Driver Behavior During Yellow Change Interval

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ABSTRACT

When drivers are approaching a signalized intersection at the onset of a yellow change interval, they must decide whether to stop or cross the intersection. This can be a difficult decision when the vehicle is located within the dilemma zone and the result is sometimes a rear-end crash due to a sudden stop. This paper presented a new pavement-marking countermeasure which purpose is to reduce the red-light running rate and assist motorists with stop/go decisions. To test the effectiveness of the pavement-marking countermeasure, this paper presented a UCF driving simulator experiment designed to collect information concerning drivers' behavior during yellow change interval at intersections with 30 mph and 45 mph speed limits, and to compare the differences of drivers' behavior between scenarios with the marking and scenarios without the marking.

Keywords: Pavement marking; Dilemma zone; Red-light running; Rear-end crash; and Yellow change interval.

Introduction

From the perspective of traffic operation and safety at signalized intersections, one of the main concerns of traffic engineers and researchers is the difficulty of driving reaction to yellow change interval within the dilemma zone. A vehicle located in the dilemma zone may either contribute to the risk of a rear-end crash due to a sudden stop or result in the driver's running the red light (Pline, 1999). Zimmerman and Bonneson (2004) reported that some traditional dilemma zone protection of some form or another may improve the safety problems to some extent. For the dilemma zone protection, green–extension systems use one or more detectors located upstream of the intersection to hold a phase in green for as long as is needed. However, in the event that the green is held to its limit, the phase "maxes-out" and ends regardless of whether a vehicle is approaching the intersection or not. At max-out, any dilemma zone protection that has been provided ceases and any number of vehicles may be in the dilemma zone, thus creating the safety problem the system was meant to prevent.

Therefore, this paper presented a new pavement-marking countermeasure which attempts to reduce the red-light running rate and assist motorists with stop/go decisions due to the yellow signal change at signalized intersections. A pavement marking with word message 'SIGNAL AHEAD' (see Figure 1) is placed on the pavement of the upstream approach of a signalized intersection and is sufficient to permit vehicles cruising around speed limit to stop safely before reaching the intersection stop bar. The proposed policy is that, when drivers are located upstream of the marking at the yellow onset, they are encouraged to stop at the intersection if they are cruising around speed limit. On the other hand, when drivers are located downstream the marking at the yellow onset, they are encouraged to cross the intersection if they are cruising around speed limit. To test the effectiveness of the pavement marking, the UCF Driving simulator was used as a tool for data collection. The ultimate goal is to compare the differences of drivers' behavior between scenarios with and without the marking. The initial experiment findings are encouraging and suggesting that the pavement marking may result in safety enhancement as far as red-light running and rear-end traffic crashes at signalized intersections.

Background

UCF driving simulator

The UCF driving simulator (see Figure 2) housed in the Center for Advanced Transportation Systems Simulation (CATSS) is an I-Sim Mark-II system with a high driving fidelity and immense virtual environments. It is mounted on a motion base capable of operation with 6 degrees of freedom. It includes 5 channels (1 forward, 2 side views and 2 rear view mirrors) of image generation, an audio and vibration system, and steering wheel feedback. The driving simulation system is composed of the following components:

- Simulator Cab: It is a Saturn, having auto transmission, the air condition, the left back mirror and the back mirror inside the cab.
- Simview: The software provides the graphical display based on the computation.
- Motion base: It provides motion when driving.
- Scenario Editor: The software helps researchers to edit a tested traffic scenario.
- APIs for reading real-time data: APIs (Application Programmer Interface) can read the real-time data from Simview. The sampling frequency is 60Hz.

Figure 1: Pavement-marking design to reduce red-light running rate

Figure 2: UCF driving simulator

Dilemma zone

In the current edition of ITE's *Traffic Engineering Handbook* (1999), a standard equation is provided as a method to calculate the yellow change interval, *YT*, is as follows:

$$YT = t_R + \frac{V_{SL}}{2a + 64.4g} \tag{1}$$

Where,

t_R = reaction time (1.0 s)

V_{SL} = the 85th percentile speed or speed limit (ft/sec)

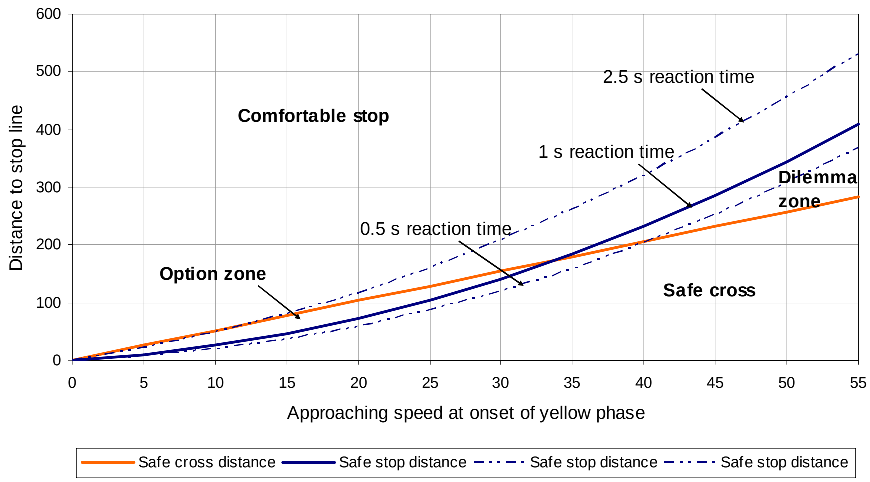
a = deceleration rate (10 ft/s^2)
g = grade of the intersection approach (g = 0, since level road is assumed).

According to the equation, the yellow change intervals are 3.5 s for 30 mph and 4.5 s for 45 mph. Considering the approaching speed (V) of vehicles, the maximum distance (X_c) to safely cross the intersection is calculated by Equation 2:

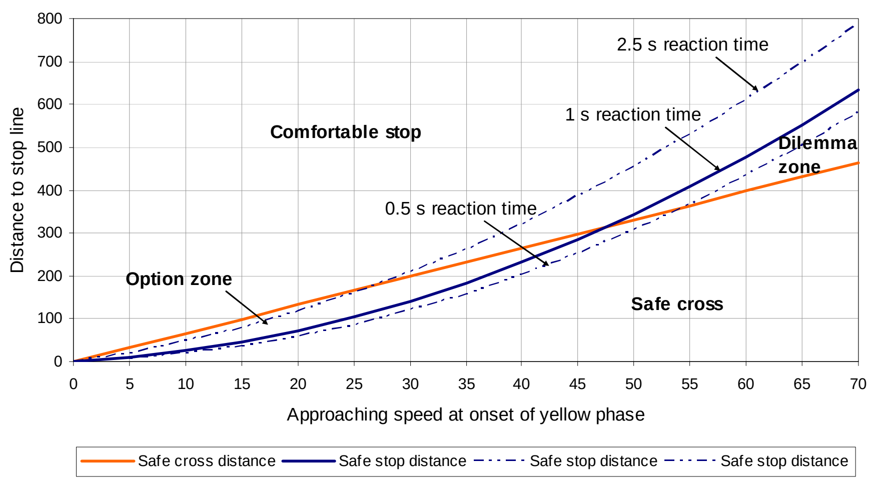
$$X_c = V * YT = V(t_R + \frac{V_{SL}}{2a}) \quad (2)$$

The minimum distance (X_S) to safely stop at the intersection is calculated by Equation 3:

$$X_S = V(t_R + \frac{V}{2a}) \quad (3)$$



a) Dilemma zone analysis for 30 mph speed limit



b) Dilemma zone analysis for 45 mph speed limit

Figure 3: Driver stop/go decision at onset of the yellow phase (Koll et al., 2002)

Figures 3-a and 3-b illustrates the tendency of driver stop/go decision at onset of the yellow at signalized intersections with 30 mph and 45 mph speed limits (as reported by Koll et al., 2002). The decision to stop is easy to make when the approach distance to the intersection is larger than X_S . Similarly, most of drivers tend to continue to travel through the intersection when the approach distance to the intersection is less that X_c. However, a vehicle can possibly execute neither crossing nor stopping maneuvers safely and comfortably if it happens to be located within the dilemma zone if the approach distance is larger than X_S but less that X_c. There is also a possible option area as shown in the figures where the driver can either stop or cross the intersection safely. The length of the dilemma zone is dynamic and increases with the increment of approaching speeds, which can be calculated by Equation 4. So, the speeding drivers are most likely involved in the dilemma zone problem. Dilemma zone analyses of comparison between with marking and without marking may help estimate the effect of the pavement-marking countermeasure.

$$X_s - X_c = V(t_R - YT + \frac{V}{2a}) \tag{4}$$

Methods

Experiment factors

This experiment utilized a within-subjects repeated measures factorial design to test the effectiveness of the pavement-marking countermeasure on red-light running. The three treatment design factors included speed limit, pavement-markings and yellow phase onset distance. There were two levels for speed limits (30 mph and 45 mph), two levels for program types (with marking or without marking), and eight yellow phase onset distances. This distance was measured from the position of the approaching vehicle when yellow phase starts to the stop bar of the intersection approach. The factorial manipulation of the three factors described above (speed, pavement-markings, and yellow onset distance) resulted in 32 unique intersection-approach types.

For the 30 mph speed limit, the eight points for yellow onset distances range from 82 to 278.8 ft with 28.11 ft increment; for the 45 mph speed limit, the eight points range from 180.4 to 360.8 ft with 25.77 ft increment. The yellow onset distances were identical for both program types (with and without marking) and were randomly assigned to those approaches of test-signalized intersections. Moreover, there were additional signalized intersections, intermingled with the test intersections, which always display continuous green phase. The continuous green intersections are designed to keep the subject from continually expecting a signal change at every intersection.

Pavement-marking position

The marking position is related to speed limit and vehicle's deceleration rate. The distance from the marking to the intersection stop bar should be sufficient to permit vehicles to stop safely before reaching the intersection stop bar. According to the deceleration rate suggested by ITE, the distance from the marking to the stop bar is calculated by the following equation:

$$X = Vt + \frac{V^2}{2a + 64.4g} \tag{5}$$

Where,

X = distance from the marking to the stop bar (ft)
V = the 85th percentile speed or speed limit (ft/sec)
t = reaction time (1.0 s)
a = gravitational acceleration (10 ft/s^2)
g = grade of the intersection approach (g = 0, since level road is assumed).

According to equation 5, the results of the marking-stop bar distance calculations for 30 mph and 45 mph intersections are shown as the following:

For 30 mph speed limit: X= 140.8 ft (42.9 m)
For 45 mph speed limit: X= 283.8 ft (86.5 m)

Subjects

As shown in Table 1, a total of 42 paid test subjects in two age groups were recruited and completed the experiment, including 18 younger subjects (<26 years) and 24 middle-age subjects (26-55 years). According to gender, there were 24 male subjects and 18 female subjects. The ratios of male to female and the younger group to the middle-age group closely represent Florida's driver population distribution in the Qausi-induced exposure method.

Every participant has a full driving license with a minimum of 1-year driving experience. Most of subjects were recruited from students/faculties in the University of Central Florida. Data analysis was based on the responses and decisions made by the 42 subjects approaching 32 signalized intersections. Each subject responded to 16 test signalized intersections with marking and 16 regular signalized intersections without marking for a total of 1344 driver-intersection encounters.

Table 1: Age and Sex Structure of the Subject Sample

Age	<26 years	26-55 years	Total
Male	10	14	24 (57.1%)
Female	8	10	18 (42.9%)
Total	18 (42.9%)	24 (57.1%)	42 (100%)

Results

Operation speed

Operation speed is measured at each intersection at termination of the green phase. For the 30 mph speed limit, the means of the speed without marking and with marking were 33.38 mph and 33.14 mph; for 45 mph speed limit, the means of the speed without marking and with marking were 47.47 mph and 47.05 mph (see Table 2). In the simulation environment, average operation speeds of drivers tend to be slightly higher than the speed limit, presumably because the simulator vehicle is always the leading vehicle in the traffic stream and the drivers were more likely to drive at free-flow speeds. Moreover, between scenarios without marking and with marking, there is no significant difference found in the operation speeds. Therefore, the proposed marking design didn't have a significant effect on the speed.

Table 2: Descriptive Statistics of Operation Speed

Speed Limit	Scenario	Mean	N	Std. Deviation	Minimum	Maximum
30 mph	Without	33.3776	336	3.5269	23.85	55.68
	With	33.1431	336	3.2774	23.98	49.53
	Total	33.2603	672	3.4039	23.85	55.68
45 mph	Without	47.4796	336	4.4003	32.76	67.87
	With	47.0461	336	3.7099	35.96	61.98
	Total	47.2628	672	4.0725	32.76	67.87

Red-light running rate

Comparison of red-light running rates between scenarios with marking and without can directly reflect the effect of the pavement marking countermeasure. As shown in Figure 4, red-light running rate without marking information is apparently higher than that with. For 30 mph speed limit without marking, there were 15 red-light running events representing red-light running rate of 4.5 percent; for 45 mph speed limit without marking, there were 11 red-light running events representing a rate of 3.3 percent. However, with the help of marking, there were only four red-light running events representing a rate of 1.2 percent for 30 mph speed limit; for 45 mph speed limit with marking, there were five red-light running events representing a rate of 1.5 percent. Potentially, the pavement marking could results in a 74.3 percent reduction in red-light running. Chi-square test showed that the p-value is 0.005 and the reduction in red-light running rate with the marking is statistically significant based on the 0.05 significance level.

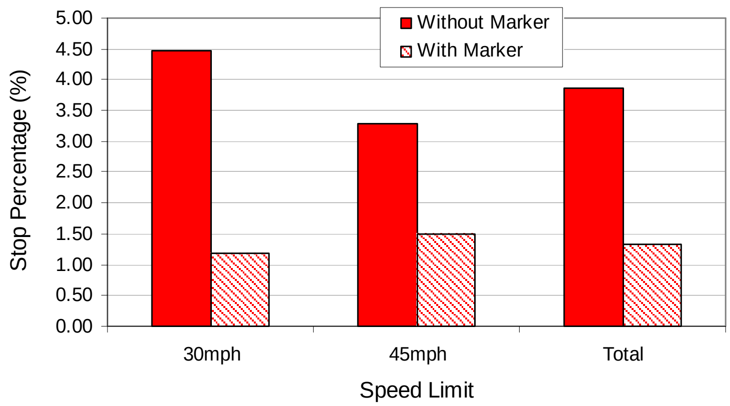


Figure 4: Red-light running rate comparison between with marking and without

Dilemma zone analyses

Table 3 shows the proportions of stopping and crossing decisions at intersections with markings and without markings. The situation that drivers were located in a stop zone, cross zone, optional zone, or dilemma zone are based upon a kinematics analysis using driver velocity and distance values at the onset of the yellow phase. In comparison, the pavement marking reduced the number of occurrences where drivers chose to continue through an intersection when it was not safe to proceed (4.36%) compared to the without marking (10.6%). This reduction in unsafe crossings appears to be due to the marking information as drivers were located upstream of the marking. Chi-square test showed that the p-value is 0.008 and the reduction in unsafe crossings with the marking is statistically significant based on the 0.05 significance level.

In the other hand, the pavement marking reduced the number of occurrences where drivers chose to stop at an intersection when it was not safe to stop (20.2%) compared to the without marking (24.3%). This reduction in unsafe stops appears to be due to the marking information as drivers were located downstream of the marking. However, the Chi-square test showed that the p-value is 0.301 so that the reduction in unsafe stops with the marking is not significant. Furthermore, situations in which a driver could not safely stop or safely cross an intersection were defined as dilemma situations and situations in which the driver could either safely choose to stop or safely choose to cross the intersection were defined as option situations. It appears that when they are located in option zones, drivers are more likely to stop at intersections with markings (64.7% Vs 42.9%) but the tendency is not statistically significant (P=0.601); when they are located in dilemma zones, the drivers are more likely to stop at intersections with marking (92.6% Vs 79.2%) but the difference is not statistically significant (P=0.226).

Table 3: Dilemma Zone Analysis

		Situation that drivers are encountering				
		Stop	Cross	Optional	Dilemma	Total
Without Marking	Cross	30	271	4	5	310
		10.6%	75.7%	57.1%	20.8%	46.1%
	Stop	253	87	3	19	362
		89.4%	24.3%	42.9%	79.2%	53.9%
	Total	283	358	7	24	672
		100.0%	100.0%	100.0%	100.0%	100.0%
With Marking	Cross	12	276	6	2	296
		4.3%	79.8%	35.3%	7.4%	44.0%
	Stop	270	70	11	25	376
		95.7%	20.2%	64.7%	92.6%	56.0%
	Total	282	346	17	27	672
		100.0%	100.0%	100.0%	100.0%	100.0%

Brake deceleration rate

The deceleration rate was measured for speeds ranging from the speed of the vehicle following the appearance of the yellow phase to a speed of 5 mph. Zero mph was not used because few drivers maintained a crawling speed until they reached the stop bar, which would bias the experiment results. A four-factor analysis of variance (ANOVA) for each speed limit type was conducted with deceleration rate as the dependent variable and four independent variables including Age, Gender, Marking, and Distance.

For the 30 mph speed limit, the ANOVA analysis shows that distance and age are significant factors but marking, gender and any two-way interactions are not at the 0.05 significance level. A Scheffe test for multiple comparisons on the distance factor showed that most of deceleration rates for the larger distance are significantly less than those for the smaller distance. This tendency does make sense because drivers at larger yellow onset distance have more space and time to slowly decelerate their vehicles to stop safely. A Scheffe test on the age factor showed that the deceleration rate for the middle group is 0.717 ft/s^2 significantly larger than the younger group. However, since the result comparisons between with marking and without are not significantly different, the marking did not have an effect on the driver behavior related to the brake deceleration rate for the 30 mph limit. For the 45 mph speed limit, the ANOVA variance analysis shows that distance and marking are significant factors but gender, age and any two-way interactions are not under the 95% confidence level. A Scheffe test on the marking factor showed that the deceleration rate without marking is 1.959 ft/s^2 significantly larger than that with marking. With the marking information, the probability that drivers make a too conservative stop will decrease if they are located in the downstream of marking at the onset of yellow, which contributes to the gentler deceleration rate with marking.

Conclusions

Compared to regular intersections, the pavement marking could results in a 74.3 percent reduction in red-light running because of poor stop-go judgment. In comparison, the pavement marking reduced the number of occurrences where drivers chose to continue through an intersection when it was not safe to proceed compared to the without marking, and this result is correlated to the less red-light running rate with marking. It was also found that for those stopping drivers, the brake deceleration rate without marking is 1.959 ft/s^2 significantly larger than that with marking for the higher speed limit. At intersections, the smaller deceleration rate may contribute to the less probability that rear-end crashes happen. Moreover, according to survey results, all of subjects gave a positive evaluation on the pavement-marking countermeasure and nobody felt confused or uncomfortable when they made a stop-go decision with marking. According to the results of the driving simulator experiment, the pavement-marking countermeasure has a significantly positive effect on the signalized-intersection safety.

References:

1. Institute of Transportation Engineers (ITE), Traffic Engineering Handbook, Washington, DC: Institute of Transportation Engineers, 1999.
2. Koll, H., Bader, M., and Axhausen, K.W., 2002. Driver behavior during flashing green before amber: a comparative study, ETHZ, Institute of Transportation, Traffic, Highway- and Railway- Engineering.
3. Pline, J. L., ed. Traffic Engineering Handbook, 5th ed. Institute of Transportation Engineers, Washington, D.C., 1999.
4. Zimmerman K. and Bonneson J. A., 2004. Number of Vehicles in the Dilemma Zone as a Potential Measure of Intersection Safety at High-speed Signalized Intersections, TRB 83rd Annual Meeting, Jan 11–15, 2004, Washington, D.C.