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EFFICIENCY UTILIZATION OF GREEN TIME AT COUNTDOWN SIGNALIZED INTERSECTION

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ABSTRACT

The use of countdown traffic signals, although not common in North America, is increasing in Asia and European countries. Past studies conducted albeit outside the United States have addressed some operational benefits and issues associated with the use of countdown traffic signals, including but are not limited to effect on saturation flow rate, and red light running. Experience from the successful use of pedestrian countdown signals at urban traffic intersections has engendered some local interest in the use of countdown traffic intersections has engendered some local interest in the use of countdown traffic signal devices in the United States. The purpose of this research was to analyse using driver behaviour survey the efficiency of green-time utilization rate at countdown traffic signal devices in the United States. Specifically, this research performed a comparative analysis based on the postulation that countdown traffic signal is associated with underutilized effective green time when compared to the scenario at intersections controlled by traditional (non-countdown) traffic signals. Binary regression models were developed, using data obtained from the driver behaviour survey, to estimate decision probabilities for different combinations of vehicle position (i.e. distance to the stop line) and available green time (i.e. time left before the transition to yellow phase). A comparison between the estimated decision probabilities (determined from deductive reasoning) for traditional traffic supported a pattern of underutilization of green time for the countdown signal scenario. The underutilization of green time was associated with the likelihood of drivers slowing down prematurely to stop in reaction to the visual display of available green time before the change of signal phase. Underutilization of effective green time before the change of signal phase. Underutilization of effective green time translates into a lower saturation flow rate and hence reduced intersection capacity. The findings of this research could motivate additional studies pertaining to the determination of net operational benefits or plausibility of using countdown signal devices at urban traffic intersection in the United States.

Keywords: Countdown traffic signals, effective green time, binary regression models, decision probabilities

1. INTRODUCTION

A countdown traffic signal provides visual information and guidance to drivers regarding the amount of time remaining to safely cross an intersection. Specifically, a countdown traffic signal will provide the number of seconds left for each phase of green, yellow and red lights, enabling drivers to visualize the amount of time left to cross an intersection. A strategy currently being implemented at intersections is the countdown pedestrian traffic signal to improve safety of pedestrian crossing. Countdown traffic signals are sparingly used, mostly in Asian countries. There is little evidence in the use of countdown traffic signals in North America. However, it is conceivable that the recent widespread use of countdown pedestrian signals and their potential to aid drivers in making informed “stop or go” decisions at intersections could motivate the use of countdown traffic signals in the United States.

2. BACKGROUND

In 1967, countdown traffic signal was tested in the city of Clearwater, Florida. During the test period, accident decreased by 48% and property damage by 62%. After the removal of the countdown traffic signal, the intersection became one of the most hazardous, in both the number of accidents and property damaged. Although not many studies have been carried out in the United States, a few Asian and European countries have implemented the concept of using traffic signal heads that is equipped with timers. Many factors characterize intersection performance; however, safety and capacity issues are considered paramount. Some studies have revealed that countdown pedestrian signal tends to alter driver's behaviour and impact intersection safety. A similar effect is anticipated from the use of green countdown traffic signals made to inform drivers on the number of seconds remaining before changing to a red phase. Drivers ability to have real time information on the time remaining before a phase change reduces start-up lost time, red-light running and crashes at intersections.

3. RESEARCH OBJECTIVES

The overall objective of this research is to estimate the efficiency in the utilization of green time at countdown signal-controlled intersections. Analysis is done to determine how vehicle drivers utilize countdown green time information in making stop and go decisions at signalized intersections. Since countdown traffic signal is almost non-existent in the United States, this research relied on data from driver behaviour survey. The research objective was motivated by findings from the 1967 Clear Water, Florida study which showed that during the early stage of its countdown traffic signal deployment, 64.2% of vehicles sampled, stopped at yellow light and 26.4% stopped at green countdown. However, it should be stated that after one month of green countdown signal installation, premature stops decreased by 50%. The decrease was attributed to motorists getting use to countdown traffic signals. The notion of drivers stopping prematurely at an early stage of countdown traffic signal led to the following supplemental objectives:

- Determining the distance from which motorist will react to green countdown traffic signal, and Estimating the contribution of countdown signal to green time utilization at urban intersections

4. METHODOLOGY

The research methodology involved the following main components: Data Collection, Data Analysis, Model Development and Calibration, and Discussion of Findings.

4.1 Data Analysis

The data analysis involved forty-eight (48) scenarios, each representing paired distance and time, and the associated decisions. The decision variable was represented as binary codes 0 and 1 (stop = 0 and go = 1). Two separate models were developed for the two categories of speed limit (35 mph and 45 mph) considered in the survey. The data worksheet, analyzed in excel, comprises 6 columns and 11,040 rows of data, i.e., 48 rows of data per respondent. To better manage the large size of data associated with 115 records obtained from the survey, a random selection method was used to select sixty (60) respondents, resulting in a total of 2,880 (48x 60) rows of data for each of the two (35mph and 45mph) speed limit categories.

4.2 Model Development and Calibration

A binary Linear model was developed using variables to assess driver's reaction to countdown signal devices. Specifically, the model was intended to predict drivers' decision to either stop or proceed through the intersection for different for different scenarios of paired distance (distance to intersection stop line) and time (green time remaining before transition to yellow phase). The model takes the following general:

$$Y=\beta 0+\beta 1X1+ \beta 2\ X2+ \beta 3\ X3+ \beta 4\ X4+ \beta 5\ X5+\beta 6t$$

where,
Y= Binary decision variable (go=1 and stop=0)
β0=Regression constant restricted to 0
β1, β2, β3, β4, β5, β6, =respective coefficients of independent variables
×1 = >50ft
×2 = 50 ft -100ft
×3 = 100ft-150ft
×4 = 150ft-200ft
x5=200ft/above
x6=>200

4.3 Regression Results

Results of the first and final stages of the stepwise process are summarized in Tables 1 through 12 for 35 and 45 mph speed limit.

Table 1. Regression Coefficients for 35 mph

Multiple R	0.9002
R Square	0.8104
Adjusted R Square	0.8092
Standard Error	0.3658
Observations	1801

Table 2. Regression Coefficients for 35 mph 7.5 sec and >50ft

	Coefficients	Standard Error	Statistic	P-value	Lower 95%	Upper 95%
Intercept	0.0000	N/A	N/A	N/A	N/A	N/A
>50ft	0.4990	0.0218	22.7883	0.000	0.4561	0.5420
50_100ft	0.4796	0.0218	21.9005	0.000	0.4366	0.5225
100_150ft	0.4046	0.0218	18.4758	0.000	0.3616	0.4475
150_200ft	0.3101	0.0218	14.1632	0.000	0.2672	0.3531
200ft/abv	0.2629	0.0218	12.0069	0.000	0.2199	0.3059
secs	0.1069	0.0035	30.0594	0.000	0.1000	0.1139

Table 3. Regression Coefficients for 45 mph less than 50ft and 7.5sec

Multiple R	0.9689
R Square	0.9389
Adjusted R Square	0.9382
Standard Error	0.2378
Observations	1799

Table 4. Regression Coefficients for 45 mph 7.5sec and less than 50ft

	Coefficients	Standard Error	Statistic	P-value	Lower 95%	Upper 95%
Intercept	0.0000	N/A	N/A	N/A	N/A	N/A
>50ft	0.9002	0.01423	63.2454	0.000	0.8723	0.928
50_100ft	0.9002	0.01423	63.2454	0.000	0.8723	0.928
100_150ft	0.8808	0.01423	61.8793	0.000	0.8528	0.909
150_200ft	0.7669	0.01423	53.8783	0.000	0.7389	0.795
200ft/abv	0.6656	0.01426	46.6632	0.000	0.6376	0.694
secs	0.0342	0.00231	14.7835	0.000	0.0296	0.039

The above tables summarizing results obtained from the regression analysis indicate significantly high adjusted-R2 values, and all coefficients of the models have p-values of approximately 0.00 (considered highly significant at the 95 percent level of confidence). The results also indicate that approximately

76.69% of the survey participants would proceed through the intersection under the scenarios of 35 mph posted speed limit, available green time threshold of 0 sec to 10 sec, and distance within 200 feet to the intersection stop line. Under the 45-mph posted speed limit, approximately 94.89% of the survey participants would proceed through the intersection for similar scenarios of available green time and distance to the stop line thresholds.

Notwithstanding that the binary linear model developed from the driver behavior survey is characterized by highly significant adjusted 2 and p-values, the model's output is not restricted to (0,1) interval as it should. The dependent variable value exceeds 1 (one) albeit very slightly in some extreme scenarios. For example, if the distance to the stop line is less than 50ft and available green time is 5 seconds, the corresponding decision variable (Y) values are 1.034 and 1.071 for posted speed of 30 mph and 45 mph, respectively. Two options were considered to address the (0, 1) domain issue. The first option considered was conversion of linear models to equivalent logit model as follows:

4.4 Efficiency Reduction Analysis

Participants drove through scenarios with level of service A, B, C, D, E and F. Data; acceleration, brake, steering control, deviation from lane center and others were collected, and the acceleration, braking, throttle-handling and lane-change behaviour were analysed.
The use of countdown traffic signal has been associated with drivers' tendency to stop premature even during the green indication. In this research, a comparative analysis was undertaken (based on survey data and deductive reasoning) on the utilization of green time at countdown versus non-countdown (traditional) signalized intersections. The following heuristic rules were applied in the efficiency analysis:

- Drivers usually will not stop in the green phase at traditional (non-countdown) signalized intersections
- Drivers usually will stop in the yellow phase if they perceive that they will not be able to safely cross the intersection before the signal changes to red, and their distance to the intersection stop line is adequate to stop their vehicles
- Drivers will decelerate at a maximum rate of 0.4g or 12.8ft/sec^2 to stop [see Gates et al, (2007)]
- In the dilemma zone (distance perceived to be too long to safely cross or inadequate to safely stop), 50% of the drivers will proceed through intersection and 50% will attempt stopping
- If their distance to the stop line is perceived to be adequate to either safely proceed through the intersection or stop, 50% of the drivers will stop and 50% will proceed.

Figure 1 is an illustrative example of a vehicle approaching an intersection at a speed of 35 mph. In one second, the vehicle's displacement from its initial position of 100 ft to the intersection stop line is approximately 51.45ft, which translates into approximately 48.55ft upstream of the stop line. In this example, the vehicle will have adequate time (3 seconds of yellow time) to safely proceed through the intersection; and requires a stopping distance greater than 48.55ft.

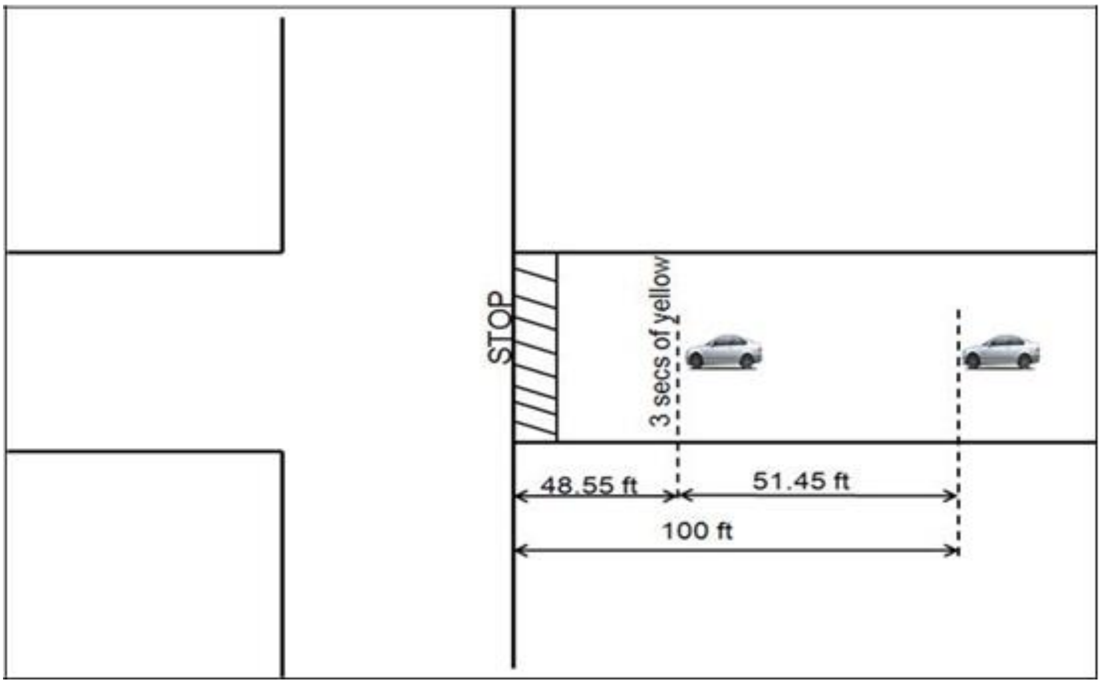

Figure 1. Minimum clearing distance to the Intersection

- Logit of Binary Linear Model

$$Logit\,(Y) = \beta_0 + \beta_1 X_1 1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 t$$

.........(Eq 1)

$$Y = \frac{exp(\beta_0 + \beta_1 X_1 1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 t)}{(1 + exp(\beta_0 + \beta_1 X_1 1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 t)}$$

- Logit of Y

$$Logit\,(Y) = Log\frac{Y}{1-Y}$$

........(Eq 2)

Table 5. Minimum Stopping Distance

Minimum Stopping Distance		
Distance	45 mph	35 mph
50 ft	237.08	154.85
100 ft	237.08	154.85
150 ft	237.08	154.85
200 ft	237.08	154.85
250 ft	237.08	154.85

Table 6. Efficiency Table

	45 mph	35 mph
Mean for traditional signal Probability	0.8857	0.9571
Mean for GSCD 45mph	0.7034	0.85
Difference in the Mean	0.1823	0.1071
Reduction of Efficiency	20.50%	11.19%

Minimum Distance Analysis

Table 7. Minimum Drive-on Distance

	35 mph -Available green + yellow time distance (Drive-on distance)						
secs	0	1	2	3	4	5	7.5
50 ft	154.35	205.8	257.25	308.7	360.15	411.6	540.225
100 ft	154.35	205.8	257.25	308.7	360.15	411.6	540.225
150 ft	154.35	205.8	257.25	308.7	360.15	411.6	540.225
200 ft	154.35	205.8	257.25	308.7	360.15	411.6	540.225
250 ft	154.35	205.8	257.25	308.7	360.15	411.6	466.875

Table 8. Minimum Drive-on Distance

	45 mph - Available green + yellow time Distance (Drive-on distance)						
secs	0	1	2	3	4	5	7.5
50 ft	198.45	264.6	330.75	396.9	463.05	529.2	694.6
100 ft	198.45	264.6	330.75	396.9	463.05	529.2	694.6
150 ft	198.45	264.6	330.75	396.9	463.05	529.2	694.6
200 ft	198.45	264.6	330.75	396.9	463.05	529.2	694.6
250 ft	198.45	264.6	330.75	396.9	463.05	529.2	694.6

Using the heuristic rules described earlier with information in Tables 4-22 and 4-24, decision probabilities for 35 mph and 45 mph speed-limit groups were developed for non-countdown (traditional) signalized traffic intersection.

Table 9. Non-Countdown Decision Probability for 35mph

secs	0	1	2	3	4	7.5
50 ft	1	1	1	1	1	1
100 ft	0	1	1	1	1	1
150 ft	0	0.5	1	1	1	1
200 ft	0	0	0.5	1	1	1

Table 10. Non-Countdown Decision Probability for 45mph

secs	0	1	2	3	4	7.5
50 ft	1	1	1	1	1	1
100 ft	1	1	1	1	1	1
150 ft	0	1	1	1	1	1
200 ft	0	0.5	1	1	1	1

Table 9 and 10 show the decision probabilities for 35 mph and 45mph speed limits, respectively. Probability of 1 was assigned red, 0.5 was assigned purple, and 0 was assigned red. The mean decision probabilities were determined from Table 9 and 10 as 0.70 (21/30) and 0.85 (25.5/30) for 35 mph and 45 mph, respectively.

The mean decision probabilities for the survey data were determined as 0.89 and 0.96 for 35 mph and 45 mph speed limit, respectively. Tables 11 and 12 summarize the difference in green time utilization at countdown and non-countdown (traditional) signalized intersections, respectively. For 35 mph speed limit, the estimated reduction in green time utilization associated with GSCD was approximately 20.50%; and for 45 mph speed limit, the estimated reduction was approximately 11.19%.

Table 10. Efficiency Reduction in green time Utilization for 35mph

Efficiency Table for 35 mph	
Mean for traditional Signal Prob	0.8857
Mean for GSCD for 35mph	0.7034
Difference in mean	0.1823
Reduction of Efficiency	20.50%

Table 11. Efficiency Reduction in green time Utilization for 45mph

Efficiency Table for 45mph	
Mean for traditional signal Prob	0.9571
Mean for GSCD 45mph	0.85
Difference in the Mean	0.1071
Reduction of Efficiency	11.19%

5. CONCLUSION

Results indicated that drivers' ability to see the real-time display of seconds remaining before the transition to yellow light negatively affects their green time utilization. When analytically compared to operating situation of traditional (non-countdown) signalized intersections, the efficiency of green time utilization dropped by approximately 20% and 11% for 35 mph and 45 mph speed limit scenarios, respectively. It was also concluded from the analysis of survey data that the presence of red-light camera further reduces the efficiency of green time utilization. Approximately 66% of drivers in the survey indicated that the presence of red-light camera would more likely contribute to premature stopping during the transition from green to yellow or yellow to red light. Since countdown signals are not used in the United States, findings from this research can serve as a guide for assessing the plausibility of using the technology.

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