Guidebook on Determining Yellow and Red Intervals to Improve Signal Timing Plans for Left-Turn Movements

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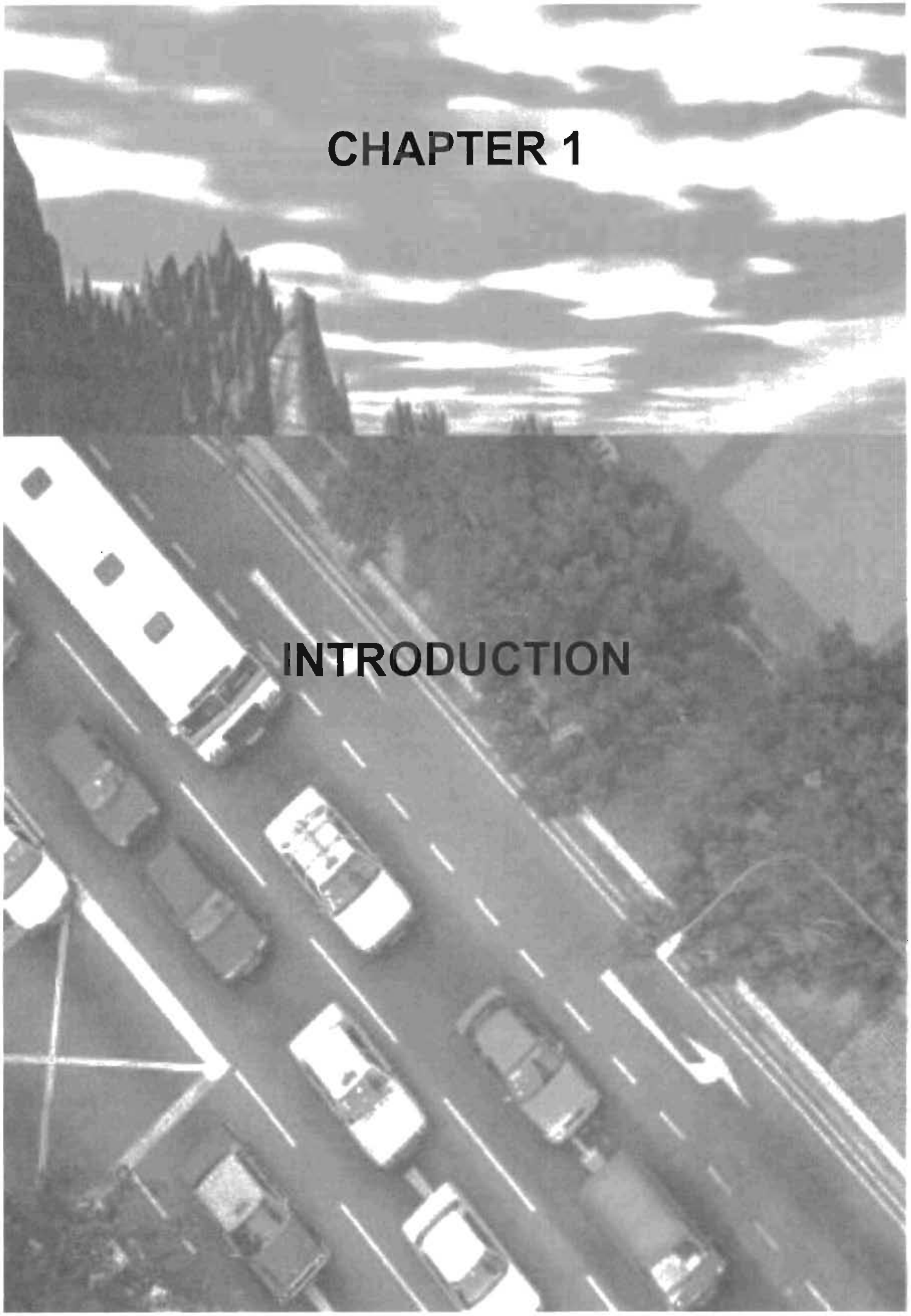
INTRODUCTION



PROBLEM STATEMENT

The signal interval between conflicting traffic movements has long been an important operational problem, in which the human comfort and perception factors, the traffic safety, the vehicle's driving behavior, the interpretation of the traffic laws, and the signal timing settings are all framed together. For years, the stop/proceed dilemma for motorists approaching a signal-controlled intersection has been studied, and an appropriate method for setting the yellow change and red clearance intervals for the straight movement has been developed. However, the yellow change and red clearance intervals for the left-turn movements are only now being studied. The lack of an appropriate method for determining the left-turn yellow change and red clearance intervals results in signal timings which may be insufficient for left-turn needs.

CURRENT MEHODLOGIES AND PRACTICES

A number of mathematical formulas have been proposed for the calculation of the yellow change interval in the past years by scientists and engineers. More recent studies are reflected in the evolution of ITE equations and guidance. However, most of these formulas are too simple to compute different configurations of intersections, and very few parameters are considered in the calculation. Furthermore, almost all of them were developed based on the through-movement, and the research specifically designed for the left-turn movement is scarce.

Compared with the yellow change interval, the red clearance interval is more related to geometry parameters than to human factors. Again, most of the relevant published research is for the through-movement, which incorporated the red clearance interval with the yellow change interval as a single interval called the change interval. The key point that existing methodologies suggest is how to determine the length of vehicles' moving curve and the speed, which is left to the field engineers to figure out. Liu et al. (2001) proposed an approach for the calculation of the yellow change and red clearance intervals that considered many parameters. But their methodology did not include the red clearance deduction reflecting the travel time between the conflict point and the conflicting stopline. This might result in a red clearance interval longer than necessary. In addition, the parameters that are used in Liu et al.'s approach need to be further calibrated by more Texas intersections.

As for the state-of-the-practice regarding yellow change and red clearance intervals, no nationwide techniques have existed until recently. The case of city of Lewisville, Texas, provides an Excel spreadsheet that was developed to calculate vehicle clearances (yellow change and red clearance) and pedestrian clearance for a single intersection. Some engineers would prefer to choose an empirical time, or calculate based on the width of intersection, or use the ITE recommendation.

Research objective

The objective of this research is to develop and test a comprehensive framework for setting yellow change and red clearance intervals for the left-turn movement, which can be used directly by the field traffic engineers in Texas. This guidebook provides a general description of the procedures entailed in this framework.

Overview of guidebook

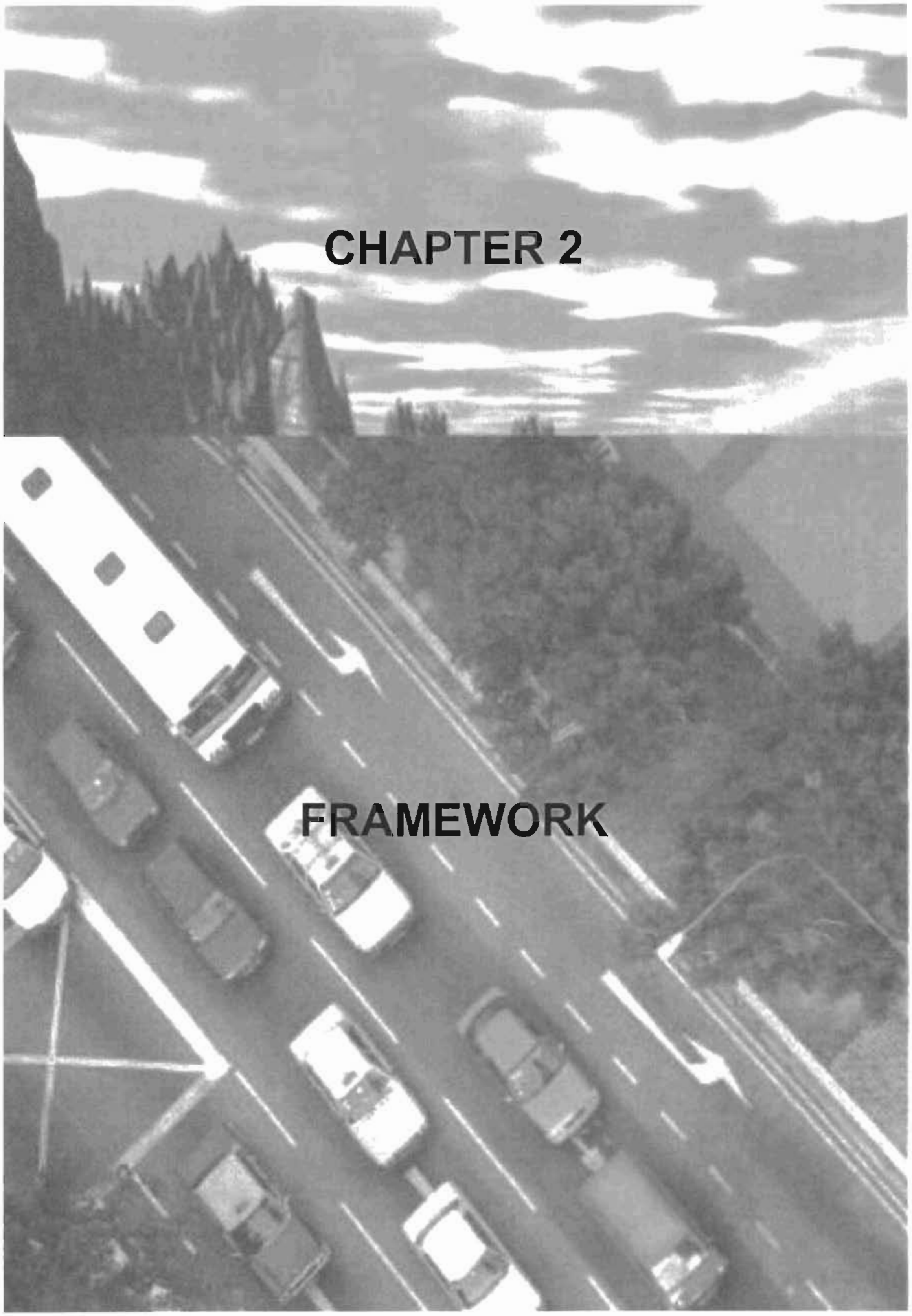
This guidebook contains three basic chapters that summarize the guidance for determining the yellow and red intervals to improve signal timing plans for the left-turn movement. The three chapters are as follows:

Chapter 1. Introduction – provides an introduction to the problem statement, current methodologies, and the research objectives for determining the yellow and red intervals to improve signal timing plans for the left-turn movement.

Chapter 2. Framework – provides descriptions of and procedures within the framework for determining the yellow and red intervals to improve signal timing plans for the left-turn movement.

Chapter 3. Summary and Recommendations – provides a summary of the framework. This chapter also includes recommendations for the implementation plan.

CHAPTER 2



FRAMEWORK

This chapter provides a description of the framework for determining the yellow change and red clearance intervals to improve signal timing plans for the left-turn movement. The following aspects are included:

- Description of the framework;
- Recommended values for three dimensionless parameters; and
- Procedure realizing the framework.

DESCRIPTION OF THE FRAMEWORK

The framework for calculating the yellow change and red clearance intervals includes three stages. In stage 1, the background information that will be used to calibrate and calculate the parameters in the framework should be prepared. In stage 2, the background information will be used in preparing the parameters that are necessary in calculating the yellow change and red clearance intervals. There are three dimensionless parameters, the calibrated values of which will be provided later in detail. In stage 3, the yellow change and red clearance intervals will be calculated based on the calibrated parameters.

Preparing Background Information of the Intersection

The intersection background information is the base source of the calibration and calculation process. Most of the background information can be collected directly from target intersections. Some of them will be used to calculate the parameters that can be incorporated into the calculation framework, while others will be used for the calibration of parameters. Some empirical values, such as comfortable acceleration or deceleration rate, and drivers' reaction time, are also treated as raw field data, although they might not be collected from each intersection. The following is a brief description of the needed information.

1. Drivers' perception-reaction time.

Drivers' perception-reaction time, which is the time drivers need to capture any signal change and respond to the change, is one of the major reasons for setting the yellow change interval. This value directly affects the calculation of the yellow change interval.

2. Visibility of traffic signals (traffic signal position, etc.)

When a vehicle approaches an intersection, the position of the traffic signal obviously influences the driver's decision whether to continue through the intersection or stop. Then, if derivers cannot clearly discern the red or green signal from a reasonable distance, those drivers' decisions will be delayed, affecting the yellow change interval they need. From the above analysis, visibility of traffic signals is defined as the maximum distance between the signal stand and the vehicle at which its driver can see the signal clearly while driving.

3. Widths of approaching and crossing lanes and streets.

Widths of approaching streets and crossing streets are major factors that determine the distance a vehicle must traverse in order to clear the intersection.

4. Left-turn traffic volumes on approaching street.

At intersections with high left-turn volumes, the distances between the vehicles might be too short to allow the vehicles to travel at relatively high speed. Under these circumstances, vehicles may enter the intersection at a lower speed. Further analysis, however, finds that for the vehicles approaching an intersection at a speed lower than the calculated entering speed (a parameter used as a standard speed to calculate the yellow change interval and will be discussed later), the yellow change interval needed to eliminate the dilemma zone is always shorter. Therefore, the yellow change interval adopted should always satisfy these situations.

5. Vehicle types.

Generally, since different types of vehicles have different acceleration/deceleration abilities, all vehicle types should be considered in the interval calculation. However, too many vehicle types make it impossible to give specific consideration to each vehicle type. For the convenience of calculation, a "general" vehicle type considering every type of vehicle has been used in this research. Nevertheless, we might consider some intersections where trucks make up a significant percentage. For an intersection where truck percentage against total volume increases to a certain level, a correction factor might be given for trucks' special speed, acceleration/deceleration capability, and length.

6. Lane assignment on approaching street.

There are different types of lane assignment on approaching streets, including left-turn lanes and shared lanes. The differently assigned lanes will be numbered separately in the research. The number of these lanes as well as the lane assignment may affect the turning curve length.

7. Drivers' comfortable deceleration rate.

At the onset of yellow, if the driver decides to stop before the stop line, the time the vehicle needs from the application of brakes to a complete stop is partly decided by deceleration rate. This time is the other part in the yellow change interval other than drivers' perception-reaction time. Mostly, the comfortable deceleration rate is set as 10 feet/sec^2, as in the Recommended Practice by ITE in 1985.

8. Drivers' toleration of centrifugal acceleration force.

Clearly, centrifugal acceleration force is totally dependent on the turning speed, given a certain turning curve. Accordingly, this is a major factor in setting the red clearance interval.

9. Historical accident data.

Historical accident data also belong with the field data. However, the causes of accidents may include geometry problems and signal timing problems. Moreover, accurate accident data are very difficult, if not impossible, to obtain. It is therefore hard to incorporate historical accident data directly into the calculation model. For considering this important factor, the historical accident data, together with the current yellow change and red clearance settings, can be used to judge the effectiveness of the model. In a situation with a high historical accident rate, the clearances may have been calculated with previous methods which do not consider left-turn characteristics.

10. Traffic laws.

Traffic law may or may not allow a vehicle to enter the intersection during the yellow phase. In some cases, this creates a portion before the intersection called dilemma zone. This model is intended to eliminate this dilemma zone through proper setting of yellow change and red clearance intervals.

11. Other field data.

The field data may also include some data related to the physical characteristics of intersections and vehicles: distances between potential conflicting points and stop lines; turning angle (or angle between approaching and crossing streets); numbers of approaching and crossing lanes and streets; speed limits on approaching and crossing streets; number of total left-turn lanes; number of shared lanes for left-turn movement; and vehicle sizes.

Calibrating Parameters for the Framework

Several parameters can be calibrated and/or calculated from the field data. Setting of yellow change and red clearance intervals will be directly based on these parameters. The calculation of some parameters may involve more than one type of field data, while others may be related to the other parameters.

1. Correction factor for numbers of approaching and crossing lanes.

In an intersection with multiple left turn lanes and/or crossing lanes, vehicles at the outer left turn curve might take more time to clear the intersection than vehicles in the inner curve. Thus, the red clearance may be decided based on the outer curve. These time gaps are solely caused by the curve length (Figure 1, curve AB and $A'B'$). Considering the fact that the curves are somewhat in parallel, a correction factor is included in the red clearance model for the single

left-turn approaching and crossing lane, which is always the inside lane.

In an intersection where the number of crossing lanes is t and the number of the approaching left-turn exclusive and shared lanes is l, the correction factor is calculated by the distance of circles of the outside left-turn lanes, according to the intersection width and lane width. The formula is:

$$\xi = \sqrt{(W_t + (l-1)W_{ll})^2 + (W_l + (t-1)W_{ll})^2} \,/ \sqrt{W_t^2 + W_l^2} \quad (1)$$

where, ξ is the intended correction factor.

For the case of multiple approaching left-turn lanes and crossing lanes, this factor is defined as the ratio of the length of the outside curve to the length of the inside curve, which are illustrated in Figure 1 as curve $A'B'$ and curve AB. Because actual left-turn curves are not available, this ratio is estimated by the length of line $A'B'$ and AB. When the turning angle is not the right one, the length of line $A'B'$ and AB may involve angle θ. But because the lines themselves are used to estimate the ratio of curves, we can also use the above equation to approximate the real case.

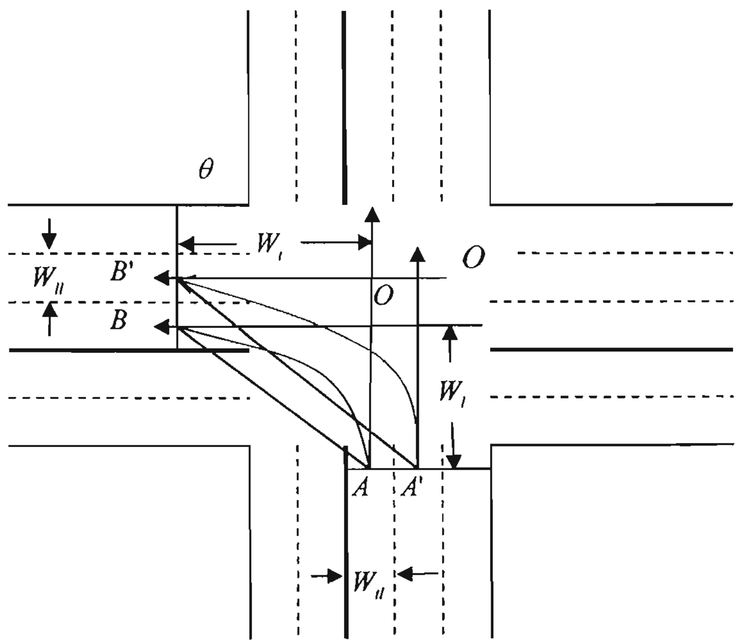


FIGURE 1 Turning Curve for Different Lanes

2. Time delay from low visibility of traffic signals (traffic signal position, etc.)

As mentioned before, visibility of traffic signals is defined as the maximum distance between the signal face and the vehicle at which its driver can see the signal clearly while driving. The yellow change interval may be affected by insufficient visibility.

In some situations, the visibility of traffic signals may delay the driver's perception. If drivers cannot see the signals clearly from a certain distance when approaching the intersection, there may not be enough time to discern the signals and then react. When the visibility distance is longer than a threshold within which the drivers begin to make the decision, it has no effect on the calculation of yellow change and red clearance. In the intersection where visibility distance is shorter than the threshold, a time T_{vi} should be incorporated into yellow change. The time T_{vi} will be the additional time for the driver to cover the loss because of the short visibility of signals.

$$T_{vi} = Max[0, 0.6820(L_{threshold} - L_{vi}) / V_{0.85}\ ] \tag{2}$$

where, 0.6820 is set for different units in the equation, $V_{0.85}$ is 85% percentile speed on the approaching lanes, in miles/h. L_{vi} is the distance of visibility of traffic signals, in feet. $L_{\text{threshold}}$ is the threshold distance, in feet, which will be determined after the calibration.

If L_{vi} is longer than $L_{\text{threshold}}$, T_{vi} should be zero.

3. Entering speed calculated from speed limits on approaching and crossing streets.

For the yellow change interval, the speed limit on the approaching street will affect a vehicle's entering speed. When entering the intersection, a motorist can either decelerate or accelerate toward the intended entering speed that can be less than or equal to the speed limit on the approaching street. The entering speed V_i might be expressed in terms of speed limit of the approaching street V_t and 85% percentile speed $V_{0.85}$:

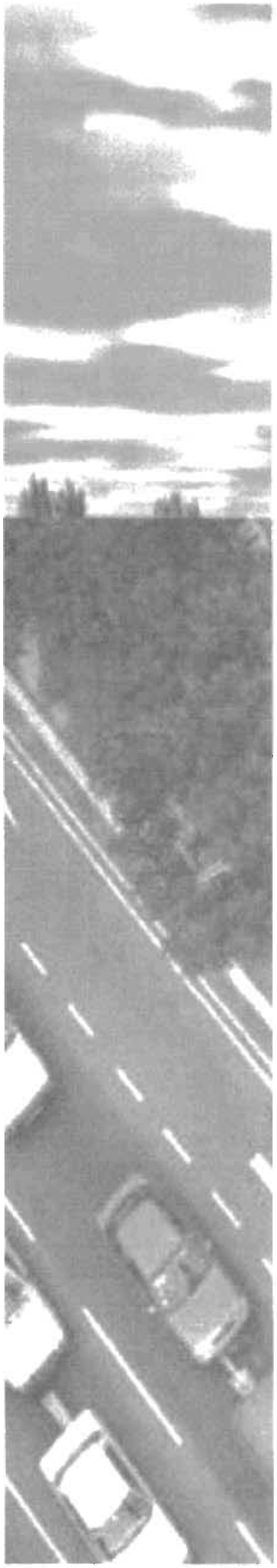
$$\begin{cases} V_i = \alpha V_t + (1-\alpha)V_{0.85} & \text{If } V_{0.85} \le V_t \\ V_i = V_t & \text{Otherwise} \end{cases} \tag{3}$$

Parameter α, located in the interval [0, 1], is to be chosen for a turning movement from the calibration of the model. If $V_{0.85}$ and V_t are equal, the sec term in the right hand side of the equation will be independent of α.

For the red clearance setting, speed limits will also affect the calculation of average driving speed on the curve V_c, which will later be described in detail.

4. Length of turning curve based on the widths of approaching and crossing lanes and streets.

The actual turning curve, which can be estimated as $\sqrt{W_l^2 + W_t^2 + 2W_lW_t\cos\theta}$, is not available, but should be somewhere



between the two extremes, which are the longest distance, W_l+W_t, and the shortest cut distance.

The following equation calculates the length of the actual turning curve.

$$S = \beta(W_l + W_t) + (1-\beta)\sqrt{W_l^2 + W_t^2 + 2W_l W_t \cos\theta} \tag{4}$$

where, the parameter β is used to adjust and simulate the actual curve and will be calibrated by the field data and *L* is the vehicle length.

5. Average driving speed on the curve.

There are two factors that will affect the average driving speed on the curve. First is the comfortable centrifugal acceleration. The turning speed may not be limited by the comfortable centrifugal force for the driver. According to the centrifugal force law, given "comfortable" centrifugal force as γg, the speed should not exceed the $0.6820\sqrt{\gamma g S/\theta}$. The other factor is speed limits on the approaching street and crossing street. We might consider the average speed to be $\lambda V_t + (1-\lambda)V_l$, for either accelerating from V_t to V_l, or decelerating from V_t to V_l.

Average driving speed V_c will be calculated as:

$$V_c = Min[0.6820\sqrt{\gamma g S/\theta},\ \lambda V_t + (1-\lambda)V_l] \tag{5}$$

Where S is the length of actual turning curve, and θ is the angle of the intersection. In the equation, parameter λ may be selected in an interval decided by calibration of the model.

6. Time deduction for distances between potential conflicting points and stop lines.

When the green signal is given to the conflicting traffic, it takes time for vehicles to reach the conflicting point. A portion of the time can be deducted from the red clearance. The time can be that which vehicles take from a full stop to accelerate and to reach the conflicting point (in case of driver's anticipating green in this situation, the time calculated below does not include the perception-reaction time), or the time for a driving vehicle to take from the stop line to the conflicting point, whichever is less.

Here, the L_{cs} is the distance between conflict point and opposite stop line if the signal phase is left-turn before through movement (left-turn lead scenario), or the distance between conflict point and crossing stop line if the signal phase is left-turn after through movement (left-turn lag scenario). For the safety consideration, the percentage of the time used to deduct from red clearance is set as 90%, as recommended by City of Lewisville (2001).

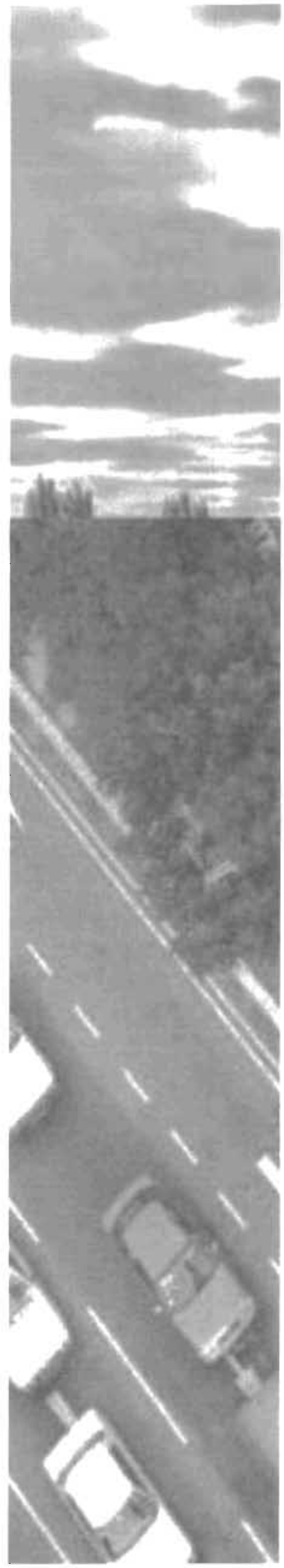
It will reduce the red clearance by subtracting a deduction factor-T_{cs}, which is calculated as follows:

$$T_{cs} = \%tRl * Min[\sqrt{\frac{2L_{cs}}{a_-}},\ 0.6820\frac{L_{cs}}{V_{0.85}} + \delta_-] \quad (6)$$

where $\%tRl$ is the percentage of perception - reaction time to be subtracted from the red clearance with an default value of 90%, and δ_- is the driver's perception-reaction time.

7. Trajectory of left-turn curve.

The value of parameter β in the calculation of length of the actual turning curve (Equation 4) reflects the trajectory of the left-turn curve.



Calculating Yellow Change and Red Clearance Intervals for Left-turn

Calculations of the yellow change and red clearance intervals are based on the parameters above and the raw field data. The values of parameters α, β, and γ involved in the above parameter calculations will be given in the next section. The yellow change interval can be calculated by the following equation:

$$y = 2(\delta_- + \frac{V_t}{2a_-})/(1+\frac{V_i}{V_t}) + T_{vi} \quad (7)$$

In this equation, $\delta_- + \frac{V_t}{2a_-}$ is normally used as yellow change calculation, while $2/(1+\frac{V_i}{V_t})$ is an adjustment factor of the entering speed. Clearly, the adjustment factor would be 1 if $V_l = V_t$, while the factor would be large than 1 if V_l is less than V_t. T_{vi} is the time delay from low visibility of traffic signals as defined before.
The red clearance interval can be calculated by the following equation:

$$r = 0.6820\frac{\xi(S+L)}{V_c} - T_{cs} \quad (8)$$

In this equation, two parameters are special: ξ and T_{cs} . As previously discussed, ξ is the correction factor for numbers of approaching and crossing lanes, while T_{cs} is the time deduction for distances between potential conflicting points and stop lines.

Recommended values of three dimensionless parameters

In the above framework, there are three undetermined dimensionless parameters α, β, and γ appearing in Equations 3, 4, and 5. Each of the three parameters stands for an undecided driver's behavior to be calibrated. The parameter α in the Equation 3 was used for the

calculation of the entering driving behavior before making the left-turn. Parameter β in the Equation 4 was used to calculate the driver's behavior on the left-turn curve. Parameter γ in the Equation 5 was used to calibrate the driver's tolerable centrifugal force during left-turn.

Based on the field data collected from 21 intersections in 8 Texas cities, the three dimensionless parameters α, β, and γ were calibrated. The detailed descriptions of field data collection and calibration procedures can be found in research report **TX-03/4273-2**. With the intersection attributes classified in Table 1, the calibrated values of the three parameters are listed in the following five tables (Table 2, Table 3, Table 4, Table 5, and Table 6).

TABLE 1 Intersection attributes for calibrating the three dimensionless parameters

Intersection Attributes	Possible Values
Approaching Speed Limit (mi/hr)	30, 35, 40, 45, 50, 55
No. of Left-Turn or Shared Lanes	1, 2 or more
Control Type	1 – PT, 2 – PT/PM
Truck Percentage	0%, 5%, 10%, 15%, 20% or More,

TABLE 2 Recommended parameters' values for each type of intersections with 0% trucks

Intersection Types			α	β	γ
Speed Limit	No of LT and Shared Lanes	Control Type			
30	1	1	0.3774	0.3535	0.9067
30	1	2	0.2865	0.2905	0.8137
30	2	1	0.3888	0.3451	0.9761
30	2	2	0.2952	0.2836	0.8759
35	1	1	0.3584	0.355	0.8198
35	1	2	0.2721	0.2917	0.7357
35	2	1	0.3693	0.3465	0.8824
35	2	2	0.2803	0.2848	0.7919
40	1	1	0.3404	0.3564	0.7411
40	1	2	0.2584	0.2929	0.6651
40	2	1	0.3507	0.348	0.7978
40	2	2	0.2662	0.286	0.7159
45	1	1	0.3233	0.3579	0.67
45	1	2	0.2454	0.2941	0.6013
45	2	1	0.3331	0.3494	0.7212
45	2	2	0.2529	0.2871	0.6473
50	1	1	0.307	0.3594	0.6057
50	1	2	0.2331	0.2953	0.5436
50	2	1	0.3164	0.3508	0.6521
50	2	2	0.2401	0.2883	0.5852
55	1	1	0.2916	0.3608	0.5476
55	1	2	0.2214	0.2965	0.4915
55	2	1	0.3005	0.3523	0.5895
55	2	2	0.2281	0.2895	0.529

TABLE 3 Recommended parameters' values for each type of intersections with 5% trucks

Intersection Types			α	β	γ
Speed Limit	No of LT and Shared Lanes	Control Type			
30	1	1	0.3604	0.3544	0.874
30	1	2	0.2736	0.2912	0.7844
30	2	1	0.3713	0.346	0.9409
30	2	2	0.2819	0.2843	0.8443
35	1	1	0.3423	0.3558	0.7902
35	1	2	0.2598	0.2924	0.7091
35	2	1	0.3526	0.3474	0.8506
35	2	2	0.2677	0.2855	0.7633
40	1	1	0.3251	0.3573	0.7144
40	1	2	0.2467	0.2936	0.6411
40	2	1	0.3349	0.3488	0.769
40	2	2	0.2542	0.2867	0.6901
45	1	1	0.3087	0.3587	0.6458
45	1	2	0.2343	0.2948	0.5796
45	2	1	0.3181	0.3502	0.6952
45	2	2	0.2415	0.2878	0.6239
50	1	1	0.2932	0.3602	0.5839
50	1	2	0.2226	0.296	0.524
50	2	1	0.3021	0.3517	0.6285
50	2	2	0.2293	0.289	0.5641
55	1	1	0.2785	0.3617	0.5279
55	1	2	0.2114	0.2973	0.4737
55	2	1	0.2869	0.3531	0.5682
55	2	2	0.2178	0.2902	0.5099

TABLE 4 Recommended parameters' values for each type of intersections with 10% trucks

Intersection Types			α	β	γ
Speed Limit	No of LT and Shared Lanes	Control Type			
30	1	1	0.3441	0.3552	0.8425
30	1	2	0.2612	0.2919	0.7561
30	2	1	0.3546	0.3468	0.9069
30	2	2	0.2691	0.285	0.8139
35	1	1	0.3268	0.3567	0.7617
35	1	2	0.2481	0.2931	0.6835
35	2	1	0.3367	0.3482	0.8199
35	2	2	0.2556	0.2862	0.7358
40	1	1	0.3104	0.3581	0.6886
40	1	2	0.2356	0.2943	0.618
40	2	1	0.3198	0.3496	0.7413
40	2	2	0.2428	0.2873	0.6652
45	1	1	0.2948	0.3596	0.6226
45	1	2	0.2238	0.2955	0.5587
45	2	1	0.3037	0.3511	0.6702
45	2	2	0.2306	0.2885	0.6014
50	1	1	0.28	0.3611	0.5628
50	1	2	0.2125	0.2967	0.5051
50	2	1	0.2885	0.3525	0.6059
50	2	2	0.219	0.2897	0.5437
55	1	1	0.2659	0.3626	0.5088
55	1	2	0.2018	0.298	0.4566
55	2	1	0.274	0.3539	0.5477
55	2	2	0.208	0.2909	0.4916

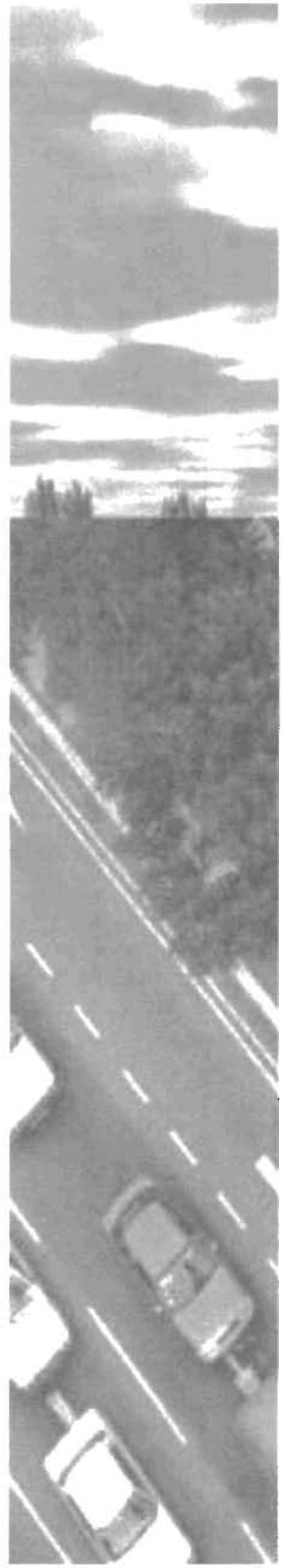


TABLE 5 Recommended parameters' values for each type of intersections with 15% trucks

Intersection Types			α	β	γ
Speed Limit	No of LT and Shared Lanes	Control Type			
30	1	1	0.3286	0.3561	0.8121
30	1	2	0.2494	0.2926	0.7288
30	2	1	0.3386	0.3476	0.8742
30	2	2	0.257	0.2857	0.7845
35	1	1	0.3121	0.3575	0.7342
35	1	2	0.2369	0.2938	0.6589
35	2	1	0.3216	0.349	0.7903
35	2	2	0.2441	0.2869	0.7093
40	1	1	0.2964	0.359	0.6638
40	1	2	0.225	0.295	0.5957
40	2	1	0.3054	0.3505	0.7145
40	2	2	0.2318	0.288	0.6412
45	1	1	0.2815	0.3605	0.6001
45	1	2	0.2137	0.2962	0.5385
45	2	1	0.29	0.3519	0.646
45	2	2	0.2202	0.2892	0.5797
50	1	1	0.2674	0.3619	0.5425
50	1	2	0.2029	0.2975	0.4869
50	2	1	0.2755	0.3533	0.584
50	2	2	0.2091	0.2904	0.5241
55	1	1	0.2539	0.3634	0.4905
55	1	2	0.1927	0.2987	0.4402
55	2	1	0.2616	0.3548	0.528
55	2	2	0.1986	0.2916	0.4738

TABLE 6 Recommended parameters' values for each type of intersections with 20% trucks

Intersection Types			α	β	γ
Speed Limit	No of LT and Shared Lanes	Control Type			
30	1	1	0.3138	0.3569	0.7828
30	1	2	0.2382	0.2933	0.7025
30	2	1	0.3233	0.3484	0.8427
30	2	2	0.2454	0.2864	0.7562
35	1	1	0.298	0.3584	0.7077
35	1	2	0.2262	0.2945	0.6351
35	2	1	0.3071	0.3499	0.7618
35	2	2	0.2331	0.2875	0.6837
40	1	1	0.283	0.3598	0.6398
40	1	2	0.2149	0.2957	0.5742
40	2	1	0.2916	0.3513	0.6887
40	2	2	0.2214	0.2887	0.6181
45	1	1	0.2688	0.3613	0.5785
45	1	2	0.2041	0.297	0.5191
45	2	1	0.277	0.3527	0.6227
45	2	2	0.2102	0.2899	0.5588
50	1	1	0.2553	0.3628	0.523
50	1	2	0.1938	0.2982	0.4693
50	2	1	0.263	0.3542	0.5629
50	2	2	0.1997	0.2911	0.5052
55	1	1	0.2425	0.3643	0.4728
55	1	2	0.1841	0.2994	0.4243
55	2	1	0.2498	0.3556	0.5089
55	2	2	0.1896	0.2923	0.4567

Procedure realizing the framework

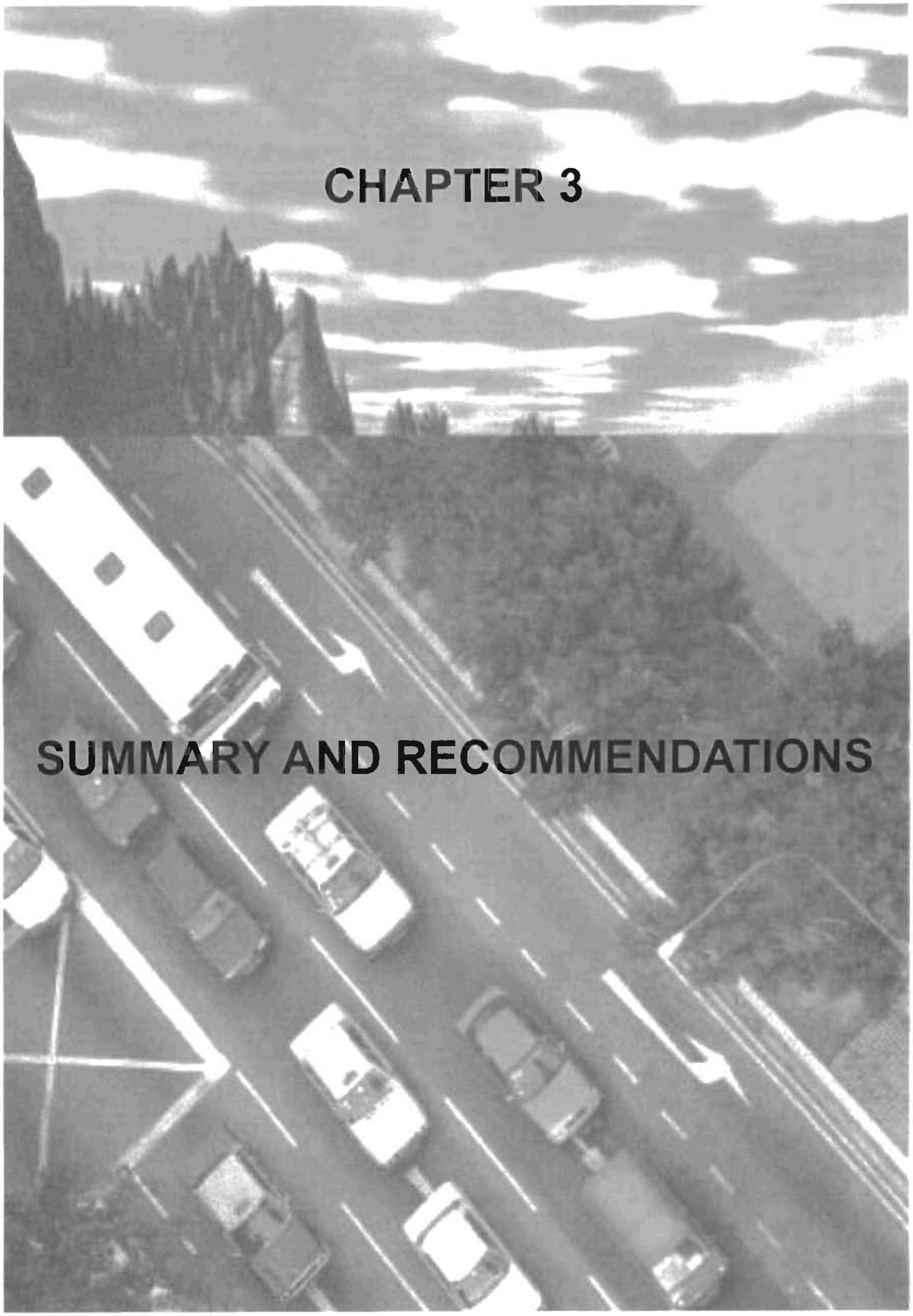
The framework determining the yellow change and red clearance intervals for left-turn can be realized by the following four steps:

Step 1: Select the proper values of the three dimensionless parameters α, β, and γ based on the intersection attributes and the percentage of trucks from Table 2 through Table 6;

Step 2: Collect the relevant background information for the intersection as is described in the previous section;

Step 3: Calculate all the necessary parameters based on equations (1)-(6); and

Step 4: Calculate the yellow change and red clearance intervals by equation (7) and equation (8).


CHAPTER 3
SUMMARY AND RECOMMENDATIONS

This chapter provides a summary as well as recommendations for the implementation plan using the proposed framework determining the yellow change and red clearance intervals for left-turn movements.

Summary

In this guidebook, the descriptions and procedures of the comprehensive framework have been provided for determining the yellow change and red clearance intervals for left-turn movements. This framework was built by incorporating significant improvement to the original work conducted by Liu et al. (2002). A comprehensive set of parameters were integrated related to safety, perception, human comfort, driver behavior, traffic ordinances, and intersection geometric characteristics. The framework has been systematically calibrated, and is flexible enough to be implemented at different types of intersections in Texas.

It should be noted that based on the framework developed and calibration of data collected from 21 surveyed intersections in Texas, the following conclusions can be drawn:

(1) Existing yellow change intervals for the left-turn movement are too long;

(2) Existing red clearance intervals are too short; and

(3) Existing total change intervals (including both the yellow change and the red clearance) are about the same as those calculated.

Probably, the primary reason is that the existing yellow change and red clearance intervals are either the empirical values or those determined based on the through movement.

It should be noted that permitted left turn is not a subject of this study, where the yellow and all-red clearance intervals are normally determined based on the through movement. This guidance can be applied only to the arrow indications for left-turn.

Recommendation for Implementation Plan

It is recommended that the proposed framework be implemented in Texas. Based on the calibration from 21 Texas intersections, the suggested yellow changes and red clearance intervals for typical intersections are listed in Table 7.

TABLE 7: Suggested intervals for typical intersections with right angle

Approach Speed	No of Lanes		Depth							
			70ft		90ft		110ft		130ft	
			Y	R	Y	R	Y	R	Y	R
30	1	PT	3.0	2.2	3.0	2.9	3.0	3.6	3.0	4.3
		PM	3.0	2.2	3.0	2.8	3.0	3.5	3.0	4.2
	2	PT	3.0	2.5	3.0	3.2	3.0	3.9	3.0	4.6
		PM	3.0	2.4	3.0	3.1	3.0	3.8	3.0	4.5
40	1	PT	3.0	2.4	3.0	2.9	3.0	3.6	3.0	4.3
		PM	3.0	2.6	3.0	2.8	3.0	3.5	3.0	4.2
	2	PT	3.0	2.6	3.0	3.2	3.0	3.9	3.0	4.6
		PM	3.0	2.8	3.0	3.1	3.0	3.8	3.0	4.5
50	1	PT	3.0	2.9	3.0	3.1	3.0	3.6	3.0	4.3
		PM	3.0	3.1	3.0	3.3	3.0	3.5	3.0	4.2
	2	PT	3.0	3.1	3.0	3.2	3.0	3.9	3.0	4.6
		PM	3.0	3.3	3.0	3.5	3.0	3.8	3.0	4.5
55 or above	1	PT	3.0	3.1	3.0	3.3	3.0	3.6	3.0	4.3
		PM	3.4	3.5	3.3	3.7	3.3	3.9	3.2	4.2
	2	PT	3.3	3.5	3.2	3.6	3.1	3.8	3.1	4.5
		PM	3.4	3.7	3.3	3.8	3.2	4.0	3.2	4.2

Note: (1) For trucks, yellow change remains same, red clearance increases 0.1s for 5%-10% trucks in the traffic; 0.3 for 10%-15% trucks; 0.4s for 15%-20% trucks; and 0.5s for 20% or above trucks. (2) PT: Protected; PM: Protected/Permitted. (3) Y: Yellow; R: Red.

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APPENDIX

TABLE 8: Recorded left-turn travel time on surveyed intersections

Intersection	Type	Turning Time	R_e	R_c
FM 2818 @ Wellborn NB	H1PM	3.6	2.0	3.4
Texas Ave @ Univ Dr SB	L2PT	4.7	2.0	3.8
WellBorn @ Rock Prairie SB	H1PM	5.1	1.5	3.9
Texas Ave @ FM 2818 SB	H1PM	3.7	2.0	2.5
Texas Ave @ Holleman NB	L1PT	2.6	2.0	1.8
Wellborn @ George Bush Dr. SB	L1PM	3.2	1.5	2.3
US 377 @ FM 167 SB	H1PT	2.8	2.0	2.1
Cooper @ Pleasant Ridge SB	H2PT	3.6	1.0	2.4
Skillman @ Abrians EB	L2PM	3.8	2.0	2.7
3040 @ Macarthur Dr. WB	L2PM	3.7	1.5	2.3
Main St. @ Old Orchard WB	L1PM	3.8	2.0	2.1
Bellaire @ Toll Rd 8 WB	H2PT	3.7	2.0	2.7
Bellaire @ Gessner EB	H1PT	4.0	1.5	3.0
Bellaire @ Bissonet EB	H2PT	4.1	2.0	2.6
Richmond @ Buffalo Speedway EB	L2PT	4.0	2.0	2.5
Richmond @ Sage Rd. EB	L1PT	4.1	2.0	2.8
Richmond Ave. @ Rice Rd WB	H1PM	3.5	1.5	2.6
SH 121 @ Corporatave Dr NB	L1PM	3.5	2.0	1.8
Cooper @ Pioneer SB	H2PT	4.0	1.0	2.6
Arbrook @ Matlock WB	L1PM	3.7	0.5	1.9
SH 121 @ 423 EB	H2PT	3.9	1.5	2.7

- H2 and L1: High or Low traffic volume, and the number of left-turn lanes;
- PT and PM: Protected and Protected-permitted left turn;
- R_e: the existing red time;
- R_c: the calculated red time;
- All time units are in seconds.