EMPIRICAL OBSERVATIONS OF DRIVING BEHAVIORS AT INTERSECTIONS WITH RED LIGHT CAMERA DEPLOYMENT

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Abstract

- This study presents the results of a two-phase evaluation of the red-light cameras' (RLC) effects on traffic safety.
  - Before-and-after study of RLC effectiveness
  - The impact of RLC on the driving behaviors
- A properly deployed RLC program has the potential to
  - Reduce side-impact crashes
  - Decrease the percentage of aggressive drivers
  - Encourage drivers to slow down and stop safely during the yellow phase
  - Reduce red-light-running vehicles
- Failing to inform drivers in advance of the RLC deployment may lead drivers to take improper decisions in the dilemma zone and result in rear-end collisions.

RLC effectiveness Analyses from Literature

Types of before-and-after crash patterns	List of Literature*
Type-1: reduction in both side-impact and rear-end crashes	[Government Report]: Brooksville, Clermont, Davie, Miami, Pinecrest, Council Bluffs, Davenport, Howard, Portland, Knoxville, Austin
Type-2: reduction only in side-impact crashes but not in rear-end crashes	[Literature]: Bochner et al. (2010), Erke et al. (2009), Høye et al. (2013), Kangwon et al.(2007), Ko et al. (2013), Persaud et al. (2005), Radali et al. (2001), Retting et al. (2002), Ahmed et al. (2015), Shin et al.(2007); [Government Report]: Phoenix, Scottsdale, San Diego, Apopka, Boynton Beach, Campbellton, Fort Lauderdale, Manatee, New Port Richey, Ocoee, Palatka, Palm Beach, Sarasota, West Park, Lafayette, Greensboro, Newark, Suffolk, Amarillo, Denton, Diboll, Frisco, Mesquite, Port Lavaca, Fairfax, Falls Church, Vienna
Type-3: reduction only in rear-end crashes but not in side-impact crashes	[Literature]: Council et al. (2005); [Government Report]： Houston, Cunningham
Type-4: no significant impacts in both side-impact and rear-end crashes	[Literature]: Claros et al. (2017); [Government Report]： Boca Raton, Clewiston, Jacksonville, Lakeland, Maitland, Miami Beach, Miami Spring, Orange, Orlando, Osceola, Palm Coast, Sunrise, Tamarac, Tampa, West Miami, Bedford, Cleveland, Garland, Haltom City, Richland Hills, University Park, Willis, Arlington

- The inconsistencies in evaluation findings are likely attributed to
  - Failures to account for regression to mean
  - Existence of spillover/halo effects

Before-and-after Comparison of RLC effectiveness in Maryland

Montgomery County		Howard County	
M1	MD 355 @ Cheltenham Dr.	H1	US 40 @ N. Ridge Rd.
M2	MD 124 @ Goshen Rd.	H2	US 1 @ Corridor Rd.
M3	Shady Grove Rd. @ Research Blvd.	**Prince George's County**	
M4	MD 355 @ Middlebrook Rd.	P1	US 301 @ Gobernor Bridge Rd.
M5	MD 355 @ Halpine Rd.	P2	MD 410 @ MD 450
M6	US 29 @ Fenton St.	P3	US 301@ Old Indian Head Rd.
M7	MD 355 @ Grosvenor Ln.	P4	MD 410 @ 64th Ave.
M8	MD 185 @ Knowles Ave.	P5	US 301 @ McKendee
M9	US 29 @ MD 193 EB	P6	MD 212 @ Adelphi Rd.
M10	MD97 @ US 29	P7	MD 410 WB @ Ager Rd.
M11	US 29 @ Tech Rd.	P8	MD 223 @ Old Branch Rd.
M12	MD 97 @ Nirbeck Rd.	P9	MD 301 @ Pointer Ridge Dr.
M13	MD 355 @ Montgomery Ln.	P10	MD 458 @ Marlboro Pike
M14	MD 185 @ Randolph Rd.		
M15	MD 650 @ Adelphi Rd.		

Length of Before | After	Summary for Side-Impact Crashes (RLC legs only)							
	Side-Impact Injury "Increase"	Side-Impact PDO "Increase"	Side-Impact Injury "Decrease"	Side-Impact PDO "Decrease"	Side-Impact Injury "Increase"	Side-Impact PDO "Decrease"	Side-Impact Injury "Decrease"	Side-Impact PDO "Increase"
B:5-yr| A:3-yr	P3		H1^{AR}, H2^{A}, M1, M2^{A}, M5, M6, M7, M8, M12, P2, P4, P8		M13^{R}, P10		M3, M4^{A}, M11^{A}, M14, M15, P1, P5, P6^{R}, P7, P9^{R}	
B:3-yr| A:3-yr	M3, P3, P10		H1^{R}, H2, M1, M2A, M5, M7, M8, P1, P4		M6, M13^{R}, P8		M4, M12, M14^{A}, M15, P2, P5, P6, P7, P9,M11^{A}	
B:2-yr| A:3-yr	M3, M5, P3, P10		H1, H2^{A}, M2^{A}, M6, M8, M15, P1^{R}, P4		M1, M7, M12, M13^{R}, P8		M4^{R}, M14^{R},M11^{A},P2, P5, P6, P7, P9^{R}	
B:5-yr| A:2-yr	M9, P3		H1A, H2, M1, M2^{A}, M3, M5, M6, M7, M8, P4^{A}		M12, M13^{R}, P8, P10		M4^{A}, M10, M14, M15, P1, P2, P5, P6, P7, P9,M11	
B:3-yr| A:2-yr	M9, M12, P3		H1, H2, M2^{A}, M5, M7, M8, P1, P4		M1, M3, M13^{R}, P8, P10		M4, M6, M10, M14, M15, P2, P5, P6, P7, P9, M11^{A}	
B:2-yr| A:2-yr	M5, P3		H1, H2^{A}, M2A, M6, M8, P1, P4^{A}		M1, M3, M7, M12, M13^{R}, P8, P10		M4^{R}, M9, M10, M14, M15, P2, P5, P6, P7, P9, M11^{A}	

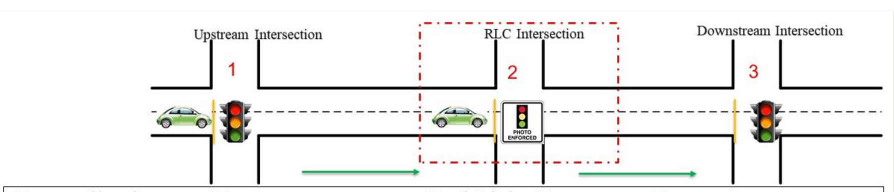
PDO: Property Damage Only
A: Side-impact crashes significant at the 90% confidence level
R: Rear-End crashes significant at the 90% confidence level
AR: Both side-impact and rear-end crashes significant at the 90% confidence level.

Length of Before | After	Summary for Rear-End Crashes of Different Severity Levels (RLC legs only)							
	Rear-end Injury "Increase"	Rear-end PDO "Increase"	Rear-end Injury "Decrease"	Rear-end PDO "Decrease"	Rear-end Injury "Increase"	Rear-end PDO "Decrease"	Rear-end Injury "Decrease"	Rear-end PDO "Increase"
B:5-yr| A:3-yr	M4, M11^{P}, M14, P3, P5, P7		H1^{I}, M1, M2^{I}, M5, M6, M13, P8		H2^{P}, M12, M15^{I}, P2, P4^{P}		M3, M7, M8^{I}, P1, P6^{P}, P9, P10	
B:3-yr| A:3-yr	M4, M11, M14, P7, P10		H1^{I}, M1, M2, M5, M7, M8, M13, P1, P8		H2^{P}, M6, M12, M15, P2, P3, P4		M3, P5, P6^{P}, P9	
B:2-yr| A:3-yr	M4^{P}, M14, P7, P10		M1, M2, M7, M8, M13, P1, P8		H2^{P},M5, M6, M12, M15, P2, P3, P4		H1, M3, M11^{P},P5, P6, P9^{P}	
B:5-yr| A:2-yr	M9, M10, M11, M14, P5, P7		H1, M1, M2^{I}, M3, M13^{P}, P4^{P}, P8, P10		H2^{P}, M5, M6, M12, M15^{P}, P2		M4, M7, M8^{I}, P1, P3, P6, P9^{P}	
B:3-yr| A:2-yr	M9, M10, M11, M14, P2, P6, P7		H1, M1, M2, M3, M13, P1, P4, P8		H2^{P}, M5, M6, M12, M15, P10		M4, M7, M8, P3, P5, P9	
B:2-yr| A:2-yr	M9, M10, M14, P2, P7		M1, M2, M3, M7, M8, P1, P3, P4, P8, P10		H2^{P}, M5, M6,M12, M15		H1, M4^{P}, M11, M13, P5, P6, P9	

I: Injury crashes significant at the 90% confidence level
P: PDO crashes significant at the 90% confidence level
IP: Both injury and PDO crashes significant at the 90% confidence level

- Findings are consistent with the literature
  - Reductions in side-impact crashes at most intersections with RLC
  - The percentage of intersections with RLC had an increase of rear-end collisions and it was at approximately the same level as those reported to have positive effects
  - A small percentage of RLC intersections seem to suffer from an increase in both rear-end and side-impact crashes

Design of Data Collection



Data collection sites	Upstream	Red Light Camera	Downstream
Site 1: MD 650	Oakview Dr.	Adelphi Rd.	Northampton Dr.
Site 2: US 301	Frank Tippett Rd.	Rosaryville Rd. (Old Indian Head Rd.)	Fairhaven Ave.

Key traffic characteristics and behavioral data

- Speed evolution of an approaching vehicle
- Distance to the stop line onset of the yellow phase
- An individual driver's decision on taking either the "stop" or "pass" action
- Acceleration and deceleration rates of each approaching vehicle
- Number of vehicles crossing the intersection during all-red and/or red phases
- Timestamp when a "passing" vehicle traverses the stop line

Empirical Observation Results

Approaching Speed Distributions

MD 650 (effective in reducing side-impact crashes; speed limit: 40 MPH)					
% of vehicle	<40 mph	40 – 45 mph	45 – 50 mph	>50 mph	Average
Upstream (N = 202)	71.29%	14.85%	12.87%	0.99%	35.3
RLC (N = 104)	40.38%	36.54%	13.46%	9.62%	41.5
Downstream (N = 103)	36.89%	33.98%	21.36%	7.77%	41.9

US 301 (Ineffective in reducing side-impact crashes; Speed limit: 55 MPH)					
% of vehicle	<55 mph	55 – 60 mph	60 – 65 mph	>65 mph	Average
Upstream (N = 203)	25.12%	24.14%	30.54%	20.20%	59.1
RLC (N = 206)	19.9%	16.02%	24.27%	39.81%	61.5
Downstream (N = 457)	62.82%	19.23%	11.54%	6.41%	54.7

- Aggressive Drivers
  - when his/her speed is +10mph than speed limit
  - At RLC-effective intersection (MD 650): 9.62%
  - At RLC-ineffective intersection (US 301): 39.81%
- Spillover effect: reduced the percentage of aggressive drivers at the downstream intersection

Speed Change during Yellow Phase

Moderate "Passing" Drivers				
Site	Intersection	Difference between the passing speed (at the stop line) and the approaching speeds (700ft)		
		< -5mph	Unchanged	> 5mph
MD650 (Effective)	Upstream	46 %	43 %	11 %
	RLC	7 %	57 %	36 %
	Downstream	13 %	75 %	12 %
US310 (Ineffective)	Upstream	9 %	56 %	35 %
	RLC	8 %	46 %	46 %
	Downstream	20 %	75 %	5 %
Aggressive "Passing" Drivers				
Site	Intersection	Difference between the passing speed (at the stop line) and the approaching speeds (700ft)		
		< -10 mph	Unchanged	> 5mph
MD650 (Effective)	Upstream	6.7 %	20 %	10 %
	RLC	29 %	36 %	7 %
	Downstream	30 %	60 %	0 %
US310 (Ineffective)	Upstream	0 %	89 %	11 %
	RLC	12 %	41 %	35 %
	Downstream	40 %	20 %	0 %

- Moderate speed drivers, who **decelerate** when passing the intersection during yellow phase **increase** from the RLC to its downstream intersection
  - MD 650: 7% → 13%; US 301: 8% → 20%
- Moderate speed drivers, who **accelerate** when passing the intersection during yellow phase **decrease** from the RLC to its downstream intersection
  - MD 650: 36% → 12%; US 301: 46% → 5%
- Spillover effect

Effects on driving behaviors in the Dilemma Zone

Site	Intersection	Choose to stop within their "must-go" zone (rear-end collisions)	Choose to pass within their "must-stop" zone (side-impact crash)	Vehicles trapped in DZ	Total No. of vehicles encountering the yellow phase
MD 650 (Effective)	Upstream	0.4% (1)	5.9% (15)	23.7% (60)	253
	RLC	12% (32)	0.7% (2)	6.7% (18)	267
	Downstream	6.1% (12)	2.3% (5)	5.1% (10)	196
US 301 (Ineffective)	Upstream	0.5% (2)	0.9% (4)	30.1% (131)	435
	RLC	3.9% (21)	1.3% (7)	37.4% (202)	540
	Downstream	2.4% (7)	4.7% (14)	27.0% (80)	296
MD 450 (Effective)		10.11% (9)	1.12% (1)	13.48% (12)	89
MD 97 (Ineffective)		2.94% (4)	0.74% (1)	29.41% (40)	136

* Numbers in parenthesis are number of cases observed during field data collection

- The percentages of drivers who decided to stop when they were actually within the "must-go" zone
  - MD 650: 12%; US301: 3.9%
  - Those drivers might cause more rear-end collisions.
- Only a relatively small percentage of drivers were observed to pass when they were in "must-stop" zone.
  - Such drivers are at risk of causing side-impact crashes.
- The percentage of drivers (37%) trapped in the dilemma zone at the RLC-ineffective intersection (US 301) was much higher than at RLC-effective intersection (MD 650, 6.7%)

Conclusions

Findings from the Two-Phase Evaluations

- Proper implementation of the RLC program has reduced side-impact crashes, but not rear-end collisions
- RLC may either increase or decrease the number of rear-end collisions (depends on behavior of the driving populations)
- RLC reduced the percentage of aggressive drivers at both the RLC and its downstream intersection
- A properly implemented RLC program has significant influence on the behaviors of drivers
- A properly implemented RLC intersection was shown to have a spillover effect to neighboring intersections.

Future Study

- Due to the limited resources this study includes four intersections for data observations. Further analysis with different locations might be needed to generalize the effectiveness of the RLC