

**ESTIMATION OF LEFT-TURN CLEARANCE TIME
BASED ON FIELD DATA**

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Abstract

The estimation of yellow and all red intervals, and the appropriateness of the all red interval is a topic with divergent views (1). Hillsborough County in Florida is also concerned on this regard, and specifically on the correctness of using the same estimated intervals for through and left turn movements. Therefore, the County requested the University of South Florida to conduct a research project to estimate the time required for vehicles to clear an intersection when making left turn. The intersections considered included different geometries, different percentages of heavy vehicles, and left turn treatment. The analyses present descriptive statistics of the estimated time to clear the intersection, a comparison of estimation of yellow and all red intervals considering posted speed and estimated speed based on field data, and curves for time for different factors based on linear regression.

INTRODUCTION

The yellow and all red intervals utilized at signalized intersections are estimated based on the equations provided by the Traffic Engineering Handbook (1). The equation employed to estimate the yellow interval generally uses the 85th percentile speed for through movement. For turning movements, some field measurements may be needed to select a representative speed (2). Consequently, the estimated yellow interval might not be adequate for vehicles making left turn due to the fact that the speeds and distances for this turning movement are different than for the through movement. In regard to the all red interval, the speed used in the required equation for estimation may not always be the same used to estimate the yellow interval, and speed samples are preferred (3).

At the present time, Hillsborough County in Florida applies the same estimated yellow and all red intervals for through movement as for left turn. As a consequence, the county is interested in estimating the intervals for vehicles making left turn considering different factors that might affect this movement. These factors include turning movement speeds, turning movement geometry, vehicle path distance and conflict geometry. The estimation of these two intervals will depend on the speed of vehicles making left turn, which will be based on the estimated time it takes vehicles to clear the intersection while doing the left turn in the field. The speed of the vehicles might be different depending on the geometry of the intersections considered.

Problem Definition

In the research project, several intersections with different geometric characteristics, different percentages of heavy vehicles, and different left turn treatment were under study. The objective was to estimate the time required for vehicles to clear the intersection when making left turn at intersections with different characteristics based on

turning approach speed and other factors. Some of the factors considered during this project were turning speed for left turn, vehicle path distance, radii, opposing road width, intersecting road width, and percentage of heavy vehicles making left turn.

Research Scope

Based on the problem defined above, field data collection was performed at intersections with different geometric characteristics in Hillsborough County in order to estimate the speed for vehicles making left turns at intersections. The data were collected by video taping vehicles at selected intersections. The data collection was performed during weekdays, non rush hour, good weather condition and dry pavement. The intersections considered for the project were selected based on the recommendation of the county to ensure a variety of sites.

This project presents descriptive statistics of the time required for vehicles to clear the intersection when making left turn considering all the data collected and only vehicles located after the 4th position of the queue. This position in the queue was selected because platoons are stabilized after this 4th position based on the Highway Capacity Manual 2000 (4). Also, yellow and all red intervals are calculated based on posted speed and speed based on the time estimated in the field. Finally, lines for time based on linear regression are presented for different intersection characteristics. The factors considered include turning speed of vehicles making left turn at intersections, vehicle path distance, radii, road widths, and heavy vehicle percentages.

METHODOLOGY:

The project included several steps: (1) selection of variables affecting left-turn movement at intersections, (2) selection of sites, (3) data collection, (4) data reduction, and (5) estimation of time, yellow and all red intervals, and time based on linear regression.

Selection of variables affecting left turn movement at intersections.

The selection of variables was done based on the recommendation of county engineers and literature review. The variables considered were turning speed for left turn movement, vehicle path distance, radii, opposing road width, intersecting road width, and percentage of heavy vehicles.

Selection of sites

For the selection of intersections for the project, Hillsborough County provided a preliminary list of fifteen possible intersections with different geometries and a variety of heavy vehicles percentages. After a preliminary survey of the candidate intersections, eight intersections, including three and four legged, were considered for the research. For almost all these intersections, two approaches were considered for data collection for each one. Finally, fourteen approaches were selected for the project. The characteristics of the approaches selected included: protected or protected/permissive left turn treatment, exclusive or share left turn lanes, single or dual left turn lanes, and divided or not. Table 1 shows a summary of the characteristics of the approaches considered for the project.

Field Data Collection

Data collection involved the videotaping of vehicles performing the left-turn movement per approach selected and the measurement of the geometric characteristics such as opposing and intersecting road width per approach at each intersection. The opposing road indicated the approach coming straight in front of the approach considered. In regard to intersecting road, this refers to the approach coming on the left side of the vehicles making left turn. The radii and vehicle path distance for each one of the curves of the approaches considered were determined from aerial photographs of the intersections. Field data collection was not performed for these two variables due to safety reasons and area restrictions. The aerial photographs for each one of the intersections considered in the project were obtained from the county database.

Vehicles making left turn from two different approaches at each intersection were videotaped simultaneously during two hours. The approaches at each intersection were selected based on approach volume, approach speed, and geometric characteristics. Some approaches were discarded during data reduction due to different reasons. The data were collected during weekdays, non-rush hour, good weather condition and dry pavement.

Data Reduction

Data were reduced at the office based on the videotapes. The time it took each one of the vehicles making left turn at the different approaches considered was determined with a program that automatically estimated this time by pressing the appropriate keys on the keyboard. The points of reference to estimate the time for each vehicle to clear the intersection were when the front wheels passed the stop line when entering the intersections and when the back wheels passed the far side of the crosswalk when clearing the intersection.

The position of each vehicle in the queue and the percentage of heavy vehicles were also determined from the videotapes. The intersection radii and travel distance were estimated from aerial photographs. For radii estimation, the green book from ASSHTO (5) was used as reference for minimum values. The remaining variables considered were determined directly at the location.

During data reduction for the time it took each vehicle making left turn to clear the intersection, any vehicle that presented any type of problem while performing the movement was not considered for the analysis. Problems observed included waiting within the intersection while making the left turn during a permitted phase, start moving too slow and stop several times when entering the intersection, and turning too sharp, almost into the intersecting lanes. Once all data were reduced for each approach, they were put together in a worksheet for further analysis.

Estimation of time, yellow and all red intervals, and time based on linear regression

The clearance time for vehicles making left turn was estimated from the videotapes. A small program was written in visual basic for this purpose. The program also recorded vehicle type and position on the queue. Table 2 presents the clearance time estimated from the videotapes as well as other variables determined from data reduction such as vehicle path distance and percentage of heavy vehicles.

For the estimation of the yellow and all red intervals, the equation used were taking from the ITE manual (1). For yellow time, it was used the following:

$$y = t + \frac{v}{2a \pm 2Gg} \quad (1)$$

where,

y = length of yellow interval, to the nearest 0.1 sec.

t = driver perception/reaction time, recommended as 1.0 sec.

v = velocity of approaching vehicle in ft/sec.

a = deceleration rate, recommended as 10 ft/sec².

g = acceleration due to gravity, 32 ft/sec².

G = grade of approach, in percent divided by 100 (downhill is negative).

As for the all red interval, pedestrian traffic was assumed not existing and the equation used was:

$$r = \frac{W + L}{V} \quad (2)$$

where,

r = length of red clearance interval, to the nearest 0.1 sec.

W = width of intersection, in feet, measured from the nearside stop line to the far edge of the conflicting traffic lane along the actual vehicle path.

L = length of vehicle, recommended as 20 ft.

V = speed of the vehicle through the intersection, in ft/sec

The intervals were estimated with the posted speed for each approach considered and with the space mean speed determined from the time estimated previously from the videotapes and the vehicle path distance. Table 3 shows the values estimated for the yellow and all red intervals based on the posted speed and the speed estimated from field data. The estimation of clearance time for vehicles making left-turn at each one of the approaches considered were also estimated based on linear regression analysis.

DATA ANALYSIS AND RESULTS

The analyses of data and results for the project were performed in several steps. The first step presents the descriptive statistics for the clearance time estimated from the data collected for all sample size and the subset of vehicles coming after the 4th position on the queue. The second step involved the comparison of the estimated yellow and all red intervals for vehicles making left turn based on approach speed and speed determined from the estimated clearance time. The final step includes the linear regression process and its results.

Descriptive Statistics

Descriptive statistics for the clearance time estimated from the data collected for all sample size and the subset of vehicles coming after the 4th position on the queue are presented in Table 4. This table presents the mean value for the clearance time estimated for the total sample size, which includes the first vehicles of the queue, and for the subset of the data that only considers vehicles on the queue after the 4th position. It would be better to only consider mean values of clearance time for the subset of vehicles but, as Table 4 shows, the number of vehicles included on this subset for several approaches is not sufficient for consideration. Furthermore, linear analysis was intended with this subset and due to the reduced data no result was obtained. More data collection was not performed due to budget restrictions.

The values of clearance time for total sample size and subset show differences in the mean value and standard deviation. The subset presented lower values of clearance time since vehicles on the first position of the queue are not considered but the number of vehicles is limited for several locations. Finally, it was decided to take the total sample of vehicles, even though the first vehicles will affect the results. It has to be mention that not all vehicles on the first positions were waiting in the queue to make a left turn since the period consider was non rush hour. Also, many of the sites have permitted or protected/permitted treatment for left turn, and many of the vehicles coming into the intersection will not have to wait. These situations may decrease the effect of the first vehicles in the sample considered.

Comparison of yellow and all red intervals

For this step, the yellow and all red intervals were estimated based on the equations 1 and 2 with the posted speed per approach and the speed determined from the clearance time estimated from the data. The posted speed was used instead of the 85th percentile speed because no speed data for vehicles in the different approaches was available. The clearance time used to determine the speed from the data was taken from the total sample size as mentioned previously.

Results showed on Table 3 indicated that the yellow intervals obtained when using the posted speed are higher than the values from the speed estimated from data. All red intervals are lower for posted speed than for estimated speed. And yellow plus all red for posted speed is much lower than for the values obtained from the estimated speed from the data. These values are reasonable if the difference between posted speed and estimated speed is considered.

Furthermore, if yellow plus all red is compared to the values of clearance time estimated from the data, the values determined from posted speed seem to be just higher than clearance time, and the values from the estimated speed are much higher than the clearance time. This consideration is not so clear if it is considered that the all red interval is indicated as the clearance interval in the ITE manual and the yellow time is the change interval, which means that the clearance time estimated from the data should be measured up to the all red interval. Also, when looking at the clearance time with the yellow plus all red values, the clearance time has not considered the perception reaction time. No comparisons are made between the estimated yellow and all red intervals based on field data to the actual values for the intersections considered since those values were not available.

Linear regression

The final step consisted of performing linear regression to find a relationship between some of the variables and the time needed for vehicles making left turn to clear the intersection. The linear regression performed is a first attempt in order to obtain this relationship but more data is necessary to better determine the effect of some of the variables considered on the dependable variable, such as speed. The confidence level used was 95% and several combinations for variables were considered. Although, variables such as vehicle path distance, radii, opposing road width, and intersecting road width are interrelated, they were considered to evaluate their effect on time. Final regression results indicated that the variables affecting clearance time were percentage of

heavy vehicles, opposing road width and intersecting road width. The R-squared value had a reasonable value and the variables were significant at a 95% confidence level. Even though the percentage of heavy vehicles was not within the confidence level, it was decided to keep it as one of the variables in the linear regression. Table 5 shows the results for the regression analysis.

Based on this final linear regression, a sample table with estimated clearance time required for vehicles making left turn and the related variables. Table 6 presents the sample table for clearance time varying percentages of heavy vehicle from 0 to 15%, and road width from 12 to 60 feet. The values on this table indicated that as the percentage of heavy vehicles increased, the clearance time would also increase. With the same trend, if either the opposing road width or intersecting road width increases, the time would also increase. Figure 1 shows graphically part of the results on the sample table through several curves.

Linear regression using only clearance time estimated from the subset that included only vehicles coming after the 4th position, did not give reasonable results. This could be attributed to the limited amount of data for several locations considered

CONCLUSIONS

Based on the results from this research project, several conclusions could be made. Yellow intervals obtained when using posted speed are higher than the values from the speed estimated from the data. All red intervals are lower for posted speed than for estimated speed. Yellow plus all red for posted speed is lower than for values obtained from the estimated speed from the data. These values are reasonable if the difference between posted speed and estimated speed is considered. This difference in speeds is produced because the time required for vehicles to pass the intersection when making left turn is greater than when going thru. These results indicated that some considerations might be necessary to adjust the time required for vehicles making left turn to clear the intersection according to field conditions.

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TABLE 1 Characteristics of the Approaches Considered

Intersection	Approach	N ^o LT lanes	Type LT lane	Opposing N ^o of lanes	Intersecting N ^o of lanes	Median	LT Treatment
1	EBLT	1	T-LT	2	2	No	Permitted
1	SBLT	1	T-LT	1	2	No	Permitted
2	EBLT	1	LT	4	1	Yes	Permitted
2	NBLT	1	LT	1	4	No	Permitted
3	SBLT	1	LT	3	2	No	Prot/Perm
3	WBLT	1	T-LT	1	3	No	Permitted
4	SBLT	2	LT	4	4	Yes	Protected
5	EBLT	1	T-LT	1	2	No	Prot/Perm
6	SBLT	1	LT	4	3	Yes	Prot/Perm
6	WBLT	1	LT	4	4	Yes	Prot/Perm
7	EBLT	2	LT	6	4	Yes	Protected
7	SBLT	2	LT	4	6	Yes	Protected
8	NBLT	1	LT	4	4	Yes	Prot/Perm
8	WBLT	1	LT	4	4	Yes	Protected

LT = left turn

T = through

EB, WB, SB, NB = East bound, west bound, south bound, north bound

TABLE 2 Summary Information for Approaches Considered

Approach	LT lane	N° of vehicles	Time (sec)	Vehicle Path Distance (feet)	Radii (feet)	Posted Speed (mph)	% Heavy Vehicles
1-EBLT	1 lane	138	5.66	126.55	36	35	8.70
1-SBLT	1 lane	42	5.55	110.55	36	35	25.00
2-EBLT	1 lane	25	5.49	114.40	41	45	0.00
2-NBLT	1 lane	93	5.88	120.11	51	45	2.15
3-SBLT	1 lane	233	4.20	56.55	36	50	3.00
3-WBLT	1 lane	159	5.01	56.55	36	45	9.43
4-SBLT	Inside	421	5.00	209.78	186	45	0.95
4-SBLT	Outside	391	5.53	232.35	198	45	1.53
5-EBLT	1 lane	163	4.26	56.55	36	35	0.61
6-SBLT	1 lane	436	4.99	150.80	96	35	4.82
6-WBLT	1 lane	133	5.89	142.23	81	45	1.50
7-EBLT	Inside	294	6.36	166.50	106	45	1.36
7-EBLT	Outside	327	7.24	185.35	118	45	6.73
7-SBLT	Inside	173	6.33	183.23	88	45	5.78
7-SBLT	Outside	204	7.49	202.08	100	45	8.82
8-NBLT	1 lane	347	6.39	198.36	156	45	4.61
8-WBLT	1 lane	264	5.75	131.00	106	45	12.50

TABLE 3 Yellow, All Red and Yellow plus All Red Intervals Estimated Values

Approach	Posted Speed (mph)	Yellow for PS (sec)	All Red for PS (sec)	Total yellow +all red (sec)	Speed for total sample (mph)	Yellow for total (sec)	All red for total (sec)	Total yellow + all red (sec)	LT time for total (sec)	LT time for subset (sec)	Travel distance (feet)
1-EBLT	51.33	3.57	2.95	6.52	22.36	2.12	6.78	8.90	5.66	5.20	126.55
1-SBLT	51.33	3.57	2.64	6.21	19.92	2.00	6.81	8.80	5.55	4.22	110.55
2-EBLT	66.00	4.30	2.11	6.41	20.84	2.04	6.69	8.73	5.49	-	114.40
2-NBLT	66.00	4.30	2.20	6.50	20.43	2.02	7.10	9.13	5.88	3.85	120.11
3-SBLT	73.33	4.67	1.11	5.78	13.46	1.67	6.06	7.73	4.20	4.03	56.55
3-WBLT	66.00	4.30	1.24	5.54	11.29	1.56	7.22	8.79	5.01	4.39	56.55
4-SBLT	66.00	4.30	3.56	7.86	41.96	3.10	5.60	8.69	5.00	4.75	209.78
4-SBLT	66.00	4.30	3.90	8.20	42.02	3.10	6.13	9.23	5.53	5.15	232.35
5-EBLT	51.33	3.57	1.59	5.16	13.27	1.66	6.14	7.81	4.26	4.05	56.55
6-SBLT	51.33	3.57	3.42	6.99	30.22	2.51	5.82	8.33	4.99	4.68	150.80
6-WBLT	66.00	4.30	2.53	6.83	24.15	2.21	6.93	9.13	5.89	5.42	142.23
7-EBLT	66.00	4.30	2.90	7.20	26.18	2.31	7.31	9.62	6.36	5.74	166.50
7-EBLT	66.00	4.30	3.19	7.49	25.60	2.28	8.22	10.50	7.24	6.72	185.35
7-SBLT	66.00	4.30	3.16	7.46	28.95	2.45	7.19	9.64	6.33	5.13	183.23
7-SBLT	66.00	4.30	3.44	7.74	26.98	2.35	8.42	10.77	7.49	7.12	202.08
8-NBLT	66.00	4.30	3.38	7.68	31.04	2.55	7.20	9.75	6.39	5.9	198.36
8-WBLT	66.00	4.30	2.36	6.66	22.78	2.14	6.85	8.99	5.75	5.42	131.00

PS = posted speed

TABLE 4 Descriptive Statistics for Clearance Time for Total and Subset Data

Approach	LT lane	Total sample	Total LT time (sec)	Standard Deviation total	Total Speed (mph)	After 4th sample	LT time (sec)	Standard Deviation after 4th	Speed after 4 th (mph)
1-EBLT	1 lane	138	5.66	1.23	15.24	30	5.20	0.91	16.59
1-SBLT	1 lane	42	5.55	2.02	13.58	4	4.22	1.32	17.86
2-EBLT	1 lane	25	5.49	0.94	14.21	0	0	No	No
2-NBLT	1 lane	93	5.88	1.08	13.93	1	3.85	No	21.27
3-SBLT	1 lane	233	4.2	0.86	9.18	56	4.03	0.76	9.57
3-WBLT	1 lane	159	5.01	1.15	7.70	8	4.39	0.57	8.78
4-SBLT	Inside	421	5.00	0.73	28.61	211	4.75	0.66	30.11
4-SBLT	Outside	391	5.53	0.74	28.65	177	5.15	0.57	30.76
5-EBLT	1 lane	163	4.26	0.76	9.05	36	4.05	0.58	9.52
6-SBLT	1 lane	436	4.99	1.04	20.60	120	4.68	1.01	21.97
6-WBLT	1 lane	133	5.89	1.11	16.46	7	5.42	0.85	17.89
7-EBLT	Inside	294	6.36	0.83	17.85	61	5.74	0.52	19.78
7-EBLT	Outside	327	7.24	0.89	17.46	81	6.72	0.58	18.81
7-SBLT	Inside	173	6.33	1.01	19.74	11	5.13	0.42	24.35
7-SBLT	Outside	204	7.49	1.01	18.40	14	7.12	1.01	19.35
8-NBLT	1 lane	347	6.39	1.03	21.17	146	5.90	0.75	22.92
8-WBLT	1 lane	264	5.75	1.09	15.53	69	5.42	0.72	16.48

TABLE 5 Statistical Output for Linear Regression

SUMMARY OUTPUT

Regression Statistics								
Multiple R	0.807354							
R Square	0.651821							
Adjusted R Square	0.571472							
Standard Error	0.586547							
Observations	17							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	3	8.37287	2.790957	8.112371	0.002669			
Residual	13	4.472483	0.344037					
Total	16	12.84535						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	3.65265	0.448892	8.13703	1.86E-06	2.682877	4.622423	2.682877	4.622423
Opp. Width	0.01981	0.007878	2.514446	0.025874	0.00279	0.03683	0.00279	0.03683
Inters width	0.023045	0.009945	2.317238	0.037441	0.00156	0.04453	0.00156	0.04453
% HV	0.046949	0.024639	1.905498	0.079071	-0.00628	0.100178	-0.00628	0.100178

TABLE 6 Sample Estimation of Clearance Time

Width (ft)		LT Time (sec)			
Intersecting	Opposing	0% HV	5% HV	10% HV	15% HV
12	12	4.17	4.40	4.64	4.87
12	24	4.40	4.64	4.87	5.11
12	36	4.64	4.88	5.11	5.35
12	48	4.88	5.11	5.35	5.58
12	60	5.12	5.35	5.59	5.82
24	24	4.68	4.92	5.15	5.39
24	36	4.92	5.15	5.39	5.62
24	48	5.16	5.39	5.63	5.86
24	60	5.39	5.63	5.86	6.10
36	36	5.20	5.43	5.66	5.90
36	48	5.43	5.67	5.90	6.14
36	60	5.67	5.91	6.14	6.38
48	48	5.71	5.94	6.18	6.41
48	60	5.95	6.18	6.42	6.65
60	60	6.22	6.46	6.69	6.93

HV = Heavy vehicles

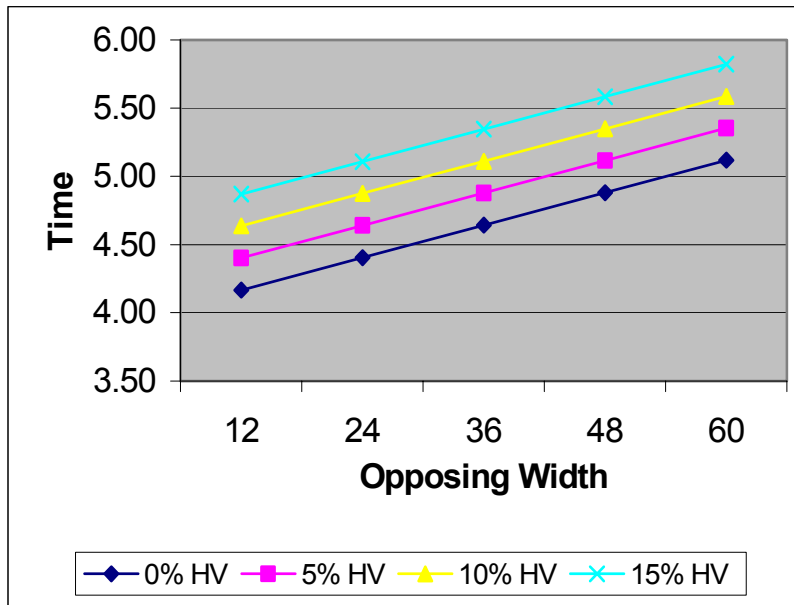


FIGURE 1 Sample Curves for Clearance Time based on Linear Regression