DEL-23-14.09/15.09 SAFETY STUDY

US 23 FROM 84 LUMBER SITE TO OAKHAVEN GOLF CLUB

URBAN NON-FREEWAY RANKING #78 (14.14-14.24)

RURAL NON-FREEWAY RANKING #18 (14.99-15.09)

ODOT DISTRICT 6 / CITY OF DELAWARE

PID # 105479

MARCH 16, 2018

PREPARED FOR:

OHIO DEPARTMENT OF TRANSPORTATION
DISTRICT 6
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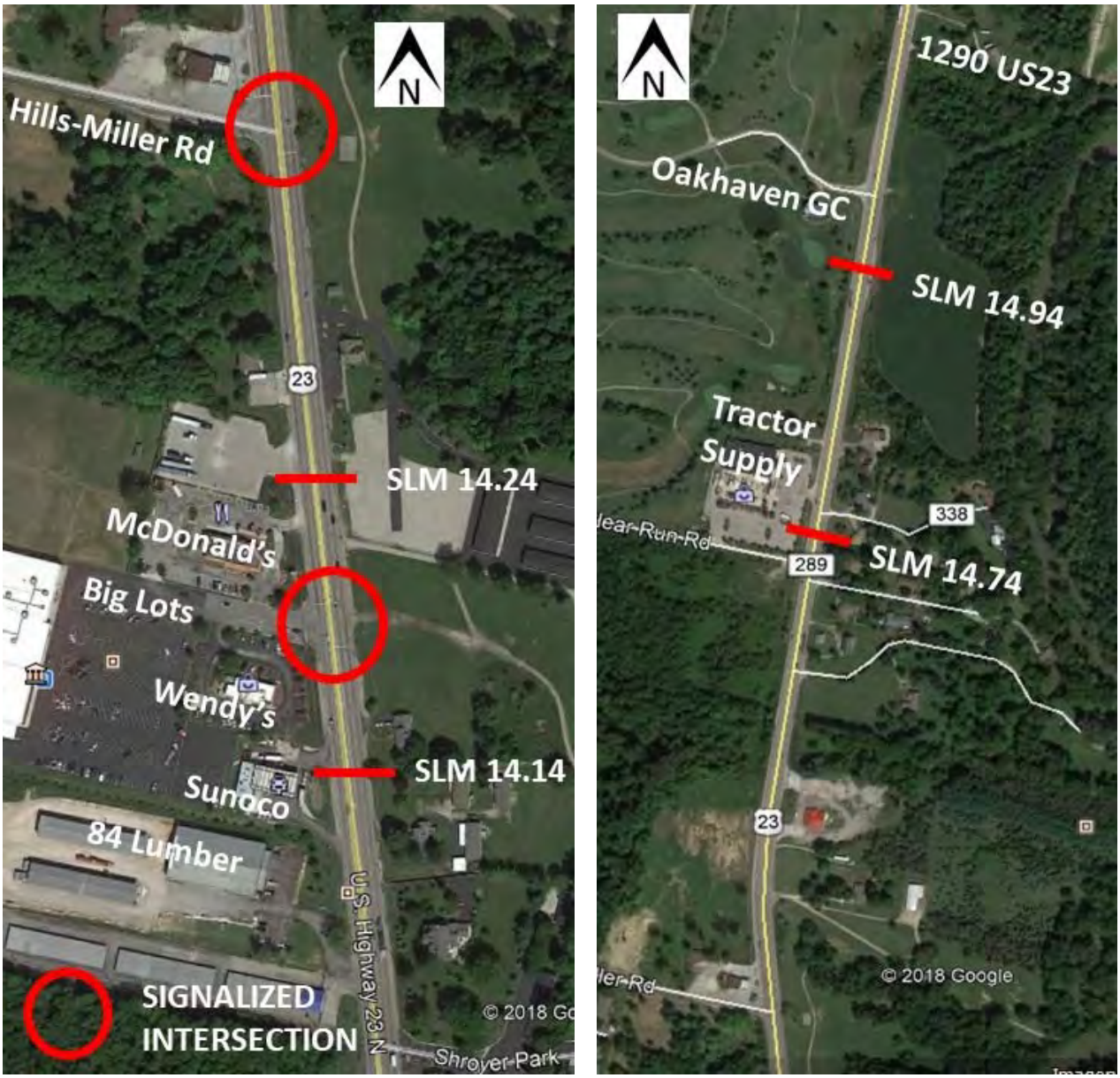
TABLE OF CONTENTS

INTRODUCTION

The purpose of this study is to evaluate the existing safety performance and to identify potential countermeasures to reduce traffic crashes on US Route 23 from the 84 Lumber site (SLM 14.09) to north of the Oakhaven Golf Club (SLM 15.09 or 1290 US Route 23). Segments of the study area are located within corporation limits of the City of Delaware, Ohio. A study area map is shown in **Figure 1**.

FIGURE 1: STUDY AREA MAP

(SLM 14.09 TO 14.42) (SLM 14.34 TO 15.09)



The posted speed limit is 45 MPH on US Route 23 south of Hills-Miller Road.

ODOT uses AASHTOWare's Safety Analyst software to prioritize safety locations across Ohio. The software system prioritizes urban segments that have higher-than-predicted crash frequencies and crash severity. The study area includes 2 segments that have appeared on the Non-Freeway priority safety list based on crash data from 2013 to 2015. The logpoint or straight line mileage (SLM) references are shown in parenthesis.

- Rural rank #18 from Oakhaven Golf Club access (SLM 14.99) to a residential driveway at 2950 US Route 23 (SLM 15.09). A total of 6 crashes occurred within this subsegment.
- Urban rank #78 from the north access to the Sunoco gas station (SLM 14.14) to the truck parking access to McDonald's site (SLM 14.24). Study limits include the existing signalized intersection at Big Lots site. A total of 36 crashes occurred within this subsegment.

An evaluation based on 3-years of crash data from 2014 through 2016 indicates safety performance continues to be an issue:

- Rural rank #10 from 14.89 to 14.99 (Oakhaven Golf Club access).
- Urban rank #39 from 14.14 (north access to the Sunoco gas station) to 14.24 (truck parking access to McDonald's site).

The study limits include the Hills-Miller Road (TR 192) signalized intersection (SLM 14.38) and the Big Lots signalized intersection (SLM 14.19).

No improvements were constructed within the study limits from 2013 to 2015 that would affect the safety performance of the corridor.

EXISTING CONDITIONS

US Route 23 is classified as a principal arterial which is oriented north-south and connects Columbus and Toledo. US Route 23 within the study area is a typical 5-lane section with 2 travel lanes in each direction and a center turn lane – the center turn lane varies between a dedicated left turn lane and a two way left turn lane (TWLTL). The lane widths of the typical section average 12'-11'-10' (center lane)-11'-12' for a pavement width between edge lines of 56 feet.

Paved shoulder widths are variable (2-4 feet). Graded shoulder widths including aggregate surface are variable (2-10 ft). The expanded aggregate shoulder widths occur south of Hills-Miller Road intersection. No parking signs are posted to discourage on street parking. **Photo 1** show rutting caused by parking on the shoulder in the northbound US Route 23 direction (east side).

PHOTO 1: AGGEGATE SHOULDER WIDTH (EAST SIDE OF US ROUTE 23)

US Route 23 is a designated Federal-Aid primary route which requires one 12-ft through lane in each direction as a minimum. For multilane urban arterials and multilane rural arterials, FHWA recognizes the expected difference in substantive safety for variations in lane width is much lesson the order of a few percentage points when comparing lane widths of 10 to 12 feet. (https://safety.fhwa.dot.gov/geometric/pubs/mitigationstrategies/chapter3/3_lanewidth.cfm).

Improvements that have occurred in 2017 within the study area include the following:

- Traffic signal upgrade at Hills-Miller Road intersection that included new signal heads, reflectorized backplates and dilemma zone detection using Wavetronics. Pavement work widened lanes on US Route 23 to 12 feet and the additional of an EB right turn lane.
- The bridge on Panhandle Road (CR125) was reconstructed in 2016 and 2017. The traffic signal equipped with dilemma zone detection.
- The McDonalds unsignalized access was converted to a right-in only (NB left turn prohibited)

Prepare to Stop When Flashing (PTSWF) signs are located 550 feet north of the Hills-Miller Road intersection (southbound SR23) and 750 feet south of the Big Lots intersection (northbound SR23). The following criteria is used when evaluating the need for PTSWF signs:

- Isolated intersections (10 mile spacing). Coover Road is located 1.25 miles north of the Hills-Miller intersection whereas Panhandle Road is located 0.33 miles south of the Big Lots intersection.
- Limited sight distance
- Grades
- Correctable crashes (i.e., rear end)

The posted speed limit is 45 MPH on US Route 23 south of Hills Miller Road. The speed limit increases to 55 MPH north of Hills Miller Road. Field observations conducted November 29, 2017 noted operating speeds higher are likely higher than the posted speeds.

The 2016 Average Daily Traffic (ADT) for US Route 23 was recorded as 28,102 vehicles per day of which 15% are trucks. **Table 1** shows hourly volumes on the US Route 23 corridor The PM peak hour is the design hour which occurs between 4:00 to 5:00 PM. ADT traffic data from the ODOT Transportation Data Management System is contained in **Appendix A**.

ACCESS MANAGEMENT

The functional area of an intersection is defined as the area beyond the physical intersection of two roadways. The functional area for a leg of an intersection includes two components:

- Upstream of the physical area of the intersection. The upstream (or intersection approach) includes additional length for decision-making, maneuvering, and required vehicle storage in auxiliary turn lanes. For the approaches to the signalized intersections on US Route 23, the functional area is 785 feet at the Big Lots access (northbound left turn storage lane length plus stopping sight distance for 45 miles per hour of 360 feet) and 710 feet at the

Hills-Miller Road intersection (southbound right storage lane length plus stopping sight distance for 45 miles per hour of 360 feet).

- Downstream of the physical area of the intersection. The downstream area consists of a conflict overlap distance that allows a through vehicle to clear the intersection in addition to downstream conflict points. The downstream distance is calculated to be 360 feet on US Route 23 based on a design speed of 45 MPH.

Based on these dimensions of the functional area of an intersection as shown in **Figure 2**, the functional areas overlap between the two signalized intersections and extend from SLM 14.04 to SLM 14.51 (2,480 feet).

TABLE 1: HOURLY VOLUME SUMMARY (US ROUTE 23)

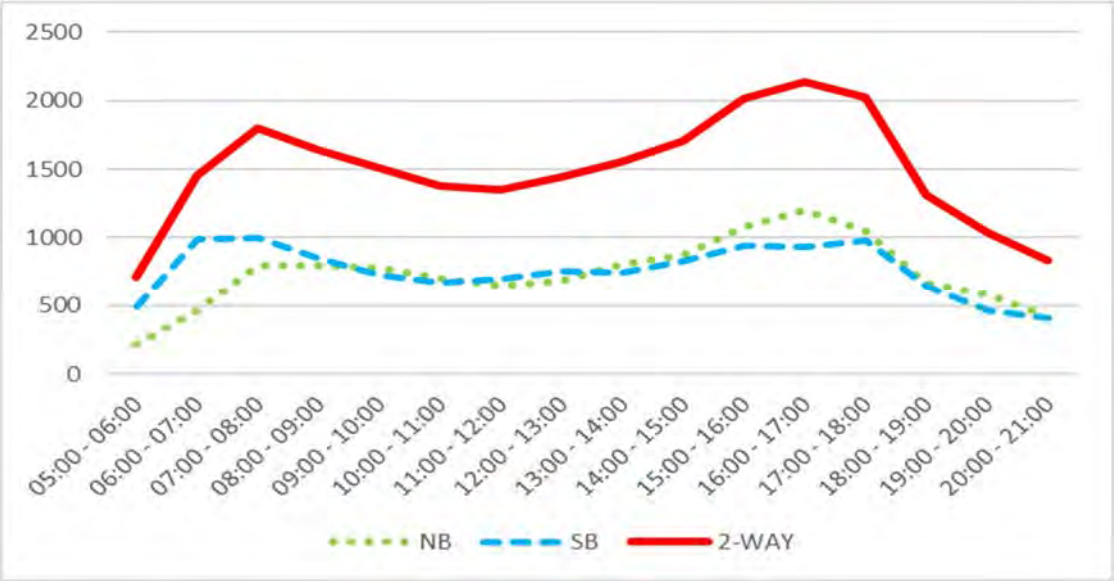
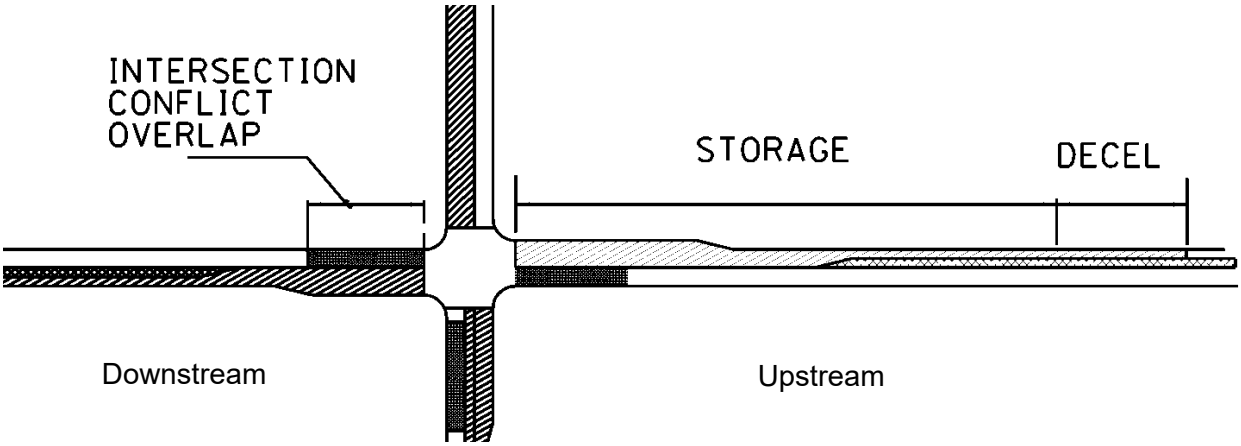


FIGURE 2: FUNCTIONAL AREA OF AN INTERSECTION



CRASH ANALYSIS

Crash data was obtained using the GIS Crash Analysis Tool (GCAT) for the study. The crash data included three years of data from 2013 to 2015. The OH-1 crash report for each documented crash was reviewed to confirm accuracy and to locate crashes properly within the study limits.

The location of several crashes at the north end of the study area were adjusted due to the offset distances on the OH-1 forms were not correct in the GCAT database. Adjustment of these crashes can be expected to change the Non-Freeway Rural rank of #18 between SLM 14.99 and SLM 15.09 to shift further south. This shift in crash location is more consistent with the crash priority ranking when 2016 data is included.

The study area includes 2 segments that have appeared on the Non-Freeway priority safety list based on crash data from 2013 to 2015. The logpoint or straight line mileage (SLM) references are shown in parenthesis.

- Rural rank #18 from Oakhaven Golf Club access (SLM 14.99) to a residential driveway at 2950 US Route 23 (SLM 15.09). A total of 6 crashes occurred within this subsegment. This segment has appeared on the statewide priority list since 2012 although the location varies between 14.89 to 15.09.
- Urban rank #78 from the north access to the Sunoco gas station (SLM 14.14) to the truck parking access to McDonald's site (SLM 14.24). Study limits include the existing signalized intersection at Big Lots site. A total of 36 crashes occurred within this subsegment. This segment has appeared on the statewide priority list since 2014 although the location varies between 14.04 to 14.24.

An evaluation based on 3-years of crash data from 2014 through 2016 indicates safety performance continues to be an issue:

- Rural rank #10 from 14.89 to 14.99 (Oakhaven Golf Club access).
- Urban rank #39 from 14.14 (north access to the Sunoco gas station) to 14.24 (truck parking access to McDonald's site).

Noteworthy crash statistics for the 3-year period between 2013 and 2015 are summarized below. Non-freeway statistics were used for comparison purposes. Statewide averages for crashes on state system, non-freeway locations are shown in parentheses based on data for years 2010 through 2014. Crash diagrams are contained in **Appendix B.**

- Total crashes: 72 total crashes
- **Injury: 26 crashes or 36.1 percent** **(26.1 percent)**
- Rear end crashes: 26 crashes or 36.1 percent (31.1 percent)
- **Sideswipe passing: 13 crashes or 18.1 percent** **(8.7 percent)**
- Angle: 6 crashes or 8.3 percent (5.3 percent)
- **Left turn: 5 crashes or 6.9 percent** **(2.6 percent)**

The crash statistics of greatest significance are those that are highlighted with bold text. **Figure 3** shows the frequency of injury crashes increased in 2014 whereas the percentage of injury crashes increased 2015.

FIGURE 3: FREQUENCY OF CRASHES BY YEAR AND SEVERITY

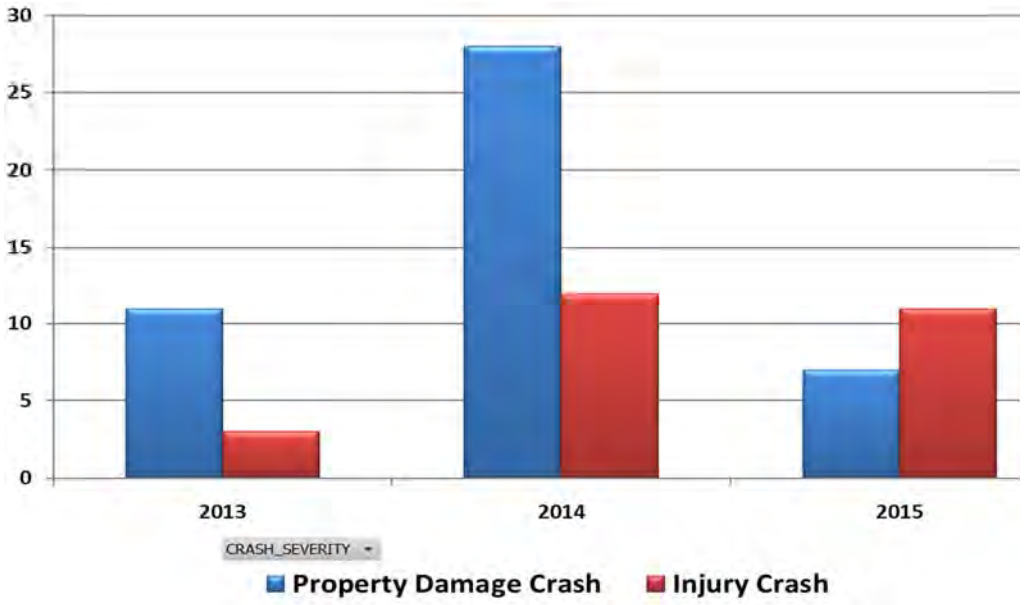
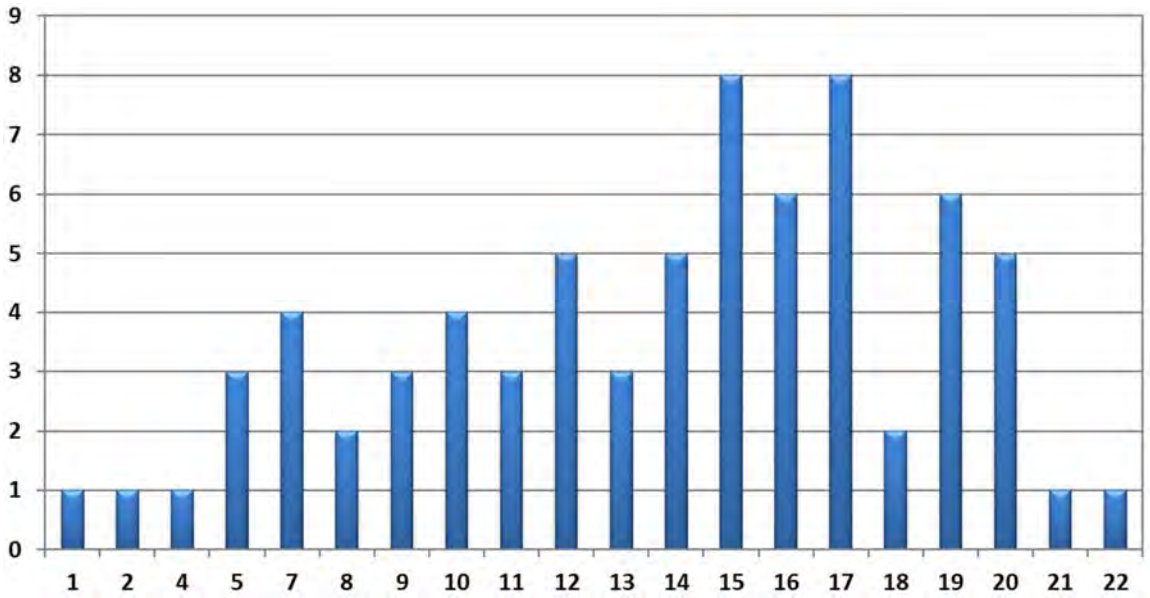


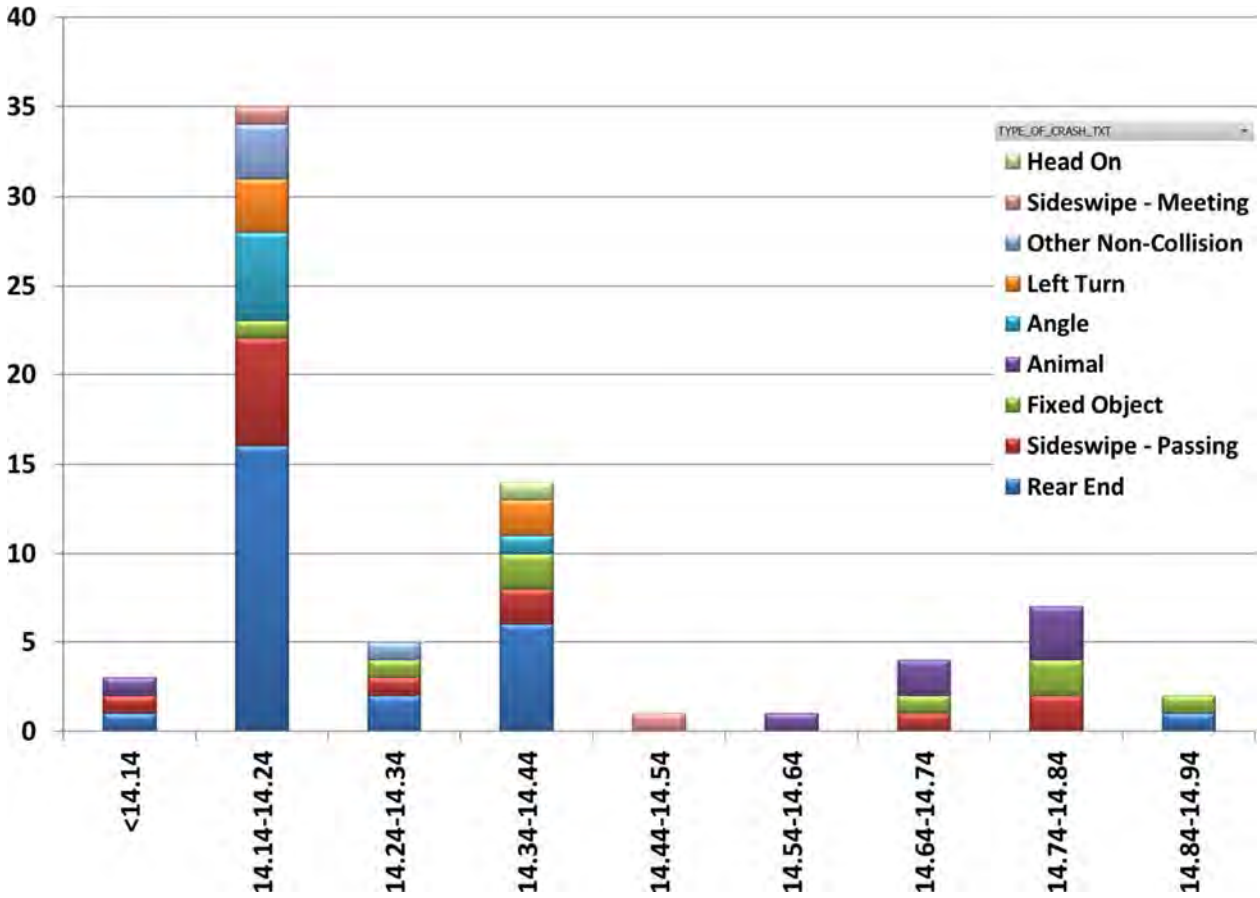
Figure 4 shows that the highest number of crashes occur during the highest volume periods of the day as shown in **Table 1**. The 16:00 hour experiences fewer crashes which is attributed to the reduction of speed associated with congestion – the 15:00 and 17:00 hours are transition periods leading up to and after congestion. The 19:00 hour is comprised of 4 animal crashes. Crashes that occurred during the 20:00 hour were located at the Big Lots traffic signal.

FIGURE 4: FREQUENCY OF CRASHES BY HOUR



The distribution of crashes by crash type are shown in **Figure 5** at 0.1 mile increments. A total of 56 crashes (or 75 percent) of all crashes occurred between the north access to the Sunoco gas station (SLM 14.14) to 300 feet north of the Hills-Miller Road intersection (SLM 14.44). The location of the signalized intersections are also shown on Figure 5. **Appendix C** contains the crash analysis in tabular format.

FIGURE 5: FREQUENCY OF CRASHES BY LOGPOINT (SLM)



The crash data was further analyzed to evaluate the crash severity by time of day for the focus area between SLM 14.14 and 14.44.

- Peak hours (7-10:00 AM, 15-18:00 PM) Seven (7) of the 22 crashes that occurred during the peak hours resulted in an injury (32 percent).

- Off peak hours. Fourteen (14) of the 32 crashes that occurred during the off peak hours resulted in an injury (44 percent). While the total number of crashes can be expected to be higher during the off-peak hours (18 hour duration) than the peak hour timeframe (6 hour duration), the higher percentage of injuries are attributed to the higher speeds that are possible during periods of lower congestion.

When the study limits are further reduced (SLM 14.14 to 14.24), the majoity of crashes (53 percent) result in injuries during the off-peak hours defined above. Safety countermeasures should address traffic operations for both peak hour and off-peak periods.

Other insights from the crash analysis for the segment between SLM 14.14 and 14.44 include the following:

- A total of 3 fixed object (FO) crashes occurred within the study subsection. Contributing factors for the other FO crashes were deer avoidance, ice, and sleep. None of the FO crashes were attributed to the typical section or geometric design of the roadway.

- Four (4) of the 5 left turn crashes occurred at the signalized intersections. The at fault driver was the left turning vehicle (failure to yield during the permissive phase) and not red light running (RLR) of the opposing through movement.

- Three (3) non-collision crashes involved a vehicle leaving the roadway to avoid a crash, debris in the roadway and a medical condition of a motorcyclist. None of the non-collsion crashes were attributed to the typical section or geometric design of the roadway.

A total of 6 animal crashes occurred north of the Hills-Miller Road intersection. This section is charactertized by narrow shoulders (4 feet) adjacent to guardrail. The posted speed limit is 55 miles per hour. The roadway section is on embankment which does not provide motorists good visibiity of deer crossing the roadway as they climb the embankment and jump over the guardrail. Foliage can also restrict sight distance of crossing animals as shown in **Photo 2**.

PHOTO 2: PAVED SHOULDER (US ROUTE 23 NORTH OF HILLS-MILLER ROAD)

Research sponsored by the Insurance Institute for Highway Safety questions the effectiveness of static warning signs for deer. Warning signs are typically not seasonal thus reducing the effectiveness of catching driver attention. Deer crashes are also highly distributed within the study area – deer related crashes occurred between SLM 14.20 and 14.80. One of the 7 animal related crashes resulted in minor injuries – all other crashes were property damage only. Countermeasures to mitigate the seasonal and distributed nature of deer crashes are not proposed as part of this study.

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 attributable to historical crash patterns.

SHORT TERM COUNTERMEASURES

TRAFFIC SIGNAL IMPROVEMENTS

Modifications to the traffic signals are recommended to mitigate various crash types.

1. **Revise left turn signal phasing.** Four (4) of the 5 left turn crashes resulted in an injury (80 percent). Converting the permissive/protected left turn phasing to protected only phasing should be analyzed before implementing to confirm the countermeasure does not adversely affect capacity during the peak periods. Options to maintain or improve capacity to offset delays of a protected only left turn phase include the following:

    - The left turn phase could be allowed to be serviced after the coordinated phases on US Route 23 to reduce delays – the signal 'backing up' to serve the protected left turn phase as a lagging phase is possible without creating a safety issue due to the lack of an opposing left turn movement in the southbound direction.
    - Add southbound right turn lane on US Route 23 approach
    - Add additional left lane on the eastbound approach (see Traffic Control countermeasures)
    - Reassign eastbound right turn overlap phase (see below)

    An option to a traditional protected-permissive left turn phase using a 5-section signal head is to utilize a flashing yellow arrow (FYA) sequence. 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 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.

    A technical memorandum providing more detailed information regarding the FYA was prepared for ODOT District 12 and is included in **Appendix D**.

2. **Reassign right turn overlap phase.** Assign loop detectors in the eastbound right turn lane at the Big Lots traffic signal to the northbound left turn phase. Cycles without eastbound left turn vehicles during off-peak periods would only require stopping southbound US Route 23 traffic. This countermeasure will reduce the frequency of rear-end crashes on the northbound approach of the Big Lots traffic signal (5 crashes).

   Note that this sequence would allow the traffic signal to appear as 'backing up' if the northbound left turn phase is serviced after the coordinated phases on US Route 23.

3. **Supplemental signal heads.** A near side, far left supplemental signal heads are proposed to increase the visibility of the traffic signal heads. Truck percentages of 15% on US Route 23 can reduce the visibility of signal heads by vehicles following truck trailers. One crash narrative on an OH-1 specifically mentioned trucks blocking the view of signal heads. Signal heads to be oriented at a distance of 400 feet from the stop line. This countermeasure is to reduce the frequency of rear end crashes on the US Route 23 approaches at both signalized intersections. This countermeasure may also be implemented in conjunction with the removal of PTSWF signs (see below).

4. **Add backplates**. Add backplates to the Big Lots traffic signal (SLM 14.19) to increase visibility of the signal heads especially on the US Route 23 approaches. The existing traffic signal plans for the Big Lots intersection and the Hills-Miller Road intersection are included in **Appendix E**. Upgrades to the signal heads at the Big Lots intersection is to be consistent with recent improvements in 2017 at the Hills-Miller Road intersection. This countermeasure is to reduce the frequency of rear end crashes on US Route 23 approaches at the Big Lots signalized intersection.

5. **Remove PTSWF signs**. The Prepare to Stop When Flashing (PTSWF) signs on the approaches to the signalized intersection do not meet typical criteria for such signs (i.e., restricted sight distance). ODOT has seen a significant reduction in crashes at 14 intersections where the signs were removed. The average crash reductions included a 23% reduction in total crashes; 35% reduction in serious crashes; 42% reduction in angle crashes; and 50% reduction in red-light running crashes.

   Implementation of dilemma zone detection at the Big Lots intersection may be a condition of the removal of the PTSWF signs.

6. **Upgrade clearance intervals**: The historical crash patterns do not suggest the need for revisions to the clearance intervals at the signalized intersections within the study area.

   The NCHRP Report 731 dated July 2012 does recommend using a design speed of 20 MPH for left turning vehicles. This finding is consistent with research conducted by the North Carolina Department of Transportation published by the ITE Journal which determined that the average operating speed for left turning traffic is 17 miles per hour. This methodology helps provide adequate all-red clearance times based on operating speeds and avoids excessively long clearance intervals (yellow + AR).

   Clearance intervals may need to be revised if countermeasures are implemented that increase the size of the intersections (i.e., stop line locations). Excerpts of the existing signal timing is contained in **Appendix F**.

8. **Coordinated Signal Timing updates**. A simple, coordinated signal timing plan was implemented in late 2016 when communication was established to the signal controllers at intersections within the study area. The coordinated timing plan is considered to be a basic plan that would benefit from a formal evaluation that includes the traffic signal at the Panhandle Road intersection.

TRAFFIC CONTROL IMPROVEMENTS

9. **Revise stop line locations**. Two left turn and two right turn angle crashes occurred at the Big Lots signalized intersection. Two of the 4 crashes resulted in an injury (50 percent). Setting back the stop line 15 feet for the eastbound left turn lane would provide 2 benefits:

    - Increase the time between opposing movements
    - Increase sight distance of eastbound right turn traffic. If the stop line for the eastbound left turn lane is not set back 15 feet, a No Right Turn on Red (RTOR) sign should be erected to provide adequate sight distance for right turning vehicles.

    Stop line locations on US Route 23 may also be setback 10 feet on both the northbound and southbound approaches. The all-red clearance interval may increase slightly to provide additional time between opposing movements. **Figure 6** shows the revised stop line locations at the Big Lots signalized intersection.

    Revising the stop line locations will require recalculation of clearance intervals.

10. **Dual left turn lane analysis**. Evaluate the benefits of a dual left turn lanes on the eastbound approach of the Big Lots signalized intersection. Stop line and signal phasing refinements to improve safety performance may support reallocating the pavement on the west leg to provide a short dual left turn lane (100 feet including 50 ft diverging taper).

    Supplemental pavement markings may be considered to prevent vehicles on the eastbound approach from blocking the Wendy's driveway. Painting a box across the approach lanes to the Big Lot traffic signal is an option to discourage motorists from blocking the intersection (thus causing queues from extending towards US Route 23). Alternative markings may be used inside the box (crosshatch or no markings) can be found in the Manual of Uniform Traffic Control Devices (2009 MUTCD).

11. **Speed zone expansion**. The existing 45 MPH speed zone on US Route 23 is located 170 feet south of the Hills-Miller Road intersection. Extending the 45 MPH speed zone to 700 feet north of the Hills-Miller Road intersection is recommended to be consistent with the urban characteristics of the corridor. Inclusion of the signalized intersection and driveway access to the gas station in the NW quadrant of the Hills-Miller Road intersection should be verified by the Speed Zone Warrant sheet (ODOT TEM form 1296-2).

    A reduction of the speed limit may also be considered if supported by the speed zone analysis. **Appendix E** contains the speed zone warrant used to calculate the speed between SLM 14.18 and 15.84. Note that a speed limit of 45 MPH was posted within the study area from 1971 to 1996. Revised speed zone analysis should re-evaluate the speed zone from SLM 14.00 (or less) to SLM 14.51. Speeds north of Hills-Miller Road are expected to be 55 MPH.

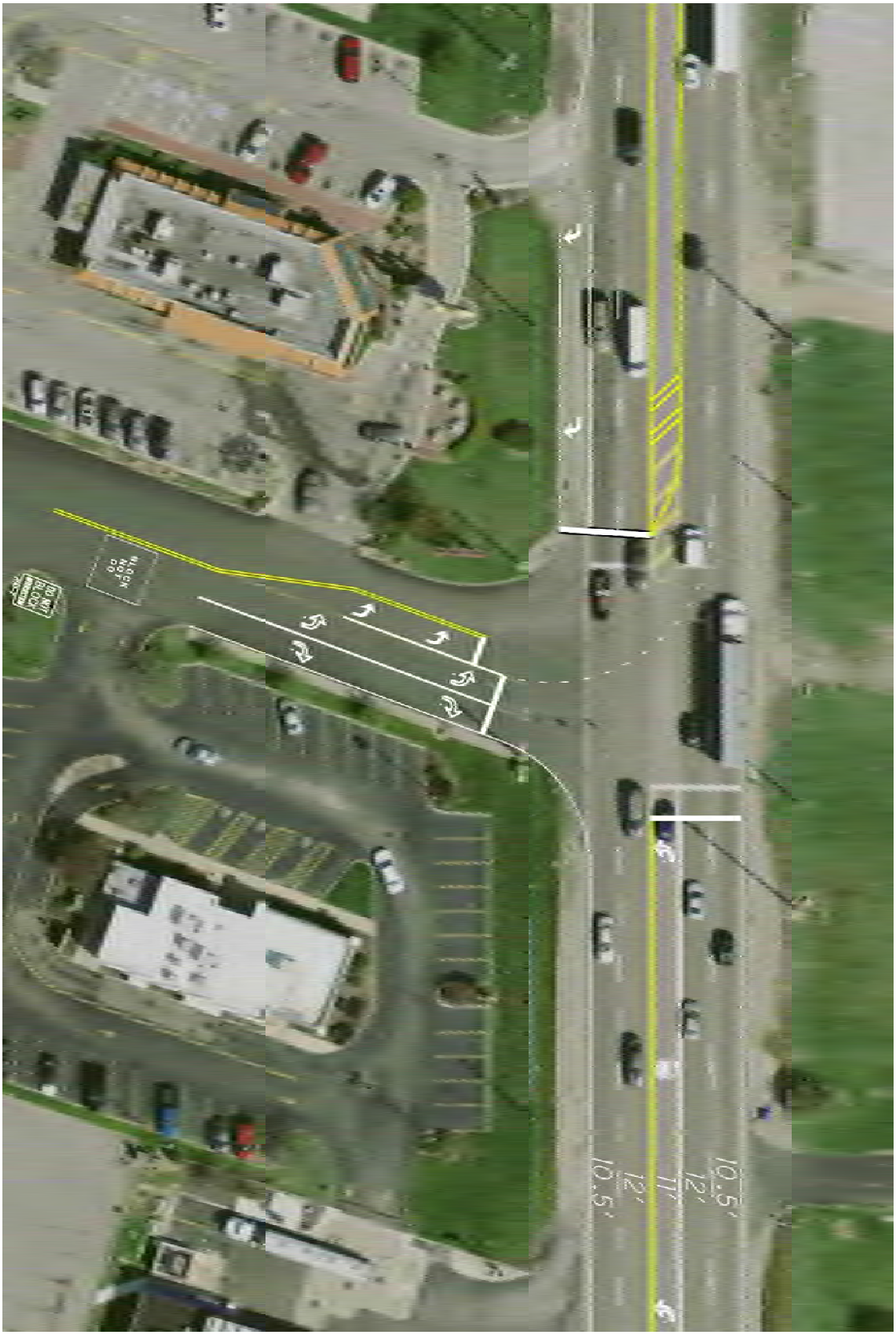
12. **Lane widths on US Route 23 (SLM 14.14 to 14.44)**. The width of the center turn lane (10 feet) and the adjacent through lane (11 feet) contributes to the percentage of sideswipe passing crashes – the majority (7 crashes) occur within the focus area between SLM 14.14 and 14.44 (0.3 miles). Vehicles maneuvering into the exclusive left turn lanes require the most space – motorists are changing direction of the vehicle over a short distance. The least pavement width needed from a traffic operations perspective are through vehicles – the horizontal curvature of US Route 23 can accommodate speeds higher than posted speeds.

    The existing pavement width between edge lines is 56 feet. Revising the existing lane width (12'-11'-10'-11'-12') to a proposed section of 10.5'-12'-11'-12'-10.5' which retains the pavement width of 56 feet. The lane width modifications shown in **Figure 6** are recommend for several reasons:

    - Increasing the left turn lane width from 10 to 11 feet better accommodates turning vehicles
    - The 12 ft lane adjacent to the turn lane is proposed to meet minimum lane widths required by the FAP designation (one 12 ft lane in each direction).
    - The majority of sideswipe passing crashes involved vehicle changing lanes into the left turn lane or into Lane 2 (adjacent to the left turn lane). Increased lane widths are desirable to better accommodate lane changes on US Route 23.
    - The 10.5 ft lane is proposed adjacent to a 3-4 ft paved shoulder (plus a variable width aggregate shoulder). Contributing factors associated with fixed object crashes are not attributed to the geometric design of the roadway (alignment or typical section). A 10.5 ft lane adjacent to the paved/graded shoulders is proposed since lane widths and shoulder widths do not contribute to the existing safety performance issues within the study area.
    - For multilane urban arterials and multilane rural arterials, FHWA recognizes the expected difference in substantive safety for variations in lane width is much lesson the order of a few percentage points when comparing lane widths of 10 to 12 feet. (https://safety.fhwa.dot.gov/geometric/pubs/mitigationstrategies/chapter3/3_lane width.cfm).

    The project limits of the revised lane widths are to extend from SLM 14.04 to 14.51 including tapers. These limits represent the functional area of the signalized intersections. The revised limits of the 45 MPH speed zone would complement changes to the lane widths north of SLM 14.30. **Figure 6** shows the revised lane widths on the US Route 23 approaches at the Big Lots intersection.

FIGURE 6: CONCEPT PLAN (BIG LOTS TRAFFIC SIGNAL)



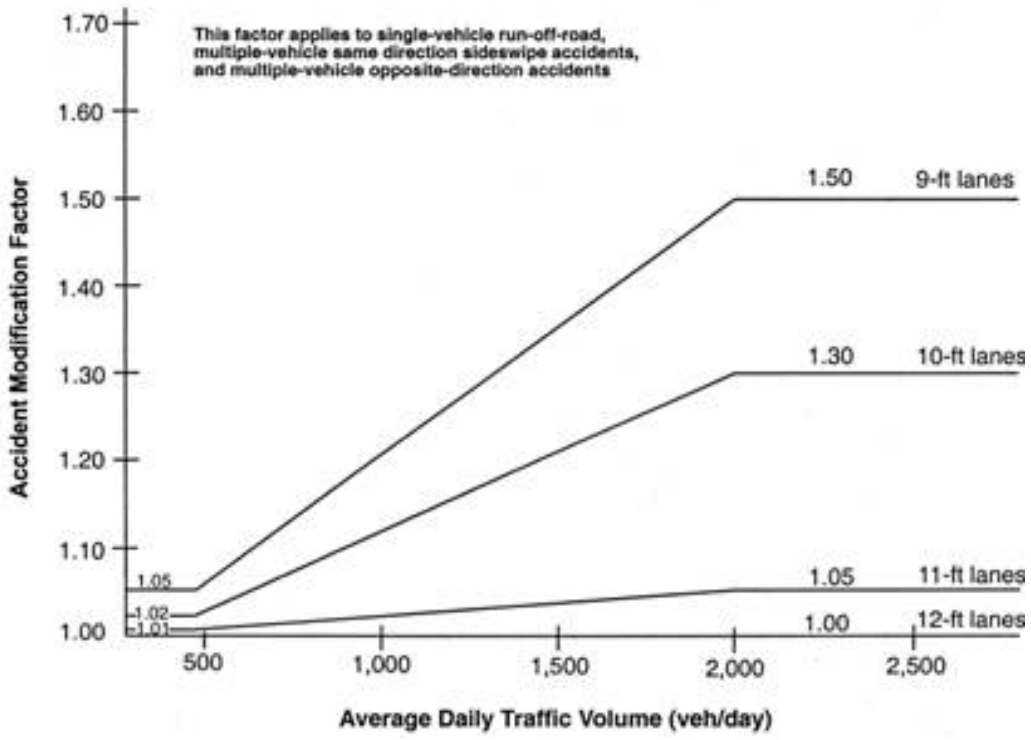
MEDIUM TERM COUNTERMEASURES

LANE WIDTHS

The lane widths proposed as a short-term countermeasure uses the existing pavement widths from SLM 14.04 to 14.51. Additional pavement widening is proposed as a medium-term countermeasure to achieve preferred lane widths that accommodates lane changing and left turning movements but not encourage higher operating speeds. **A typical section having lanes of 11'-12'-12'-12'-11' for a total width between edge lines of 58 feet is proposed.**

Figure 7 shows the relative safety performance of various lane widths. The proposed lane widths are expected to result in a net reduction of crashes within the study area.

FIGURE 7: CMF FOR LANE WIDTHS



SHOULDER WIDTHS

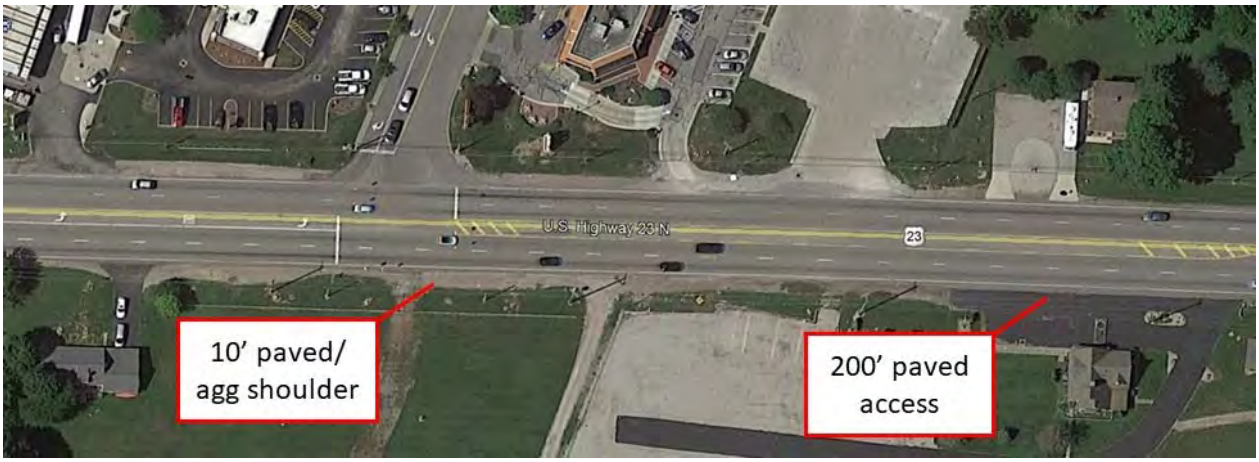
A paved shoulder of 1 ft is proposed adjacent to a Type 6 barrier curb resulting in a back to back of curb dimension of 61 feet from SLM 14.04 to 14.51.

An alternate design of a Type 2 curb and gutter section may be used adjacent to a 10.5 ft lane resulting in a back to back of curb dimension of 62 feet. The proposed shoulder widths assume that the minimum design speed for improvements are equal to the posted speed limit of 45 MPH per ODOT L&D manual, section 104.2.

In addition to delineating the urban characteristics of this sub-segment of the study area, a curbed roadway section achieves the following benefits:

- Concrete curb reduces the width of the aggregate shoulder width which is used occasionally for parking despite No Parking signs. The curb serves as a barrier to on street parking and may reduce operating speeds between SLM 14.04 and 14.51.
- Concrete curb delineates the location and size of access points. **Photo 3** shows a parcel having an undefined access for a length of 200 feet.

PHOTO 3: PAVED SHOULDER (US ROUTE 23 SOUTH OF HILLS-MILLER RD)



LONG TERM COUNTERMEASURES

ACCESS MANAGEMENT

Current volumes on US Route 23 are 28,000 vehicles which approach the operational limits of the TWLTL treatment. The TWLTL has been shown to be effective "when traffic levels are moderate…and the density of commercial driveways is low to moderate (CTRE, 2003)." Evidence suggests that the operation of a TWLTL will begin to degrade when Average Annual Daily Traffic (AADT) volumes reach 24,000 to 28,000 vehicles. The ODOT Location and Design Manual recommends an AADT between 10,000 and 20,000 vehicles for use of a TWLTL.

The ODOT Location and Design Manual also recommends a minimum length of a TWLTL as 1,000 feet or more. The existing TWLTL segments on US Route 23 are 400 to 800 feet.

Appendix H contains an access management plan from 2002. An update of the access management plan is proposed to eliminate TWLT lanes on US Route 23 and replace with a combination of medians and exclusive left turn lanes.

RIGHT TURN LANES

The Center for Transportation Research and Education at Iowa State University published a technical brief in October 2014 about the benefits of adding turn lanes at intersections. The technical brief summarized research by Rodegerdts et al. (2004) on safety and operations of signalized intersections of various treatments and best practices in use across the United States. The safety impacts for a right-turn lane on a multi-lane approach can expect to result in the following safety impacts:

- 40% estimated reduction in fatal/injury crashes
- 10% estimated reduction in head on/sideswipe crashes

Advantages of right turn lanes include the following:

- Separation of decelerating right-turn vehicles
- A reduction in rear-end collisions involving right-turning vehicles and following through vehicles due to improved signal operation
- Through vehicles will experience less delay if right turning vehicles do not have to decelerate in a through lane
- Higher right-turn capacity, shorter green time, and less delay for following through vehicles

Warrants for the construction of right turn lane to mitigate delay are outlined in Section 401.6.3 of the ODOT L&D manual, Volume 1. The installation of a right turn lane also should be considered based on the safety performance of the existing conditions and future operations. Factors for consideration of a right turn lane include operating speed of the adjacent roadway, turning speed of vehicles, and length of driveway throat to minimize conflicts between entering vehicles and site traffic.

DEL-23-14.09/15.09 SAFETY STUDY

APPENDIX A: TRAFFIC DATA

CMT

Location Info	
Location ID	9821_NB
Type	I-SECTION
Functional Class	3
Located On	US-23
Between	AND
Direction	NB
Community	DELAWARE
MPO_ID	
HPMS ID	23018820
Agency	Ohio Department of Transportation

Count Data Info	
Start Date	1/25/2018
End Date	1/26/2018
Start Time	12:00 AM
End Time	12:00 AM
Direction	
Notes	
Count Source	
File Name	
Weather	
Study	
Owner	ODOTAuto

Interval: 60 mins

Time	Hourly Count
00:00 - 01:00	145
01:00 - 02:00	94
02:00 - 03:00	112
03:00 - 04:00	87
04:00 - 05:00	141
05:00 - 06:00	220
06:00 - 07:00	465
07:00 - 08:00	796
08:00 - 09:00	796
09:00 - 10:00	776
10:00 - 11:00	706
11:00 - 12:00	649
12:00 - 13:00	683
13:00 - 14:00	808
14:00 - 15:00	876
15:00 - 16:00	1077
16:00 - 17:00	1202
17:00 - 18:00	1049
18:00 - 19:00	666
19:00 - 20:00	581
20:00 - 21:00	425
21:00 - 22:00	363
22:00 - 23:00	294
23:00 - 24:00	255
TOTAL	13266

Location Info	
Location ID	9821_SB
Type	I-SECTION
Functional Class	3
Located On	US-23
Between	AND
Direction	SB
Community	DELAWARE
MPO_ID	
HPMS ID	23018820
Agency	Ohio Department of Transportation

Count Data Info	
Start Date	1/25/2018
End Date	1/26/2018
Start Time	12:00 AM
End Time	12:00 AM
Direction	
Notes	
Count Source	
File Name	
Weather	
Study	
Owner	ODOTAuto

Interval: 60 mins

Time	Hourly Count
00:00 - 01:00	90
01:00 - 02:00	78
02:00 - 03:00	53
03:00 - 04:00	103
04:00 - 05:00	256
05:00 - 06:00	498
06:00 - 07:00	992
07:00 - 08:00	1002
08:00 - 09:00	847
09:00 - 10:00	732
10:00 - 11:00	676
11:00 - 12:00	698
12:00 - 13:00	759
13:00 - 14:00	747
14:00 - 15:00	835
15:00 - 16:00	942
16:00 - 17:00	935
17:00 - 18:00	979
18:00 - 19:00	643
19:00 - 20:00	462
20:00 - 21:00	411
21:00 - 22:00	291
22:00 - 23:00	216
23:00 - 24:00	143
TOTAL	13388

Location Info	
Location ID	9821
Type	I-SECTION
Functional Class	3
Located On	US-23
Between	AND
Direction	2-WAY
Community	DELAWARE
MPO_ID	
HPMS ID	23018820
Agency	Ohio Department of Transportation

Count Data Info	
Start Date	1/25/2018
End Date	1/26/2018
Start Time	12:00 AM
End Time	12:00 AM
Direction	
Notes	
Count Source	
File Name	
Weather	
Study	
Owner	ODOTAuto

Interval: 60 mins

Time	Hourly Count
00:00 - 01:00	235
01:00 - 02:00	172
02:00 - 03:00	165
03:00 - 04:00	190
04:00 - 05:00	397
05:00 - 06:00	718
06:00 - 07:00	1457
07:00 - 08:00	1798
08:00 - 09:00	1643
09:00 - 10:00	1508
10:00 - 11:00	1382
11:00 - 12:00	1347
12:00 - 13:00	1442
13:00 - 14:00	1555
14:00 - 15:00	1711
15:00 - 16:00	2019
16:00 - 17:00	2137
17:00 - 18:00	2028
18:00 - 19:00	1309
19:00 - 20:00	1043
20:00 - 21:00	836
21:00 - 22:00	654
22:00 - 23:00	510
23:00 - 24:00	398
TOTAL	26654

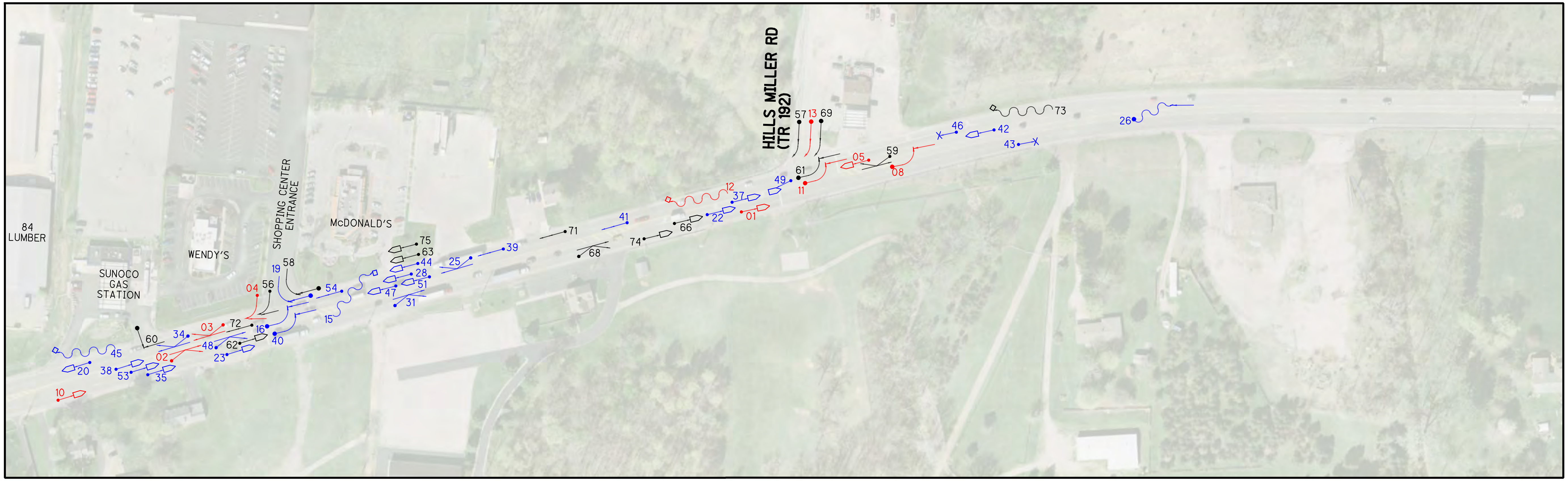
DEL-23-14.09/15.09 SAFETY STUDY

APPENDIX B: CRASH DIAGRAM

CMT

FIGURE B-1

CRASH DIAGRAM - US 23 - 84 LUMBER PROPERTY TO OAKHAVEN GOLF CLUB



DEL-23-14.09/15.09 SAFETY STUDY

APPENDIX C: CAM TOOL ANALYSIS

- - (-) From // to //

	Number
Total	**72**

CRASH_SEVERITY	Number	%
Injury Crash	**26**	36.1%
Property Damage Crash	**46**	63.9%
Grand Total	**72**	**100.0%**

TRAFFIC_CRASH_YEAR	Number	%
2013	**14**	19.4%
2014	**40**	55.6%
2015	**18**	25.0%
Grand Total	**72**	**100.0%**

DAY_OF_WEEK	Number	%
Thursday	**14**	19.4%
Friday	**13**	18.1%
Sunday	**12**	16.7%
Tuesday	**10**	13.9%
Monday	**10**	13.9%
Wednesday	**7**	9.7%
Saturday	**6**	8.3%
Grand Total	**72**	**100.0%**

HOUR_OF_DAY	Number	%
1	**1**	1.4%
2	**1**	1.4%
4	**1**	1.4%
5	**3**	4.2%
7	**4**	5.6%
8	**2**	2.8%
9	**3**	4.2%
10	**4**	5.6%
11	**3**	4.2%
12	**5**	6.9%
13	**3**	4.2%
14	**5**	6.9%
15	**8**	11.1%
16	**6**	8.3%
17	**8**	11.1%
18	**2**	2.8%
19	**6**	8.3%
20	**5**	6.9%
21	**1**	1.4%
22	**1**	1.4%
Grand Total	**72**	**100.0%**

TYPE_OF_CRASH	Number	%
Rear End	**26**	36.1%
Sideswipe - Passing	**13**	18.1%
Fixed Object	**8**	11.1%
Animal	**7**	9.7%
Angle	**6**	8.3%
Left Turn	**5**	6.9%
Other Non-Collision	**4**	5.6%
Sideswipe - Meeting	**2**	2.8%
Head On	**1**	1.4%
Grand Total	**72**	**100.0%**

- - (-) From // to //

WEATHER_CONDITION	Number	%
Clear	41	56.9%
Cloudy	21	29.2%
Rain	7	9.7%
Sleet, Hail	2	2.8%
Snow	1	1.4%
Grand Total	**72**	**100.0%**

ROAD_CONDITION	Number	%
Road - Dry	54	75.0%
Road - Wet	13	18.1%
Road - Snow	4	5.6%
Other Road Condition	1	1.4%
Grand Total	**72**	**100.0%**

LIGHT_CONDITION	Number	%
Daylight	54	75.0%
Dark - No Lights	9	12.5%
Dark - Lighted	6	8.3%
Dawn	2	2.8%
Dusk	1	1.4%
Grand Total	**72**	**100.0%**

NUMBER_OF_VEHICLES	Number	%
(blank)	72	100.0%
Grand Total	**72**	**100.0%**

LOCATION	Number	%
Not An Intersection	52	72.2%
T-Intersection	12	16.7%
Driveway/Alley Access	8	11.1%
Grand Total	**72**	**100.0%**

CRASH_MONTH_NBR	Number	%
1	8	11.1%
2	7	9.7%
3	6	8.3%
4	9	12.5%
5	2	2.8%
6	2	2.8%
7	3	4.2%
8	12	16.7%
9	5	6.9%
10	8	11.1%
11	5	6.9%
12	5	6.9%
Grand Total	**72**	**100.0%**

ROAD_CONTOUR	Number	%
Straight - Level	67	93.1%
Straight - Grade	4	5.6%
Curve - Level	1	1.4%
Grand Total	**72**	**100.0%**

SPECIAL_AREA	Number	%
Unknown or Not in Work Zone	72	100.0%
Grand Total	**72**	**100.0%**

ANIMAL_TYPE	Number	%
Animal Not Stated	65	90.3%
Deer Hit	7	9.7%
Grand Total	**72**	**100.0%**

- - (-) From // to //

ACTION1	Number	%
Straight Ahead	**44**	61.1%
Changing Lanes	**10**	13.9%
Making Left Turn	**7**	9.7%
Slowing Or Stopped In Traffic	**7**	9.7%
Making Right Turn	**3**	4.2%
Driverless	**1**	1.4%
Grand Total	**72**	**100.0%**

CONTRIBUTING_FACTOR1	Number	%
Followed Too Closely/ACDA	**28**	38.9%
Improper Lane Change/Passing/Offroad	**12**	16.7%
None	**9**	12.5%
Failure To Yield	**9**	12.5%
Failure To Control	**4**	5.6%
Left Of Center	**3**	4.2%
Ran Red Light	**2**	2.8%
Unsafe Speed	**1**	1.4%
Swerving To Avoid	**1**	1.4%
Load Shifting/Falling/Spilling	**1**	1.4%
Operating Defective Equipment	**1**	1.4%
Unknown	**1**	1.4%
Grand Total	**72**	**100.0%**

	Number	%
Total	**72**	**100.0%**

TRAFFIC_CONTROL1	Number	%
Pavement Markings	**48**	66.7%
Traffic Signal	**21**	29.2%
No Controls	**3**	4.2%
Grand Total	**72**	**100.0%**

DRIVER_ALCOHOL1	Number	%
None	**63**	87.5%
0	**5**	6.9%
Yes - Alcohol Suspected	**3**	4.2%
Yes - Alcohol And Drugs Suspected	**1**	1.4%
Grand Total	**72**	**100.0%**

DRIVER_DRUGS1	Number	%
(blank)	**72**	100.0%
Grand Total	**72**	**100.0%**

- - (-) From // to //

DIRECTION_FROM1	Number	%
North	**36**	50.0%
South	**27**	37.5%
West	**8**	11.1%
East	**1**	1.4%
Grand Total	**72**	**100.0%**

DIRECTION_TO1	Number	%
South	**38**	52.8%
North	**23**	31.9%
West	**5**	6.9%
East	**4**	5.6%
Unknown	**2**	2.8%
Grand Total	**72**	**100.0%**

POSTED_SPEED1	Number	%
Posted Speed 41-45	**50**	69.4%
Posted Speed 51-55	**16**	22.2%
Posted Speed 31-35	**2**	2.8%
Posted Speed Not Stated	**2**	2.8%
Posted Speed 21-25	**1**	1.4%
Posted Speed 20 and Under	**1**	1.4%
Grand Total	**72**	**100.0%**

ESTIMATED_SPEED1	Number	%
Unit Speed 20 and Under	**24**	33.3%
Unit Speed 41-45	**12**	16.7%
Unit Speed 51-55	**10**	13.9%
Unit Speed 21-25	**7**	9.7%
Unit Speed 36-40	**7**	9.7%
Unit Speed 31-35	**5**	6.9%
Unit Speed 46-50	**3**	4.2%
Unit Speed 26-30	**2**	2.8%
Unit Speed 56-60	**2**	2.8%
Grand Total	**72**	**100.0%**

VEHICLE_TYPE1	Number	%
Mid Size	**19**	26.4%
Sport Utility Vehicle	**13**	18.1%
Pickup	**11**	15.3%
Compact	**11**	15.3%
Full Size	**5**	6.9%
Minivan	**4**	5.6%
Tractor/Semi-Trailer	**4**	5.6%
Motorcycle	**1**	1.4%
Bus/Van (9-15 Seats Inc Driver)	**1**	1.4%
Single Unit Truck/Trailer	**1**	1.4%
Van	**1**	1.4%
Single Unit Truck Or Van 2 Axle, 6 Tires	**1**	1.4%
Grand Total	**72**	**100.0%**

VEHICLE_TYPE2	Number	%
Mid Size	**16**	22.2%
	16	22.2%
Sport Utility Vehicle	**14**	19.4%
Compact	**5**	6.9%
Pickup	**5**	6.9%
Minivan	**4**	5.6%
Full Size	**3**	4.2%
Single Unit Truck Or Van 2 Axle, 6 Tires	**2**	2.8%
Single Unit Truck/Trailer	**2**	2.8%
Tractor/Semi-Trailer	**2**	2.8%
Van	**2**	2.8%
Unknown Or Hit/Skip	**1**	1.4%
Grand Total	**72**	**100.0%**

- - (-) From // to //

ACTION2	Number	%
Slowing Or Stopped In Traffic	**28**	38.9%
Straight Ahead	**24**	33.3%
	16	22.2%
Changing Lanes	**2**	2.8%
Making Right Turn	**1**	1.4%
Making Left Turn	**1**	1.4%
Grand Total	**72**	**100.0%**

CONTRIBUTING_FACTOR2	Number	%
None	**54**	75.0%
	16	22.2%
Other Improper Action	**1**	1.4%
Operating Defective Equipment	**1**	1.4%
Grand Total	**72**	**100.0%**

DIRECTION_FROM2	Number	%
North	**33**	45.8%
South	**18**	25.0%
	16	22.2%
West	**5**	6.9%
Grand Total	**72**	**100.0%**

DIRECTION_TO2	Number	%
South	**32**	44.4%
North	**19**	26.4%
	16	22.2%
East	**4**	5.6%
West	**1**	1.4%
Grand Total	**72**	**100.0%**

DRIVER_ALCOHOL2	Number	%
None	**55**	76.4%
	16	22.2%
0	**1**	1.4%
Grand Total	**72**	**100.0%**

DRIVER_DRUGS2	Number	%
(blank)	**72**	100.0%
Grand Total	**72**	**100.0%**

- - (-) From // to //

SEVERITY	CRASH_SEVERITY	
TRAFFIC_CRASH_YEAR	Property Damage Crash	Injury Crash
2013	11	3
2014	28	12
2015	7	11
Grand Total	**46**	**26**

TRAFFIC_CRASH_YEAR	Fatalities	Incapacitating Injuries
2013	0	2
2014	0	5
2015	0	0
Grand Total	**0**	**7**

TRAFFIC_CRASH_YEAR	INJ_TYPE2_SERIOUS_VISIBLE	INJ_TYPE3_MINOR_VISIBLE	INJ_TYPE4_NO_VISIBLE
2013	2	0	5
2014	5	7	10
2015	0	5	13
Grand Total	**7**	**12**	**28**

DEL-23-14.09/15.09 SAFETY STUDY

APPENDIX D: FLASHING YELLOW ARROW TECH MEMO

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.

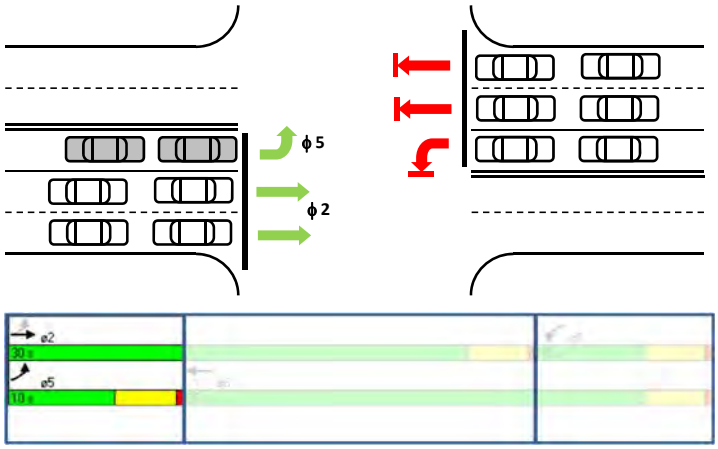
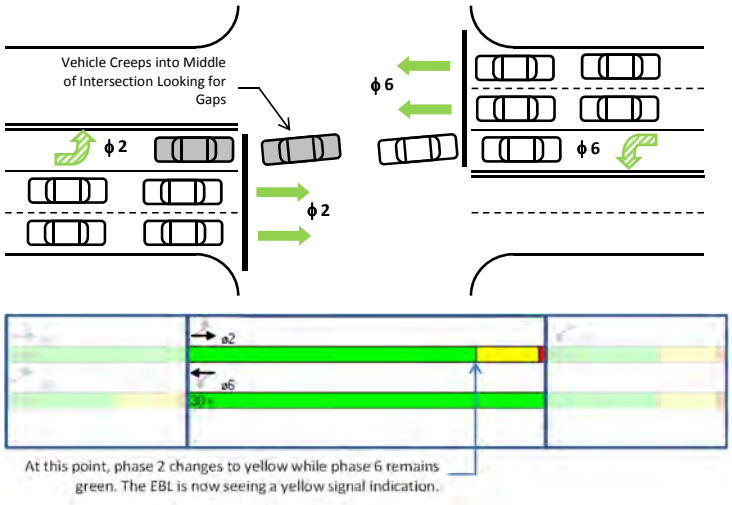
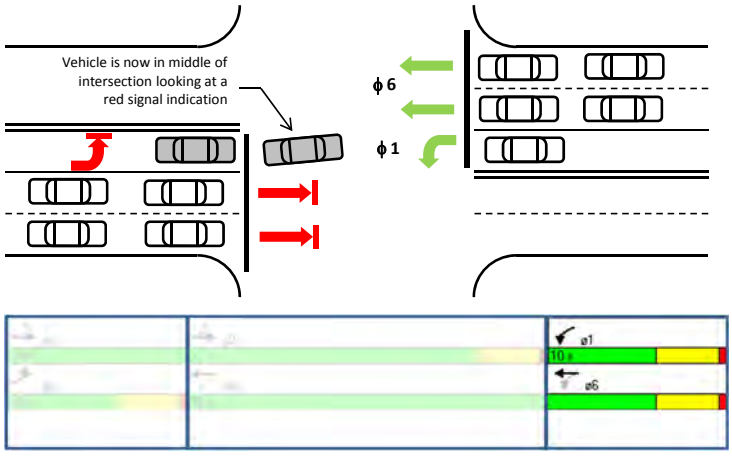
The following link is a video illustrating the left turn trap with a traditional five-second protected/permissive signal with lead/lag left turn phasing.

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:

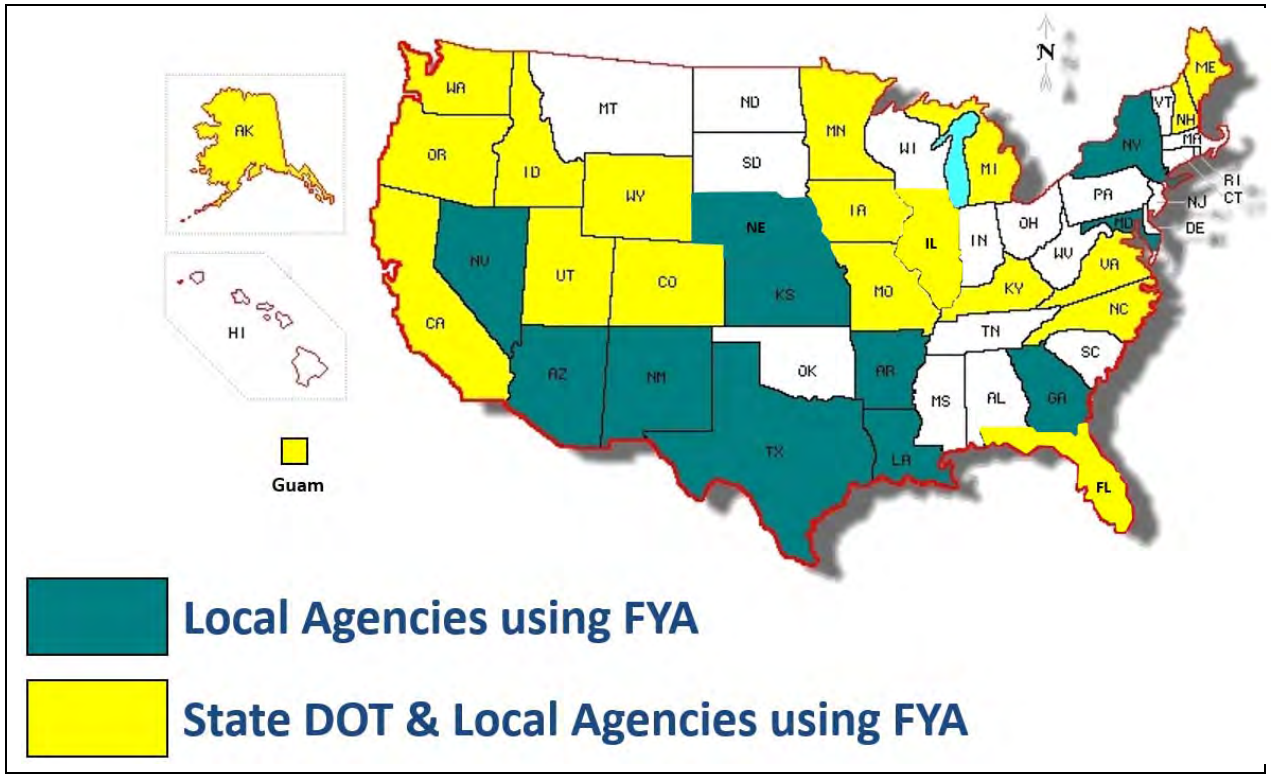
- LT-related crashes at FYA approach CMF = 0.617
- LT-related crashes at FYA approach with supplemental sign CMF = 0.589
- LTOT crashes at FYA approach CMF = 0.714
- LTOT crashes at FYA approach with supplemental sign CMF = **0.711**

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.

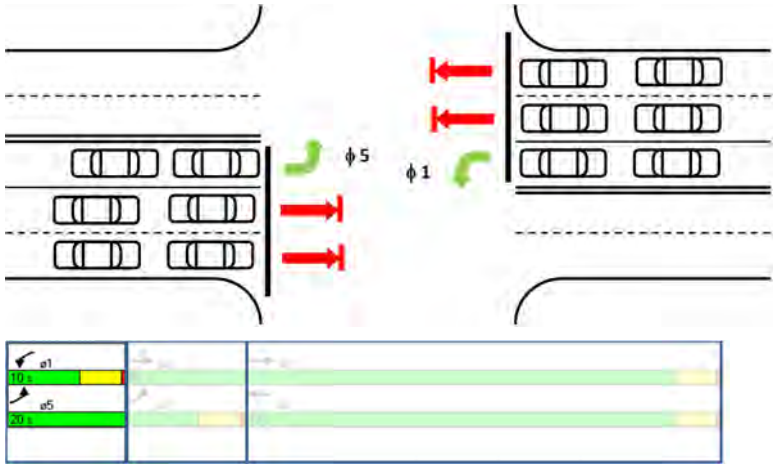
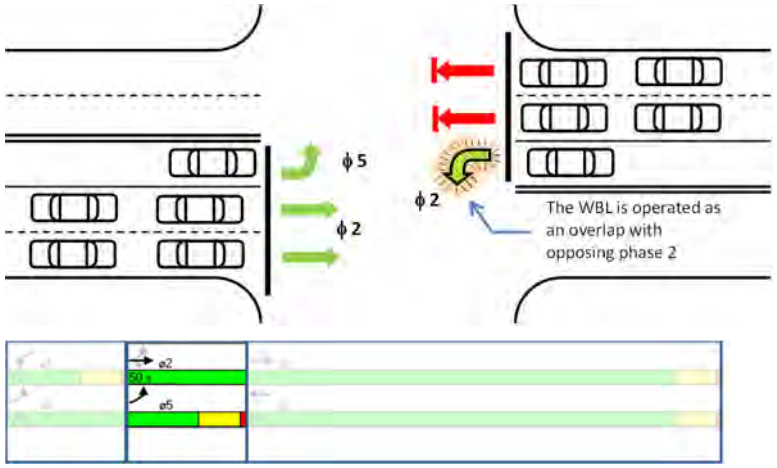
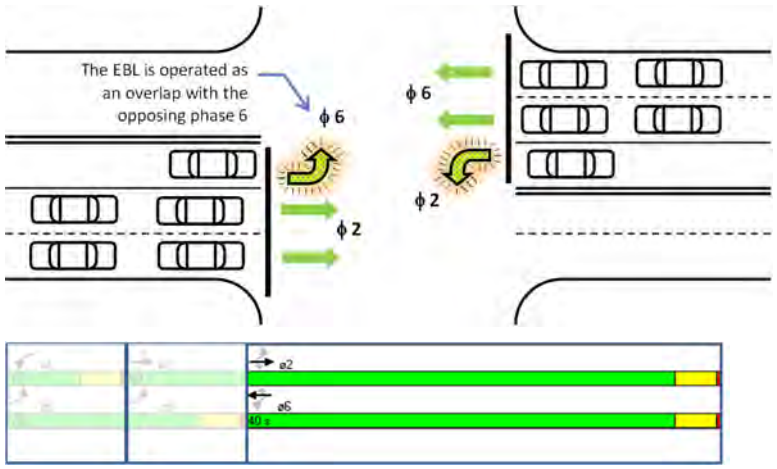
Disadvantages of FYA

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

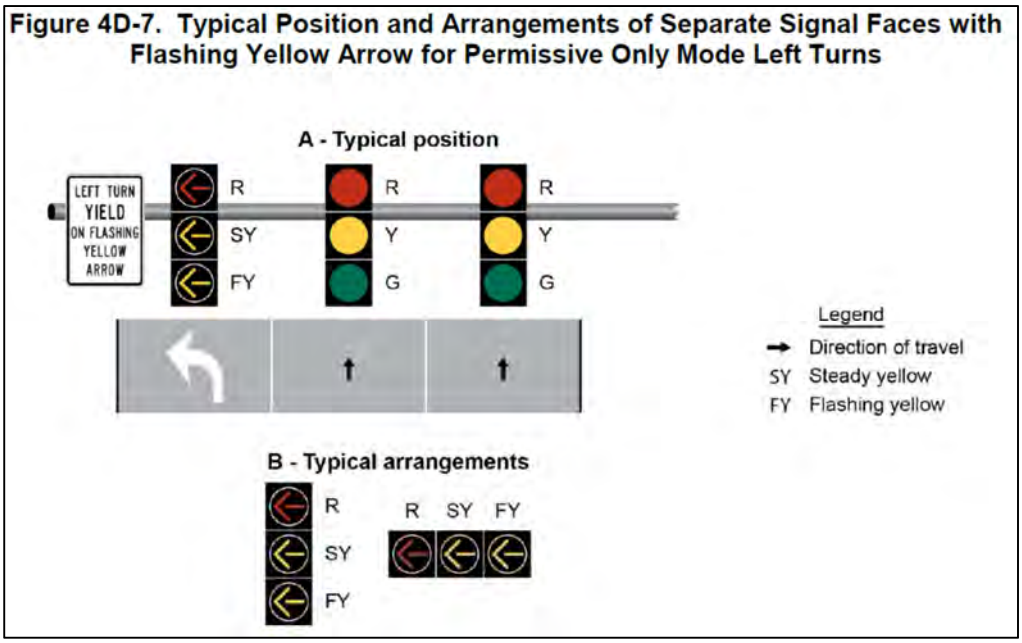
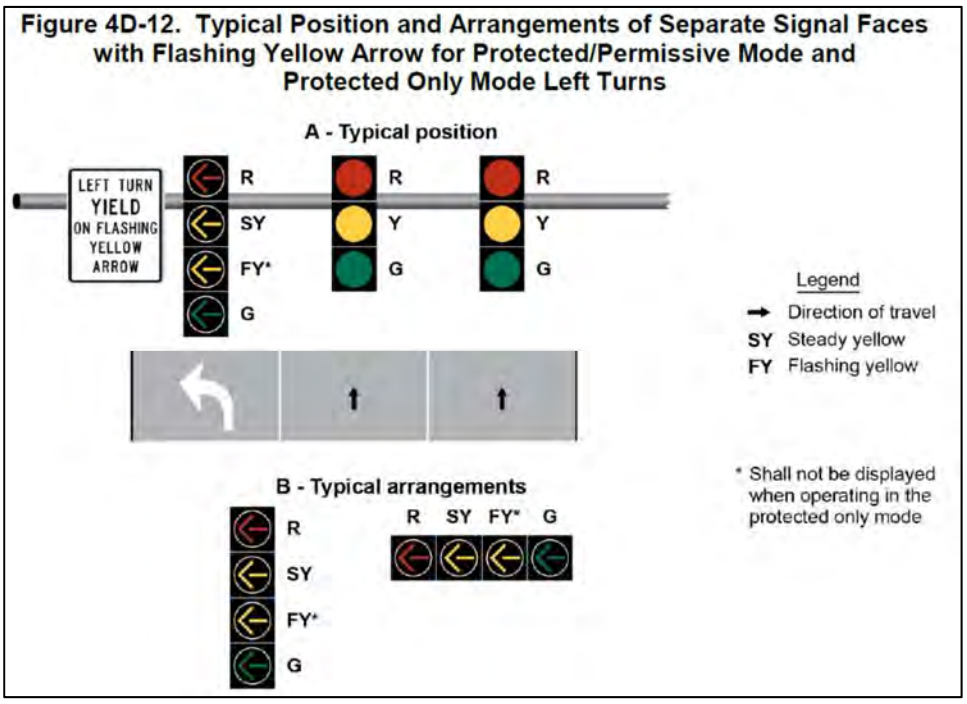


Exhibit 5 is Figure 4D-12 from the OMUTCD and is the typical position and arrangement of separate signal faces with FYA for protected/permissive mode and protected-only mode left turns.

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.

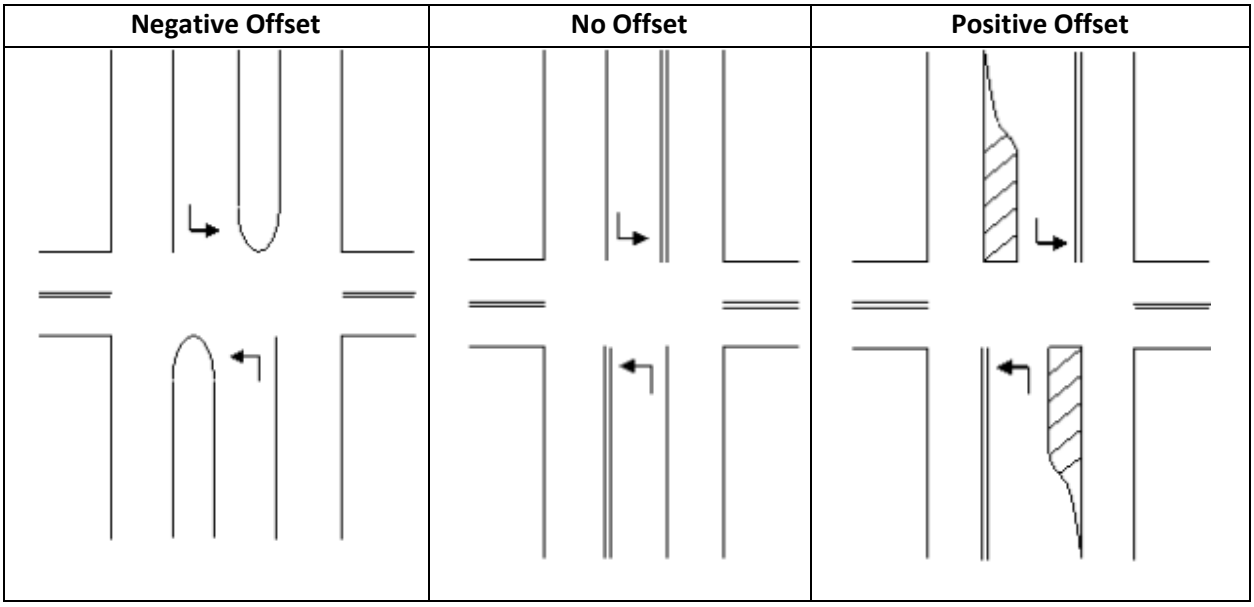
In order for the conflict monitor to prohibit conflicting indications in accordance with Section 4D.05 of the 2012 OMUTCD, the flashing yellow arrow indication should be wired so it is monitored by a separate channel from the steady red arrow, steady yellow arrow and steady green arrow indications in 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



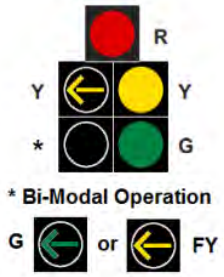
Shared Left/Through Lane Installations

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.

DEL-23-14.09/15.09 SAFETY STUDY

APPENDIX E: TRAFFIC SIGNAL PLANS

FHWA REGION	STATE	PROJECT	
5	OHIO		

1/4

CITY OF DELAWARE, OHIO
US-23 & MCDONALDS - HARTS
TRAFFIC CONTROL PLAN

TRAFFIC CONTROL
GENERAL NOTES AND SPECIFICATIONS

GENERAL:

The contractor shall furnish and install traffic control equipment and materials in conformance to these plans and specifications and the 1985 State of Ohio Department of Transportation Construction and Material Specifications and all Supplmental Specifications. He shall install all traffic control equipment in conformance to the Ohio Manual of Uniform Traffic Control Devices for Streets and Highways and in conformance to the Ohio Department of Transportation Bureau of Design Services Standard Construction Drawings.

Before any equipment is ordered or the installation of traffic control is begun, six (6) sets of a complete schedule of equipment including catalog cuts, diagrams, drawings, brochures or other descriptive data shall be submitted to the contracting agency. One copy will be returned marked "approved" if found satisfactory. Work may begin when the approved copy is received by the Contractor. The contractor shall submit a schedule of work for the project in writing to the contracting agency not less than two (2) weeks in advance of starting work.

Reference to a particular trade name, manufacturer's catalog or model number are made for descriptive purposes to guide the bidder in interpreting the requirements of the contract. They should not be construed as excluding proposals on other materials, equipment or supplies that are equal to or better than those referred to:

NOTIFICATION OF UTILITIES:

The Contractor shall contact all utilities having installations in the area of work to secure and affirm data on utility locations. These agencies and utilities shall be notified prior to any excavations in areas containing their installations in conformance with the policies of the individual agencies and utilities.

632 VEHICULAR SIGNAL HEADS:

Vehicular signal heads shall conform to Specification 632 and shall be installed in conformance to Standard Construction Drawing TC-85.20 except that the 1-1/2 inch variable length drop pipe shall not be used unless advance approval in writing is obtained from the contracting agency.

632 LOOP DETECTOR PAVEMENT CUTTING:

Loop detector pavement cutting shall comply with specification 632.10 except that the flexible sealant used to seal the slots shall be an elastic epoxy resin compound.

632 POWER SERVICE:

The Contractor shall make arrangements with the power company for the power service. He shall install service cable from the power source to the signal controller. If the local agency has a flat rate arrangement with the power company, a meter base shall not be provided. All power cable shall be run inside of signal poles. A quantity of service cable is provided in the plans for estimating purposes.

861 CONTROLLER, ACTUATED BY PHASE, SOLID STATE DIGITAL MICROPROCESSOR:

In addition to supplemental specification 861, the controller shall utilize highly accurate digital timing with keyboard entry for setting timing functions. The controller manufacturer shall submit with his catalog cuts a certified statement from an independent testing laboratory indicating that the controller and conflict monitor meet the above standards.

All load switches and interface relays shall be furnished with neon indicator lights.

861 CONTROLLER, ACTUATED BY PHASE, SOLID STATE DIGITAL MICROPROCESSOR: (AUTOMATIC SIGNAL) (ALTERNATE BID):

The controller furnished under this item shall meet the specifications described in "Controller, Actuated By Phase, Solid State Digital Microprocessor". In addition it shall be a model 314 as manufactured by the Automatic Signal Company.

861 RELAY ASSEMBLY, AS PER PLAN:

The relay assembly to controll the "Prepare To Stop When Flashing" sign shall be constructed in conformance with the detail included in these plans. It shall be installed in the intersection controller cabinet.

861 FLASHER CONTROLLER, AS PER PLAN:

The flasher controller shall conform to Supplemental Specification 861 and shall be solid state. It shall not require its own cabinet but shall be installed in the intersection controller cabinet.

614 MAINTENANCE TRAFFIC:

Hours of work shall be limited to 8:30 AM to 3:30 PM Monday through Saturday, or as approved in writing by the appropriate representative of the governing agency. The entire traveled portion of the roadway shall be open to traffic when the Contractor is not working. For the purpose of erecting span wire, the Contractor may close the entire intersection for a total of ten (10) minutes withn a thirty (30) minute period. Each closure shall be for a maximum period of three (3) minutes followed by a total opening for a minimum period of one (1) minute. Such closures must be shown to be necessary and must be approved by the appropriate representative of the governing agency before any closure is made. The Contractor shall provide a uniformed special duty officer to direct traffic during such closures.

The Contractor shall provide all traffic control devices for construction operations in conformance to the "Ohio Manual of Uniform Traffic Control Devices".

614 MAINTENANCE OF TRAFFIC SIGNAL INSTALLATION:

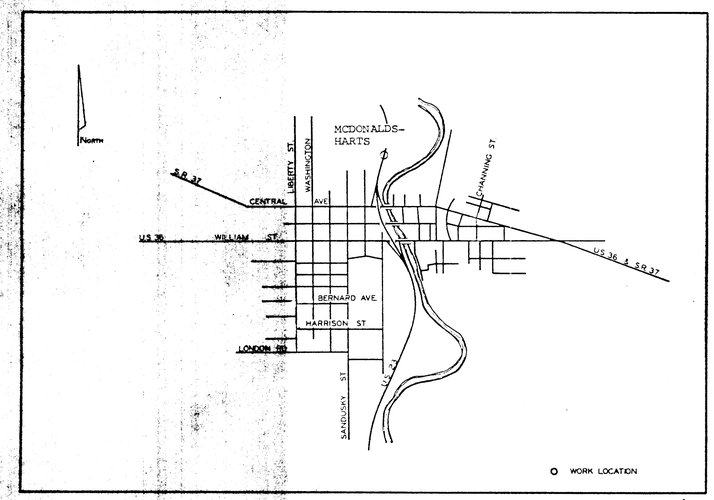
The Contractor shall be responsible for the maintenance of the traffic signal(s) from the date he begins work on the installation(s) until such time as the testing requirements are satisfied and the signal installation(s) is complete and accepted except that burned out light bulbs will be replaced by the governing agency.

The Contractor shall correct all outages and malfunctions as quickly as possible. He shall provide the appropriate representatives from the governing agency and the contracting agency such addresses and phone numbers where his maintenance forces are located. The Contractor shall provide one or more persons to receive calls and dispatch the necessary maintenance forces to correct outages. All outages or malfunctions shall be corrected to the satisfaction of the governing and contracting agencies within four (4) hours after notification of the contractor.

In the event new signal equipment or materials are damaged prior to acceptance, such damaged equipment shall be replaced by the Contractor to the satisfaction of the governing and contracting agencies and the signal(s) shall be placed back in service within eight (8) hours after notificaton of the Contractor. Where outages or damages are the result of a vehicular accident, the Contractor shall be responsible for the collection of compensation from those parties responsible for the damages.

The governing agency will bill the Contractor and the Contractor shall pay the governing agency for all police services or traffic maintenance by their own forces or those of another contractor which may become necessary when the Contractor fails to perform or is unable to respond within the established time.

This item shall be considered subsidiary work and shall be included in the cost of other bid items.



VICINITY MAP

1/4 1/2 1 MILE

APPROVALS
FOR THE CITY OF DELAWARE:

CITY MANAGER _____ DATE _____

DIRECTOR OF PUBLIC WORKS _____ DATE _____

SUPERINTENDENT OF PUBLIC WORKS _____ DATE _____

FOR THE STATE OF OHIO:

DISTRICT DEPUTY DIRECTOR OF TRANSPORTATION _____ DATE _____

ENGINEER, BUREAU OF TRAFFIC _____ DATE _____

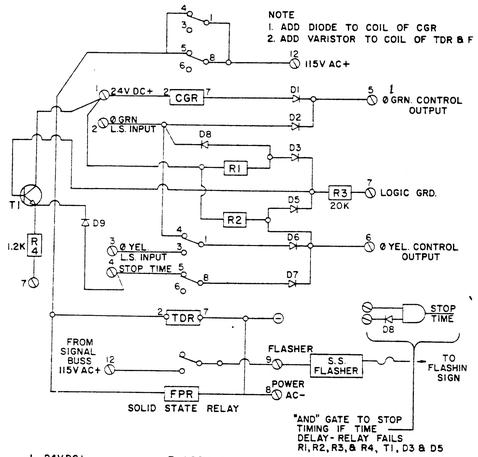
STANDARD DRAWINGS	SUPPLEMENTAL SPECIFICATIONS
HL-1, HL-2, HL-3	861
TC-21.20, TC-81.10, TC-82.10, TC-83.10,	
TC-83.20, TC-84.20, TC-85.20	
TC-41.20, TC-42.10, TC-42.20	

RDW0197

FHWA REGION	STATE	PROJECT	
5	OHIO		

2/4

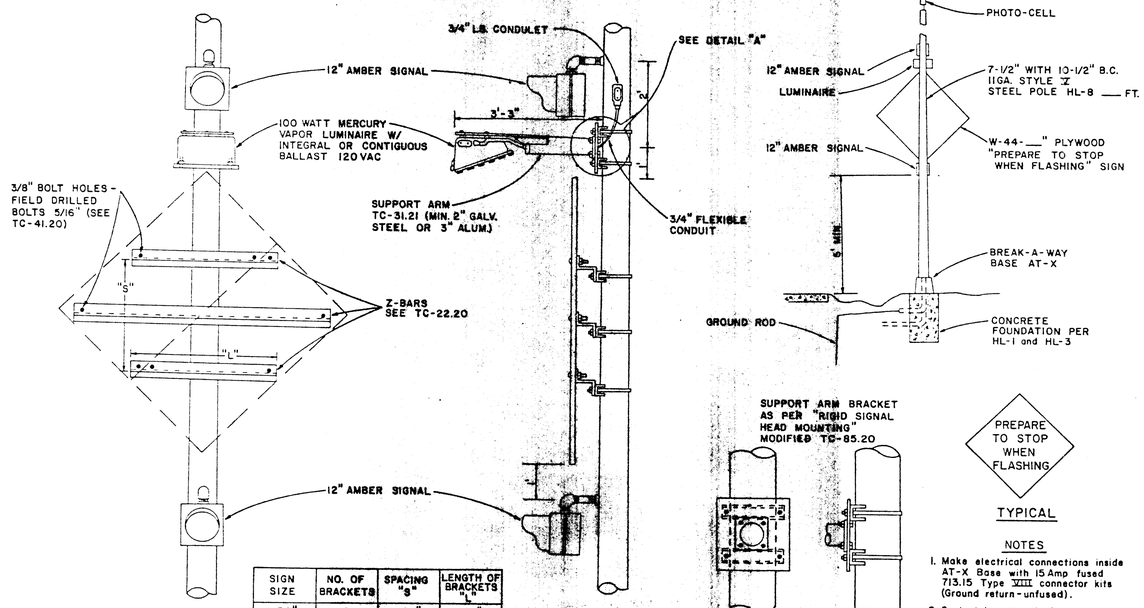
"PTSWF" RELAY ASSEMBLY WITH NEMA CONTROLLER



1	24V DC+	7	LOGIC GRD.
2	Ø GRN. L.S. INPUT	8	AC-
3	Ø YEL. L.S. INPUT	9	FLASHER POWER
4	STOP TIME	10	FP No. 1
5	Ø GRN. CONT. OUT	11	FP No. 2
6	Ø YEL. CONT. OUT	12	115V AC+

R1-R2 - 2K~
D1-D9 - IN2071
D8 - BLOCKING DIODE
R3-20K, R4-1.2K
T1 - 2N1711

CGR = CONTROL GREEN RELAY —— KRP11DG 24V
TDR = TIME DELAY RELAY —— .1-10 SEC. 120 AC
FPR = FLASH POWER RELAY —— SOLID STATE RELAY — SPST CRYDON MODEL TA-122E
T1 = EMITTER FOLLOWER —— 2N1711 ADDED 4-1-83



SIGN SIZE	NO. OF BRACKETS	SPACING "S"	LENGTH OF BRACKETS "L"
54"	2	32"	40"
60"	2	36"	46"
72"	3	42"	54(2), 90

SUPPORT ARM BRACKET AS PER "RIGID SIGNAL HEAD MOUNTING" MODIFIED TC-85.20

DETAIL "A"

PREPARE TO STOP WHEN FLASHING

TYPICAL

NOTES

1. Make electrical connections inside AT-X Base with 15 Amp fused 713.15 Type VIII connector kits (Ground return-unfused).
2. Contact between aluminum and galvanized parts shall be prevented with a minimum 1/16" thick chloroprene gasket or approved substitute. Gaskets are not required between stainless steel and aluminum.

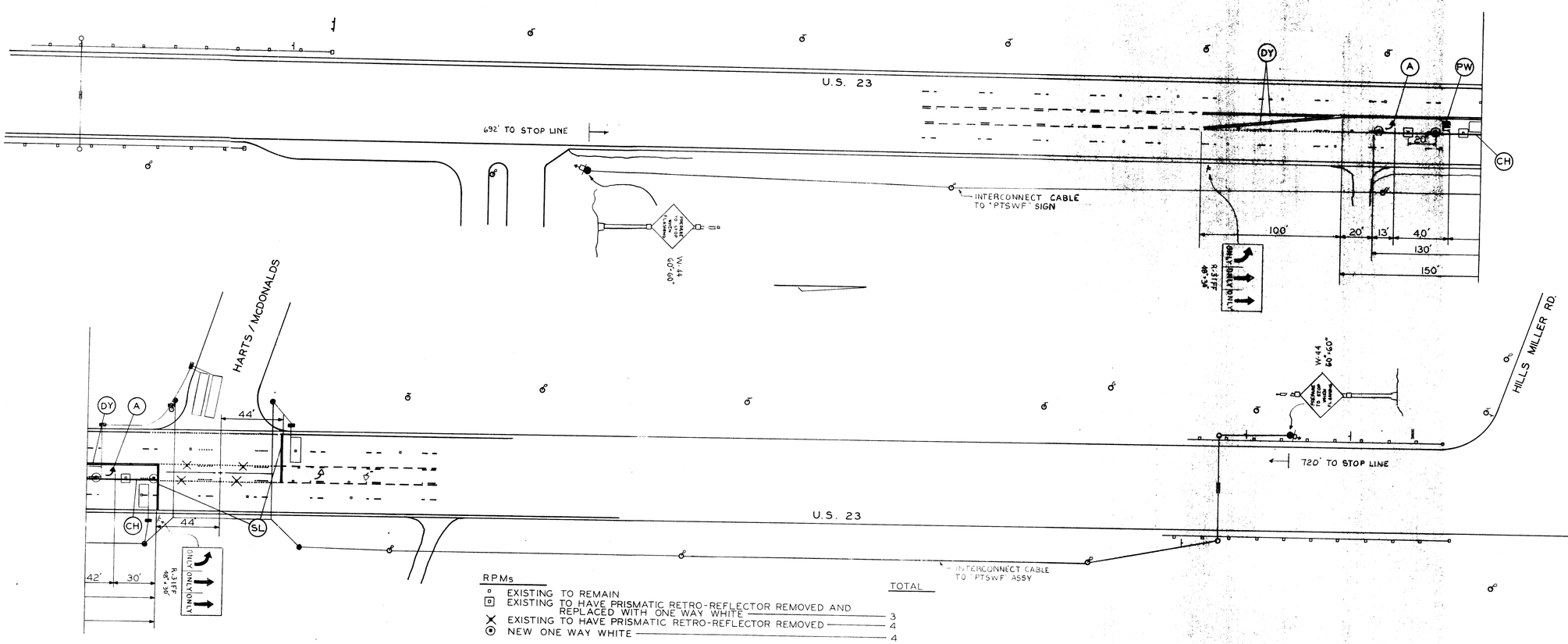
NOT TO SCALE

"PREPARE TO STOP WHEN FLASHING" SIGN INSTALLATION DETAIL

DR. BY	APPD BY		
SCALE	DR NO.	REVISED	BY

US 23 @ McDONALDS-HARTS DELAWARE, OHIO
TRAFFIC CONTROL DETAILS

2/4



RPMs

		TOTAL
▫	EXISTING TO REMAIN	
⊡	EXISTING TO HAVE PRISMATIC RETRO-REFLECTOR REMOVED AND REPLACED WITH ONE WAY WHITE	3
X	EXISTING TO HAVE PRISMATIC RETRO-REFLECTOR REMOVED	4
⊙	NEW ONE WAY WHITE	4

PAVEMENT MARKING	621				
	DY CENTER LINE DUB. SOLID YELLOW 4	CH CHANNELIZING LINE WHITE 8	SL STOP LINE WHITE 24	LA LEFT ARROW	PW PAVEMENT WORD
U.S. 23	LIN. FT.	LIN. FT.	LIN. FT.	EACH	EACH
	350	130	66	2	1
TOTAL	350	130	66	2	1
TOTAL MILES					

SIGNS	630	
	GROUND MOUNTED SUPPORTS 6" POST	SIGNS FLAT SHEET
	LN. FT.	SQ. FT.
	44	20
TOTAL	44	20

EXISTING MARKINGS
EXISTING MARKINGS TO BE REMOVED
NEW MARKINGS

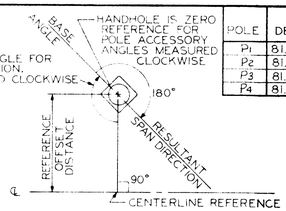
DR. BY	APPD BY		
SCALE	DR NO.	REVISED	BY

US-23 & McDONALDS-HARTS DELAWARE, OHIO
TRAFFIC SIGN-PAVEMENT MARKING PLAN

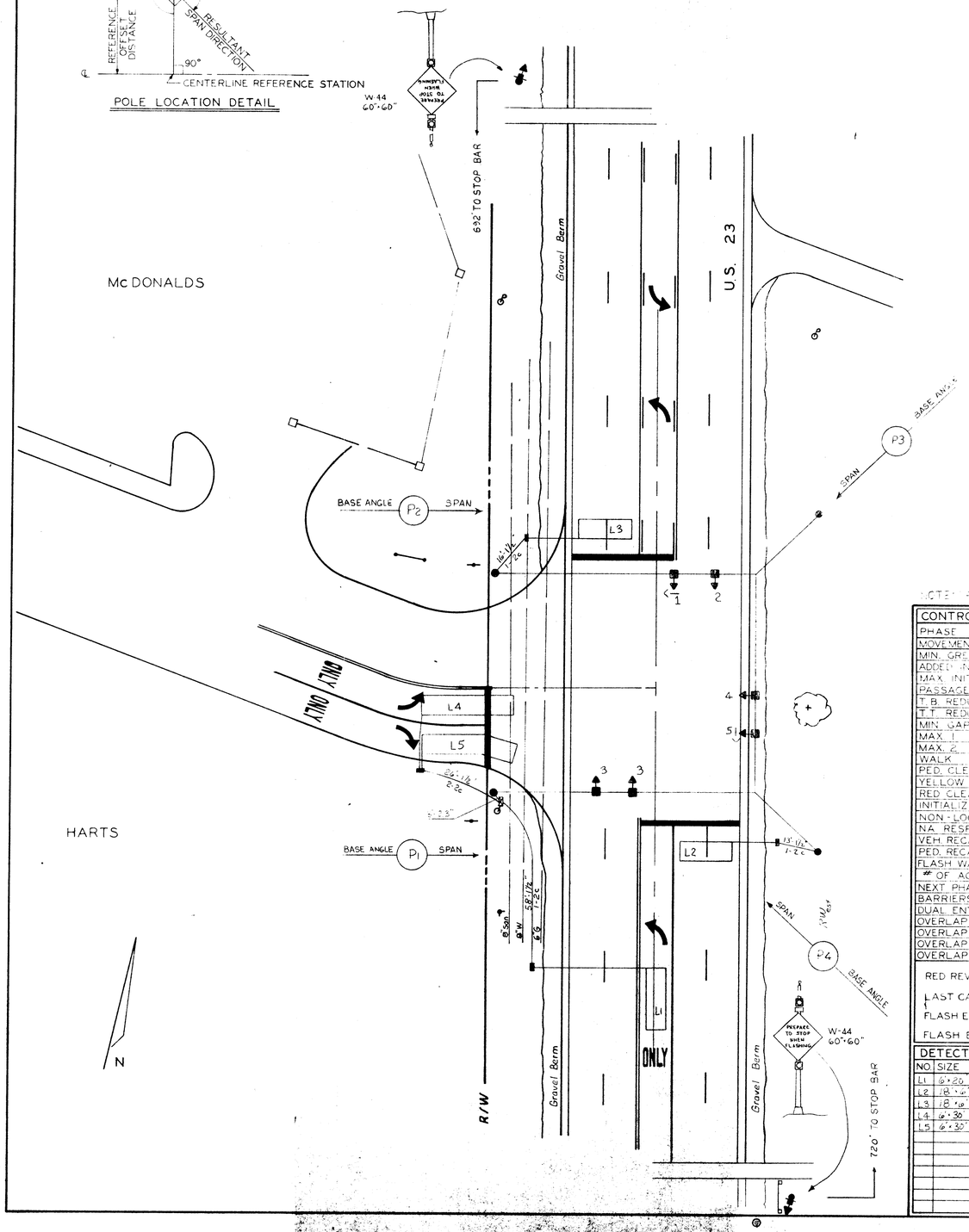
3/4

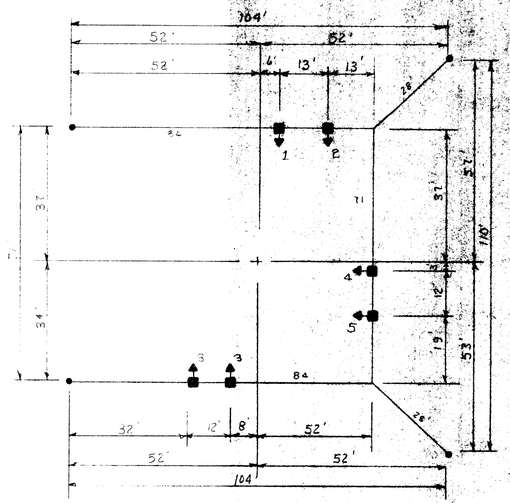
POLE	DESCRIPTION	STATION	OFFSET	BASE ANGLE FOR FOUND	SPAN ANGLE (S)	BLIND COUP SIZE	BLIND COUP ANGLE	BLIND COUP FROM TOP	TOP OF FOUNDATION ELEVATION	CONTROL CABINET ANGLE	PED SIGNAL ANGLE (S)	PED PUSH BTN ANGLE (S)	PUSH BTN SIGN ANGLE (S)
P1	81.10 DESIGN 5	—	Lt 52'	180°	180°	—	—	—	—	—	—	—	—
P2	81.10 DESIGN 5	—	Lt 52'	180°	180°	—	—	—	—	—	—	—	—
P3	81.10 DESIGN 5	—	Rt 52'	137°	180°	—	—	—	—	—	—	—	—
P4	81.10 DESIGN 5	—	Rt 52'	225°	180°	—	—	—	—	—	—	—	—

LEGEND:
- SPAN WIRE SUPPORT
- SIGNAL HEAD
- PEDESTRIAN SIGNAL
- CONDUIT
- PULL BOX
- LOOP DETECTOR

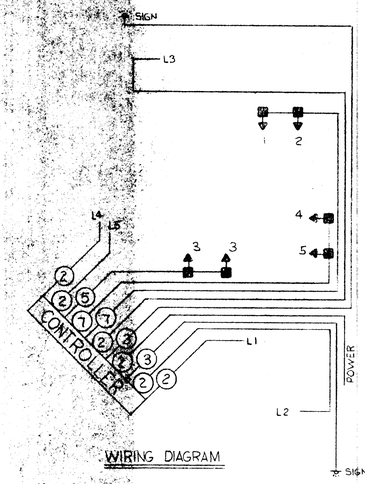


POLE LOCATION DETAIL





SPAN DIAGRAM



WIRING DIAGRAM

NOTE: "POWER" TIME DELAY RELAY TO BE SET AT 10 sec.

CONTROLLER PROGRAM

PHASE	1	2	3
MOVEMENT	NBSB	N S	E B
MIN. GREEN	8	25	8
ADDED INIT.	—	—	—
MAX. INIT.	—	—	—
PASSAGE	3	10	3
T.B. REDU.	8	10	8
T.T. REDU.	15	10	20
MIN. GAP	3	10	3
MAX. 1	25	60	30
MAX. 2	25	60	30
WALK	—	—	—
PED. CLEAR	—	—	—
YELLOW	3.7	4.1	3.2
RED CLEAR	1.3	1.3	1.8
INITIALIZE	—	—	—
NON-LOCK	ON	ON	ON
NA. RESP.	—	—	—
VEH. RECALL	OFF	ON	OFF
PED. RECALL	OFF	OFF	OFF
FLASH. WALK	OFF	OFF	OFF
# OF ACT.	—	—	—
NEXT PHASE	—	—	—
BARRIERS	—	—	—
DUAL ENTRY	—	—	—
OVERLAP A	—	—	—
OVERLAP B	—	—	—
OVERLAP C	—	—	—
OVERLAP D	—	—	—

RED REVERT SEC. = ____ 5" UP FLASH SEC. = ____

LAST CAR PASSAGE ENABLE = ____

FLASH ENTRY PHS. = RING 1( ) & RING 2( )

FLASH EXIT PHS. = RING 1( ) & RING 2( )

DETECTORS

NO.	SIZE	PH	DET	CH	TNS	DLY TIME	EXT TIME	OPER
L1	6'x20'	1	1	6	—	—	—	
L2	18'x6'	2	2	10	—	—	2	
L3	18'x6'	2	2	2	—	—	2	
L4	6'x30'	3	3	2	—	3		
L5	6'x30'	3	3	2	—	3		

PHASING – DISPLAY

PHASE	MOVEMENT	INTERVAL	SIGNAL NO. 1	2	3	4	5
1		RW	G	G	R	R	R
		C1	G	G	R	R	R
		C2	G	G	R	R	R
2		RW	G	G	G	R	R
		C1	Y	Y	Y	R	R
		C2	R	R	R	R	R
3		RW	R	R	R	G	G
		C1	R	R	R	Y	Y
		C2	R	R	R	R	R
FLASH			Y	Y	Y	R	R

SIGNAL HEADS

SIGNS

QUANTITIES

QUAN	UNIT	ITEM	DESCRIPTION
2	Ea	632	Vehicular signal head, 5-section, 12 inch lens, 1-way
4	Ea	632	Vehicular signal head, 3-section, 12 inch lens, 1-way
3	Ea	632	Loop detector unit
342	Ln.ft	632	Loop detector pavement cutting
9.5	Cu.yd	632	Concrete for anchor base foundations
4	Ea	632	Strain pole, type 81.10, design 5
1	Ea	632	Cable support assembly
295	Ln.ft	632	Messenger wire, 7 strand 3/8 in dia, with accessories
402	Ln.ft	632	Signal cable, 7 conductor No 14 AWG
97	Ln.ft	632	Signal cable, 5 conductor No 14 AWG
381	Ln.ft	632	Signal cable, 3 conductor No. 12 AWG
1484	Ln.ft	632	Interconnect cable, integral messenger wire type, 3-conductor No 12 AWG
820	Ln.ft	632	Loop detector wire, type E
609	Ln.ft	632	Loop detector lead-in cable
44	Ln.ft	632	Power cable, 2-conductor No 6 AWG
132	Ln.ft	632	Service cable, 2-conductor No 6 AWG
1	Ea	632	Power service
4	Ea	632	Covering of vehicular signal head
1	Ea	861	Controller, actuated 3 phase, solid state digital microprocessor
1	Ea	861	Concrete for cabinet foundation
1/8	Mile	625	Trench
1/8	Mile	625	Conduit 1½" (7/3.07 DB)
3	Ea	625	Pull box, 10"x14" (7/3.08)
1	Ea	625	Ground rod
	Mile	625	Conduit 3" (7/3.07 DB)
2	Ea	625	Light pole Style V, 22 ft
2	Ea	625	Light pole foundation
2	Ea	625	Bracket arm Type TC-31.21, 3 ft-3 in
2	Ea	625	Luminaire, 100 watt mercury vapor w photo cell
50	Sq.ft	630	Signs, flat sheet
2	Ea	630	Sign attachment assembly
4	Ea	632	Vehicular signal head, 1-section, 12 inch lens, 1-way
1	Ea	861	Relay assembly, as per plan
1	Ea	861	Flasher controller, as per plan
1	Ea	861	Controller, actuated 3 phase solid state digital microprocessor (Automatic Signal Value Plus)

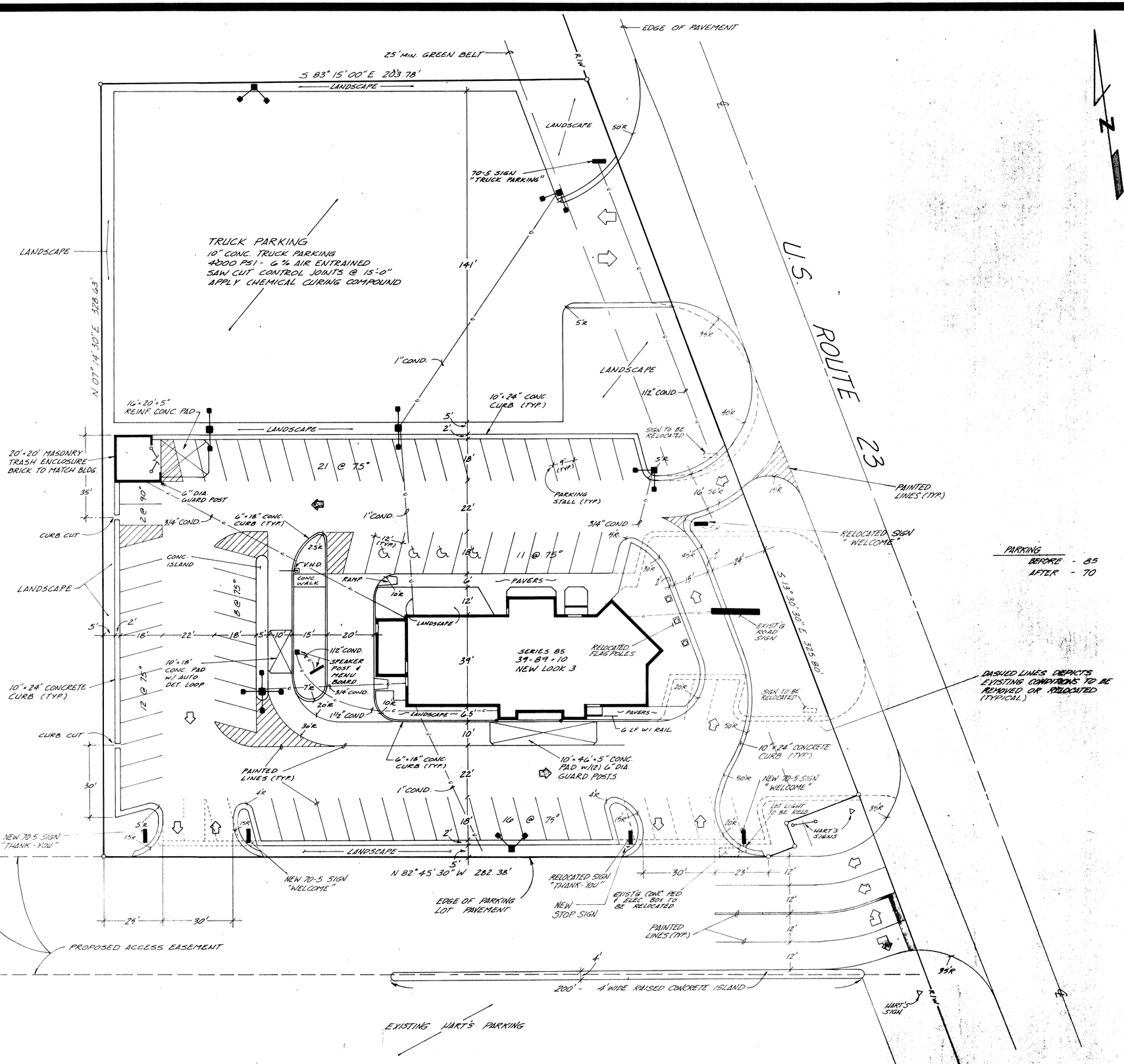
RIDGEWAY & ASSOC.

ENGINEER ____ DATE ____

DR. BY	APPD BY
SCALE	DR NO.
REVISED	BY

McDONALDS-HARTS DELAWARE, OHIO

SIGNAL PLAN



GENERAL NOTES:

1. McDonald's Road Sign and Base are by the Sign Contractor. Conduit and Wiring are by the General Contractor.
2. Bases, Anchor Bolts, Conduit, and Wiring for All Other Signs are by the General Contractor.
3. ¾" Empty Conduit to Locations Shown at the Lot Perimeter for Lot Lighting is by the General Contractor. Lighting Fixtures, Bases, Poles, Conduit, and Wiring are by the Owner/Operator.
4. Bases for Flagpoles are by the General Contractor. Anchor Bolts are by the Flagpole Supplier.
5. Proposed Utilities are Shown in Schematic Only. Exact Locations shall be Field Determined to Allow for the Most Economical Installation.
6. The Contractor shall Coordinate with All Utility Companies to Determine Exact Point of Service Connection at Existing Utility. Refer to the Building Electrical and Plumbing Drawings for Utility Service Entrance Locations, Sizes, and Circuiting.
7. All Elevations Shown are in Reference to the Benchmark and must be Verified by the General Contractor At Groundbreak.
8. Finish Walk and Curb Elevations shall be 6" Above Finish Pavement.
9. All Landscape Areas shall be Rough Graded to 6" Below Top of All Walks and Curbs. Finish Grading, Landscaping, and Sprinkler Systems are by the Owner/Operator.

PAVING SPECIFICATION:
(Minimum 3" Total Compacted Asphalt Thickness.)

A MINIMUM OF 2.5" OF ASPHALTIC CONC. UNDER 1.5" OF SURFACE COURSE PLACED ON 8" OR MORE OF WELL GRADED COMPACTED GRANULAR BASE MATERIAL

Note: McDonald's Engineer Reserves The Right To Request A Compaction Test And/Or A Core Sample. If Tests Prove Correct, Per Above Specifications, Tests Will Be At The Expense Of McDonald's, Otherwise, G.C. Will Be Charged.

LOT LIGHTING RECOMMENDATION:

1 SINGLE, 1 QUAD, 1 6 DOUBLE ARM, 400 WATT - HIGH PRESSURE SODIUM LAMPS AT 20' ABOVE GRADE (CLASSIC SERIES)

Note. Electrical Contractor To Circuit Lot Lighting As Noted.

PARKING INFORMATION:

Total Spaces: 85					
	4	Spaces	12'	x 18'	@ 75°
	4	Spaces	9'	x 18'	@ 90°
	77	Spaces	9'	x 18'	@ 75°
		Spaces		x	@ °

UTILITY INFORMATION:

	Size:	Type:	Location:
Sanitary Sewer	8"		738'± SOUTH ON RT. 23
Water	8"		EXTENDED FROM E. SIDE RT 23
Storm Sewer	27"		FRONT OF PROPERTY (R/W)
Electric			FRONT OF PROPERTY (R/W)
Gas	6"		FRONT OF PROPEERTY (R/W)

SURVEY INFORMATION:

Prepared By: KOSANCHICK & ASSOCIATES
6119 E. BROAD ST.
COLUMBUS, OHIO 43213
Dated: OCTOBER 1984 #1478

LEGEND:

Sanitary Sewer	S	Gas	G
Water	W	Lot Light	LP:30
Storm Sewer	ST	Existing Elevation	(76.5)
Electric	E	Proposed Elevation	77.0

PLAN SCALE: 1" = 20'

STREET ADDRESS:
2091 U.S. ROUTE 23

CITY: DELAWARE
STATE: OHIO

COUNTY: DELAWARE

PLAN APPROVALS:

Signature: (2 required)	Date:
Regional Mgr.	
Const. Mgr.	
Operations	

CO-SIGN SIGNATURES:

Contractor	
Owner	

McDonald's

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MCD 2035

PLAN STATUS:

	Description	Date:	By:
5	Preliminary Drawn	10-11-84	WL
6			
7			
8	Revisions	4-14-85	VC
9		2-19-86	VC
	Plan Checked		
	As-Built Drawn		

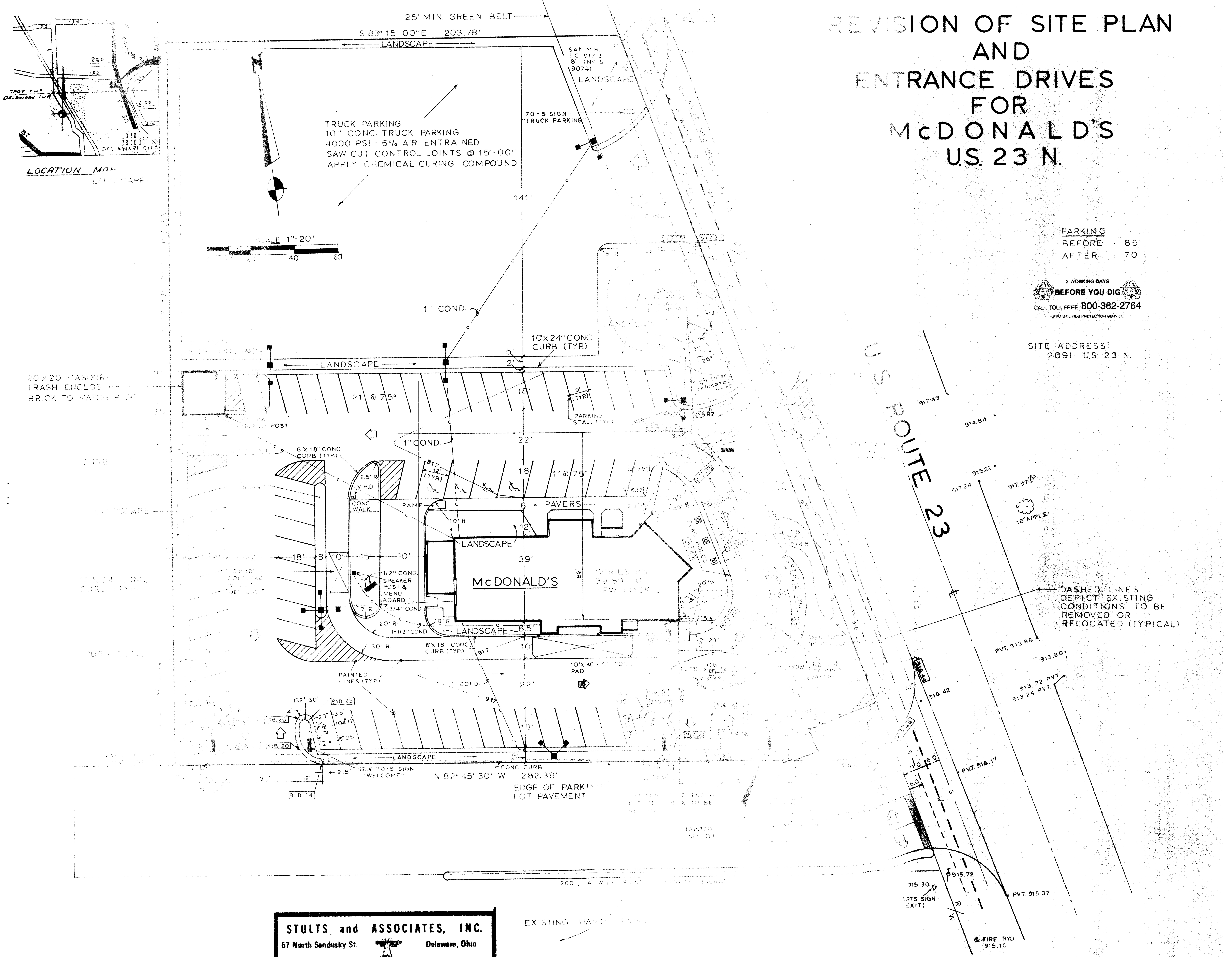
1	FELD. FREEZER DOOR, REMOVED WALK & RAMP	
2	REV. ENTR/EXIT OPNGS	
3		
4		

REGIONAL DWG. NO.:
COL-84-09

CORPORATE DWG. NO.:

SP-1

REVISION OF SITE PLAN AND ENTRANCE DRIVES FOR McDONALD'S U.S. 23 N.



PARKING
BEFORE - 85
AFTER - 70

2 WORKING DAYS BEFORE YOU DIG
CALL TOLL FREE 800-362-2764
OHIO UTILITIES PROTECTION SERVICE

SITE ADDRESS:
2091 U.S. 23 N.

DASHED LINES DEPICT EXISTING CONDITIONS TO BE REMOVED OR RELOCATED (TYPICAL)

STULTS and ASSOCIATES, INC.
67 North Sandusky St. Delaware, Ohio
TELEPHONE (614) 363-6792 (614) 369-4124
Columbus TELEPHONE (614) 436-5238
Engineering · Surveying

DEL-23-14.09/15.09 SAFETY STUDY

APPENDIX F: EXISTING SIGNAL TIMING

Vehicle Basic Timing

Phase	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Min. Green	6	30	0	12	0	30	0	0	0	0	0	0	0	0	0	0
Passage	4	4	0	4	0	4	0	0	0	0	0	0	0	0	0	0
Maximum 1	10	50	0	25	0	50	0	0	0	0	0	0	0	0	0	0
Maximum 2	10	50	0	30	0	50	0	0	0	0	0	0	0	0	0	0
Yellow Change	4.3	4.3	3	3	3	4.3	3	3	3	3	3	3	3	3	3	3
Red Clearance	1.6	1.6	0	3.3	0	1.6	0	0	0	0	0	0	0	0	0	0
Green Delay	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow Delay	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Pedestrian Timing

Phase	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Walk	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pedestrian Clear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Flashing Walk	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Extended Pedestrian Clear	0 - Nrm	0 - Nrm	0 - Nrm	0 - Nrm	0 - Nrm	0 - Nrm	0 - Nrm	0 - Nrm	0 - Nrm	0 - Nrm	0 - Nrm	0 - Nrm	0 - Nrm	0 - Nrm	0 - Nrm	0 - Nrm
Actuated Rest In Walk	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Walk Offset Time	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Walk Offset Mode	0 - Adv	0 - Adv	0 - Adv	0 - Adv	0 - Adv	0 - Adv	0 - Adv	0 - Adv	0 - Adv	0 - Adv	0 - Adv	0 - Adv	0 - Adv	0 - Adv	0 - Adv	0 - Adv

General Control

Phase	Initial	Non-Actuated Response	Vehicle Recalls	Ped Recalls	Recall Delay
1	1 - Inactive	0 - None	0 - None	0 - None	0
2	4 - Green	0 - None	2 - Min	0 - None	0
3	0 - None	0 - None	0 - None	0 - None	0
4	1 - Inactive	0 - None	0 - None	0 - None	0
5	0 - None	0 - None	0 - None	0 - None	0
6	4 - Green	0 - None	2 - Min	0 - None	0
7	0 - None	0 - None	0 - None	0 - None	0
8	0 - None	0 - None	0 - None	0 - None	0
9	0 - None	0 - None	0 - None	0 - None	0
10	0 - None	0 - None	0 - None	0 - None	0
11	0 - None	0 - None	0 - None	0 - None	0
12	0 - None	0 - None	0 - None	0 - None	0
13	0 - None	0 - None	0 - None	0 - None	0
14	0 - None	0 - None	0 - None	0 - None	0
15	0 - None	0 - None	0 - None	0 - None	0
16	0 - None	0 - None	0 - None	0 - None	0

Miscellaneous

Phase	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Non-Locking Memory	☑	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Dual Entry	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Last Car Passage	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Conditional Service	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No Simultaneous Gap Out	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Special Sequence

Phase	Omit	Minus Yellow	Omit Call
1	2	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0
11	0	0	0
12	0	0	0
13	0	0	0
14	0	0	0
15	0	0	0
16	0	0	0

Vehicle Detector

Detector	Assigned Phase	Operation Mode	Switch	Extend	Delay	Pas3	Max3	Pas4	Max4
1	1	0 - Veh	0	0	0	-	-	-	-
2	6	0 - Veh	0	0	0	-	-	-	-
3	2	0 - Veh	0	0	0	-	-	-	-
4	0	0 - Veh	0	0	0	-	-	-	-
5	4	0 - Veh	0	0	0	-	-	-	-
6	4	0 - Veh	0	0	0	-	-	-	-
7	0	0 - Veh	0	0	0	-	-	-	-
8	0	0 - Veh	0	0	0	-	-	-	-
9	0	0 - Veh	0	0	0	-	-	-	-
10	0	0 - Veh	0	0	0	-	-	-	-
11	0	0 - Veh	0	0	0	-	-	-	-
12	0	0 - Veh	0	0	0	-	-	-	-
13	0	0 - Veh	0	0	0	-	-	-	-
14	0	0 - Veh	0	0	0	-	-	-	-
15	0	0 - Veh	0	0	0	-	-	-	-
16	0	0 - Veh	0	0	0	-	-	-	-
17	0	0 - Veh	0	0	0	-	-	-	-
18	0	0 - Veh	0	0	0	-	-	-	-
19	0	0 - Veh	0	0	0	-	-	-	-
20	0	0 - Veh	0	0	0	-	-	-	-
21	0	0 - Veh	0	0	0	-	-	-	-
22	0	0 - Veh	0	0	0	-	-	-	-
23	0	0 - Veh	0	0	0	-	-	-	-
24	0	0 - Veh	0	0	0	-	-	-	-
25	0	0 - Veh	0	0	0	-	-	-	-
26	0	0 - Veh	0	0	0	-	-	-	-
27	0	0 - Veh	0	0	0	-	-	-	-
28	0	0 - Veh	0	0	0	-	-	-	-
29	0	0 - Veh	0	0	0	-	-	-	-
30	0	0 - Veh	0	0	0	-	-	-	-
31	0	0 - Veh	0	0	0	-	-	-	-
32	0	0 - Veh	0	0	0	-	-	-	-
33	0	0 - Veh	0	0	0	-	-	-	-
34	0	0 - Veh	0	0	0	-	-	-	-
35	0	0 - Veh	0	0	0	-	-	-	-
36	0	0 - Veh	0	0	0	-	-	-	-
37	0	0 - Veh	0	0	0	-	-	-	-
38	0	0 - Veh	0	0	0	-	-	-	-
39	0	0 - Veh	0	0	0	-	-	-	-
40	0	0 - Veh	0	0	0	-	-	-	-
41	0	0 - Veh	0	0	0	-	-	-	-
42	0	0 - Veh	0	0	0	-	-	-	-
43	0	0 - Veh	0	0	0	-	-	-	-
44	0	0 - Veh	0	0	0	-	-	-	-
45	0	0 - Veh	0	0	0	-	-	-	-
46	0	0 - Veh	0	0	0	-	-	-	-

DST & Equates

DST Begin		DST End		Cycle Zero	
Month	Week	Month	Week	Hour	Minute
3	2	11	1	0	0

	Source Day	Equate 1	Equate 2	Equate 3	Equate 4	Equate 5	Equate 6	Equate 7
1	1	7	0	0	0	0	0	0
2	2	3	4	5	6	0	0	0

Traffic

	Program			Pattern			Ph Func														
	Day	Hour	Min	Dial	Split	Offset	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1	0	1	0	0	4																
2	1	8	0	3	1	1																
3	1	20	0	0	0	4																
4	2	6	0	3	1	1																
5	2	9	0	3	1	1																
6	2	15	0	3	2	1																
7	2	20	0	0	0	4																

Dial 3/Split 1

Cycle Length	90

Phase	1	2	3	4	5	6	7	8
Time	14	40	0	21	0	40	0	0
Mode	0 - AP	1 - CP	0 - AP	0 - AP	0 - AP	1 - CP	0 - AP	0 - AP
Min Veh Time	13	37		20		37		
Min Ped Time	0	0		0		0		

Phase	9	10	11	12	13	14	15	16
Time	0	0	0	0	0	0	0	0
Mode	0 - AP	0 - AP	0 - AP	0 - AP	0 - AP	0 - AP	0 - AP	0 - AP
Min Veh Time								
Min Ped Time								

Offset	1	2	3
Time	5	0	0
Mode	0 - Normal	0 - Normal	0 - Normal
Alt Sequence	0	0	0
Ring 2 Lag Time	0	0	0
Ring 3 Lag Time	0	0	0
Ring 4 Lag Time	0	0	0

Dial 3/Split 2

Cycle Length	100

Phase	1	2	3	4	5	6	7	8
Time	14	50	0	21	0	50	0	0
Mode	0 - AP	1 - CP	0 - AP	0 - AP	0 - AP	1 - CP	0 - AP	0 - AP
Min Veh Time	13	37		20		37		
Min Ped Time	0	0		0		0		

Phase	9	10	11	12	13	14	15	16
Time	0	0	0	0	0	0	0	0
Mode	0 - AP	0 - AP	0 - AP	0 - AP	0 - AP	0 - AP	0 - AP	0 - AP
Min Veh Time								
Min Ped Time								

Offset	1	2	3
Time	5	0	0
Mode	0 - Normal	0 - Normal	0 - Normal
Alt Sequence	0	0	0
Ring 2 Lag Time	0	0	0
Ring 3 Lag Time	0	0	0
Ring 4 Lag Time	0	0	0

DEL-23-14.09/15.09 SAFETY STUDY

APPENDIX G: SPEED WARRANT ANALYSIS (1996)

Revision 9471
Est 6/28/96 VOL 81 pg 4

inter-office communication

district six transportation studies team

TO: Douglas Kullman, Office of Traffic
FROM: Thomas M. Lyden, Transportation Studies Engineer
SUBJECT: DEL US 23 - Speed Study
DATE: May 20, 1996

Attached for your review and journalization is the speed study on US 23 between Hills-Miller Road and Main Road.

As you may know, this section is currently posted at 45 MPH and has been posted at this speed since 1971.

The results of this study show that a 55 MPH speed limit is warranted and we request journalization of this speed limit. We intend to study, and submit if warranted, other now journalized speed limit zones along US 23 in Delaware County.

TML

OHIO
WARRANTS FOR SPEED ZONES

DATE: 5-17-96

UNTY: Del ROUTE/STREET: US 23

GIN: 14.18 END: 15.84 LENGTH: 1.66 ADT: 26078

HIGHWAY DEVELOPMENT

(A) BUILDING DEVELOPMENT
TYPE 1 - UNITS 21 X 1 = 21
TYPE 2 - UNITS 5 X 2 = 10
TYPE 3 - UNITS 0 X 3 = ____
TYPE 4 - UNITS 0 X 4 = ____
TOTAL TYPE (A)-------- = 31

(B) INTERSECTION CLASSIFICATION
CLASS A - NO. 4 X 2 = 8
CLASS B - NO. 0 X 3 = ____
CLASS C - NO. 0 X 4 = ____
TOTAL CLASS (B) ------ = 8

HIGHWAY DEVELOPMENT = $\frac{31\text{ (A)} + 8\text{ (B)}}{1.66\text{ LENGTH (MILES)}}$ = ____ = 23.49

ROADWAY FEATURES

CTORS	8	9	10	11	12	
LANE WIDTH, FEET	<9	9	10	11	(>=12)	12
SHOULDER: UNIMPROVED	<2	<4	<6	(>=6)		
IMPROVED		<2	<4	<6	>=6	11
CHARACTERISTICS	E	D	C	(B)	A	11
VOLUME (ADT/LANE)	(>3500)	2501-3500	1501-2500	501-1500	1-500	8

TOTAL ROADWAY FEATURES = 42

CIDENT CALCULATION: $\frac{2740 \times 11\text{ ACC.}}{26078\text{ ADT} \times 1\text{ YR.} \times 1.66\text{ MILES}}$ = .69 ≈ 1 ACC. / MIL. VEH. MILES

D LIMIT FACTORS	45	55	64	73	82	91	100	
GHWAY DEVELOPMENT	>100	86-100	66-85	51-65	36-50	(21-35)	<21	91
CADWAY FEATURES	32	33-34	35-36	37-38	39-40	(41-42)	>42	91
85%TILE(MPH) 57/58 48-57	23-27	28-32	33-37	38-42	43-47	48-52	(>52)	100
PACE(MPH) 50-59	13-27	18-32	23-37	28-42	33-47	38-52	(43-57)	100
CIDENTS / MVM	>8.5	7.1-8.5	5.8-7.0	4.7-5.7	3.7-4.6	2.8-3.6	(<=2.7)	100

TOTAL FACTORS = 482

CALCULATED SPEED = $\frac{\text{TOTAL FACTORS}}{5} \times \frac{55}{100}$ = 53.02 MPH.

EST RUN, AVE. 55 MPH. WARRANTED SPEED = 55 MPH.

BY: D. Smith

5/22/92

SPEED STUDY DATA SHEET

Date 5-15-96 County Del Municipality

Highway name & number Street Classification

Indicate North

Log Point	PHYSICAL CONDITION	TRAFFIC CONTROL DEVICES	SPEED 85%	SPEED PACE	ACCIDENTS	TEST RUNS	HORIZONTAL CURVES	VERTICAL CURVES
14.70	Golf Course Restaurant; Right of Way or Fence Line; Edge of Berm; Edge of Pavement; ℄ of Pavement; Edge of Pavement; Edge of Berm; House; Right of Way or Fence Line	45 MPH; 45 MPH						
14.60	House; Jacksap House				X PD			
14.50	T&C Hard Mark; Clear Run; Kirkwood JDR; Stream Brook No 2	45 MPH						
14.40	House; Edge House; dr	T						
14.30	Tracy's TK Stop House; Right of Way	T; PRE PARF STOP						
14.20	House; Gas Station; Hills; Miller Rd	T; R R; ♀ ♀			X PD X – PD XXX – INJ XX – PD			
14.10								

SHEET 1 OF 3 SHEETS

SPEED STUDY DATA SHEET

Date 5-15-96 County Del Municipality

Highway name & number Street Classification

Indicate North

Log Point	PHYSICAL CONDITION	TRAFFIC CONTROL DEVICES	SPEED 85%	SPEED PACE	ACCIDENTS	TEST RUNS	HORIZONTAL CURVES	VERTICAL CURVES
15.40	COOPER RD; HOUSE; HOUSE; CRANE RENTAL; Right of Way or Fence Line; Edge of Berm; Edge of Pavement; ℄ of Pavement; Edge of Pavement; Edge of Berm; HOUSE; Right of Way or Fence Line; FARM DRIVE; WATER PLANT PARK; OLD HOUSE; RENTAL REC; FIELD DR; HOUSE; FIELD DR	TT; FLASHER; 23; HE						
15.30								
15.20								
15.10								
15.00								
14.90								
14.80								

SHEET 2 OF 3 SHEETS

SPEED STUDY DATA SHEET

Date 5-15-96 County Del Municipality

Highway name & number Street Classification

Indicate North

Log Point	PHYSICAL CONDITION	TRAFFIC CONTROL DEVICES	SPEED 85%	SPEED PACE	ACCIDENTS	TEST RUNS	HORIZONTAL CURVES	VERTICAL CURVES
15.90	Right of Way or Fence Line; Edge of Berm; Edge of Pavement; ℄ of Pavement; Edge of Pavement; Edge of Berm; Right of Way or Fence Line							
15.80	MAIN RD				X INJ			
15.70		11 ⊥						
15.60	HOUSE; HOUSE				X PD			
15.52	HOUSE; HOUSE	⊕ T ⊥ 45 MPH						

SHEET 3 OF 3 SHEETS

TRAFFIC ACCIDENT ANALYSIS

Division No. 06 | Time Period: From 1-1-95 to 12-31-95 | Report No.

Location US 23 SLM 14.18 – 15.84 | County Del | Page No. 1 of 3

LOCATION OF ACCIDENT / DATE OF ACCIDENT	TIME	LIGHT	K.	INJ.	PD – $	WEATHER	ROAD COND.	TYPE & DAY	VEH.	DRIVERS: DIR.	SPEED	COND.	VIOLATIONS	COLLISION DIAGRAM
9501611148	AM								1	N	0 / C	OMV	IMPROPER TURN	
2-18-95	2:00	N	0	01		CLEAR	DRY	HO	2	S	C / 40	UNK		
#1 - M - 32 - DELAWARE, OH								SAT	3					
								SLM 14.18						
9520400973	PM								1	S	C / 40	N		
1-19-95	6:00	N	0	03		SNOW	WET	LT	2	N TOW	C / 10	N	FAILURE TO YIELD	
#2 - F - 68 - DELAWARE, OH								THUR	3					
								SLM 14.18						
9522291072	PM								1	N	VAN / 55	N		NO DIAGRAM
7-13-95	10:00	N	0	00		RAIN	WET	RE	2	N	C / 40	UNK	LEFT SCENE	
#1 -								THUR	3					
#2 - HIT SKIP								SLM 14.18						
9524911091	AM								1	N TOW	C / 10	N	IMPROPER TURN	
11-22-95	7:00	D	0	01		CLEAR	DRY	LT	2	S	C / 40	N		
#1 - M - 25 - DELAWARE, OH								WEN	3					
								SLM 14.18						
9525213660	AM								1	E TO S	RU / 2-5	N		ON HILLS MILLER
12-9-95	9:00	D	0	00		CLEAR	ICE	RE	2	E TO N	C / 10	N	ACDA	
#2 - E - 27 - DELAWARE, OH								SAT	3					
								SLM 14.18						

LEGEND

DIRECTIONAL ANALYSIS

- Motor vehicle movement before accident
- Vehicle movement after accident
- Pedestrian movement
- Skidding vehicle
- Vehicle overturning out of control
- Sideswipe
- Head-on collision
- Rear-end collision
- Vehicle struck fixed object
- Parked vehicle

CONDITION OF DRIVER

- N – Normal
- D – Drinking
- I – Intoxicated
- A – Asleep or Fatigued
- PD – Physical defect

Form TS-AR-12 Ohio Department of Highways-Bureau of Traffic

TRAFFIC ACCIDENT ANALYSIS

Division No. 06 | Time Period: From 1-1-95 to 12-31-95 | Report No.

Location US 23 SUM 14.18 - 15.84 | County DEL | Page No. 2 of 3

LOCATION OF ACCIDENT / DATE OF ACCIDENT	TIME	LIGHT	K.	INJ.	PD-$	WEATHER	ROAD COND.	TYPE & DAY	VEH.	DRIVERS DIR.	SPEED	COND.	VIOLATIONS	COLLISION DIAGRAM
REMARKS														
952410158	PM								1	S	C 25	N		
10-5-95	5:00	D	0	00		RAIN	WET	RE						
#2-F-40-MARION, OH								THUR	2	S	C 30	N	ACDA	
								SUM 14.19	3					
952000417	AM								1	N	SEMI 40	N	IMPROPER LANE CHANGE	
2-9-95	9:00	D	0	00		CLEAR	DRY	SS						
#1-M-55-BEAR LAKE, PA								THUR	2	N	C 40	N		
								SUM 14.20	3					
952140944	PM								1	S	SEMI 30	N	IMPROPER LANE CHANGE	
3-23-95	1:00	D	0	00		CLEAR	DRY	LT						
#2-M-64-VASSAR, OH								WED	2	E TO N	C 10	N	FAILURE TO YIELD	
								SUM 14.60	3					
952060247	NOON								1	S	C 50	N		
1-8-95		D	0	00		CLEAR	DRY	SS						
#1-M-57-GALDWIN, MI								SUN	2	S	C 50	N	UNSAFE SPEED	
#2-M-23-TOLEDO, OH								SUM 15.20	3					
952320265	PM								1	S	C 30	N		
7-25-95	1:00	D	0	00		RAIN	WET	RE						
#2-F-30-FOSTORIA, OH								TUE	2	S	C 40	N	VEHICLE DEFECT	
								SUM 15.60	3					

NO DIAGRAM

LEGEND

DIRECTIONAL ANALYSIS

- Motor vehicle movement before accident
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Form TS-AR-12 Ohio Department of Highways-Bureau of Traffic

TRAFFIC ACCIDENT ANALYSIS

Division No. 06 | Time Period: From 1-1-95 to 12-31-95 | Report No.

Location US 23 SM 14.18 – 15.84 | County Del | Page No. 3 of 3

LOCATION OF ACCIDENT								TYPE & DAY	VEH.	DRIVERS					
DATE OF ACCIDENT	TIME	LIGHT	K.	INJ.	PD.– $	WEATHER	ROAD COND.				DIR.	SPEED	COND.	VIOLATIONS	INDICATE NORTH / COLLISION DIAGRAM
REMARKS															
952510094 11-27-95	P.M. 4:00	D	0	01		RAIN	WET	RE	1	1	S	C 30	N	UNSAFE LANE CHANGE	
										2	N to S	C 40	N	UNSAFE LANE CHANGE	
#1 – M – 19 – Columbus, OH										3	S	C 30	N	ACDA	
#2 – M – 78 – ASHLE										4	S	C 40	N	ACDA	
#3 – M – 50 – [illegible]ANA OH										2					
#4 – F – 21 – MARION, OH										3					
										1					
										2					
										3					
										1					
										2					
										3					
										1					
										2					
										3					

SM 15.80

LEGEND

DIRECTIONAL ANALYSIS

- Motor vehicle movement before accident
- Vehicle movement after accident
- Pedestrian movement
- Skidding vehicle
- Vehicle overturning out of control
- Sideswipe
- Head–on collision
- Rear–end collision
- Vehicle struck fixed object
- Parked vehicle

CONDITION OF DRIVER

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Form TS–AR–12 Ohio Department of Highways–Bureau of Traffic

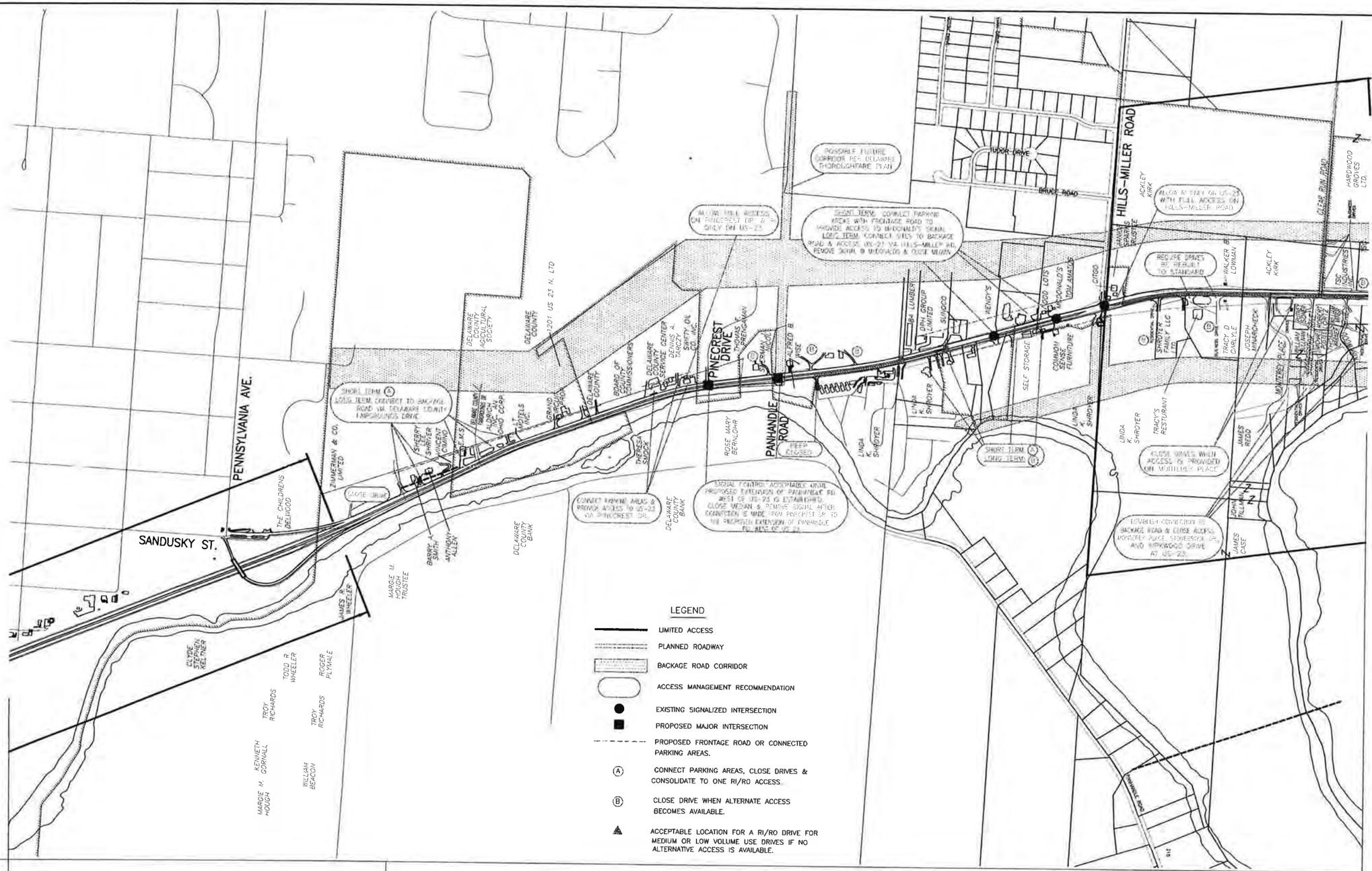
HAND HELD RADAR GUN

LOCATION US 23 500' from Coover Rd (So. of)
DATE 5-1-96 DAY Wed COUNTY Del
OBSERVER D. Smith
TYPE PAVEMENT Asphalt DRY ____ WET ____ CONDITION Good WIDTH 24'
WEATHER Clear TEMPERATURE ____

South bound, Time ____ M, to ____ M						North bound, Time ____ M, to ____ M				
CUM. %	CUM. TOTAL	NO.	VEHICLES: COMMERCIAL	VEHICLES: PASSENGER CARS	M.P.H.	VEHICLES: PASSENGER CARS	VEHICLES: COMMERCIAL	NO.	CUM. TOTAL	CUM. %
					OVER					
					70					
					69					
					68					
					67	1			100	
					66					
	100			1	65					
	99			II	64					
					63	1			99	
					62	1			98	
	97			II	61	II			97	
	95			1	60	II	1		95	
	94		1	II	59	IIII			92	
	91			III	58	IIII			86	
	88			IIII IIII	57	IIII	1		82	
	78		1	IIII IIII	56	IIII II			75	
	67			IIII IIII III	55	IIII II	1		67	
	55		1	IIII IIII	54	IIII IIII III			54	
	43			IIII IIII	53	IIII III	1		41	
	32		II	IIII III	52	IIII IIII			30	
	20			IIII	51	IIII II	1		21	
	14			III	50	IIII			12	
	11		1	II	49	II	1		8	
	8			IIII	48	III			5	
	4			III	47	1			2	
					46	1			1	
					45					

DEL-23-14.09/15.09 SAFETY STUDY

APPENDIX H: US23 ACCESS PLAN (2002)



SPEED LIMIT	55 MPH	45 MPH	55 MPH
MEDIAN	GRASS	TWO-WAY LEFT TURN LANE (TWLTL)	
EXISTING ACCESS CLASS	(1)	HIGH (3)	
DESIRED ACCESS CLASS	(1)	(2)	

DRWN: BY: DATE:
CALC: BY: DATE:
DSGN: BY: DATE:
CHKD: BY: DATE:

CENTRAL AVENUE TO CLEAR RUN ROAD
U.S. 23 ACCESS MANAGEMENT PLAN

DEL-23-0.00

7
11