# Design and Field evaluation of the Dilemma Zone Protection System (DZPS) at US 40 \& MD 910C 

By Traffic Safety and Operations Lab

- Location overview
- Accidents history
- Field data collection (pre-deployment)
- Field implementation
- Key activities and issues
- Field data collection (post-deployment)
- Evaluation of Short-term impacts
- Speeds, acceleration/deceleration rates, decisions of drivers, distributions of dilemma zones
- Performance evaluation
- Summary of findings


## Location Overview

- US 40@ Western Maryland Parkway
- 4 -lanes divided highway (US 40), 3 approach lanes for Western Maryland Parkway (2-left, 1-right)
- Isolated intersection
- 55 mph speed limit
- Ramp from I-81 for eastbound

- 5\% HV



## Accident History

- Historical accidents data (2011 ~2013)
- 7 crashes potentially related to dilemma zone decisions for 3 years (side-angle crashes)
- 3 injuries



## Field Data Collection (before deployment)

- 4 video camcorders with two reference points
- $900 \mathrm{ft}, 650 \mathrm{ft}, 500 \mathrm{ft}$, and 200ft
- 1 camcorder for the stop line and the signal
- Data Collection Period
- Oct 10 ${ }^{\text {th }} 2014$ from 11:30 AM to 12:30 PM and 3:00 PM to 6:00 PM
- Data Processing
- Video times are synced with the GPS satellite time


900 ft video capture

signal video capture

## Field Deployment of the system



- Two sensors on EB on US 40
- EB sensor1: Green Extension, Allred Extension
- EB sensor 2: All-red Extension
- One sensor on WB on US 40
- WB sensor 1: Green Extension


## Key deployment Activities

- Check the sensor's function
- Validate the speed and location of approaching vehicle with sensor data
- Checked whether or not the sensor sending proper calls to the signal controller
- Using camcorders to record and measure signal timings
- Identify if there are all-red extension calls from the recorded video
- Identify red-light running vehicles
- Compare all-red extensions and red-light running vehicles to identify missed calls, false alarm, and correct calls


## DZPS Activated on Oct 13, 2016



## Evaluation of the Short-Term impacts



- Purposes:
- To evaluate the effectiveness of the system
- Impacts on driver behaviors and traffic conditions
- The performance of DZPS with respect to preventing side-crash accidents.


## Impacts by the roadside sensors?



US 40 @ MD
910C

- Impacts on the traffic?
- any change in the Speed?
- any change in acceleration/decelerati on rates?
- any change on decisions of drivers during the yellow phase?


## Field Data Collection after deployment



| Date | Time | Veh ID | Speed | Location | Signal | Date | Time | Veh ID | Speed | Location | Signal |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $10 / 14 / 2016$ | $57: 55.9$ | 28168 | 49 | 510 | Green | $10 / 14 / 2016$ | $57: 59.7$ | 28168 | 48 | 245 | Yellow |
| $10 / 14 / 2016$ | $57: 56.1$ | 28168 | 49 | 500 | Green | $10 / 14 / 2016$ | $57: 59.8$ | 28168 | 48 | 235 | Yellow |
| $10 / 14 / 2016$ | $57: 56.3$ | 28168 | 49 | 490 | Green | $10 / 14 / 2016$ | $58: 00.0$ | 28168 | 48 | 225 | Yellow |
| $10 / 14 / 2016$ | $57: 56.4$ | 28168 | 49 | 480 | Green | $10 / 14 / 2016$ | $58: 00.1$ | 28168 | 48 | 220 | Yellow |
| $10 / 14 / 2016$ | $57: 56.5$ | 28168 | 49 | 465 | Green | $10 / 14 / 2016$ | $58: 00.3$ | 28168 | 48 | 205 | Yellow |
| $10 / 14 / 2016$ | $57: 56.7$ | 28168 | 49 | 455 | Yellow | $10 / 14 / 2016$ | $58: 00.5$ | 28168 | 47 | 195 | Yellow |
| $10 / 14 / 2016$ | $57: 56.9$ | 28168 | 49 | 445 | Yellow | $10 / 14 / 2016$ | $58: 00.6$ | 28168 | 47 | 185 | Yellow |
| $10 / 14 / 2016$ | $57: 57.0$ | 28168 | 49 | 430 | Yellow | $10 / 14 / 2016$ | $58: 00.7$ | 28168 | 47 | 175 | Yellow |
| $10 / 14 / 2016$ | $57: 57.2$ | 28168 | 49 | 420 | Yellow | $10 / 14 / 2016$ | $58: 00.9$ | 28168 | 47 | 160 | Yellow |
| $10 / 14 / 2016$ | $57: 57.3$ | 28168 | 50 | 410 | Yellow | $10 / 14 / 2016$ | $58: 01.1$ | 28168 | 47 | 150 | Yellow |
| $10 / 14 / 2016$ | $57: 57.5$ | 28168 | 50 | 395 | Yellow | $10 / 14 / 2016$ | $58: 01.2$ | 28168 | 46 | 140 | Yellow |
| $10 / 14 / 2016$ | $57: 57.6$ | 28168 | 50 | 385 | Yellow | $10 / 14 / 2016$ | $58: 01.4$ | 28168 | 46 | 135 | Yellow |
| $10 / 14 / 2016$ | $57: 57.8$ | 28168 | 50 | 375 | Yellow | $10 / 14 / 2016$ | $58: 01.5$ | 28168 | 46 | 120 | Yellow |
| $10 / 14 / 2016$ | $57: 57.9$ | 28168 | 50 | 360 | Yellow | $10 / 14 / 2016$ | $58: 01.7$ | 28168 | 46 | 115 | Red |
| $10 / 14 / 2016$ | $57: 58.1$ | 28168 | 50 | 350 | Yellow | $10 / 14 / 2016$ | $58: 01.8$ | 28168 | 46 | 105 | Red |
| $10 / 14 / 2016$ | $57: 58.3$ | 28168 | 49 | 345 | Yellow | $10 / 14 / 2016$ | $58: 02.0$ | 28168 | 46 | 90 | Red |
| $10 / 14 / 2016$ | $57: 58.4$ | 28168 | 48 | 335 | Yellow | $10 / 14 / 2016$ | $58: 02.2$ | 28168 | 45 | 80 | Red |
| $10 / 14 / 2016$ | $57: 58.6$ | 28168 | 48 | 325 | Yellow | $10 / 14 / 2016$ | $58: 02.3$ | 28168 | 45 | 70 | Red |
| $10 / 14 / 2016$ | $57: 58.7$ | 28168 | 48 | 315 | Yellow | $10 / 14 / 2016$ | $58: 02.5$ | 28168 | 45 | 65 | Red |
| $10 / 14 / 2016$ | $57: 58.9$ | 28168 | 48 | 305 | Yellow | $10 / 14 / 2016$ | $58: 02.6$ | 28168 | 45 | 55 | Red |
| $10 / 14 / 2016$ | $57: 59.1$ | 28168 | 48 | 290 | Yellow | $10 / 14 / 2016$ | $58: 02.8$ | 28168 | 45 | 40 | Red |
| $10 / 14 / 2016$ | $57: 59.2$ | 28168 | 48 | 280 | Yellow | $10 / 14 / 2016$ | $58: 02.9$ | 28168 | 45 | 30 | Red |
| $10 / 14 / 2016$ | $57: 59.3$ | 28168 | 48 | 270 | Yellow | $10 / 14 / 2016$ | $58: 03.1$ | 28168 | 45 | 20 | Red |
| $10 / 14 / 2016$ | $57: 59.5$ | 28168 | 48 | 260 | Yellow | $10 / 14 / 2016$ | $58: 03.3$ | 28168 | 45 | 10 | Red |

- Signal timings
- camcorders
- Traffic speeds and locations
- sensors
- Six-day day for decisions of drivers during the yellow phase
- One day for system performance


## Impacts on Traffic Flow Speed

Average Speed for different locations


- Average speed reduced at 900 feet and 200 feet
- Not very significant reduction at 500 feet

| Location | 900 feet |  | 500 feet |  | 200 feet |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Data Collection Period | Before | After | Before | After | Before | After |
| Average speed (mph) | 49.7 | 44.6 | 46.4 | 45.33 | 40 | 34.9 |
| Standard Deviation | 10.6 | 6.24 | 6.7 | 6.95 | 9.07 | 10.48 |
| Minimum speed (mph) | 18.9 | 23 | 10.9 | 12 | 4.58 | 4 |
| Maximum speed (mph) | 74.1 | 75 | 69.4 | 67 | 61.2 | 60 |
| Sample Size | 1233 | 2943 | 1371 | 3000 | 1343 | 3000 |

## Impacts on Traffic Flow Speed

Cumulative Speed Distribution 900 Feet



- Percentage of the high-speed drivers (above speed limit at 900 feet) reduced from 29 \% to $16 \%$
- Vehicles Slowdown when they approaching the intersection

| Speed | Before |  | After |  |
| :---: | :---: | :---: | :---: | :---: |
|  | Framuncy | Dercentoce | Eramuency | Dercontaco |
| 75+ | 14 | 1\% | 0 | 0\% |
| 70-75 | 36 | 3\% | 3 | 0\% |
| 65-70 | 58 | 5\% | 6 | 0\% |
| 60-65 | 92 | 7\% | 94 | 3\% |
| 55-60* | 160 | 13\% | 375 | 13\% |
| 50-55 | 189 | 15\% | 850 | 29\% |
| 45-50 | 206 | 17\% | 951 | 32\% |
| 40-45 | 236 | 19\% | 432 | 15\% |
| 35-40 | 153 | 12\% | 166 | 6\% |
| 30-35 | 68 | 6\% | 56 | 2\% |
| 25-30 | 19 | 2\% | 10 | 0\% |
| Over Speed <br> Limit (total) | 360 (1231) | 29\% | 478 (2943) | 16\% |
| * Speed limit: 55 MPH |  |  |  |  |

## Distribution of the dilemma zones

Distributions of the dilemma zone Before and After the deployment


- Deceleration rate
- Before the deployment: $--7.28 \mathrm{ft} / \mathrm{s}^{2}$
- After the deployment: $-11.27 \mathrm{ft} / \mathrm{s}^{2}$
- Maximum length of the DZ
- Before the deployment: 960 feet
- After the deployment: 670 feet
- Distributions of the DZ reduced


## Drivers' decisions during the yellow phase

Moderate Speed (45-55 MPH)


High Speed (55+ MPH)


- More drivers at moderate speeds choose "STOP" decisions (below or around speed limit)
- Not significant impact on high-speed drivers

| Speed of vehicle on set of yellow (sample size) | Location of vehicles from stop line onset of yellow |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 0-100 ft |  | 100-200 ft |  | 200-300 ft |  | 300-400 ft |  | 400+ ft |  |
|  | Before | After | Before | After | Before | After | Before | After | Before | After |
| 45-55 mph | $\begin{gathered} 100 \% \\ (78) \end{gathered}$ | $\begin{gathered} 100 \% \\ (24) \end{gathered}$ | $\begin{aligned} & 100 \% \\ & (100) \end{aligned}$ | $\begin{aligned} & 94 \% \\ & (32) \end{aligned}$ | $\begin{aligned} & 74 \% \\ & (73) \end{aligned}$ | $\begin{aligned} & 59 \% \\ & (41) \end{aligned}$ | $\begin{aligned} & 50 \% \\ & (24) \end{aligned}$ | $\begin{array}{r} 43 \% \\ (40) \end{array}$ | $\begin{gathered} 20 \% \\ (5) \end{gathered}$ | $\begin{gathered} 5 \% \\ (59) \end{gathered}$ |
| 55+ mph | $\begin{gathered} 100 \% \\ (9) \end{gathered}$ | $100 \%$ <br> (7) | $\begin{gathered} 100 \% \\ (20) \end{gathered}$ | $\begin{gathered} 100 \% \\ (9) \end{gathered}$ | $\begin{aligned} & 88 \% \\ & (47) \end{aligned}$ | $\begin{aligned} & 91 \% \\ & (22) \end{aligned}$ | $\begin{aligned} & 50 \% \\ & (16) \end{aligned}$ | $\begin{aligned} & 54 \% \\ & (13) \end{aligned}$ | $\begin{aligned} & 10 \% \\ & (20) \end{aligned}$ | $\begin{gathered} 9 \% \\ (44) \end{gathered}$ |
| *1: Field: percentage of drivers taking the "Pass" decision from the field observations *2: the number in parenthesis denotes the sample size. |  |  |  |  |  |  |  |  |  |  |

## Safety evaluation with the total length of Dilemma zone

$$
x_{d z}=x_{c}-x_{0}=v_{0} \delta_{2}+\frac{v_{0}^{2}}{2 a_{2}^{*}}-v_{0} \tau+(w+L)-\frac{1}{2} a_{1}^{*}\left(\tau-\delta_{1}\right)^{2}
$$

where:
$x_{c}=$ the critical distance for a smooth stopunder the maximum develeration rate;
$x_{0}=$ the critical distance for "intersection clearance" under the maximum acceleration rate;
$\tau=$ duration of the yellow interval;
$\delta_{1}=$ reaction time - lag of the driver - vehicle complex;
$\delta_{2}=$ decision - making time of a driver;
$v_{0}=$ approach speed of vehicles;
$a_{1}=$ average vehicle accerlaeration rate;
$a_{1}^{*}=$ maximum accerleration rate of the approaching vehicles;
$a_{2}=$ average vehicle deceleration rate;
$a_{2}^{*}=$ maximum deceleration rate of the approaching vehicles;
$w=$ intersection width; and
$L=$ average vehicle length.

- Total length of the dilemma zone weighted by volume in each speed bin

$$
D Z_{L}=\sum L_{i} * \frac{\text { Vol }_{i}}{\text { Vol }_{\text {Total }}}
$$

$L_{i}$ is the length of the dilemma zone for $i^{\text {th }}$ speed bin $V o l_{i}$ is the number of the volume in the $i^{\text {th }}$ speed bin Vol $_{\text {Total }}$ is the total number of vehicle

- Before: 73 feet and After: 44 feet
- $40 \%$ reduction


## Performance Evaluation on Detection and Activation



## Summary of Findings

## - Deployed DPZS can

- Reduce the average approaching vehicle speed
- Reduce the percentage of high-speed vehicles
- Encourage drivers to take the "stop" action during the yellow phase
- High-Speed vehicles
- Are more likely to be reduced
- Side-street vehicles are protected by all-red extensions

