative permissive left-turn displays such as flashing yellow arrow, flashing circular yellow, etc.

This concern was partially mitigated with guidance added to Section 4D.13 of the 2009 MUTCD which recommends against locating signal heads with a circular green over or directly in line with an exclusive left-turn lane as follows:

> "For new or reconstructed signal installations, on an approach with an exclusive turn lane(s) for a left-turn (or U-turn to the left) movement and with opposing vehicular traffic, signal faces that display a CIRCULAR GREEN signal indication should not be post-mounted on the far-side median or mounted overhead above the exclusive turn lane(s) or the extension of the lane(s)."

NCHRP Report 493 found the FYA to have a high level of understanding and correct response by left-turn drivers and a lower fail-critical rate than the circular green, and drivers had fewer crashes with flashing yellow left-turn arrows than with traditional yield-on-green signal configurations.

Left-Turn Trap

The combination of a permissive left turns with lead-lag operation creates a situation commonly called the “left-turn trap” (when no FYA is used).

Consider **Exhibit 1** for an eastbound leading left scenario. There is no real problem with the westbound situation here; these left turners are presented in Stage 2 with a circular green after a period of obvious opposing flow. It is clear they must yield to the eastbound through traffic. In Stage 3 this movement is protected and, again there is no problem. The transition is given by circular green direct to green arrow, but even if a circular yellow was displayed at the end of Stage 2, there is no problem.

The problem is with the eastbound left turns. If this scenario is allowed, any left-turning motorist who had not been able to find a gap during the Stage 2 green would be presented with a yellow indication at its end. Since these drivers see a yellow indication on all facing displays (through and left), they may incorrectly presume that the westbound through is likewise receiving a yellow indication and is about to stop. When the signal turns red (eastbound) the left-turning motorist will: 1) be stuck in the middle of the intersection with nowhere to go, or 2) attempt the left turn thinking the opposing traffic is stopping.

Refer to page **12** for information on how the flashing yellow arrow can eliminate the left-turn trap condition.

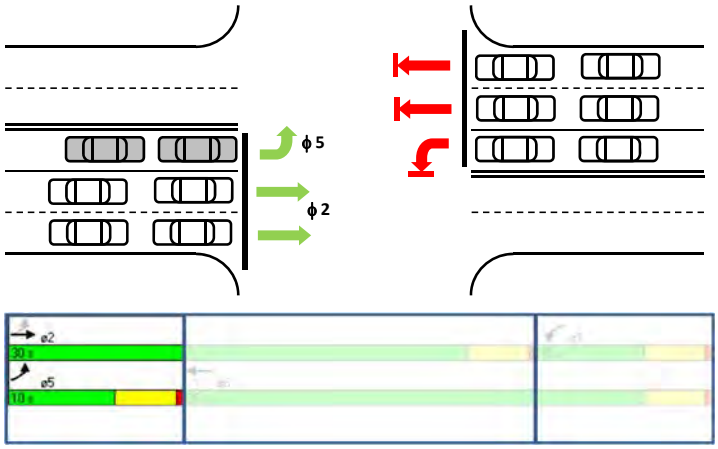
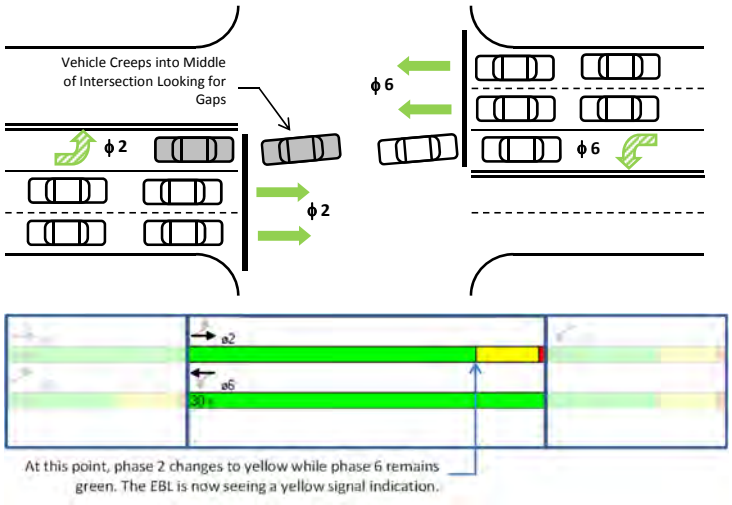
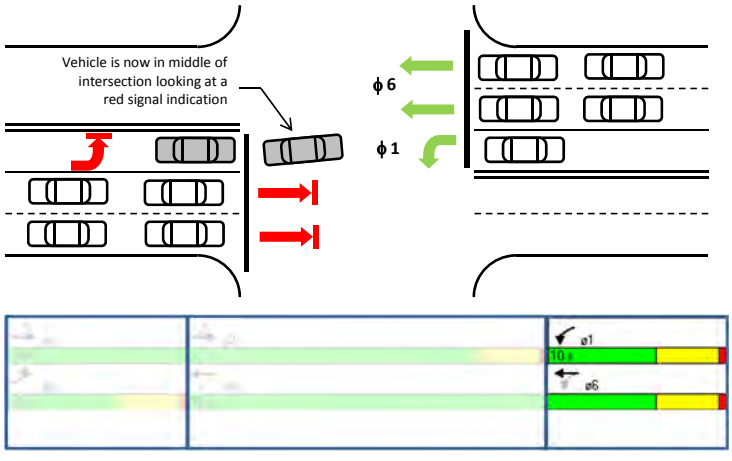
The following link is a video illustrating the left turn trap with a traditional five-second protected/permissive signal with lead/lag left turn phasing.

https://shareSync.serverdata.net/web/s/0Fy9OVuMbIg5xO71dCoUvN.

A left turn trap is also possible even when the protected/permissive five-second indications are both lagging. The following video illustrates this issue.

https://shareSync.serverdata.net/web/s/7DH5s98MC8TRU5d2fhXYYx.

Exhibit 1 Lead/Lag Left-Turn Trap

	**Stage 1**: Phase 5 eastbound (EBL) shows a protected left-turn arrow while phase 2 eastbound shows a circular green. The opposing WB movements are stopped. No issues during this stage; the left-turn vehicles have a protected movement.
	**Stage 2**: The EBL and WBL now operate as permissive lefts (sees a circular green indication). During this stage, the EBL may creep into the middle of the intersection looking for gaps in the opposing traffic. Note that the EBL is actually operating as Phase 2 permissive. At the end of this stage is when the problem occurs. Phase 2 indications will change to yellow. The EBL vehicle now has to consider how to clear the intersection and may falsely assume the opposing through is seeing a yellow indication and is about to stop. In fact, the WBT remains green since phase 1 WBL is up next.
	**Stage 3**: Now, phase 1 WBL shows a green arrow (protected) operation while phase 6 WBT remains green. The EBL may have assumed the WBT was stopping and attempts to sneak through the intersections creating a crash situation.

Protected/Prohibited Operation during Low Volume Periods

Protected/prohibited left-turn phasing requires all left-turning vehicles to wait for a green arrow to complete the turn. Aside from geometric considerations, the primary criteria for establishing a protected/prohibited left-turn phase is based on high volumes of left-turn traffic and/or high volumes of opposing traffic. Implementation of protected/prohibited left-turn phasing based on volume thresholds for peak hours can lead to operational inefficiencies and delays for the remainder of the day when the left-turn motorist would have adequate gaps and sight distance to safely proceed through as a permissive left turn. This would occur during periods of lower opposing volumes.

Left-Turn Display Research

NCHRP 3-54 Research on PPLT Displays

NCHRP Project 3-54, *Evaluation of Traffic Signal Displays for Protected/Permitted Left-Turn Control*, evaluated the safety and effectiveness of different signal displays and phasing for protected/permissive left-turn control. Many agencies had sought alternatives to the circular green indication used in PPLT since the circular green can produce yellow trap situations if not used properly (i.e., lead/lag phasing schemes). NCHRP 3-54 conducted several studies of both the circular green permissive display and several other displays.

NCHRP Report 493 published the following key findings from NCHRP Project 3-54:

- The FYA indication was found to be the best overall alternative to the circular green as the display for the permissive left-turn mode.
- The FYA indication was found to have a high level of understanding and correct response by left-turn drivers, and a lower fail-critical rate than the circular green.
- Drivers had fewer crashes with flashing yellow left-turn arrows than with traditional yield-on-green signal displays.
- The flashing yellow arrow display was shown to offer the highest level of safety.
- The circular green indication using the Dallas Display and the flashing yellow arrow display was shown to rank “best” in the category of operations.
- The circular green indication was shown to rank “best” as being implementable.
- The flashing yellow arrow display was shown to be the “best” in the category of human factors.
- The flashing yellow arrow display was shown to have the most versatile characteristics and the circular green indication was the least versatile.

Full details on the NCHRP Report 493 can be found at:
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_493.pdf.

NCHRP Web Only Document 123

NCHRP Web Only Document 123, *Evaluation of the Flashing Yellow Arrow Permissive-Only Left-Turn Indication Field Implementation*, summarized the results of a follow-up study recommended by NCHRP Project 493. The study evaluated crash data for 50 intersections nationwide. Intersections with at least

one year of FYA implementation were chosen for analysis. Crash data was used as the main performance variable to evaluate the effectiveness of the FYA operation. The main findings of the follow-up study for FYA operation are summarized as follows:

- Safety was improved at intersections that operated with PPLT before the field implementation of the FYA indication and continued with PPLT operation afterwards.
- Safety was not improved at intersections that operated with protected-only left-turn phasing before the implementation of the protected and permissive operation with FYA.

Short-term analysis involved conflict rate analysis, follow-up headway, and driver hesitation as indicators of changes in the driver's behavior due to FYA display for PPLT operation. For long term analyses, crash data was the main performance measure used to evaluate safety for field implementations of FYA signal displays. Drivers' perceptions/reactions were measured under controlled conditions in a simulated environment. No naturalistic driving studies have been performed to evaluate drivers' perceptions of FYA displays for PPLT.

Drivers' Comprehension of the FYA

National studies have shown the flashing yellow arrow indication is more understandable and operationally more efficient than traditional protected/permissive left-turn indications such as a five-section cluster signal head, and these results have been confirmed by agency experience. These studies are well documented. Recent and relevant information is summarized below.

FHWA-ICT-13-021 Driver Comprehension and Operations Evaluation of FYA (2013)

A driver comprehension survey was disseminated to assess Peoria area drivers' understanding of various permissive left-turn indications, and especially the FYA indication. The survey was conducted in two phases: The first phase was disseminated 5 months after the initial implementation of the FYA signals, and the second phase was disseminated 16 months after the first FYAs were operational. A comparison of the survey results of both phases was conducted to determine changes in driver comprehension over time and impacts on a driver's learning curve.

The survey that included seven left-turn scenarios of the protected and permissive indications of PPLT phasing, with the flashing modes of the FYA indication being animated. The results of the driver comprehension survey revealed the following:

- Participating drivers had very high comprehension of the correct action to take at both the FYA and Circular Green (CG) permissive left-turn indications. However, the analysis of the fail-critical responses revealed significantly higher incorrect "go" responses for the CG scenario, compared with the FYA with supplemental sign. These results provide evidence of some drivers' misinterpreting the meaning of a permissive left-turn with CG display and incorrectly and unsafely interpreting the meaning as "go" under some circumstances.
- The provision of the supplemental sign at the FYA approaches with text "Left-turn Yield on Flashing Arrow" significantly improved drivers' understanding of the correct "yield" message,

regardless of the color of the adjacent through traffic signal (green or red). This finding was further confirmed by the fail-critical responses, which showed that the FYA with supplemental sign has significantly lower fail-critical "go" responses than the FYA without a supplemental sign.

- When survey participants were asked, "If oncoming traffic has a green light and you wish to turn left permissively, what signal indication best informs you that you must yield to oncoming traffic before completing your turn?" the majority (66%) felt that the FYA presented the best message in a permissive left-turn.
- The results of the static driver comprehension survey of correct responses and fail critical responses provide evidence of heightened driver understanding of the FYA message over the CG. The message of the FYA is further enhanced when the supplemental sign with text "Left-turn Yield on Flashing Arrow" is provided. However, conclusive recommendations regarding the supplemental sign cannot be made based on the results of the static survey alone.

Intermediate operational measures and traffic conflict data were collected at a sample of test sites to assess the impacts on safety and operations of converting the CG permissive left-turn indication to the FYA. The following variables were used: gap size accepted, red-light running, yellow-light running, and traffic conflicts involving left-turning vehicles.

The "before" data was collected mid-September 2010; beginning in spring 2011, the "after" data was collected at the same intersection approaches during the same weekday peak as collected in the "before" period. The signal operations did not change from the "before" to the "after" periods; the only change was in the traffic signal's permissive left-turn indication from CG in the "before" period to FYA in the "after" period.

The results of the statistical analysis conducted for this study at 95% level of confidence revealed the following key points:

- No significant differences were observed in the median gap size accepted.
- The results of this analysis suggest that red light running (RLR) and yellow light running (YLR), following either the protected interval or the permissive interval of PPLT phasing, is minimally, if at all, affected by the installation of the FYA.
- No significant differences in the traffic conflict experience were observed for any of the traffic conflict variables studied.

Overall, the findings of this study suggest that drivers have high comprehension and acceptance of the FYA message in areas without previous experience with FYA. Additionally, the FYA does not appear to have any negative impacts on traffic operations.

FHWA-ICT-16-010 Safety Evaluation of Flashing Yellow Arrows for PPLT Control (2016)

The Illinois Department of Transportation initiated an area wide implementation of the flashing yellow arrow (FYA) as the display for the left-turn permissive interval at more than 100 intersections operating

with protected/permissive left-turn (PPLT) control in the Peoria, Illinois, area in 2010. The effectiveness of FYAs on safety were evaluated at 86 intersections and 164 approaches where no other improvements were made. The effectiveness evaluation was performed using three years of "before FYA installation" crash data and three years of "after FYA installation" crash data. In the "before" condition, the left-turn signals operated with a circular green ball for the permissive interval of PPLT control and a five section signal head, while in the "after" condition, the FYA was displayed for the permissive interval of PPLT with a four-section signal head. The main findings of the comprehensive study are summarized as follows:

1. A 23.3% reduction in LT-related crashes and a 24.8% reduction in left-turn opposing-through (LTOT) crashes were observed with the implementation of FYA.
2. When FYA supplemental signs were also installed, larger percent reductions were observed, which provides evidence that the FYA supplemental sign may improve safety at the study approaches in Peoria, Illinois, because the FYA is still a relatively new countermeasure. At the 90 FYA approaches with the supplemental sign, significant percent reductions of 31.9% and 30.9% were observed for LT-related crashes and LTOT crashes, respectively.
3. The evaluation results for older drivers indicates that the FYAs did not have an impact on the crash experience of this subset of drivers (no statistically significant changes were found).
4. A comparison of the crash reductions for younger drivers versus all drivers reveals that relatively larger percent reductions in crashes were observed for the younger driver group. For example, the comparison at an approach basis for LTOT crashes were 24.8% reduction for drivers of all ages versus a 36.1% reduction for drivers age 16 to 21 years.

Crash Modification Factors (CMF) were developed using the procedures outlined in the Highway Safety Manual (HSM) and the *Guide to Developing Quality Crash Modification Factors*, CMFs. Specifically, CMFs were found to be statically significant (95% confidence level) for the following crash types:

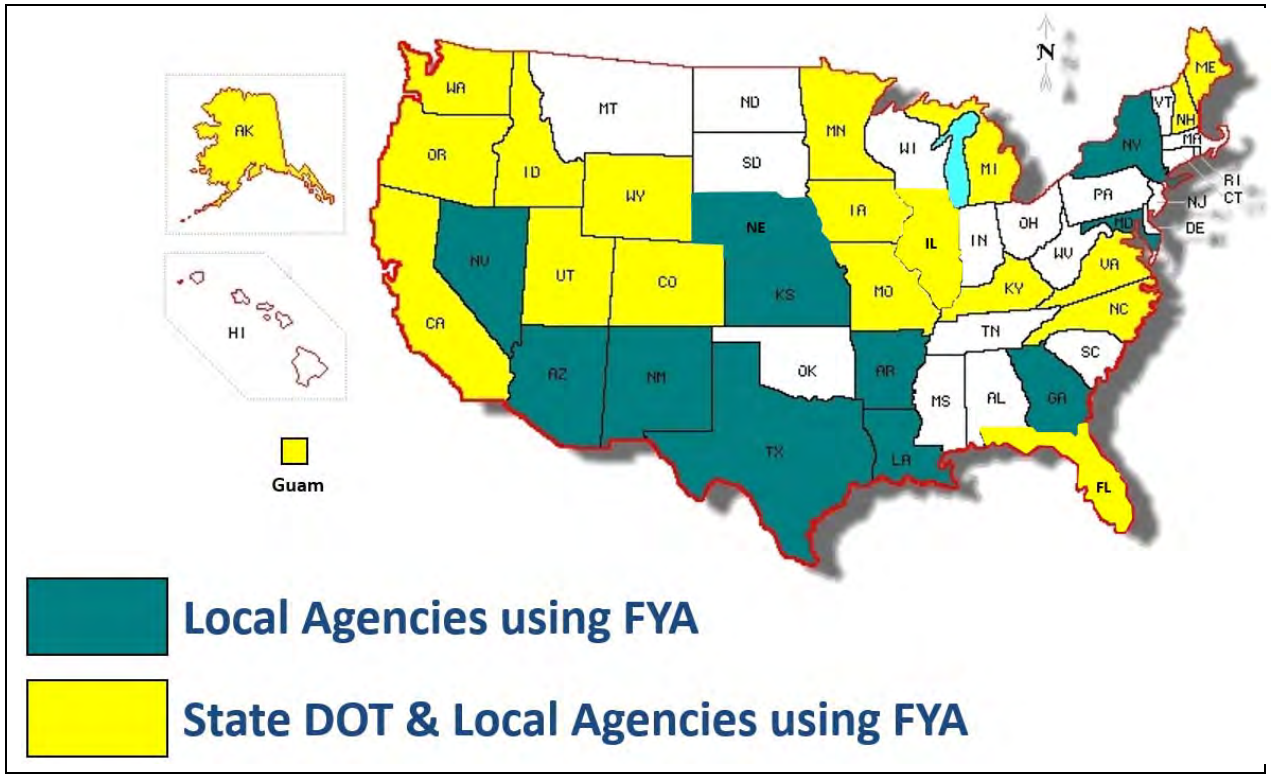
- LT-related crashes at FYA approach CMF = 0.617
- LT-related crashes at FYA approach with supplemental sign CMF = 0.589
- LTOT crashes at FYA approach CMF = 0.714
- LTOT crashes at FYA approach with supplemental sign CMF = **0.711**

Economic costs and benefits (in 2010 dollars) of the FYA were calculated and annualized in order to determine the benefit to cost ratio of the FYA implementation. The resulting benefit to cost ratio for the implementation of the FYAs at 86 intersections is 19.8 to 1.0, which indicates that the accrued benefits in dollar value exceeds the annualized cost of the FYA over a period of 15 years by a factor of nearly 20.

Agencies using FYA

There were 19 state departments of transportation and 46 additional agencies (cities, counties, territories, etc.) that received interim approval for the use of the FYA prior to inclusion of the FYA in the 2009 MUTCD. The number of additional states implementing the FYA since the 2009 MUTCD was adopted has not been tracked. **Exhibit 2** shows the agencies (by state) that were using the FYA under the interim approval.

Exhibit 2 Agencies Using the FYA under Interim Approval



Nearby Agency Use of the FYA

Below is information on implementation of the FYA in three spotlight states selected based on the project team's knowledge of the operation within these states.

Minnesota

The Minnesota Department of Transportation (MnDOT) encourages the use of FYA whenever appropriate. MnDOT has issued a Technical Memorandum (No. 12-10-T-03) that emphasizes the use of the FYA:

> "The purpose of this technical memorandum is to require the installation of the flashing yellow arrow (FYA) left-turn indication on all new traffic signal dedicated left-turn lane approaches on the State trunk highway system unless the left turner has limited intersection sight distance (as defined in Chapter 9, Table 9–14 of the 2011 AASHTO "A Policy on Geometric Design of Highways and Streets"), or conflicting (i.e. overlapping) left-turn paths are present."

MnDOT bases this stance on the national research that has shown that the FYA is more easily understandable, is more flexible (operationally) and safer. MnDOT first implemented the FYA in 2006 and their experience confirms the results of the national studies.

Virginia

The FYA is now the Virginia Department of Transportation's (VDOT's) preferred method for signalizing protected/permissive left turns and FYA may be used for permissive-only left turns as well. VDOT recognizes that the flashing yellow arrow (FYA) indication is an increasingly popular treatment for improving driver comprehension of traffic signals at locations with permissive left-turning movements.

VDOT includes the following changes to the 2011 Virginia Supplement to the MUTCD, Revision 1:

- Recommends the FYA for all protected/permissive left-turn movements where exclusive left-turn lanes are present.
- Adds an Option to utilize FYA for permissive-only left-turn movements where exclusive left-turn lanes exist.
- Removes the previous recommendation for circular green indications for permissive-only left-turn movements.
- Incorporates an Option to use of a four-section FYA signal face for permissive-only or protected-only left turns where there is a potential for future conversion to protected/permissive mode.

North Carolina

In North Carolina, a five-section cluster signal head has traditionally been used for protected/permissive turning movements. According to the North Carolina Department of Transportation (NCDOT) Signal Design Manual:

> "The new preferred display for protected/permissive left turns is the Flashing Yellow Arrow (FYA). This head is intended to be an exclusive head for the turn lane and displays only ARROW

indications. A FYA is displayed for the permissive movement, instead of the traditional CIRCULAR GREEN. Vehicles may make the turn indicated by the FYA after yielding to pedestrians and conflicting movements. A solid GREEN ARROW is used to indicate a protected movement. The FYA head should be centered over the turn lane(s). Note that the FYA head is an exclusive for the left turn, and 2 signal heads containing CIRCULAR RED, YELLOW, and GREEN displays are still required for the through movement."

Additionally, the NCDOT Signal Design Manual states:

"FYAs for left turns should be used:

- When the turn lanes are offset (separated from the through lanes)
- When the opposing travel lanes use (three-section or four-section) FYAs or fully protected (single or dual) lefts to avoid "yellow trap"
- Along corridors, where other FYA displays are used for left turns
- At Railroad preempt locations, which eliminate the need for blankout signs"

Advantages of FYA

The FYA has numerous advantages:

- Direct replacement for a Protected/Permissive Left-Turn Phase
- The FHWA study found the FYA was better understood by the motoring public
- Provided similar safety benefits while providing more flexibility in how it operates
- High level of motorist understanding
- Best overall alternative to circular green
- More versatility in field operation
- Lead/lag and left turn re-service
- Time of day flexibility to run protected-only, PPLT, or permissive-only.
- Eliminates left-turn trap when implemented correctly
- Allows permissive left turns when the adjacent through phase is red and opposing through phase is green

Elimination of the Left-Turn Trap

Exhibit 1 illustrates a left-turn trap with traditional lead/lag phasing (i.e., a circular green indication is used for the permissive left turns). Using a FYA indication can eliminate the trap condition illustrated in this exhibit.

Once again, consider the EBL vehicle. During stage 1, the EBL receives a green arrow and proceeds under the protected movement. During stage 2, the EBL shows the flashing yellow arrow indication and the movement operates as a permissive movement. In stage 3, the EBL remains a flashing yellow arrow indication instead of turning red. The EBL FYA actually operates as an overlap to phase 6. Therefore, the EBL and opposing WBT terminate at the same time as expected by the driver.

Exhibit 3 illustrates the signal operation of the FYA even under the "soft-trap" condition and how this can be eliminated.

Note: The soft-trap occurs when opposing through movements have different clearance times and permissive lefts are allowed. In this case, one direction sees the solid yellow ball indication while the opposing through is still green. As with the left turn trap, the left turn that sees the yellow indications assumes the opposing through see the yellow at the same time. This is not as critical as a full left turn trap, yet it can be problematic. As noted, the FYA eliminates this situation since the flashing left is tied to the opposing through phase.

A video illustrating the FYA left turn trap fix can be found at:

https://shareSync.serverdata.net/web/s/dN31cIdVlMwlQaeztRLMQE.

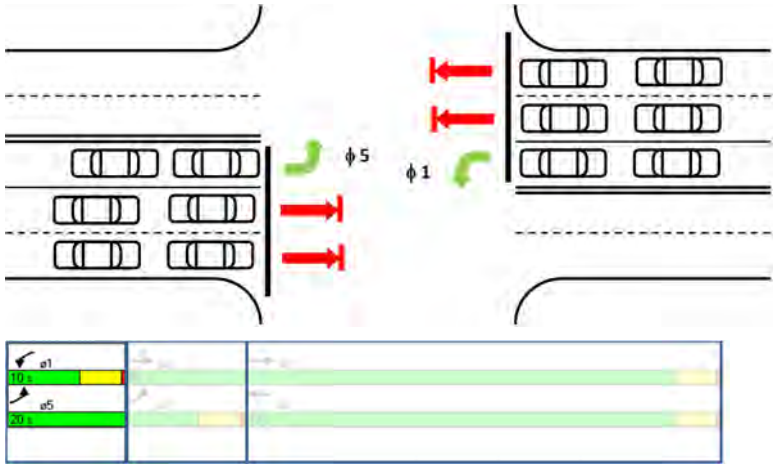
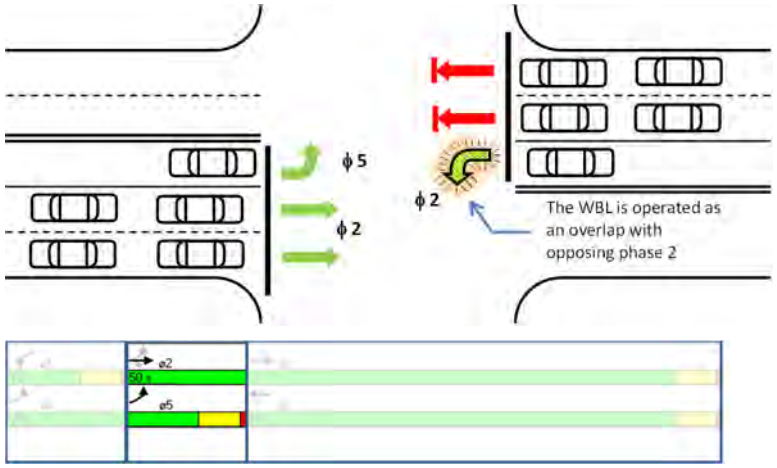
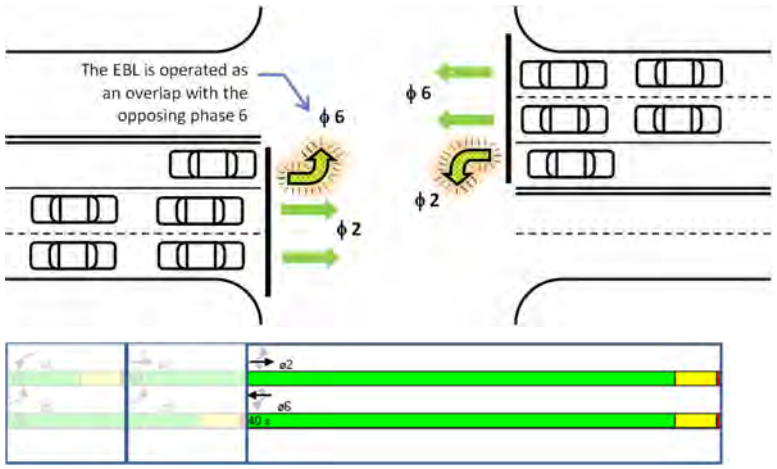
Disadvantages of FYA

There are a few issues that have raised some concern regarding the use of the FYA. One of them is the "disco effect". In an urban environment with traffic signals every block (or even more), all the arrows flashing at different rates adds visual clutter.

The second is called the "perceived yellow trap", if the driver was looking down and then looks up at the flashing yellow arrow when it's illuminated at the same time the other lights are turning yellow, the driver may think he or she's about to get "yellow trapped". But this is much less of a problem than the real yellow trap, because it will usually be obvious he or she is mistaken before getting a chance to start out.

There is also a concern that some drivers don't understand the meaning of the FYA. There are anecdotal reports of situations where the driver thought the FYA indication meant they had the right of way. In these cases the "Left Turn Yield on Flashing Yellow Arrow" signs were used as an interim treatment to address the situation.

Exhibit 3 FYA to Eliminate Left-Turn Trap

	**Stage 1**: During this stage, normal leading protected and opposing left-turn phases operate. This is the typical operation even with a traditional five-section signal indication. At the end of this stage, phase 1 clears the intersection with a solid yellow arrow.
	**Stage 2**: During this stage phase 2 begins green as phase 5 continues green in normal operation. The opposing left turn is operated as a FYA. In a traditional five-section operation, the opposing left turn would be red.
	**Stage 3**: In this stage, phase 2 and 6 throughs receive a circular green indication. The opposing lefts are operated as an FYA overlap with the opposing through. This will ensure that the left turn clears (turns yellow) and then red with the opposing through, thus eliminating the left-turn trap.

IV. FYA Design

The FYA was added as an optional configuration for protected/permissive and permissive left-turn signal heads in the 2009 Manual on Uniform Traffic Control Devices (MUTCD) and is currently being used in a majority of states nationwide. As a result, there has been increased interest in implementing FYA for left-turn signal phasing within Ohio. Several isolated communities in Ohio have implemented the FYA.

The FYA head is now the recommended left-turn head in the 2009 Federal MUTCD. This version of the MUTCD, Section 4D.04, includes language on the use of the flashing yellow arrow for permissive left turns that states:

> "Vehicular traffic, on an approach to an intersection, facing a flashing YELLOW ARROW signal indication, displayed alone or in combination with another signal indication, is permitted to cautiously enter the intersection only to make the movement indicated by such arrow, or other such movement as is permitted by other signal indications displayed at the same time.
>
> Such vehicular traffic, including vehicles turning right or left or making a U-turn, shall yield the right-of-way to:
>
> i. Pedestrians lawfully within an associated crosswalk, and
> ii. Other vehicles lawfully within the intersection.
>
> In addition, vehicular traffic turning left or making a U-turn to the left shall yield the right-of-way to other vehicles approaching from the opposite direction so closely as to constitute an immediate hazard during the time when such turning vehicle is moving across or within the intersection."

OMUTCD

The implementation of the FYA for permissive left turns is governed by relevant provisions in the OMUTCD. Relevant provisions within the OMUTCD are found in the following sections of Chapter 4D, Traffic Control Signal Features:

- Section 4D.05, *Application of Steady Signal Indications,* allows the use of an FYA indication before a steady yellow arrow.
- Section 4D.09, *Positions of Signal Indications Within a Vertical Signal Face,* specifies the proper location of flashing yellow and flashing red indications, including:
  - The flashing yellow indication cannot be placed in the same vertical position as the signal section that displays a steady yellow signal indication.
  - The flashing yellow indication shall be placed below the steady yellow signal indication.
- Section 4D.17, *Signal Indications for Left-Turn Movements—General*, begins the discussion of signal indications for left-turn movements.
- Section 4D.18, *Signal Indications for Permissive Only Mode Left-Turn Movements*, provides information on permissive mode operation.

- Section 4D.20, *Signal Indications for Protected/Permissive Mode Left-Turn Movements*, Paragraph 03 provides the requirements associated with use of the FYA using a separate left-turn signal face in a PPLT mode.

Figures from the OMUTCD related to the position and arrangement of FYA signal displays:

- Figure 4D-7, Typical Position and Arrangements of Separate Signal Faces with Flashing Yellow Arrow for Permissive Only Mode Left Turns.
- Figure 4D-12, Typical Position and Arrangements of Separate Signal Faces with Flashing Yellow Arrow for Protected/Permissive Mode and Protected Only Mode Left Turns.
- Figure 4D-14, Typical Position and Arrangements of Separate Signal Faces with Flashing Yellow Arrow for Permissive Only Mode Right Turns.
- Figure 4D-19, Typical Position and Arrangements of Separate Signal Faces with Flashing Yellow Arrow for Protected/Permissive Mode and Protected Only Mode Right Turns.
- Figure 4D-20, Signal Indications for Approaches with a Shared Left-Turn/Right-Turn Lane and No Through Movement (Sheet 2 of 3).
- Figure 4D-20, Signal Indications for Approaches with a Shared Left-Turn/Right-Turn Lane and No Through Movement (Sheet 3 of 3).

Of particular interest, Section 4D.18 indicates the following:

> "If a separate left-turn signal face is being operated in a permissive only left-turn mode and a flashing left-turn YELLOW ARROW signal indication is provided, it shall meet the following requirements (see Figure 4D-7, **Exhibit 4** in this paper):
>
> A. It shall be capable of displaying the following signal indications: steady left-turn RED ARROW, steady left-turn YELLOW ARROW, and flashing left-turn YELLOW ARROW. Only one of the three indications shall be displayed at any given time.
> B. During the permissive left-turn movement, a flashing left-turn YELLOW ARROW signal indication shall be displayed.
> C. A steady left-turn YELLOW ARROW signal indication shall be displayed following the flashing left-turn YELLOW ARROW signal indication.
> D. It shall be permitted to display a flashing left-turn YELLOW ARROW signal indication for a permissive left-turn movement while the signal faces for the adjacent through movement display steady CIRCULAR RED signal indications and the opposing left-turn signal faces display left-turn GREEN ARROW signal indications for a protected left-turn movement.
> E. During steady mode (stop-and-go) operation, the signal section that displays the steady left- turn YELLOW ARROW signal indication during change intervals shall not be used to display the flashing left-turn YELLOW ARROW signal indication for permissive left turns.
> F. During flashing mode operation (see Section 4D.30), the display of a flashing left-turn YELLOW ARROW signal indication shall be only from the signal section that displays a steady left-turn YELLOW ARROW signal indication during steady mode (stop-and-go) operation.

G. If the permissive only mode is not the only left-turn mode used for the approach, the signal face shall be the same separate left-turn signal face with a flashing YELLOW ARROW signal indication that is used for the protected/permissive mode (see Section 4D.20) except that the left-turn GREEN ARROW signal indication shall not be displayed when operating in the permissive only mode.

Support:

Research and field experience with the flashing left-turn YELLOW ARROW signal indication has found that most road users recognize the meaning of this application. However, it has also been noted that an educational campaign in advance of installation, and supplemental signing during implementation aids in comprehension.

Guidance:

A public information campaign should be used in advance of projects introducing this device in an area to make road users aware of the planned introduction of the new signal display type and its meaning. Once the flashing left-turn YELLOW ARROW signal indication has been in use within an area for a while, public information campaigns should not be needed.

For consistency, when installing a flashing left-turn YELLOW ARROW signal indication for protected/permitted operation at a new location, the same treatment should be considered for nearby signal installations with a similar operation.

Standard

The LEFT TURN YIELD ON FLASHING YELLOW ARROW (R10-H12c) sign (see Figure 4D-7) shall be used with the installation of each flashing left-turn YELLOW ARROW signal indication within a jurisdiction for at least five years."

Traffic Engineering Manual (TEM)

The Traffic Engineering Manual (TEM) has been developed to assure uniformity in application of ODOT traffic engineering policies, guidelines, standards and practices. The OMUTCD establishes the basic, minimum traffic control standards for any street, highway, bikeway or private road open to public travel in Ohio, and all supplemental ODOT traffic engineering design, construction and operations related information is either contained in the TEM or referenced from it.

The TEM contains standards, policies, etc. established for use in ODOT work; however, various situations will present themselves where engineering knowledge, experience and judgment will have to be used to determine how to apply the information included herein to specific situations. Section 403-7 within the TEM contains the current guidance provided by ODOT regarding Flashing Yellow Arrow (FYA) Operation.

"The **OMUTCD Section 4D.18** permits the use of a flashing yellow arrow (FYA) indication on applicable protected/permissive left-turn phases. However, the FYA indication shall not be used with traffic control signals on **ODOT**-maintained highways until such time as design and traffic signal cabinet standards approved by the **Offices of Roadway Engineering (ORE) and Traffic Operations (OTO)** have been developed and tested, and educational materials on the intended use of this new signal indication have been made available to the public.

Once the cabinet standards have been developed and tested, permission for pilot installation of the FYA may only be granted by **OTO** on a case-by-case basis to monitor and determine any crash and safety benefits. An education campaign shall be part of any project introducing this device in an area, and as noted in **OMUTCD Section 4D.18**, the LEFT TURN YIELD ON FLASHING YELLOW ARROW (R10-H12c) sign shall be used with the FYA for at least five years (see **OMUTCD Figure 4D-7**)."

Meaning of FYA Display Indications

The Flashing Yellow Arrow (FYA) head is a signal that uses a flashing yellow arrow indication for permissive left turns instead of using a circular green. The NCHRP study 493 determined that the four-section FYA signal head with a red arrow on top, followed by a steady yellow arrow, a flashing yellow arrow, and then a green arrow on the bottom was the best and safest type of left-turn signal head based on driver confirmation and field implementation studies.

The following link is a video comparing a traditional five-section protected/permissive signal compared to the flashing yellow arrow, https://shareSync.serverdata.net/web/s/62c5v0xjctNiJSJ8E2TEgM.

FYA Head Location and Configuration

In accordance with Section 4D.13 of the OMUTCD, the FYA signal head shall be positioned between the extension of the left-hand and right-hand edges of the exclusive turn lane. NCHRP Report 493 recommended this type of configuration since it was rated higher in terms of safety, drivers' perception, and operations. **Exhibit 4** is Figure 4D-7 from the MUTCD. This is for the typical position and arrangement of separate signal faces using FYA for permissive-only left turns.

Exhibit 4 OMUTCD FYA Position for Permissive-Only Mode

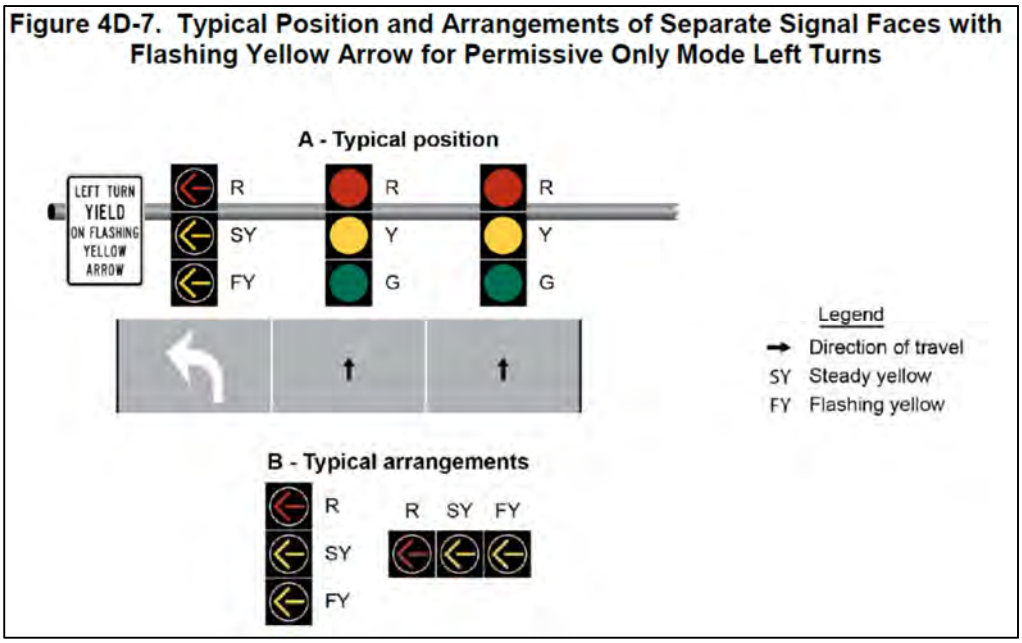
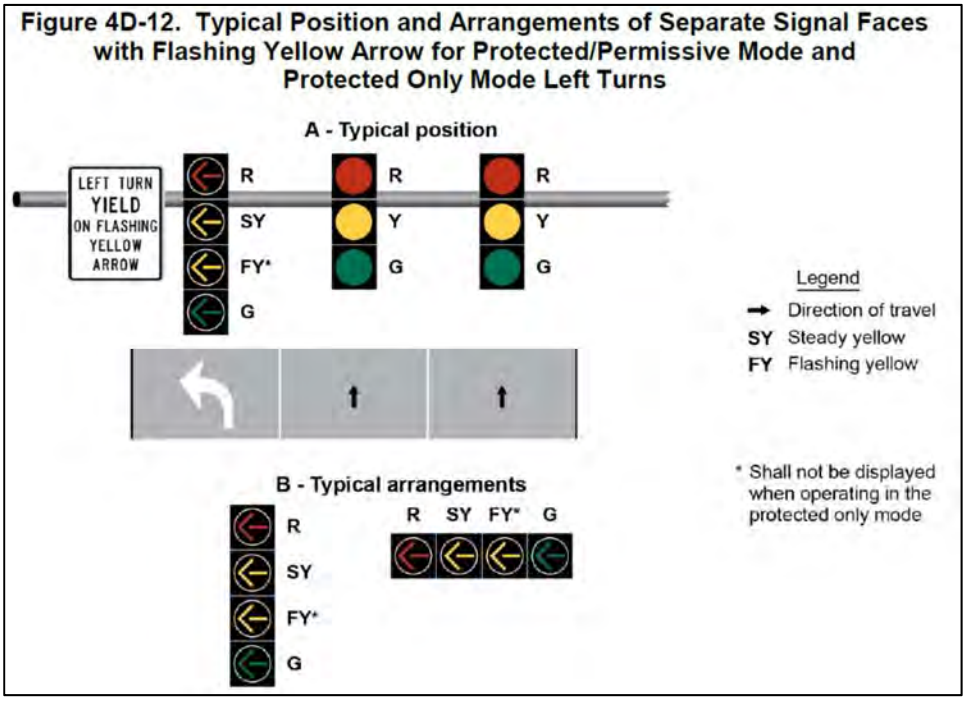


Exhibit 5 is Figure 4D-12 from the OMUTCD and is the typical position and arrangement of separate signal faces with FYA for protected/permissive mode and protected-only mode left turns.

Exhibit 5 2012 OMUTCD FYA Position for Protected/Permissive Mode



With the use of the four-section FYA signal display, the FYA signal head indications can change in response to the three left-turn modes of operation (permissive-only, protected/permissive and protected-only), providing additional operational flexibility. This flexibility is indicated in **Exhibit 6**.

Exhibit 6 Indications Used with Various Operational Modes of FYA Head

Four Section FYA Head and Indications	Permissive-Only Mode	Protected/Permissive Mode	Protected-Only Mode
 Steady Red Arrow			
 Steady Yellow Arrow			
 Flashing Yellow Arrow			Not Used During Protected-Only Mode
 Steady Green Arrow	Not Used During Permissive-Only Mode		

FYA Signing

As noted earlier, national studies determined that the FYA is the best type of head for understanding by motorists. However, because it is a new operation, a FYA sign stating "Left Turn Yield on Flashing Yellow Arrow" shall be used as an educational message. Specifically, Section 4D.18 of the OMUTCD states:

> "The LEFT TURN YIELD ON FLASHING YELLOW ARROW (R10-H12c) sign (see Figure 4D-7) shall be used with the installation of each flashing left-turn YELLOW ARROW signal indication within a jurisdiction for at least five years."

As previously discussed, the study FHWA-ICT-13-021 concludes that the provision of the supplemental sign at the FYA approaches with text "Left-turn Yield on Flashing Arrow" significantly improved drivers' understanding of the correct "yield" message, regardless of the color of the adjacent through traffic signal (green or red).

FYA Wiring

A traditional signal head for the protected/permissive left-turn mode contains five indications with the three circular indications running off the output for the adjacent through phase and the two arrow indications running off the output for the left turn phase. The steady red arrow, steady yellow arrow, and steady green arrow in a FYA display can be wired the same as a traditional three-section protected/prohibited display. The FYA signal head introduces the requirement for a fourth output, a

flashing indication, which cannot be run from the output for a steady indication and thus introduces the requirement to output and monitor an additional signal indication.

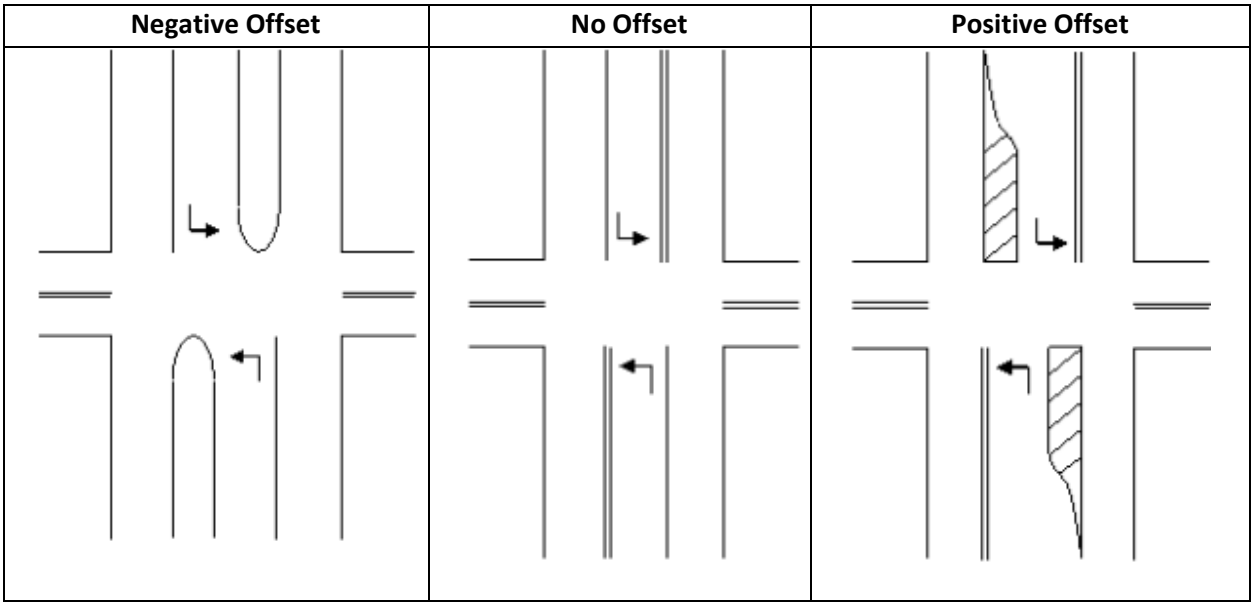
In order for the conflict monitor to prohibit conflicting indications in accordance with Section 4D.05 of the 2012 OMUTCD, the flashing yellow arrow indication should be wired so it is monitored by a separate channel from the steady red arrow, steady yellow arrow and steady green arrow indications in the FYA head. Typically the FYA indication is wired to an overlap or the unused third output of a pedestrian load switch.

If an existing five-section protected/permissive signal head is replaced with a four-section FYA signal head, the existing wiring between the signal head and cabinet can be reused with connection to different outputs.

Positive Offset for Permissive Left-Turn Operation

Consideration of lateral offset for left-turning vehicles is important with the widespread installation of the FYA left-turn indication, or any permissive left-turn movement, to ensure vehicles waiting in the opposite left-turn lane do not restrict sight distance to oncoming through traffic. A positive left-turn lane lateral offset helps FYA permissive operation in terms of safety and efficiency (see **Exhibit 7**).

Exhibit 7 Left Turn Lane Lateral Offsets



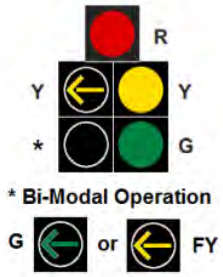
Shared Left/Through Lane Installations

The application of flashing yellow arrows for shared left/through lanes are not common at this time. The Minnesota DOT did receive an FHWA interpretation for a special signal indication they have started using for these situations. This interpretation can be found at,

http://mutcd.fhwa.dot.gov/resources/interpretations/4_09_15.htm.

The signal indication is a 5-section dog-house style head with a bi-modal arrow that displays a solid green or a flashing yellow left turn arrow as shown in **Exhibit 8**.

Exhibit 8 MnDOT Bi-Modal FYA Indication for Share Left/Through Lanes

R-Y-G-YLA-FYLA-GLA This is also referred to as a 5-section "doghouse" head with a bi-modal arrow selection. It does have 5 signal heads with 6 possible intervals since the lower left indication can be a solid green or flashing yellow.	Five-Section Red, Yellow, Green Ball and Yellow, bi-modal Green Left Turn Arrow/Flashing Yellow Left Turn Arrow ** Note: The lower left indication is a bi-modal left turn arrow will be a solid green arrow or flashing yellow left turn arrow.*	

[Source: MnDOT Traffic Signal Design Manual]

The application of the FYA for shared left-through lanes would provide similar benefits as for more traditional configurations. One location that applies the FYA for a shared lane can be found at the US61 and Buffalo Street intersection near Whte Bear Lake in Minnesota. The design is included in the MnDOT Signal Design Manual found at the following link (see Chapter 3),

http://www.dot.state.mn.us/trafficeng/publ/signaldesign/2016signaldesignmanual.pdf.

The operation will be monitored and may be considered for future use in Ohio.

Cost of Conversions

For new signal construction, the costs associated with using FYA compared with other signal configurations is typically negligible. The cost of a four-section FYA signal head is not significantly greater than a three-section signal head, and a four-section FYA head is less than a five-section signal head. Additional costs could be experienced to ensure the mast arm (if used) extends to allow the placement of the FYA signal head(s) over the exclusive left-turn lanes (currently, five-section PPLT signal heads must be placed over the lane line between the exclusive left turn lane and the adjacent through lane, not centered over the left turn lane.) A second through-movement three-section signal head would be required with the installation of the FYA head to ensure there are the minimum required two heads for the through movement, and there would be corresponding additional wiring costs.

Retrofit installations could vary widely on cost and would need to be evaluated on a case by case basis. In some cases, the structures are adequate and the controller/cabinet are capable of a straightforward conversion. In other cases, this may not be true and the costs could be substantial. Retrofit costs could include the cost of FYA signal heads, an additional three-section signal head, hardware, wiring, controller modifications (reprogramming or hardware), possible pedestal pole for locations with medians and insufficient mast arm length, possible mast arm modifications, and labor costs. The Minnesota Department of Transportation has developed a retrofit assessment worksheet to assist in determining the costs which could be adapted for use in Ohio. This worksheets considers items such as mast arms, signal heads, labor cost, controller updates, etc. A copy of this worksheet can be found at:

http://www.dot.state.mn.us/trafficeng/signals/worksheets/Retrofit%20Assessment%20-%20Blank%20-%204-25-13.xlsx

A 2009 presentation by the Oregon Department of Transportation indicated an average cost of $9,100 per intersection to retrofit a typical intersection. The cost was derived from the following:

- 30 intersections were converted from doghouse left-turn heads to the FYA head.
- Most conversions involved 2 doghouse heads.
- Average cost of $9,100 per intersection included:
    - Site assessment and engineering
    - Hardware
    - Installation labor
    - Temporary traffic control
- Yielded a benefit to cost ratio of 8:1.

Plans Presentation

Based on the recommendations of this technical memo, no substantial modifications to plans presentation will be required. It is recommended that a standard symbol or label for the flashing yellow arrow indication be developed to use in the signal head diagrams.

V. FYA Operations

The following sections are general guidelines on determining when to use the various modes of left-turn operation (Permissive-only, Protected/permissive, or Protected-only) capable with the FYA indication and the corresponding FYA signal head operation during and between each mode (also see **Exhibit 6**). In all cases, engineering judgment must be exercised and the information below used as guidance.

Change and Clearance Intervals

Steady yellow arrow time for clearing the green arrow for leading or lagging left turns will be the same as the current yellow change interval for protected left-turn operation.

Steady yellow arrow time for clearing the FYA will be same as the opposing through circular yellow change interval time, as the FYA will be driven by an overlap with the opposing through phase.

Although not required by the Federal MUTCD, many states include a FYA red clearance interval when transitioning from the protected to permissive phases, with the red arrow being shown. If used, the red clearance time will be the same as the current all-red clearance time for protected left-turn operation.

Permissive Operation When Adjacent through Head is Red

The PPLT FYA display will allow for a permissive operation when the adjacent through head is red. This situation could occur if one left-turn movement runs longer than the opposing left-turn movement and the shorter left turn will get the permissive flashing yellow arrow while the opposing left turn is causing the adjacent through head to still be red. Permissive operation in this circumstance is not possible with the five-section cluster signal head currently used with PPLT phasing.

Adjacent through heads may also be red when lagging lefts are implemented using FYA heads for protected/permissive operation. Lagging lefts and concurrent permissive opposing left turns are also an operation that wasn't possible with the five-section protected/permissive head as it would cause a left-turn trap.

Varying FYA Operations by Time-of-Day

In the past, the operation of the left-turn phase was determined during the design process based on legacy criteria. Often, design criteria for establishing left-turn phasing, with the primary criteria being the "conflict factor." The conflict factor is the product of the left-turn volume and the opposing through traffic volume for any one-hour period on a normal weekday. The geometric considerations for establishing a protected/prohibited left-turn phase indicates protected/prohibited left-turn phasing should be considered if any of the following conditions exist:

- Dual left-turn lanes.
- Three or more opposing through lanes.
- Multi-legged intersections with more than four approaches.

- Approaches that have experienced five or more crashes (including non-reportable) of a type that would be susceptible to corrected by the protected/prohibited phasing within a continuous 12-month period over the most recent 3 years. (Non-reportable crashes must be police-verified and documented to enable consideration.)
- Approaches with significant non-correctable, sight distance deficiencies, including deficiencies created by stopped opposing left-turn vehicles.

Even when a protected/prohibited left-turn phase may have been needed for one hour in the day (i.e., high conflict factor only during peak hour(s)), when a protected/prohibited left-turn indication is designed, it is a static operation and would need to run in this mode 24-hours per day.

For new designs, the designer should consider the use a FYA indication at dedicated left turns when appropriate. With a four-section FYA head, the mode of operation for the left-turn phase is flexible and can vary between protected-only, protected-permissive or permissive-only on a time-of-day (TOD) basis with the following considerations:

- Each signal approach will need to be analyzed individually to determine the time-of-day FYA operation by considering the conflict factor during each hour of the day
- Where protected/prohibited phasing is necessary due to the geometric considerations the FYA head shall not be used and the left turn shall operate with protected/prohibited phasing at all times.

Emergency Vehicle Preemption Operation under FYA

With traditional five-section, protected/permissive operation, there are cases where an emergency vehicle preemption can create a left-turn trap. This occurs when an EVP detection brings up a left-turn arrow when the opposing through is currently green. The EVP detection will require the opposing through and permissive left to terminate causing the trap. The FYA eliminates this since the opposing left will continue to flash even though the adjacent through terminates.

RR Preemption Operation

The FYA four-section head helps railroad preemption operations with the flexibility to operate in either protected, protected/permissive, or permissive modes with no concern of a left-turn trap issue. It might be possible to run the left turn as a FYA UNLESS railroad preemption occurs (in which case it would run in protected-only operation). This issue is currently under development and more information is forthcoming.

Pedestrian Omit

It is possible to omit the permissive FYA indication during phases when a pedestrian actuation results in a conflicting pedestrian phase. Since motorists are required to yield to pedestrians when conducting a permissive left turn pedestrian omit is not required, but could provide an extra factor of safety if desired.

Permissive Operation Delay

Some agencies have experimented with a FYA permissive operation delay. In cases where a left-turn FYA leads the protected green arrow, as may be implemented for a lagging left-turn phase, the onset of the FYA is delayed to allow the opposing through to start. In this case, the opposing through starts to move seconds before the FYA, allowing the through to occupy the intersection thus minimizing confusion for the left turning motorist.

Detection

In most cases, existing detection within the exclusive left turn used for protected left-turn phases will be adequate for the protected period of operation with the FYA head. The detector within the exclusive left-turn lane can also be programmed to extend the permissive period of operation with the FYA head, which is typically run as an overlap of the opposing through phase in the controller.

VI. Cabinet and Controller

In general, the following steps are required to setup a FYA operation in the cabinet and controller:

- Program the channel assignments
- Program the appropriate overlaps
- Map Flashing Yellow Arrow Output to Unused Pedestrian Load Switch Input
- Program preemption (if applicable)
- Review/Modify Detector Vehicle Parameters
- Review/Modify Phase Call, Inhibit, Redirect
- Program the Malfunction Management Unit (MMU) i.e. Conflict Monitor
- Make the appropriate cabinet modifications

Installation of the FYA can present issues with older controller equipment. Chapter 5 of NCHRP Web Document 123 includes a list of successful FYA installations by controller type. This document can be read at the following link, http://www.trb.org/Publications/Blurbs/159759.aspx. The amount of effort and steps will vary greatly depending on the type of equipment used.

NEMA FYA Standards

In order to provide consistency in vendor specification to be capable of handling the FYA, NEMA has developed standards on the FYA. The NEMA Standards Publication TS 2-2003, *Traffic Controller Assemblies* with NTCIP Requirements, were developed as a design guide for traffic signaling equipment. This information is available from,

https://www.nema.org/Standards/ComplimentaryDocuments/NEMA%20TS%202%20Amendment%204%20WATERMARKED.pdf.

VII. Recommendations for Ohio

Basis for Recommendation

FYA is recommended for implementation in Ohio based on the following benefits:

Safer

FYA signals have been shown to help drivers make fewer mistakes. They keep motorists safer during heavy traffic and reduce delays when traffic is light. A national study demonstrated that drivers found flashing yellow left-turn arrows more understandable than traditional permissive (yield-on-green) indications.

Less Delay

There are more opportunities to make a left turn with the flashing yellow left-turn arrow than with the traditional protected-only left-turn indications.

Operational Flexibility

The FYA provides traffic engineers with more options to handle varying traffic volumes by allowing multiple left-turn phasing modes for an exclusive left-turn lane. The FYA signal head can be operated to provide left-turn control for permissive-only, protected/permissive, and protected-only modes by determining and operating the corresponding indications in the signal head. It also allows for lead/lag left turn operation. This flexibility can improve operational efficiency at an intersection and also allow for better corridor coordination and thus better operational efficiency of an entire corridor. Use of the FYA during normal operation has been shown to have several benefits including minimizing delays and enhancing safety by reducing driver errors.

Consistency with Other States

Since the inclusion of FYA in the national 2009 MUTCD, a majority of states have implemented the use of the FYA. As a result a large number of newly installed traffic signals in the U.S. will have FYA signal heads for left-turn movements. In keeping with the intent of the MUTCD, application of uniform traffic control devices aids in motorist recognition and understanding and reduces perception time/reaction time. From this it can be inferred that motorists in Ohio will encounter FYA as they travel in other states and visitors to Ohio will likely have experience in appropriately responding to FYA signal installations they encounter here. Implementing FYA in Ohio would support the uniformity of devices encouraged in the MUTCD.

New Signal Design

ODOT should consider using FYA in the design of new signals with exclusive left-turn lanes in addition to three-section protected or five-section protected/permissive head for new signal installations. The flashing yellow arrow may be used as a permissive left-turn indication at any intersection at any time but the most typical use will be at intersections and times-of-day that have lower volumes, lower speeds

and other favorable conditions that would not require the implementation of a protected left turn phase. Designs shall conform to the OMUTCD and the criteria additional ODOT design publications.

Even if a left-turn movement may not have a high enough left-turn volume (or conflict factor) to justify left-turn phasing at the time of design, a FYA head can be considered for exclusive left-turn lanes as it gives flexibility in case volumes increase in the future, and it also gives a clearer message to left-turning vehicles that they must yield to opposing traffic when turning left.

The incremental increase in cost of a four-section FYA signal head is insignificant in the overall cost of the new signal. In fact, the four-section signal head may be less expensive than the five-section protected/permissive signal head.

Retrofit Signal Design

An existing signal with exclusive left-turn lanes may be retrofitted with FYA operation. Consideration should take into account the type of cabinet, controller, vehicle detection, and mast arm locations when retrofitting a signal for FYA.

Locations where retrofitting existing signals to include FYA operation would be most beneficial and should be prioritized include the following:

- Corridors where changing to lead/lag rather than lead/lead left-turn phasing would improve progression.
- Locations where left-turn demand is low during off-peak periods and variable modes of left-turn phasing would be beneficial.
- Locations where crash patterns involve left-turning vehicles and could be attributed to driver misunderstanding of shared signal indications.
- Locations with frequent railroad or emergency vehicle preemption which currently results in a left-turn trap.

FYA Design

Based on the information provided in the memo, the following design recommendations are presented.

FYA Display

The four-section, all-arrow display face is the recommended display for most applications. The FYA operation should only be used in an exclusive signal arrangement.

As a result of the FHWA Interim Approval for the Optional Use of Three-Section Flashing Yellow Arrow Signal Faces (IA-17), the three-section display face with bi-modal lens may also be considered for retrofits where installation of a four-section head is infeasible. If Ohio desires to allow use of the three-section display face with bi-modal lens, a written request must be submitted to the Office of Transportation Operations at FHWA to request approval pursuant to Interim Approval IA-17.

Placement

For new installations, the left-turn signal face shall be centered over the left-turn lane.

When designing a retrofit FYA for an exclusive left turn, attempt to place the new FYA as close to the center of the exclusive left-turn lane as possible. When this is not feasible, the FYA can be placed in a location other than the center of the turn lane but must be aligned within the extended lane edge lines in accordance with OMUTCD Section 4D.13 paragraph 07. Use engineering judgment to determine this offset amount (2' from center is generally acceptable, more in certain cases). Note that this indication must be no closer than 8' from any adjacent signal head based on OMUTCD requirements. In some cases, such as diamond interchanges, the FYA head could be pedestal-mounted within the median if existing overhead supports are inadequate.

Supplemental Signs

Per the OMUTCD, the LEFT TURN YIELD ON FLASHING YELLOW ARROW (R10-H12c) sign shall be used with the installation of each flashing left-turn YELLOW ARROW signal indication within a jurisdiction for at least five years.

Operation

When used for left-turn treatments, the FYA display shall be tied to the opposing through green indication/display. This eliminates the left-turn trap.

An evaluation of the mode of operation should be made on a time of day basis. Currently, guidance on when to change operating modes is unavailable and should be determined by the operating agency. Note that the Minnesota DOT is working on guidelines for varying the mode of operation on a TOD basis and should be available in the future.

If used, the all-red time when transitioning from a protected left turn to a permissive left turn in protected/permissive operations shall be calculated for the protected left-turn phase, with the red arrow being shown.

VIII. Implementation

The following items summarize the implementation plan of the FYA in Ohio.

Locations

Since the FYA has been extensively studied by NCHRP and FHWA and implemented in the majority of states, a pilot may be unnecessary prior to large scale implementation in Ohio. In addition, several locations have been implemented in Ohio. If a corridor was undergoing planned design updates, the FYA could be implemented on a corridor wide basis.

Public Education

To alert the public of the change in signal presentation and phasing, the following elements are recommended for the educational campaign:

- A news release informing the public of the implementation of the FYA signal head should be issued through the press office.
- A brochure detailing the operation of the FYA and the associated signal phasing modes should be promoted.
    - An existing brochure is posted on the ODOT website and could be referenced in the news release.
    - http://www.dot.state.oh.us/Divisions/Engineering/Roadway/DesignStandards/traffic/OhioMUTCD/Documents/0_2012OMUTCD_Brochure_ODOT-FlashingYellow-2012_050812_013013copy.pdf.
- Create and provide educational videos.
    - Videos could be posted to the ODOT website and referenced in the news release.
    - Short video spots could be made available to TV news portals in association with the press release.
- Provide location specific education for a short duration prior to implementation and a longer duration after implementation (ex. 1 week /6 weeks.)
    - Portable Dynamic Message Signs can be used in advance of an intersection to display the following message:
        - Phase 1: New Signal Display
        - Phase 2: Yield on Flashing Yellow Arrow

A regional educational campaign should also be developed. Educational campaigns should include a focus for both law enforcement and the public.

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APPENDIX E: COST ESTIMATE