Investigating the Capacity Reduction at Signalized Intersections with Red Light Camera along Urban Arterials

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Abstract: - The presence of a red light camera at signalized intersections can contribute to drivers' behavioral changes. One particular behavioral change may be attributed to the fear of a possible red light running situation. This situation while may improve safety, may result in ineffective use of yellow time interval. This may affect the capacity of the intersection since less vehicles may be serviced in a given signal cycle resulting in increased queuing and congestion. Field observations have shown that drivers tend to stop at red light camera monitored intersections during yellow even in cases where there is enough clearing distance before the onset of the red signal. In this paper we improve upon our previous research in modeling driver behavior at red light camera equipped signalized intersections by using field data along signalized intersections with and without red light cameras in Baltimore. Using field data on the number of vehicles delayed at the intersections we calculate the hourly delay of vehicles from which we estimate the capacity loss at each red light camera monitored intersection along a heavily traveled arterial. The results show that the cumulative reduction in capacity due to the presence of red light camera may be quite significant, which may play a major role in contributing to the peak hour congestion in urban areas. The trade-off between safety and congestion consequences of RLCs can be investigated in future works.

Key-Words: - Red Light Camera, Red Light Running, Intersection Capacity, Yellow Time Interval

1 Introduction

In recent years several cities in the United States and overseas have installed Red Light Camera (RLC) at signalized intersections. The main reason behind installing the cameras is to reduce Red Light Running (RLR) accidents. The Insurance Institute for Highway Safety (IIHS) reports that as of May 2009 RLC are used over 400 cities in the United States including several communities in Maryland [1].

In our earlier works [2&3] using field data from Baltimore, Maryland for a pair of ten signalized intersections equipped with and without RLCs we developed a probabilistic approach to estimate the possible increase of the dilemma zone and introduced a red light reduction factor in calculating the capacity of

RLC equipped intersections. The Highway Capacity Manual (HCM) at present does not address the issue of reduced capacity due to RLC [4]. We also do not believe that RLC laid capacity reduction scenarios will be addressed in the upcoming version of HCM since research efforts related to RLC, driver behavioral influences due to RLCs, and capacity reduction are still emerging topics. A literature review [5-10] reveals that several studies have been undertaken in connection with RLC and RLR incidents. However, most of those studies mainly discuss the advantage of using RLCs qualitatively such as reducing accidents and ignore theoretical, analytical, and empirical analyses. Moreover, none of the studies investigated the effects of RLC on driver behavior during the yellow interval.

In this paper we improve upon our previous research in modeling driver behavior at signalized intersections with RLC. To capture drive behavior due to sudden appearance or absence of RLCs we choose ten RLC monitored intersections immediately followed or proceeded by ten non-RLC intersections. We also conducted a survey of 100 drivers to investigate their perception of increased dilemma zone due to RLCs. Using vehicle stoppage data during yellow intervals we investigate further the effective use of the yellow signal time and compute the hourly delay for each RLC intersection. From the hourly delay of vehicles during yellow we estimate the possible capacity losses at each RLC intersection.

2 Intersection Characteristics

Figure 1 shows a GIS map of the study intersections where the RLC and non RLC intersections are shown with a single star symbol. Table 1 shows the major characteristics of the study intersections. The posted speed limit at the ten RLC intersections range from 25 mph to 40 mph. The highest speed patterns are found at Northern Pkwy and Loch Raven Blvd, and the lowest speed patterns are found at Cold Spring Lane and Loch Raven Blvd. The number of lanes range from 2 to 6. Light Street and Loch Raven Blvd have the highest and lowest number of lanes respectively. The green time at the intersections ranged between 44 to 60 seconds. The yellow time at the ten intersection pairs is 4 seconds. The all-red time at the intersection pairs is 2 seconds. The cycle lengths are 100 to 120 seconds.

3 Survey Data Analysis

A survey is conducted with 100 drivers in Baltimore to investigate their perception about the RLR behavior and the effective use of the yellow time when cameras are present. The drivers represent all age groups. In the survey questionnaire the drivers are asked if they had RLR experience, the reason for RLR, how they were going to act if they were aware of the presence of RLC, the average yellow time at signalized intersections, if they knew how the RLC system worked, and some general questions about the RLC program. The survey results revealed that the majority of drivers already had multiple experiences with RLR, some more than once at the same intersection. After RLR experience 79% of drivers stop during yellow, which shows how the yellow time may not have been used effectively. This, in turn could affect the efficiency or capacity of the intersection. Moreover, 30% of drivers think that they get RLR ticket if they pass the intersection during yellow. 24% of drivers do not know the average length of the yellow time length. Figures 2 and 3 shows the survey analysis for driver’s reaction to the presence of RLC and their knowledge of when they could get a ticket for RLR.

4 Capacity Analysis

The additional vehicle stoppage during yellow due to the presence of RLC will affect the intersection capacity [2&3]. Using k, the average number of vehicle stoppage at each RLC and non RLC intersection pairs; $P(e)$, the percentage of vehicle stoppage during yellow due to the presence of RLC, and the cycle length at the intersection pairs the total number of vehicles delayed at each intersection per hour can be estimated using Equation (1). The values for k and $P(e)$ at each intersection were computed in our earlier works [2&3].

$$H = \frac{3600}{C} \cdot k \cdot \frac{P(e)}{100} \tag{1}$$

where:
H = number of vehicles delayed per hour at the RLC intersection;
C = cycle length at the intersection, sec;
k = average number of vehicles stopped during yellow per cycle; and
$P(e)$ = percentage of vehicles stopped during yellow due to RLC

5 Estimating Capacity Reduction

From the HCM [4] the saturation flow rate for each lane group is computed according to Equation (2).

$$S = s_o \times N \times f_w \times f_{HV} \times f_g \times f_p \times f_{bb} \times f_a \times f_{LU} \times f_{LT} \times f_{RT} \times f_{Lpb} \times f_{Rpb} \tag{2}$$

By introducing a red-light reduction factor, f_{RLR} we modify the above formula for computing saturation flow rate at RLC intersections as follows:

$$S = s_o \times N \times f_w \times f_{HV} \times f_g \times f_p \times f_{bb} \times f_a \times f_{LU} \times f_{LT} \times f_{RT} \times f_{Lpb} \times f_{Rpb} \times f_{RLR} \tag{3}$$

where:
S = saturation flow rate for subject lane group, expressed as a total for all lanes in lane group (veh/h);
S' = saturation flow rate for subject lane group with RLC (pc/h/ln);
s_o = base saturation flow rate per lane (pc/h/ln);
N = number of lanes in lane group;
f_w = adjustment factor for lane width;
f_{HV} = adjustment factor for heavy vehicles in traffic stream;
f_g = adjustment factor for approach grade;
f_p = adjustment factor for existence of a parking lane and parking activity adjacent to lane group;
f_{bb} = adjustment factor for blocking effect of local buses that stop within intersection area;

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f_a = adjustment factor for area type;

f_{LU} = adjustment factor for lane utilization;

f_{LT} = adjustment factor for left turns in lane group;

f_{RT} = adjustment factor for right turns in lane group;

f_{Lpb} = pedestrian adjustment factor for left-turn movements; and

f_{Rpb} = pedestrian-bicycle adjustment factor for right-turn movements.

f_{RLR} = Red Light Running reduction factor

The number of delayed vehicles per hour at each intersection is then used to find the saturation flow rate for subject lane group with RLC as:

$$S' = S - H \qquad (4)$$

Table 2 shows the computation of the hourly vehicle delay and the saturation flow rates for each RLC and non RLC intersection pairs using Equations (1) through (4).

6 Conclusions and Future Work

Using the same adjustment factors for the RLC and non RLC intersection pairs it is found that on average 72 vehicles are delayed per hour at each intersection (Table 2). From Table 2 it can be seen that the saturation flow rates at RLC intersections are lower than non-RLC intersections, which contribute to the reduced intersection capacity. The cumulative impact of such reduction is quite significant as it might contribute to the peak hour traffic congestion in urban areas. This research thus begs the question to investigate the trade-off between safety benefits and congestion consequences due to RLCs.

The research findings suggest that the presence of RLCs influence drivers' behavior and its impact should be carefully examined in calculating intersection capacity. The findings also suggest that RLCs contribute to arterial congestion, especially during rush hours. Therefore, the trade-off between the safety benefits of RLCs and congestion consequences should be investigated in future works.

Also, in the future we will perform additional field observation and data analysis by considering more intersections and signal cycles to support intersection capacity losses at RLC intersections. The proposed research is expected to be a valuable tool for more precise calculation of signalized intersection capacity, inclusion of the red light reduction factor in future versions of HCM and HCS, and inclusion of the red light reduction factor in next generation of traffic simulation software.

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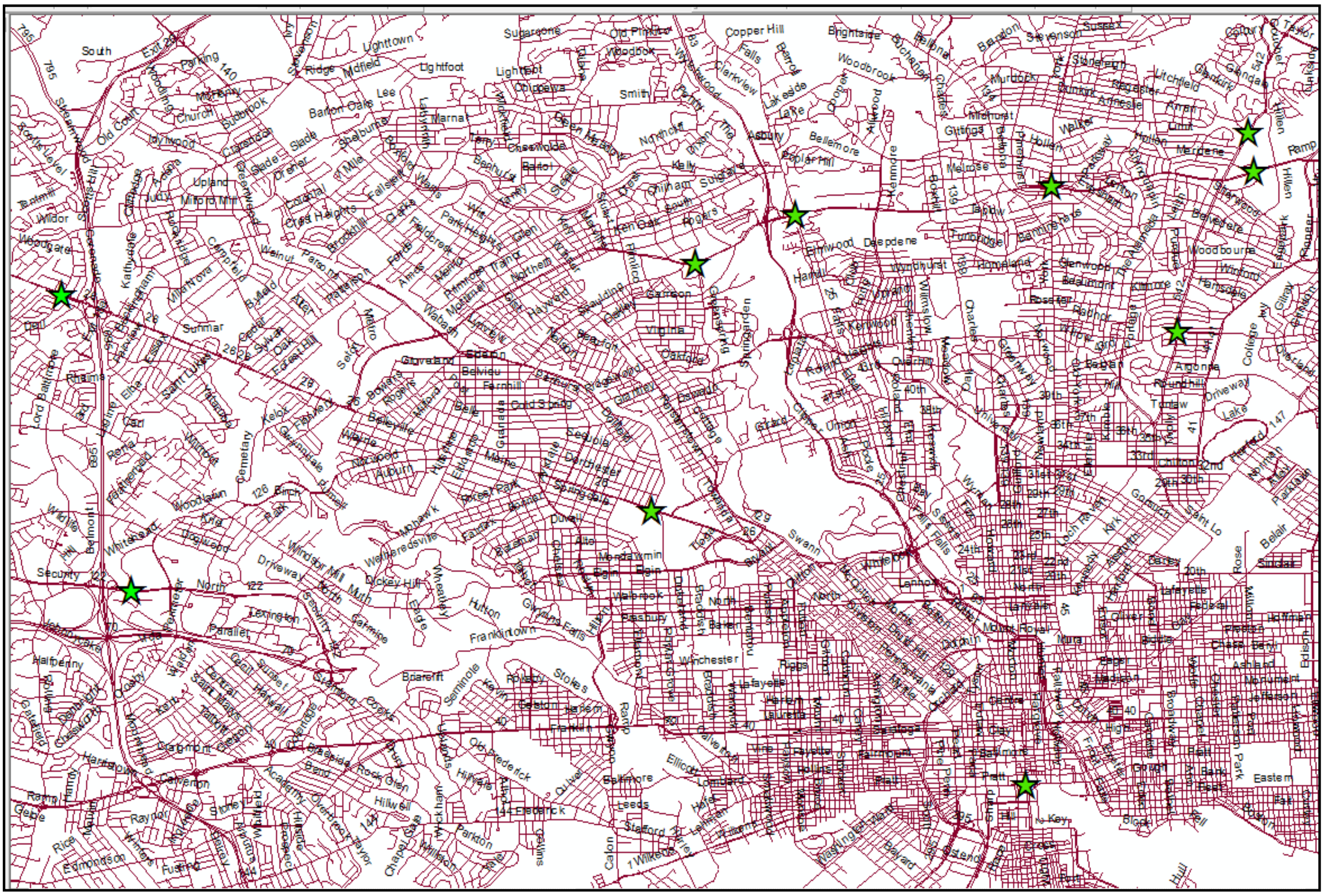

Figure 1. GIS Map of the Study Section

Table 1. Characteristics of Study Intersections

	RLC Intersections Non RLC Intersections	Speed Limit (mph)	Number of lanes	Green time (sec)	Yellow time (sec)	All-Red Time (sec)	Cycle length (sec)
1	**Security Blvd** at Whitehead Rd / Whitehead Ct Security Blvd at Woodlawn Drive	35	4	58	4	2	120
2	**W. Northern Pkwy** at Green Spring Ave W. Northern Pkwy at Green Spring Ave	40	4	46	4	2	100
3	**E. Northern Pkwy** at Waverly Way E. Northern Pkwy at Loch Raven Blvd	40	4	50	4	2	100
4	**Loch Raven Blvd** at Loch Hill Rd Loch Raven Blvd at Walker Ave	40	2	44	4	2	100
5	**W. Northern Pkwy** at Falls Rd W. Northern Pkwy at Ronald Ave	35	4	60	4	2	120
6	**Liberty Rd** at Washington Ave Liberty Rd at Lord Baltimore Dr	35	4	60	4	2	120
7	**Liberty Heights Ave** at Wabash Ave Liberty Heights Ave at Druid Park Dr	35	4	48	4	2	100
8	**Light Street** at Pratt Street Light Street at Lombard Street	35	6	60	4	2	120
9	**Cold Spring Ln** at Loch Raven Blvd Cold Spring Ln at The Alameda	25	3	56	4	2	120
10	**E. Northern Pkwy** at York Rd E. Northern Pkwy at Bellona Ave	35	4	60	4	2	120

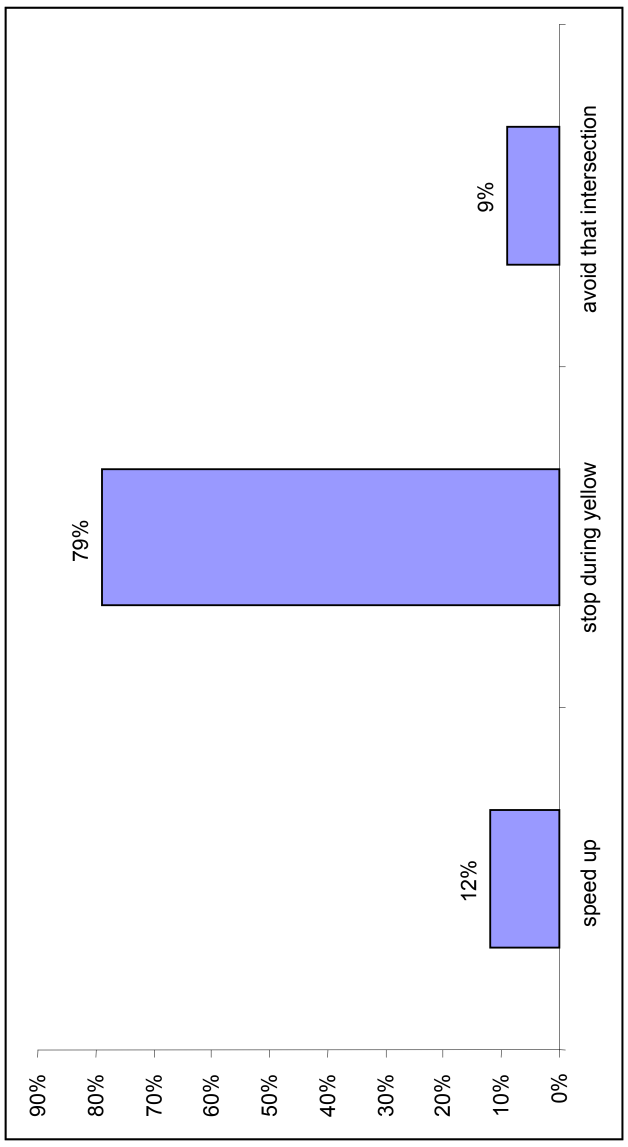

Figure 2. Drivers' Reaction to the Presence of a RLC

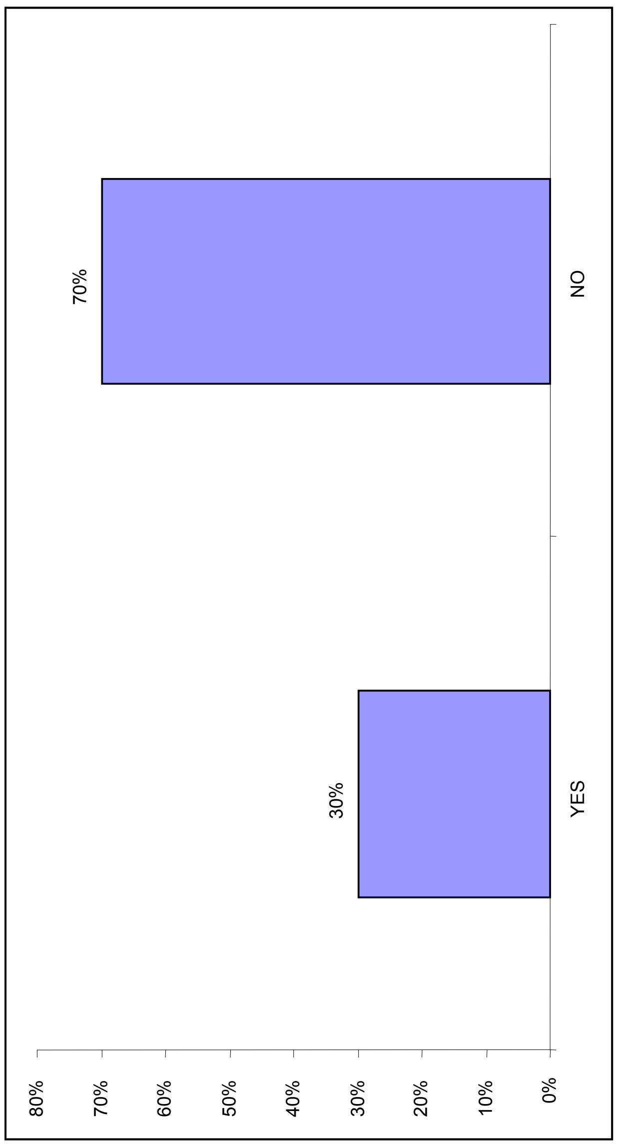

Figure 3. Do you get Ticket For Passing on Yellow?

Table 2. Computations of Saturation Flow Rates

	Intersection	K	$P(e)$	H	S	S'
1	**Security Blvd** at Whitehead Rd/Whitehead Ct	4.33	70.0	90.930	5910.7	5819.77
	Security Blvd at Woodlawn Drive	0.33	7.50	0.7425	5128.45	5127.7
2	**W. Northern Pkwy** at Green Spring Ave	3.33	67.5	67.4325	5925.25	5857.82
	W. Northern Pkwy at Green Spring Ave	0.16	3.30	0.1584	5925.25	5925.09
3	**E. Northern Pkwy** at Waverly Way	3.50	68.7	72.135	5661.28	5589.14
	E. Northern Pkwy at Loch Raven Blvd	0.16	4.20	0.2016	5661.28	5661.08
4	**Loch Raven Blvd** at Loch Hill Rd	3.33	62.8	62.7372	3307.61	3244.87
	Loch Raven Blvd at Walker Ave	0.16	3.30	0.1584	3307.61	3307.45
5	**W. Northern Pkwy** at Falls Rd	3.50	65.7	68.985	5112.01	5043.02
	W. Northern Pkwy at Ronald Ave	0.33	7.50	0.7425	5112.01	5111.27
6	**Liberty Rd** at Washington Ave	3.16	66.2	62.7576	5954.87	5892.12
	Liberty Rd at Lord Baltimore Dr	0.16	3.30	0.1584	5061.64	5061.48
7	**Liberty Heights Ave** at Wabash Ave	3.50	68.2	71.610	5747.49	5675.88
	Liberty Heights Ave at Druid Park Dr	0.16	4.20	0.2016	5747.49	5747.29
8	**Light Street** at Pratt Street	3.66	71.5	78.507	7733.55	7655.04
	Light Street at Lombard Street	0.33	7.50	0.7425	6919.49	6918.75
9	**Cold Spring Ln** at Loch Raven Blvd	3.33	64.8	64.7352	3777.35	3712.61
	Cold Spring Ln at The Alameda	0.00	0.00	0.0000	3777.35	3777.35
10	**E. Northern Pkwy** at York Rd	3.50	70.3	73.815	5036.46	4962.65
	E. Northern Pkwy at Bellona Ave	0.33	6.70	0.6633	5036.46	5035.8
Average hourly delay at the ten RLC intersections H =72 veh/h						