

Horizontal Curve Assessment Project

PRESENTATION TO: AASHTO SUBCOMMITTEE ON TRAFFIC ENGINEERING

JUNE 6, 2016



Delaware Department
of Transportation



JOHNSON, MIRMIRAN & THOMPSON
Engineering A Brighter Future®



Horizontal Curve Assessment Project

WHY IS THIS PROJECT IMPORTANT?

- FHWA Mandate - *Towards Zero Deaths* Initiative
- Over representation of fatal crashes
- Low cost countermeasures have proven effective



MUTCD Table I-2 (Target Compliance Dates) requires all horizontal curves with >1,000 AADT (Collectors and above) to meet horizontal alignment sign standards specified in Sections 2C-06 through 2C-14 by December 31, 2019

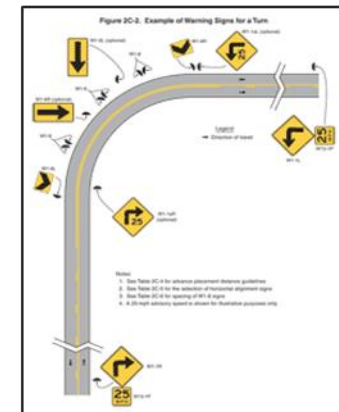
Horizontal Curve Assessment Project

MUTCD KEY POINTS

- **Table 2C-5 – summary of requirements**
- **Section 2C.08 – new Ball Bank recommendations**
- **Section 2C.09 – updated chevron spacing recommendations**
- **Correct/remove other signs within curve limits (e.g., sign size)**

BALL BANK ALLOWABLE READINGS

SPEED	DEGREES
35 MPH AND HIGHER	12
25 MPH – 30 MPH	14
20 MPH OR LESS	16



Horizontal Curve Assessment Project

SIGN AND CURVE GUIDELINE TABLE

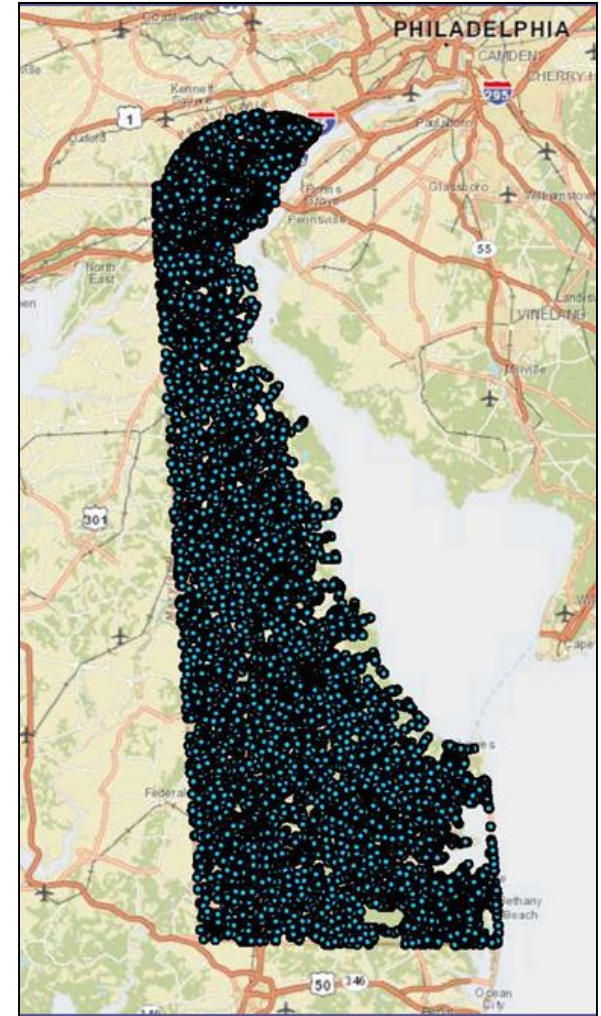
**Table 2C-5. Horizontal Alignment Sign Selection
(Delaware Revision)**

Type of Horizontal Alignment Sign	Difference Between Approach Speed and Curve Advisory Speed*				
	5 mph	10 mph	15 mph	20 mph	25 mph or more
Turn (W1-1), Curve (W1-2), Reverse Turn (W1-3), Reverse Curve (W1-4), Winding Road (W1-5), and Combination Horizontal Alignment/Intersection (W1-10 series) (see Section 2C.07 to determine which sign to use)	Recommended	Required	Required	Required	Required
Advisory Speed Plaque (W13-1P)	Recommended	Required	Required	Required	Required
Chevrons (W1-8) and/or One Direction Large Arrow (W1-6)	Optional	Recommended	Required	Required	Required
Exit Speed (W13-2) and Ramp Speed (W13-3) on exit ramp	Optional	Optional	Recommended	Required	Required

Horizontal Curve Assessment Project

PROJECT SCOPE

- Arterial and collector roadways
> 1,000 AADT
- 3,500 locations Statewide
- Comprehensive Approach
- Schedule:
 - Initial NTP: *June 2013*
 - Completion Goal:
December 2019



Horizontal Curve Assessment Project

COST

- Original guestimate - \$15 M
- Refined estimate:
 - \$1500 design per curve
 - \$900 installation per curve
 - \$2400 total per curve
 - 3500 locations
 - TOTAL: \$8.4 M



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STUDY DETAILS

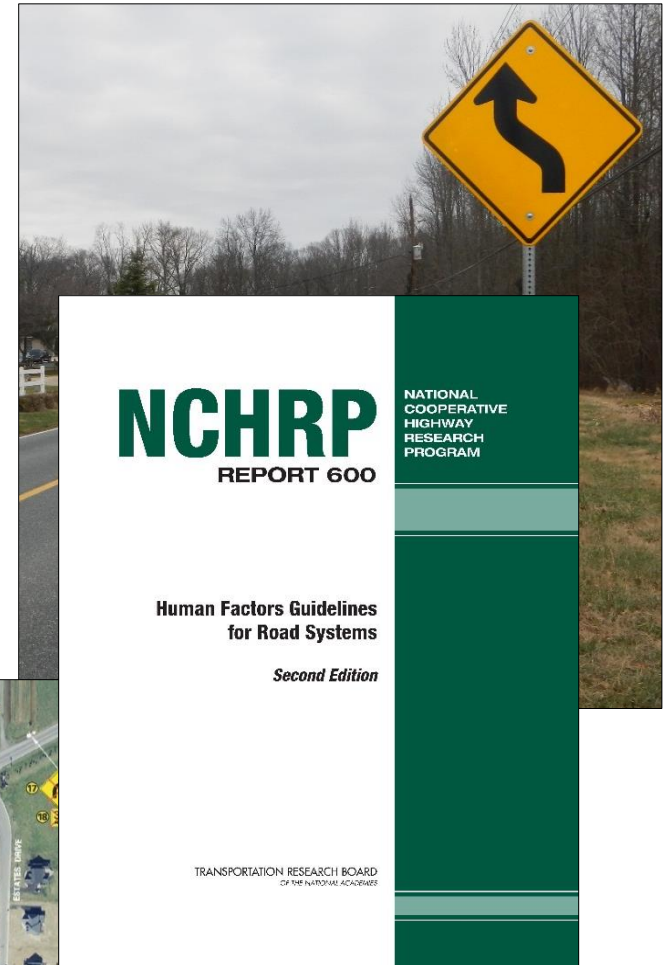
- Existing sign inventory
- Generally using Speed Limit
- Ball-bank indicator study
- MIRE Data Collection
- Visual trap review
- Engineer / Tech team visit every site



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RECOMMENDATION HIGHLIGHTS

- Sign Provision - Curve warning and advisory speed
- Curve warning sign placement
- Reducing sign clutter
- Reducing driving task model





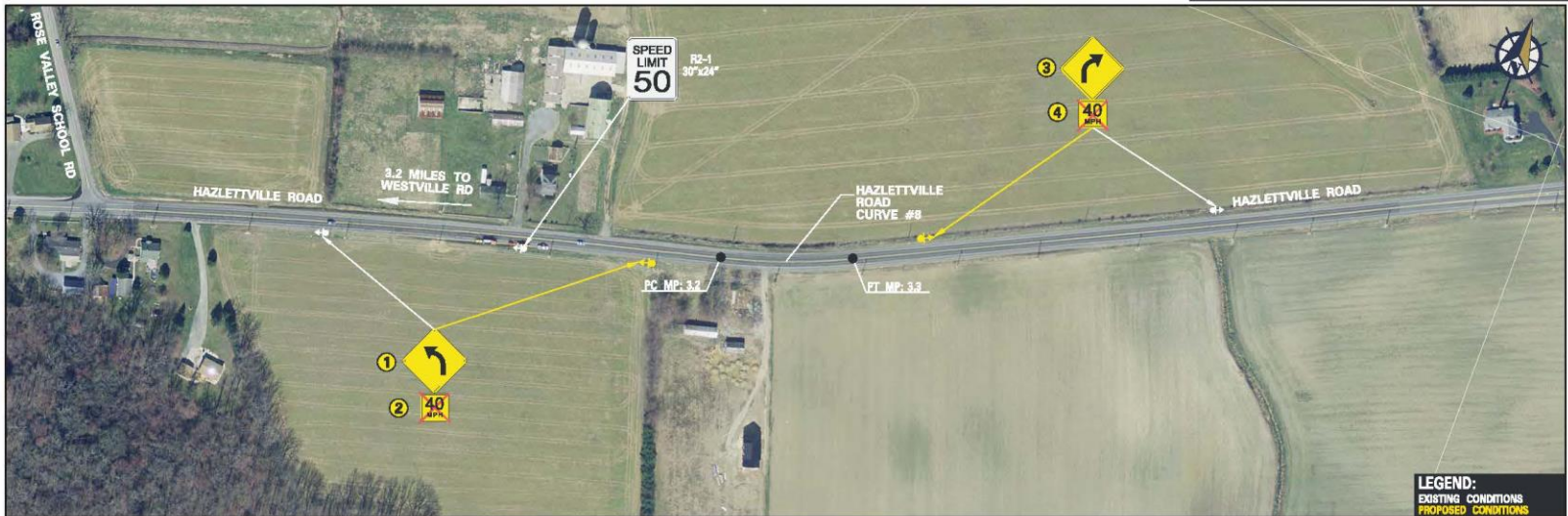
LEGEND:
EXISTING CONDITIONS
PROPOSED CONDITIONS

SHEET NO.
15
TOTAL SHTS.
15

Horizontal Curve Assessment Project

CORRIDOR: HAZLETTVILLE ROAD (K073)

KENT COUNTY - COLLECTORS > 1,000 ADT



LEGEND:
EXISTING CONDITIONS
PROPOSED CONDITIONS

DATA COLLECTED: 08-29-2013

**Sign
Placement /
Advisory
Speed
Removal**

EXISTING RECOMMENDATIONS

LOCATION / ACTION	SIZE	NOTES
RELOCATE	30"x30"	REMOVE ADVISORY SPEED BASED ON RESULTS OF BALL BANK INDICATOR STUDY. RELOCATE HORIZONTAL ALIGNMENT SIGN 600' EAST ON EXISTING SIGN POST
REMOVE	18"x18"	
RELOCATE	30"x30"	REMOVE ADVISORY SPEED BASED ON RESULTS OF BALL BANK INDICATOR STUDY. RELOCATE HORIZONTAL ALIGNMENT SIGN 600' WEST ON EXISTING SIGN POST
REMOVE	18"x18"	

RECOMMENDATIONS 1 & 2



RECOMMENDATIONS 3 & 4



BALL BANK ALLOWABLE READINGS

SPEED	DEGREES
35 MPH AND HIGHER	12
25 MPH - 30 MPH	14
20 MPH OR LESS	15

CURVE #8 GOVERNING BALL BANK STUDY RESULTS

DIRECTION OF TRAVEL	SPEED (MPH)	MAX READING (DEG)
EAST	50	8
	50	8
	50	6
WEST	45	7
	45	8

CURVE & ROADWAY INFORMATION: CURVE #8

PC MILEPOST	3.2 (APPROX.)
PT MILEPOST	3.3 (APPROX.)
DIRECTION	LEFT
RADIUS	1,300'
DEFLECTION ANGLE	12 DEG
LENGTH	286'
CURVE SUPERELEVATION	3.5% (APPROX.)
FEATURE TYPE	INDEPENDENT
LANE WIDTH	EB: 11' WB: 11'
SHOULDER WIDTH	EB: 6' WB: 6'
SURFACE TYPE	BITUMINOUS
SURFACE CONDITION	GOOD
EXISTING LIGHTING?	NO
EXISTING GUARDRAIL?	EB: NO WB: NO
DRIVEWAY W/IN CURVE?	YES
VISUAL TRAP?	EB: NO WB: NO
VISUAL TRAP TYPE:	N/A
FUTURE DEVELOPMENT?	NO
POSTED SPEED LIMIT	60 MPH
EXISTING ADVISORY SPEED	EB: 40 MPH WB: 40 MPH
PROPOSED ADVISORY SPEED	EB: NONE WB: NONE

DELAWARE
DEPARTMENT OF TRANSPORTATION

ADDENDUMS / REVISIONS

NOT TO SCALE

STATEWIDE HORIZONTAL CURVE
SAFETY PROJECT: PHASE I

CONTRACT
T200650017
COUNTY
KENT
DESIGNED BY: JAV / CDD
CHECKED BY: MAW

HAZLETTVILLE ROAD
CURVE #8

SHEET NO.
15
TOTAL SHEETS
21

Horizontal Curve Assessment Project

CORRIDOR: BURNITE MILL ROAD (K004)

KENT COUNTY - COLLECTORS > 1,000 ADT



LEGEND:
EXISTING CONDITIONS
PROPOSED CONDITIONS
DATA COLLECTED: 02-11-2014

Sign Clutter
Reduction

HORIZONTAL CURVE SIGNING RECOMMENDATIONS

#	SGN CODE	DESCRIPTION	DISPOSITION / REMARKS	SIZE	NOTES
1	W1-2	HORIZONTAL ALIGNMENT	REMOVE	30"x30"	
2	W1-10 CUSTOM	COMBINATION HORIZONTAL ALIGNMENT/INTERSECTION	INSTALL	26"x36"	INSTALL APPROX 530' WEST OF INTERSECTION ON NEW SIGN POST
3	W16-8aP	ADVANCE STREET NAME	INSTALL	16"x30"	
4	W2-2	INTERSECTION WARNING	REMOVE	30"x30"	
5	W16-8aP	ADVANCE STREET NAME	REMOVE	16"x30"	
6	W2-2	INTERSECTION WARNING	REMOVE	30"x30"	
7	W16-8aP	ADVANCE STREET NAME	REMOVE	16"x30"	
8	W1-10 CUSTOM	COMBINATION HORIZONTAL ALIGNMENT/INTERSECTION	INSTALL	26"x36"	REPLACE EXISTING SIGNS WITH PROPOSED SIGNS ON EXISTING SIGN POST
9	W16-8aP	ADVANCE STREET NAME	INSTALL	16"x30"	
10	W1-2	HORIZONTAL ALIGNMENT	REMOVE	30"x30"	

BALL BANK ALLOWABLE READINGS

SPEED	DEGREES
35 MPH AND HIGHER	12
25 MPH - 30 MPH	14
20 MPH OR LESS	16

CURVE #6 GOVERNING BALL BANK STUDY RESULTS

DIRECTION OF TRAVEL	SPEED (MPH)	MAX. READING (DEG)
EAST	50	7
	50	3
	50	2
WEST	50	5
	50	5
	50	5

RECOMMENDATION 1



RECOMMENDATIONS 2 & 3



CURVE & ROADWAY INFORMATION: CURVE #6

PC MILEPOST	3.59 (APPROX.)
PT MILEPOST	3.74 (APPROX.)
DIRECTION	RIGHT
RADIUS	1,475'
DEFLECTION ANGLE	30 DEG
LENGTH	776'
CURVE SUPERELEVATION	10% (APPROX.)
FEATURE TYPE	INDEPENDENT
LANE WIDTH	EB: 11' WB: 11'
SHOULDER WIDTH	EB: 8' WB: 0'
SURFACE TYPE	BITUMINOUS
SURFACE CONDITION	GOOD
EXISTING LIGHTING?	NO
EXISTING GUARDRAIL?	EB: NO WB: NO
DRIVEWAY WIN CURVE?	YES
VISUAL TRAP?	EB: NO WB: NO
VISUAL TRAP TYPE:	N/A
FUTURE DEVELOPMENT?	NO
POSTED SPEED LIMIT	50 MPH
EXISTING ADVISORY SPEED	EB: NONE WB: NONE
PROPOSED ADVISORY SPEED	EB: NONE WB: NONE



DELAWARE
DEPARTMENT OF TRANSPORTATION

ADDENDUMS / REVISIONS

NOT TO SCALE

STATEWIDE HORIZONTAL CURVE
SAFETY PROJECT: PHASE I

CONTRACT	WANT. NO.
1200650017	K057
COUNTY	DESIGNED BY: CDO
KENT	CHECKED BY: MAW

BURNITE MILL ROAD
CURVE #6

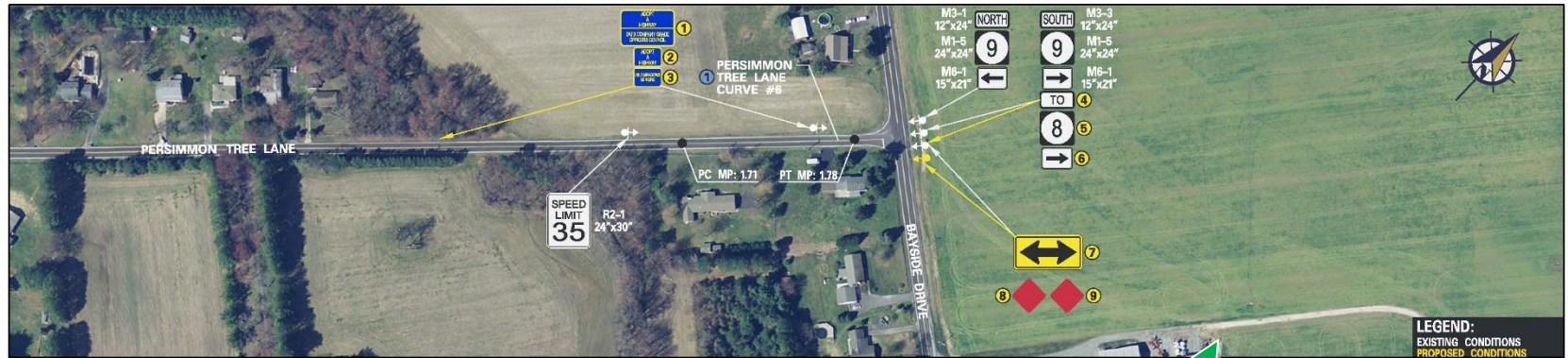
SHEET NO.	7
TOTAL SHETS.	14

PLOTTED BY: CDOE DATE: 8/8/2014
C:\Users\101012\OneDrive\Engineering\K004\3\Study\0527 Burnite Mill Road\

Horizontal Curve Assessment Project

CORRIDOR: PERSIMMON TREE LANE (K337)

KENT COUNTY - COLLECTORS > 1,000 ADT



DATA COLLECTED: 08-04-2014

HORIZONTAL CURVE SIGNING POTENTIAL IMPROVEMENTS

#	SIGN CODE	DESCRIPTION	DISPOSITION / REMARKS	SIZE	NOTES
1		LOCATION IS NOT WARRANTED TO BE SIGNED AS A CURVE PER MUTCD REQUIREMENTS. RECOMMEND REMOVAL FROM RIMS DATABASE BASED ON CURVE DEFLECTION ANGLE, RADIUS, LENGTH, AND FIELD VERIFICATION. RIMS "MILEPOINT OF CURVE" = 1.64			

HORIZONTAL CURVE SIGNING RECOMMENDATIONS

#	SIGN CODE	DESCRIPTION	DISPOSITION / REMARKS	SIZE	NOTES
1	D14-3-DE	ADOPT-A-HIGHWAY	RELOCATE	24"x36"	RELOCATE APPROX 750' WEST USING EXISTING SIGN POST
2	D14-3-DE	ADOPT-A-HIGHWAY	RELOCATE	12"x18"	
3	D14-3-DE	ADOPT-A-HIGHWAY	RELOCATE	12"x18"	
4	M4-5	TO	RELOCATE	12"x24"	RELOCATE SIGN ASSEMBLY TO NEW SIGN POST ADJACENT TO EXISTING STATE ROUTE 9 ASSEMBLIES
5	M1-5	STATE ROUTE	RELOCATE	24"x24"	
6	M6-1	DIRECTIONAL ARROW	RELOCATE	15"x21"	RELOCATE TO POSITION ADJACENT TO RELOCATED STATE ROUTE 9 SIGN ASSEMBLY USING EXISTING SIGN POSTS
7	W1-7	TWO DIRECTION LARGE ARROW	RELOCATE	24"x48"	
8	OM4-3	OBJECT MARKER	RELOCATE	18"x18"	
9	OM4-3	OBJECT MARKER	RELOCATE	18"x18"	

NO CURVE WARNING SIGNAGE WARRANTED PER DELAWARE MUTCD

Curve Removal

BALL BANK ALLOWABLE READINGS

SPEED	DEGREES
35 MPH AND HIGHER	12
25 MPH - 30 MPH	14
20 MPH OR LESS	16

CURVE #6 GOVERNING BALL BANK STUDY RESULTS

DIRECTION OF TRAVEL	SPEED (MPH)	MAX READING (DEG)
EAST	40	4
	40	3
	40	3
	40	2
WEST	40	2
	40	2

CURVE & ROADWAY INFORMATION: CURVE #6

PC MILEPOST	1.71 (APPROX.)
PT MILEPOST	1.78 (APPROX.)
DIRECTION	LEFT
RADIUS	18,229'
DEFLECTION ANGLE	1 DEG
LENGTH	350'
CURVE SUPERELEVATION	2% (APPROX.) (CROWN)
FEATURE TYPE	INDEPENDENT
LANE WIDTH	EB: 10' WB: 10'
SHOULDER WIDTH	EB: 0' WB: 0'
SURFACE TYPE	BITUMINOUS
SURFACE CONDITION	GOOD
RUMBLE STRIPS?	NO
EXISTING LIGHTING?	YES
EXISTING GUARDRAIL?	EB: NO WB: NO
DRIVEWAY W/IN CURVE?	YES
VISUAL TRAP?	EB: NO WB: NO
VISUAL TRAP TYPE:	N/A
FUTURE DEVELOPMENT?	NO
POSTED SPEED LIMIT	35 MPH
EXISTING ADVISORY SPEED	EB: NONE WB: NONE
PROPOSED ADVISORY SPEED	EB: NONE WB: NONE

RECOMMENDATIONS 1-3



RECOMMENDATIONS 4-9



NOT TO SCALE

STATEWIDE HORIZONTAL CURVE SAFETY PROJECT: PHASE II



DELAWARE
DEPARTMENT OF TRANSPORTATION

ADDENDUMS / REVISIONS

CONTRACT

1200950017

COUNTY

KENT

WANT NO.

1200950017

CHECKED BY: MAM

DESIGNED BY: CDD

K337

PERSIMMON TREE LANE
CURVE #6

SHEET NO.

8

TOTAL SHEETS

8

Horizontal Curve Assessment Project

CORRIDOR: SEVEN HICKORIES ROAD (K045)

KENT COUNTY - COLLECTORS > 1,000 ADT



LEGEND:
EXISTING CONDITIONS
PROPOSED CONDITIONS
DATA COLLECTED: 06-15-2013

HORIZONTAL CURVE SIGNING RECOMMENDATIONS					
#	SGN CODE	DESCRIPTION	DISPOSITION / REMARKS	SIZE	NOTES
①	W3-5	REDUCED SPEED LIMIT AHEAD (35 MPH)	RELOCATE	48"x48"	RELOCATE EXISTING "REDUCED SPEED LIMIT AHEAD" SIGN 600' EAST ON EXISTING SIGN POSTS.
②	W11-1	BICYCLE	REMOVE	30"x30"	
③	W16-1P	SHARE THE ROAD			

BALL BANK ALLOWABLE READINGS	
SPEED	DEGREES
35 MPH AND HIGHER	12
25 MPH - 30 MPH	14
20 MPH OR LESS	16

CURVE #1 GOVERNING BALL BANK STUDY RESULTS		
DIRECTION OF TRAVEL	SPEED (MPH)	MAX READING (DEG)
EAST	50	6
	50	6
	50	4
WEST	50	4
	50	4

CURVE & ROADWAY INFORMATION: CURVE #1	
PC MILEPOST	0.33 (APPROX.)
PT MILEPOST	0.47 (APPROX.)
DIRECTION	LEFT
RADIUS	2,886'
DEFLECTION ANGLE	15 DEG
LENGTH	760'
CURVE SUPERELEVATION	2% (APPROX.)
FEATURE TYPE	INDEPENDENT
LANE WIDTH	EB: 11' WB: 11'
SHOULDER WIDTH	EB: 10' WB: 10'
SURFACE TYPE	BITUMINOUS
SURFACE CONDITION	GOOD
EXISTING LIGHTING?	NO
EXISTING GUARDRAIL?	EB: NO WB: NO
DRIVEWAY WIN CURVE?	YES
VISUAL TRAP?	EB: NO WB: NO
VISUAL TRAP TYPE:	N/A
FUTURE DEVELOPMENT?	YES (LANDS OF W. VANE & MARY E. MASTEN)
POSTED SPEED LIMIT	60 MPH
EXISTING ADVISORY SPEED	EB: NONE WB: NONE
PROPOSED ADVISORY SPEED	EB: NONE WB: NONE

Driving Task
Model
Reduction

RECOMMENDATION 1



RECOMMENDATIONS 2 & 3



DATE: 8/17/2014
DESIGNED BY: CDD
CHECKED BY: MAW
KENT COUNTY



DELAWARE
DEPARTMENT OF TRANSPORTATION

ADDENDUMS / REVISIONS

NOT TO SCALE

STATEWIDE HORIZONTAL CURVE
SAFETY PROJECT: PHASE I

CONTRACT
1200650017
COUNTY
KENT

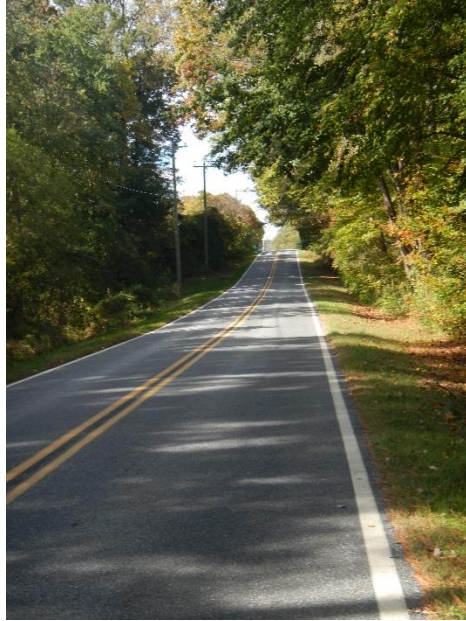
MAINT. ID.
K045
DESIGNED BY: CDD
CHECKED BY: MAW

SEVEN HICKORIES ROAD
CURVE #1

SHEET NO.
2
TOTAL SHEETS
6

Horizontal Curve Assessment Project

VISUAL TRAPS



- **Obstructed by Vertical Curves and Vegetation**

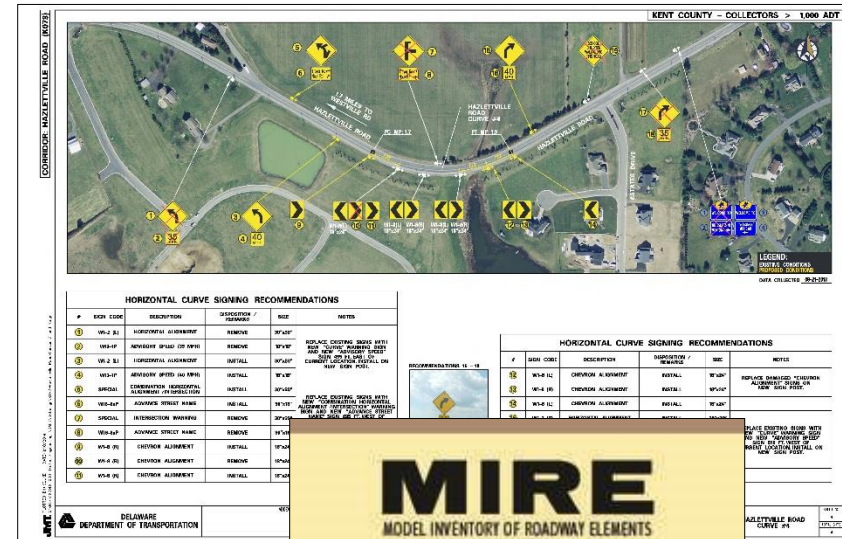


- **Obstructed by Utility Lines**

Horizontal Curve Assessment Project

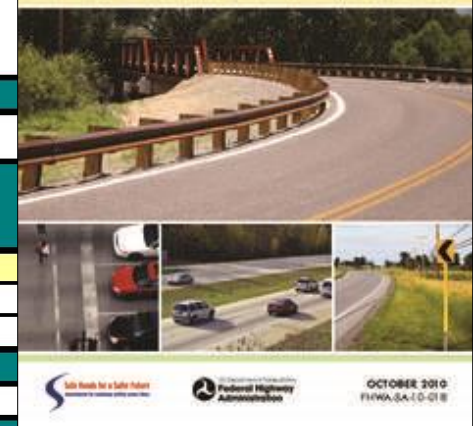
DELIVERABLES

- Plan Sheet Recommendations
- Quantity Tabulations
- MIRE Data Spreadsheets
- KMZ Files



TRAFFIC PROJECT COST SUMMARY CORRIDOR: WESTVILLE ROAD (K206)

DESCRIPTION	ENGINEER'S ESTIMATE
TOTAL ROADWAY SIGNING ESTIMATE:	\$5,231.94
TOTAL ROADWAY STRIPING ESTIMATE:	\$88.25
TOTAL ESTIMATE FOR CORRIDOR:	\$5,320.19



Horizontal Curve Assessment Project

PROJECT STATS – KENT COUNTY COLLECTORS

- **86** out of **430** curves had an advisory speed posted
 - **12** were consistent with study results
 - **68** were too low or not needed
 - **6** too high



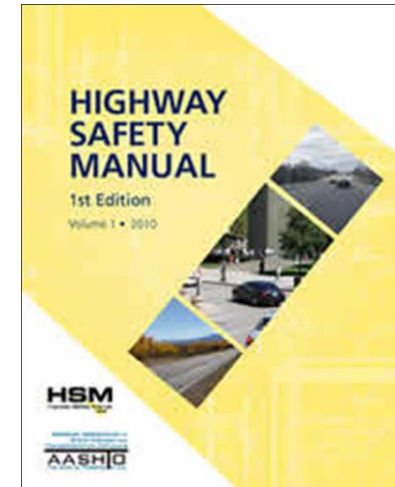
Horizontal Curve Assessment Project

QUANTITATIVE EFFECT ON SAFETY

- Highway Safety Manual: Predictive Model for Rural Two-Lane, Two-Way Roadway Segments

$$N_{\text{predicted,rs}} = N_{\text{SPF,rs}} * (CMF_1 * CMF_2 ... * CMF_x) * C$$

- $N_{\text{SPF,rs}} = AADT * L * 365 * 10^{-6} * e^{(-0.312)}$
- CMFs considered in analysis:
 - Lane width
 - Shoulder width
 - Superelevation variance
 - Horizontal curve length, radius
 - Presence of curve warning/advisory speed signs
 - $CMF = 0.76$ (combined)



Horizontal Curve Assessment Project

QUANTITATIVE EFFECT ON SAFETY

- **32** locations that warranted a posted advisory speed, but did not currently have one
- $N_{\text{predicted}} = \text{crashes / year}$

Road Name (Maint. #)	Curve #	$N_{\text{predicted}}$ Before	$N_{\text{predicted}}$ After
Lynnbury Woods Rd (K152)	2	0.08	0.06
Lockwood Chapel Rd (K171)	2	0.11	0.09
Westville Rd (K206)	1	0.14	0.11
Westville Rd (K206)	6	0.06	0.05

Total / Year	32	7.00	5.32
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Horizontal Curve Assessment Project

QUANTITATIVE EFFECT ON SAFETY

- 1 crash saved per year
- \$2400 total cost per curve

Cost : Societal Benefits

1 : 175

over 5 year period

Crash Severity Level	% of Total
Fatal + Injury	32.1
PDO	67.9

Collision Type	Societal Crash Costs
Fatal (K)	\$4,008,900
Disabling Injury (A)	\$216,000
Evident Injury (B)	\$79,000
Possible Injury (C)	\$44,900
PDO (O)	\$7,400

1 crash = \$420,000

Horizontal Curve Assessment Project

QUESTIONS?

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Delaware DOT
Chief Traffic Engineer
302-659-4062
Mark.Luszcz@state.de.us

