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)





Field Data Collection (before deployment)

- 4 video camcorders with two reference points
 - **900** ft, 650ft, 500 ft, and 200ft
- 1 camcorder for the stop line and the signal
- Data Collection Period
 - Oct 10th 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 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 500 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	Bef	fore	After				
speed	Frequency	Percentage	Frequency	Percentage			
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 Limit (total)	360 (1231)	29%	478 (2943)	16%			
* Speed limit: 55 MPH							

Distribution of the dilemma zones



- Deceleration rate
 - Before the deployment: --7.28 ft/s^2
 - After the deployment: -11.27 $ft/_{s^2}$
- 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





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

Speed of vehicle	Location of vehicles from stop line onset of yellow									
on set of yellow	0 - 100 ft		100 - 200 ft		200 - 300 ft		300 - 400 ft		400 + ft	
(sample size)	Before	After	Before	After	Before	After	Before	After	Before	After
45 55 mmh	100%	100%	100%	94%	74%	59%	50%	43%	20%	5%
45 - 55 mpn	(78)	(24)	(100)	(32)	(73)	(41)	(24)	(40)	(5)	(59)
55	100%	100%	100%	100%	88%	91%	50%	54%	10%	9%
55+ mpn	(9)	(7)	(20)	(9)	(47)	(22)	(16)	(13)	(20)	(44)
*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

 $x_{dz} = x_c - x_0 = v_0 \delta_2 + \frac{v_0^2}{2a_2^*} - v_0 \tau + (w + L) - \frac{1}{2}a_1^*(\tau - \delta_1)^2$

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;

 $\tau = duration of the yellow interval;$

 δ_1 = reaction time - lag of the driver - vehicle complex;

 δ_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

$$DZ_L = \sum L_i * \frac{Vol_i}{Vol_{Total}}$$

 L_i is the length of the dilemma zone for ith speed bin Vol_i is the number of the volume in the ith speed bin Vol_{Total} is the total number of vehicle

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

Performance Evaluation on Detection and Activation

MOE	Simulation	Field Operation*	5 vehicles ran on the red phase
Red-light-running rate (RLR) (RLR / 100 cycle)	9.5	1.6**	System Provides all-red extension to all
Extension call rate (extension call / cycle)	30%	31.7%	 100% detection rate 30% false alarm rate
Detection rate (protected RLR)	100%	100%	
False alarm rate (false alarm / cycle)	21%	30.1%	

* Based on the 6 hours field observations, total of 312 Cycles.

** Five red light running vehicles during the data collection.

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