



Frequently Asked Questions

TE-306.1 Yellow Change Intervals and Red Clearance Intervals

Version 1.0



INTRODUCTION

This document contains additional information to support the engineer's application of the policy options, recommendations, and requirements outlined in TE-306.1. This Frequently Asked Questions (FAQs) document does not represent VDOT policy, nor does it include any further requirements to TE-306.1; rather, its sole purpose is to aid the engineer in its application. As a guidance document, there are no "shall statements" included (except when clarifying the existing requirements of TE-306.1) and there is no requirement mandating use of this FAQ document.

Practices and supporting information contained in this document are applicable only for use in calculating yellow change and red clearance intervals. It is not advisable for these contents to be used for other engineering determinations such as speed limits, advisory speeds, general classification counts, or other studies not related to yellow change and red clearance intervals.

The intent of this FAQ document is to provide information and clarification that can be used in the application of engineering judgement and engineering decision-making when calculating change and clearance intervals, as well as to share change and clearance interval calculation & application best practices that have developed across the state.

This FAQ summary has been developed solely for use by engineers applying TE-306.1 for VDOT. While many different situations that engineers may encounter are discussed, this FAQ document does not cover every possible intersection type or situation that may arise. Due to the large variation in intersection types and operational strategies, it is neither possible nor practical to provide a single, consistent process that can be applied to every intersection across the Commonwealth. The engineer is responsible for considering the specific characteristics of each intersection and determining if the general guidance provided herein is appropriate for the location. Therefore engineering judgement is essential in applying the standards and guidance in TE-306.1 as well as the practices described in this document.

QUESTION	TOPIC	TITLE	PAGE
1	Red Clearance Interval	Red Clearance Interval “Minus One”	4
2	Speed and Operations	Speeds Used in Calculation of Intervals	5
3	Speed and Operations	Methods for Determination of Speed	6
4	Speed and Operations	Appropriate Methods for Speed Studies	9
5	Speed and Operations	Number of Samples for Speed Studies	9
6	Speed and Operations	Average or 85 th Percentile Speed	10
7	Speed and Operations	Detrimental to Operations - Thresholds	10
8	Speed and Operations	Detrimental to Operations – Sensitivity Analysis	11
9	Speed and Operations	Travel Time Methodology for Red Clearance Time	13
10	Speed and Operations	Short Approach Lengths	17
11	Speed and Operations	U-Turn Speed	17
12	Grade	Methods to Determine Grade	19
13	Grade	Grade Calculation Method	21
14	Intersection Width	Distance being Measured	23
15	Intersection Width	Non-Standard Intersection Configurations	23
16	Length of Vehicle	Longer Vehicle Length	32
17	Length of Vehicle	Classification Studies	32
18	Phasing Considerations	Protected & Split Phases	33
19	Engineering Judgment	Documentation Requirements	35

RED CLEARANCE INTERVAL

1) Why is there a “minus one” in the red clearance interval equation?

One second is subtracted in the red clearance interval calculation because the start-up delay for the next phase being served incorporates an inherent buffer between the vehicle exiting the intersection during the clearing phase and the vehicle entering the intersection during the next phase.

Therefore, it is appropriate and acceptable to use the “minus one” for the red clearance interval calculation. NCHRP-731 included a sensitivity analysis that examined the effect of a 1-second reduction in the red clearance interval on intersection clearance. In all scenarios examined, the clearing vehicle exited the intersection by the end of the 1-second of start-up delay of the next phase. Therefore, this additional 1-second is not needed in the all-red interval.

A more thorough technical discussion on the “minus one” is included in [NCHRP-731](http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_731.pdf).
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_731.pdf

SPEED AND OPERATIONS

2) What speeds are used in calculating yellow change and red clearance intervals per TE-306.1? Can I use a different speed than what is called for in the policy?

TE-306.1 uses different speeds for through and left-turn movements to calculate the yellow change or red clearance intervals. The tables below describe these speeds:

Yellow Change Interval Speeds

Movement	Speed Used	Default Policy Speed	Best Practice (if Default Policy Speed is Not Available and Speed Limit is Posted)	Best Practice (if Default Policy Speed is Not Available and Speed Limit is Not Posted)
Through	Speed of through vehicle approaching the intersection	85 th percentile under free-flow conditions*	Default speed can be approximated by adding 7 mph to the posted speed limit*	See FAQ No. 3 for alternate methods that can be used at locations where the speed limit is not posted and the statutory speed limit applies. See FAQ No. 10 for short approach length applications.
Left-Turn	Speed of left-turning vehicle approaching the intersection	85 th percentile under free-flow conditions*	Default speed can be approximated by subtracting 5 mph from the posted speed limit*	

Red Clearance Interval Speeds

Movement	Speed Used	Default Policy Speed
Through	Speed of through vehicle approaching the intersection	Use same speed as the through movement yellow change interval calculation*
Left-Turn	Speed of left-turning vehicle executing the left-turn movement	20 mph unless a higher left-turn vehicle speed is appropriate based on engineering judgment*

*If engineering judgment determines that the default policy speed and/or best practice speed is not representative of actual conditions, an alternate speed can be used in the calculations (see FAQ No. 3). TE-306.1 does not require that a formal speed study be completed to use an alternate speed for the speed variable. Engineering judgment can be applied. TE-306.1 does require that, “the rationale to substantiate the engineering judgment decision shall be documented” (see FAQ No. 19 for documentation requirements).

3) What are appropriate alternate method(s) to determine the speeds used in the yellow change and red clearance interval calculations?

There are several methods that can be used to determine the speed, which include: conducting a formal speed study, utilizing the posted or statutory speed limit to estimate speeds, and conducting field driving observations (i.e., replicating the actions and behavior of a typical or reasonable driver and capturing speed information). An additional option for red clearance intervals is to conduct a travel time study and use the travel time in place of the calculated interval from speed and distance.

Current Policy & Best Practices

The default policy speed used in TE-306.1 to calculate yellow change intervals for all movements and to calculate red clearance intervals for through movements is the 85th percentile speed of the approach. The default policy speed in TE-306.1 to calculate red clearance intervals for left-turn movements is 20 mph. The speeds are determined by conducting a formal speed study, but can also be estimated by applying best practices if speed data is not readily available (as described in FAQ No. 2).

Alternative Methods

Speeds different from those prescribed in TE-306.1 may be used in the calculations, and a formal speed study is not required. However, engineering judgment should be applied to determine the appropriateness of each method for obtaining the speed, based on the unique field conditions at each location. If a speed other than the prescribed default policy speed or best practice speed in TE-306.1 is used, the rationale to substantiate the engineering judgement decision shall be documented and maintained with the signed and sealed document (see FAQ No. 19). In these cases, some form of field verification is recommended to validate speeds determined through engineering judgement.

One field method for obtaining speed is field driving observations. During these observations, the observer drives through the intersection several (generally 3 to 5) times to assess the field conditions and driver experience, including the speed, travel path, and driver behavior. The success of such a field driving review is based on the observer replicating the behavior and actions of a reasonable, typical driver. A smaller number of observations can occur as compared to a formal speed study since efforts are taken to avoid “outlier” driver behavior during the review. And if multiple consistent measurements are observed, the designer can be more confident in using such values in lieu of a formal speed study.

For exceptionally wide intersections with sweeping left-turn movements where the calculated all-red clearance interval is equal to or greater than 5 seconds, conducting a

travel time study and taking the result minus one second can be used to determine the red clearance time for left-turn movements (see FAQ No. 9).

Various methods for determining speed, including pros, cons, and relative cost are summarized in the table below. This table was developed to assist engineers in the determination of the most appropriate method for each intersection.

Engineering judgment may determine that the calculated yellow change or red clearance interval is detrimental to an intersection's operations (see FAQ No. 7). In these cases, a sensitivity analysis of the TE-306.1 equation input parameters on the change and clearance intervals may help the engineer assess the potential to improve operations, which could justify a more costly speed determination method. Additional information about sensitivity analyses can be found in FAQ No. 8.

Method	Pros	Cons	Cost*
Default Policy Method			
Conduct a formal speed study <ul style="list-style-type: none"> Obtain a statistically-valid number of samples from field speed measurements, and determine 85th percentile speed. 	A speed study will give the most accurate, statistically valid result.	Conducting a speed study and reducing the data is a more labor intensive process. A large number of samples is required to obtain a statistically valid result.	\$\$\$
Alternative Best Practice			
Approximate the speed based upon the posted or statutory speed limit <ul style="list-style-type: none"> Speed limit plus 7 mph for through movement speeds Speed limit minus 5 mph for left-turn approach speeds, and 20 mph for left-turning speed. 	This method is simple to utilize if the speed limit is known, and is the most cost-effective method.	This method does not account for unique field conditions that cause deviation between actual speeds and the assumptions used in the approximation. If the speed limit is not posted, the statutory speed limit may not reflect actual field driving conditions. This method may be implemented with no validation required.	\$
Alternate Methods			
Conduct field driving observations: <ul style="list-style-type: none"> Person drives the roadway multiple (3-5 or more) times to determine the most appropriate speed based on the driving experience replicating the actions and behavior of typical or reasonable drivers. 	Such driving reviews will account for field conditions. Significantly fewer samples are used than in a formal speed study. This method can be used to assist the engineer in deciding if better/more data is needed (i.e., if variability is observed).	This resultant speeds obtained from this method will not be statistically valid and may be biased towards the driving behaviors of the individual driver conducting the field reviews. It is important that the person conducting the review attempt to replicate the behaviors of a typical or reasonable driver.	\$\$
Conduct a travel time study for left-turning vehicles for red clearance interval: <ul style="list-style-type: none"> Time vehicles making the left-turning movement. Take the resultant mean or 15th percentile travel time and subtract one second to obtain the red clearance time. 	This methodology will give a statistically valid result of actual travel times without using assumptions for vehicle length and turning path/distance.	The data collection for this method is more labor intensive and highly prescriptive. The data collector will likely only collect one sample per signal cycle, and a larger number of samples is required to obtain a statistically valid result.	\$\$\$

*The cost column represents the approximate order of magnitude cost. Specific costs may vary by geographic location.

4) If a formal speed study is desired, what are appropriate, cost-effective speed study method(s) to determine the speed parameter for through and left-turn vehicles for yellow change and red clearance intervals?

For approach speed measurements – of through (yellow change and red clearance intervals) and left-turn movements (yellow change interval only):

- Acceptable data collection methods include: stopwatch, video, Doppler (radar or laser), or pneumatic tubes.
- Spot speed measurements should be taken approximately 300 to 600 feet in advance of the stop bar for vehicles operating in free-flow conditions. Exact location should be based on site-specific conditions and engineering judgment.

For turning speed measurements of left-turn movements (red clearance interval only):

- Acceptable data collection methods include: stopwatch, video, or radar. Measurement of the travel distance should be from the approach stop bar to the receiving approach lane (refer to Figure 2 in TE-306.1). Pneumatic tubes are not desirable since the speed for the red clearance interval is “left-turn vehicle turning speed.” Tubes located in the intersection would not yield accurate results for the single movement alone.
- Spot speed measurements or space speed measurements are acceptable.

There are several sources for specific details regarding how to conduct speed studies:

- Latest edition of the ITE *Manual of Transportation Engineering Studies*;
- Iowa State University Center for Transportation Research and Education [*Handbook for Simplified Practice for Traffic Studies*](#) for Spot Speeds (including stopwatch method).

5) How many speed samples should be collected in the field when conducting a field driving observation or performing a speed study for yellow change and red clearance interval calculations?

There is no pre-determined number of speed samples that should be collected in the field when conducting a field driving review or performing a speed study. Engineering judgment should be used to determine the most appropriate number of samples to collect for each location. Factors that should be considered as part of the decision-making process are: the size of the intersection, if a statistically valid result is desired, whether the median or 85th percentile speed is desired, and how much variability there is in the operating characteristics of the intersection. Documentation of the engineering decision is required (see FAQ No. 19).

FAQ No. 8 discusses how to perform a sensitivity analysis of the TE-306.1 equation input parameters on the calculated yellow change and red clearance intervals. The results of the sensitivity analysis for a specific location can assist the engineer with determining

whether a field driving review or a formal speed study is needed and if a statistically significant result is required. For example, when determining the red clearance time for a left-turn movement, a difference in speed is more impactful at a larger intersection than the same difference in speed at a smaller intersection, and therefore a more precise speed input may be desired. Generally speaking, the larger the sample size the more likely it is that the calculated value will be closer to the actual speed of the overall population of vehicles driving through that location.

The calculated sample size in the latest ITE *Manual of Transportation Engineering Studies* can be used as a starting point for determination of statistically valid sample sizes. The minimum sample size for statistical validity is generally between 20 and 35. A larger sample is required for a statistically valid determination of the 85th percentile speed than for the mean speed, as additional data points are needed when estimating values closer to the “tail” of a distribution of samples.

When collecting data in the field, it is important to understand the operating characteristics of the intersections (e.g. school arrival/dismissal times that would yield heavy vehicles during certain times) to determine the appropriate time of day to conduct field work and if the necessary size of the speed sample should change as a result of those conditions.

6) When conducting a formal speed study, should one use average, median, 15th percentile, or 85th percentile speed?

The TE-306.1 formulas are based on the 85th percentile speed, and this is the speed that is recommended for calculation of change and clearance intervals. Should engineering judgment determine that the mean or 15th percentile speed is more appropriate for a given location, it can be used, however the rationale for the decision shall be documented. For additional information related to speed studies, see FAQ No. 4.

7) What is the threshold or criteria for determining when a calculated yellow change and/or red clearance interval is “detrimental to operations”?

There is no defined threshold or criteria to establish when calculated intervals are “detrimental to operations” as intersection operations should be evaluated on an approach, intersection, and/or corridor basis.

When examining yellow change and red clearance interval impacts to intersection operations, there should be a dialogue between the engineer calculating the intervals, signal operations personnel, and other signal stakeholders. This dialogue should include discussion of the specific impacts the calculated timing has on operational characteristics such as progression, queuing, delay, and/or other measures of

effectiveness as compared to the existing signal timing parameters. A sensitivity analysis of the impacts of the TE-306.1 equation input parameters on the change and clearance intervals may be helpful to conduct as part of this process, as adjustment of the parameters may result in improved operation (see FAQ No. 8).

TE-306.1 allows the use of engineering judgment (supported by documentation, see FAQ No. 19) to determine the appropriate yellow change and/or red clearance interval value when the calculated interval for a specific movement at a given intersection is considered “detrimental to operations”. The engineer may invoke this allowance without additional study or evaluation of the parameters used in the equations so long as the rationale to substantiate the engineering judgment is documented (see FAQ No. 19). This documentation should include a discussion of how the calculated intervals were found to be “detrimental to operations” as well as why the final value was chosen.

8) Is there a way to perform a sensitivity analysis to see the effect of the equation parameters on performance?

The speed parameter in the TE-306.1 equations has the greatest impact on the resultant yellow change and red clearance interval durations. Although TE-306.1 presents a best practice to estimate the speed based on a posted speed and a default turning speed (practices recommended in NCHRP-731), a finer measurement of site-specific speeds may produce more accurate yellow change and red clearance intervals to support operational considerations. A sensitivity analysis of the input parameters can assist the engineer in determining if a more detailed analysis of speeds deserves consideration (see FAQ No. 3 for speed determination methods).

The charts below show the sensitivity of the yellow change interval based on speed and the sensitivity of the red clearance interval based on turning speed and intersection width. The engineer may use the information in the charts and knowledge of field conditions as a screening process to determine the potential time savings to the change or clearance interval. A decision on whether to expend resources to conduct field speed measurements may then be made based on the potential time savings.

Yellow Change Interval Sensitivity Analysis:

SPEED LIMIT	DIFFERENCE IN APPROACH SPEED (POSTED SPEED LIMIT plus value indicated in mph)															
	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9	+10	+11	+12	+13	+14	+15
25	2.8	2.9	3.0	3.1	3.1	3.2	3.3	3.4	3.4	3.5	3.6	3.6	3.7	3.8	3.9	3.9
30	3.2	3.3	3.4	3.4	3.5	3.6	3.6	3.7	3.8	3.9	3.9	4.0	4.1	4.2	4.2	4.3
35	3.6	3.6	3.7	3.8	3.9	3.9	4.0	4.1	4.2	4.2	4.3	4.4	4.5	4.5	4.6	4.7
40	3.9	4.0	4.1	4.2	4.2	4.3	4.4	4.5	4.5	4.6	4.7	4.7	4.8	4.9	5.0	5.0
45	4.3	4.4	4.5	4.5	4.6	4.7	4.7	4.8	4.9	5.0	5.0	5.1	5.2	5.3	5.3	5.4
50	4.7	4.7	4.8	4.9	5.0	5.0	5.1	5.2	5.3	5.3	5.4	5.5	5.6	5.6	5.7	5.8
55	5.0	5.1	5.2	5.3	5.3	5.4	5.5	5.6	5.6	5.7	5.8	5.9	5.9	6.0	6.1	6.1
60	5.4	5.5	5.6	5.6	5.7	5.8	5.9	5.9	6.0	6.1	6.1	6.2	6.3	6.4	6.4	6.5

For a given speed limit, each row represents the yellow change interval duration using the speed limit plus the column value and an assumed 0% grade. The blue column represents the interval duration using the “speed limit plus 7 mph” best practice value.

Values in yellow are yellow change interval times within 0.5 seconds of the “plus 7” value. Values in orange are more than 0.5 seconds below the “plus 7” value and values in green are greater than 0.5 seconds above the “plus 7 value”.

As an example, for a location with a speed limit of 40 mph, applying the default best practice speed of “plus 7” results in a yellow change interval duration of 4.5 seconds. In order to reduce the yellow change interval by 0.5 seconds (yellow change interval duration of 4 seconds), the field measured 85th percentile speed would need to be 41 mph (shown in the 40 mph +1 cell in the table).

Red Clearance Interval Sensitivity Analysis:

Equation 2 Numerator (Intersection Width for Left-Turn - FT)	LEFT TURNING SPEED (MPH)										
	20 (Default)	21	22	23	24	25	26	27	28	29	30
100	4.1	3.9	3.7	3.5	3.4	3.3	3.1	3.0	2.9	2.8	2.7
105	4.3	4.0	3.9	3.7	3.5	3.4	3.3	3.1	3.0	2.9	2.8
110	4.4	4.2	4.0	3.8	3.7	3.5	3.4	3.3	3.2	3.0	2.9
115	4.6	4.4	4.2	4.0	3.8	3.7	3.5	3.4	3.3	3.2	3.1
120	4.8	4.5	4.3	4.1	4.0	3.8	3.7	3.5	3.4	3.3	3.2
125	4.9	4.7	4.5	4.3	4.1	3.9	3.8	3.7	3.5	3.4	3.3
130	5.1	4.9	4.6	4.4	4.3	4.1	3.9	3.8	3.6	3.5	3.4
135	5.3	5.0	4.8	4.6	4.4	4.2	4.1	3.9	3.8	3.6	3.5
140	5.4	5.2	4.9	4.7	4.5	4.4	4.2	4.0	3.9	3.8	3.6
145	5.6	5.3	5.1	4.9	4.7	4.5	4.3	4.2	4.0	3.9	3.7
150	5.8	5.5	5.3	5.0	4.8	4.6	4.4	4.3	4.1	4.0	3.9
155	6.0	5.7	5.4	5.2	5.0	4.8	4.6	4.4	4.3	4.1	4.0
160	6.1	5.8	5.6	5.3	5.1	4.9	4.7	4.5	4.4	4.2	4.1

For a given intersection width, each row represents the red clearance interval duration using the various left-turn speeds. The blue 20 mph column represents the interval duration using the default policy speed.

Values in orange are within 0.5 seconds of the red clearance interval duration using the default policy speed. Value in yellow are between 0.5 and 1 second, dark green values are between 1 and 1.5 seconds, light green values are between 1.5 and 2 seconds, and light blue values are greater than 2 seconds of the red clearance interval duration using the default policy speed.

As can be seen, at an intersection with a 140-foot width, a refined speed value of 25 mph would result in a red clearance interval of 4.4 seconds-reducing the red clearance interval by 1 second compared to the default policy speed.

- 9) In the all-red clearance interval calculation, the turning speed of 20 mph for left turn movements does not always seem appropriate for exceptionally wide intersections with sweeping left turn movements that operate with a larger radii. Is there an alternate method to derive the all-red clearance time for this type of intersection?**

At intersections with larger radii, which may allow left turning speeds higher than the default speed, the formula and assumptions in TE-306.1 may result in all-red clearance intervals that are longer than needed. Since these larger intersections are often located in areas with high levels of congestion, it is desirable to have an all-red clearance

interval that is only as long as is actually necessary to clear the intersection. There is an alternative methodology that can be used to determine the all-red clearance times for left-turn movements at these locations.

This alternative method utilizes field collection of a statistically valid sample of the travel time for vehicles passing through the intersection, and subtracting one second. This method may be more useful than conducting a formal speed study for left-turn movements. As a result of a careful evaluation, VDOT has determined that this alternative methodology is acceptable for the purpose of determining the length of the all-red clearance interval. It is not advisable for this methodology to be used for engineering determinations other than calculating the red clearance interval at a traffic signal.

This alternative travel time methodology is not intended to be a substitute for applying the methodology in TE-306.1. The formulas for TE-306.1 should be applied first. This alternative method will likely have the greatest benefit where the calculated all-red clearance interval is greater than or equal to 5 seconds and/or engineering judgment determines that this is detrimental to the intersection's operation.

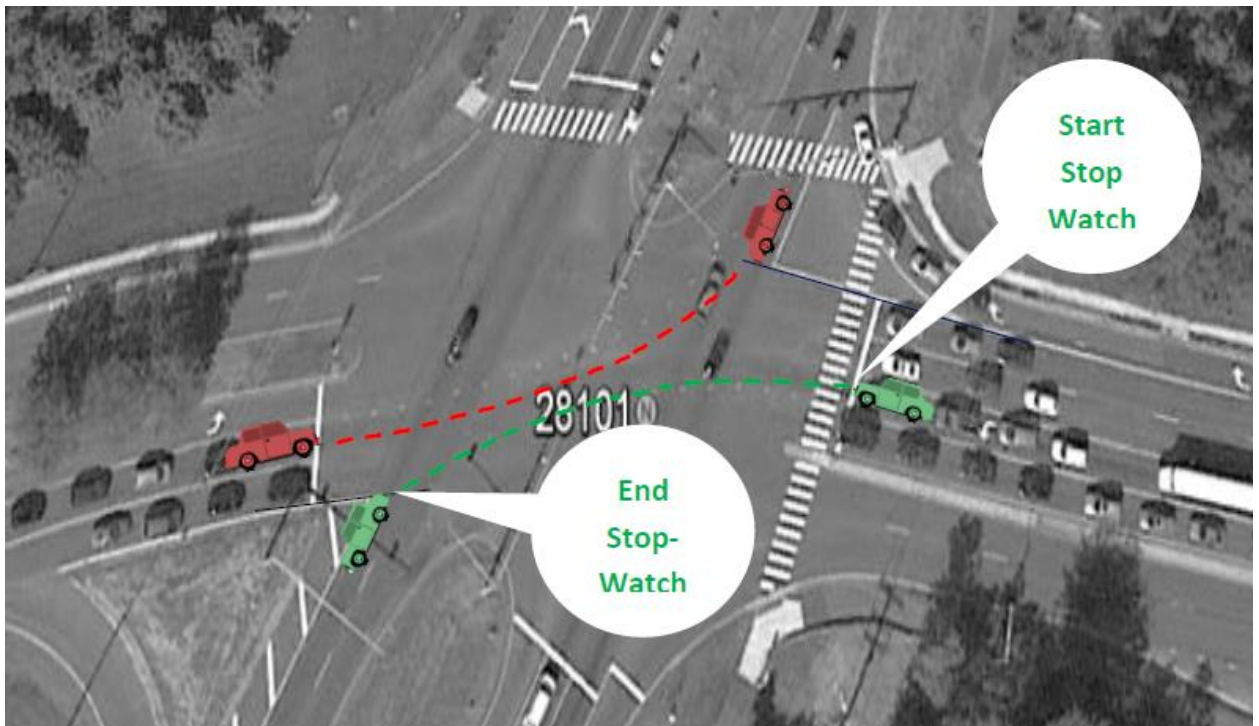
The portion of the formula for the all-red clearance interval in TE-306.1 $(w + L) / (1.47 * V)$ is used to determine the vehicle travel time through the intersection based on an estimate of the vehicle length, travel path, and speed. Since the TE-306.1 formula takes the estimated travel time less one second (see FAQ No. 1), using actual travel times observed in the field and subtracting one second will give an appropriate result without relying upon an assumed travel speed of 20 mph.

The first step of the process is to collect travel time data. In order to ensure that the field data collected is accurate, the specific process outlined below should be followed in the field. There is a minimum number of samples needed to ensure a statistically-valid result. The data collection process is as follows.

Field Data Procedures for Left Turn All-Red Travel Times where Calculated All-Red is ≥ 5 Seconds

The intent of the field data collection effort is to capture the travel time for left turning vehicles to fully clear the intersection. Specifically the travel time is the time (in seconds) taken by a vehicle already in motion, from the back edge of the stop line to the point where the vehicle intersects with the virtual extension of the curb line or outside edge of the farthest travel-lane. This is shown in the diagram below, with the travel path during the travel time measurements shown with a dashed line.

- If there are multiple left turn lanes, the outside left turn path is the more appropriate path to be measured. Please note that lane serving the outside left-turn path may be shared as a left-turn/through lane.



- As seen in the diagram above, the time to capture starts when the front/bumper of the car passes the back edge of the stop line and ends when the rear end of car passes the extension of the curb line or outside edge of the farthest travel-lane.
- Vehicles meeting the criteria below should be randomly selected for measurement.
 - The vehicle to be measured should be a passenger car, and not a heavy vehicle.
 - Police, fire, or other emergency vehicles should not be selected, as the vehicle may not be operated “normally” while emergency personnel are carrying out their duties.
 - Vehicles in full motion and preferably those traveling during yellow change interval are desirable.
 - Vehicles that are slowing at the end of the travel path due to congestion on the receiving lanes or other obstructions should not be measured.
 - The first three left turn vehicles in a cycle should not be used for the measurement due to start up lost time. Therefore data collection should be performed at times when there is sufficient left turn volume. However care should be taken not to collect data when the movement being measured and the associated receiving lanes are congested. A review of traffic volumes is

recommended to make this determination of the most appropriate time to collect data and to make the most efficient use of time at the site.

- If the travel time for a specific vehicle is collected and subsequently not included in the travel time analysis (i.e., removed as an outlier), documentation of the rationale for removing the data point should be provided. Numbers on the extremities of a data collection set should not be removed arbitrarily simply because they do not yield a desired result. One example of an acceptable reason for not including a data point is a vehicle whose driver abruptly slows to turn into a driveway on the receiving lanes. The travel time should still be collected with a notation that the data point may be invalid with a stated reason why. Otherwise, “outlier” data points should not be excluded from the analysis simply because they appear to be longer or shorter than the other measurements.
- The field data collector should position himself in a location such that he has an unobstructed view-point where he can clearly capture the front-of-vehicle leaving the stop line and end-of-vehicle exiting the virtual line. It may be helpful to mark the extension of the curb line or outside edge of the furthest travel lane across the receiving lane with chalk.
- The field data collector should use a stop watch to capture this time using the start and end points and vehicle reference location shown in the diagram and described above. The stop watch should be started when the front of the vehicle crosses the stop bar and stopped when the rear of the vehicle crosses the extension of the curb line or the outside edge of the nearest travel lane.
- The minimum number of vehicles to be timed depends upon whether the 15th percentile travel time (equivalent to the 85th percentile speed) or the average travel time is going to be used in the analysis.
 - If the mean travel time is desired, a minimum of 20 data points should be obtained in the field and used in the calculation to obtain a statistically valid result.
 - If the 15th percentile travel time is desired, the minimum number of data points for statistical validity is 35.

After the data collection is complete, the all-red clearance time is calculated by taking the mean travel time or 15th percentile travel time (depending upon the number of data points collected) rounding up to the nearest 0.1 second, and subtracting one second in order to be consistent with the formula in TE-306.1. The raw data, analysis, and associated documentation should be retained for future reference and described in the comment section of the signed/sealed worksheet (see FAQ No. 19 for additional information related to documentation).

10) How should the speed parameter be determined on short approaches (such as parking areas or commercial driveways)?

There are many factors that come into the decision as to what speed to use on short approaches, particularly exiting parking areas or other facilities with circuitous travel. Engineering judgment is necessary for any such condition and the rationale to substantiate the engineering judgment decision is required to be documented (see FAQ No. 19).

A speed study is not required; however FAQ No. 4 provides recommended methods for obtaining speeds that could be applied to short approaches.

If the speed limit is posted, it could be used as the speed limit for the calculation variables “speed limit plus 7 mph” and “speed limit minus 5 mph” unless field observations or local knowledge indicate a different speed is more appropriate.

The engineer may conduct field driving observations (see FAQ No. 3) on the approach to identify the appropriate approach speed(s). These observations would support the documentation requirement for engineering judgment (see FAQ No 19).

Additional factors and rationale impacting speed characteristics on short approaches that may be considered could include:

- The alignment of the driving aisle leading up to the traffic signal stop bar. For example, do vehicles approach from the sides similar to a service roadway or is the aisle from the parking area in direct alignment with the intersection similar to a traditional intersection approach?
- Parking space configuration. Do parking spaces introduce friction directly into the main driving aisle up to the signal?
- Circulation routes in relation to the stop bar and intersection entry point. For example, are multiple aisles in the parking area competing at one spot prior to entering the intersection?
- Storage length. Does the short signalized approach only accommodate 1-2 vehicles, thereby limiting the distance over which vehicles can achieve typical approach speed?

11) When evaluating an exclusive U-turn movement what speed should be used?

A U-turning vehicle speed depends on intersection geometric considerations such as median width, median shape, receiving lane width, and the number of receiving lanes. In some cases, the default approach and turning speeds for left-turn movements may be appropriate for determining the yellow clearance and red change intervals, however engineering judgment should verify the appropriateness of these assumptions in the field. Should a specific intersection operation and geometry suggest that a different

approach speed or turning speed be identified for an exclusive U-turn movement (i.e., a protected-only U-turn phase and exclusive U-turn movement lane), engineering judgment should be applied to determine the most appropriate speed to be used. The alternative travel time methodology presented in FAQ No. 9 may be used in lieu of determining the turning speed when calculating the all-red clearance time for an exclusive U-turn movement.

The unique contributing factors to speed in this case do not allow for more specific guidelines. The approach speed decision will depend on a case-by-case assessment by the engineer. See FAQ No. 3 for speed determination methods.

GRADE

12) What are the appropriate method(s) to determine grade?

It is important to note the relative impact of grade on the resulting yellow change interval calculation. A 1% difference in grade results in a 0.1 second difference in the yellow change interval. Precision in grade constitutes a minor component in the resulting calculations; however this should not diminish the need for obtaining the appropriate grade value.

In most cases, in-office grade measurement methods provide an acceptable means to determine grade for yellow change interval calculations. Such methods include review of roadway plans or using Google Earth elevations (or other readily available geospatial data sources). It is suggested that site observations be performed when applying a grade measurement method in the office.

In some cases, field methods must be used if there is not sufficient data to perform in-office grade measurements. Often times, changes in grade near the intersection can influence the decision on the appropriate grade to use, and it may be appropriate to reflect this through engineering judgment.

Various grade measurement methods are summarized in the table below. Accuracy and cost of different methods depends on the availability of information in the given case (survey data, road design plans, etc.).

Method	Pros	Cons
Office Methods		
Google Earth Elevations <ul style="list-style-type: none"> • Within the tool, obtaining spot elevations located a measured distance apart and calculating percent grade. 	Google Earth is a readily-available tool, grade information is quick to retrieve, and the method is cost-effective.	For a full understanding of conditions, one still needs an “on-street” view and in many cases field reconnaissance for unusual cases.
Roadway Plans <ul style="list-style-type: none"> • Obtaining % grade from roadway profile plans. 	<i>When plans are readily available</i> , the grade information is accurate, quick to retrieve, and in these cases the method is cost-effective.	It is often difficult to find roadway plans for existing intersections. For atypical scenarios, using <i>only</i> plans can be misleading for understanding the full context of geometry and operations.
Field Methods		
Survey of Spot Elevations <ul style="list-style-type: none"> • Using surveyed spot elevations at specified distances apart, calculate the percent grade. 	<i>When survey elevation data is readily available</i> , the grade information is accurate, quick to calculate, and in these cases the method is cost-effective.	Survey is more expensive in general and often times the vertical survey or elevation data are not obtained for signal design plans. If survey crews are already on-site and elevation locations can be specified by the designer in advance, then this is a viable option.
Field Measurements <ul style="list-style-type: none"> • Measuring the grade on the roadside with a level. A longer level will yield less inconsistencies due to ground conditions. A 4-ft level is desirable. 	This is a low-cost alternative that allows the designer the option to perform site reconnaissance to fully explore the operational and geometric context for the calculation. This method is relatively cost effective since the measurements can be performed during other commonly-planned field reconnaissance.	This method requires a field visit. Greater variability may result from the specific locations measured. This method is less accurate than survey data, but can be more accurate than methods performed in the office alone.

13) What are the appropriate method(s) to calculate grade once data is available?

For clearance interval applications, grade can be calculated by several methods. It is implied that the engineer will calculate the grade in the most appropriate method that best accounts for the features of the location being investigated, available data, and engineering judgment.

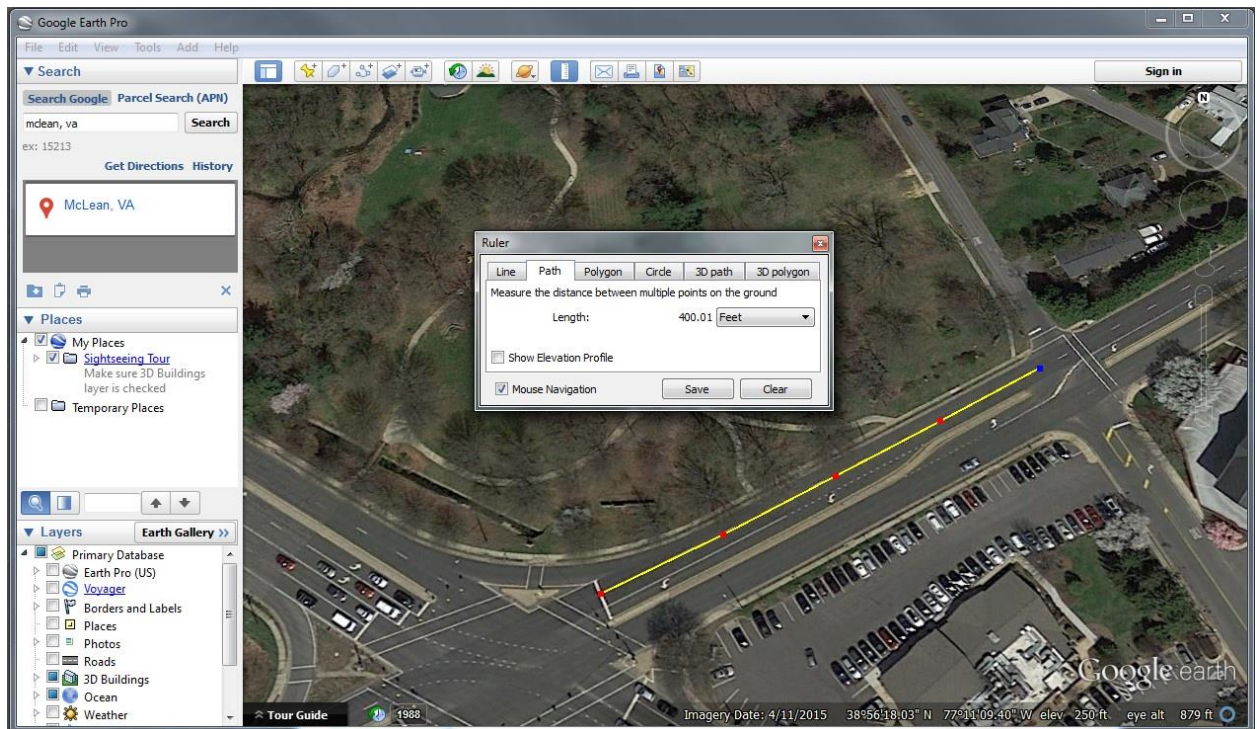
Acceptable methods include:

- 1) Calculating the elevation difference from the stop line and a point 400' upstream of the stop line;
- 2) If notable changes in grade are observed in the 400' area described in #1 above, calculating/measuring the grade at 100' intervals between the stop line and a point 400' upstream, to determine the most appropriate grade through engineering judgment;
- 3) Using the grade as indicated on plans for either of the methods in #1 and #2 above.

An example of grade calculation using Google Earth and measurements made at 100' intervals is shown below.

Example of Grade Measurements Using Google Earth Elevations at 100' intervals:

Elevation = 260' @ stop bar
 Elevation = 261' @ 100' from stop bar
 Elevation = 262' @ 200' from stop bar
 Elevation = 264' @ 300' from stop bar
 Elevation = 266' @ 400' from stop bar



---> Grade selected is 1.5% downgrade, in accordance with TE-306.1 rounded to 2%.

INTERSECTION WIDTH

14) In determining the intersection width, what distance is being measured?

When determining the intersection width and selecting the appropriate end point of the travel path, the engineer is determining the longest path through the intersection the vehicle needs to travel in order to not be in conflict with traffic entering from other approaches. The path should consider all approaches that could be entering the intersection during the next phase, not just the opposing through or left-turn movement.

Typically, a pedestrian crosswalk controlled by pedestrian signals on the receiving lane is not included in the measurement of the distance, however there is an exception to this rule-of-thumb discussed in FAQ No. 15.

The method shown in TE-306.1 (Figure 1 and Figure 2) is appropriate for most “standard” intersections where approaches meet at approximately 90-degrees. For non-standard intersections, such as those with a significant skew, less than or greater than four approaches, or offset side streets, engineering judgement should be applied to determine the intersection width. Additional information can be found in FAQ No. 15.

15) How should intersection widths be measured for non-standard intersections (e.g. 2 offset intersections, skewed intersection, exclusive U-turn lanes, etc.)?

The configurations of many atypical intersections result in vehicle travel paths that are not “straight” or do not follow a typical path for a 90-degree turn. For all cases, the most suitable distance to measure is the actual vehicle travel path to the conflict point. This can be determined through vehicle turning template software, field observation, or an assessment of aerial photos. Often times the vehicle travel paths can be discerned by a strip of discolored roadway surface where vehicles travel.

For turning movements, it is recommended that the vehicle path to the furthest receiving lane be utilized for the measurement, despite whether the natural path of vehicle travels to the nearest receiving lane. This guidance should be applied for traditional intersections, as well, and should follow the general shape of the inner-turn path. When there are dotted line markings (commonly referred to as “puppy tracks”) for the left-turn movement, the longest turning distance in reference to the dotted line markings is recommended.

The phase sequence can also be considered when determining the intersection width. In other words, the green phase(s) that can follow the clearance interval and where

vehicles for that next phase will enter the intersection. However, if a width or vehicle path is shortened from the “traditional” location as described in TE-306.1, it is important to ensure the sequencing will not be changed in the future by operations or maintenance staff. Another important consideration with this method is that phases will not be skipped in the absence of demand under any timing plan, which is the case for many actuated or semi-actuated signals, as well as signals with emergency vehicle pre-emption. This is an acceptable application of engineering judgment and should be documented.

For T-intersections, the end point of the travel path for mainline vehicles clearing the intersection prior to the side street vehicles entering the intersection may only need to extend to the centerline or median of the side street, depending on the mainline direction of travel in relation to the orientation of the side street. This is demonstrated in the second example, specifically the 156' distance shown. The end point of the travel path for left-turning vehicles entering from the stem of the T should extend to the point where the travel path crosses an extension of the side street's curb line. This is demonstrated in the third example.

For skewed intersections, the end point location of the width measurement often requires engineering judgment. In some cases, such as where there is a skewed intersection, the direct extension of the outside edge of the farthest travel lane results in a tangent line that is angled into the intersection, resulting in a shorter width measurement. For example, consider the Phase 1 approach in the figure below. The measurement of the northbound left-turn travel path onto the mainline should be measured to the point at which a vehicle would pass this approach. If a direct (tangent) extension of the outside edge of the farthest travel lane was used to define the end point, the 186' measurement would be closer to 160'. If the geometry or radius of an approach for the next phase permits a vehicle to enter the intersection further downstream of the direct extension (tangent) endpoint, an alternate endpoint may be appropriate (e.g., the 186' measurement in the example below). The determination of the end point for this width measurement is site-specific and engineering judgment is needed.

In the case of exclusive U-turn phases, there are many issues to consider that impact both speed and distance measured. It depends on the size of the turn, the number of receiving lanes, practicality of entering the left-most receiving lane, the type of vehicles likely to make U-turns, the orientation of the left turn stop bar compared to the location of the farthest edge of the intersection, and phasing (i.e., which conflicting movement follows the U-turn).

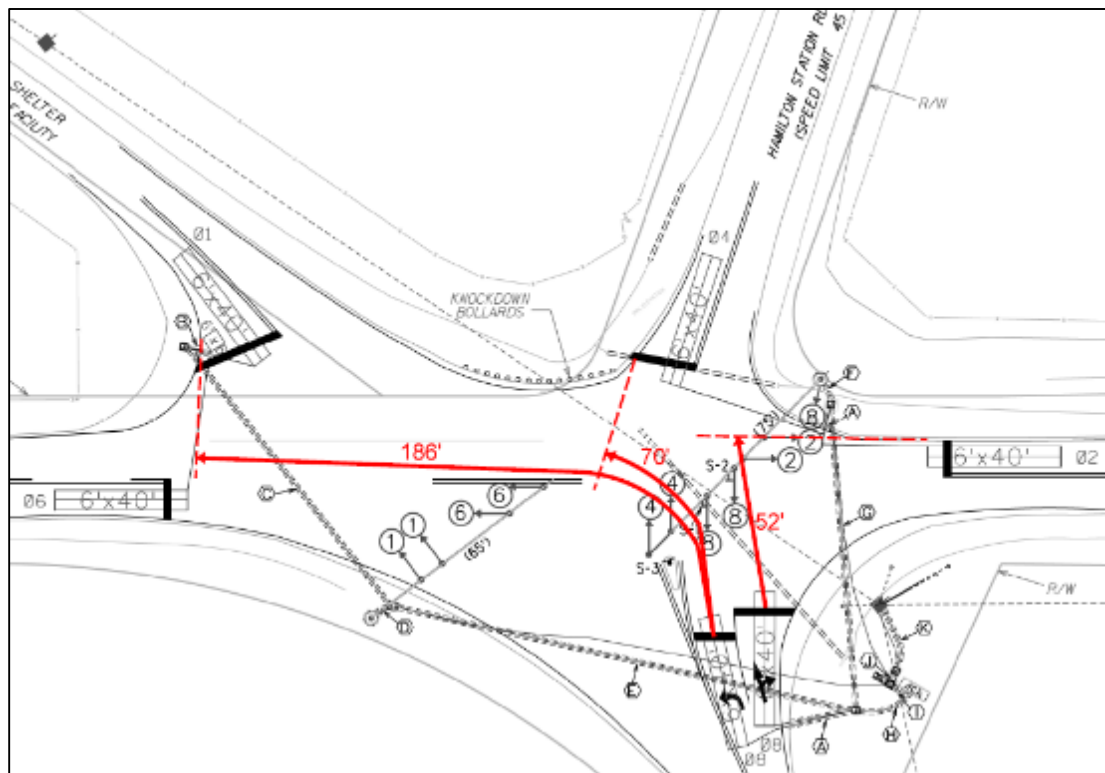
Generally speaking, the distance should be measured according to the vehicle path to a point where the vehicle has cleared the curb line of the intersecting side street.

For the vehicle path of a U-turning vehicle, a turn template software in the CAD environment can be used to measure the specific path. For multi-lane receiving approaches, measure the turn to the furthest receiving lane so as to obtain the most conservative distance.

Typically, a pedestrian crosswalk controlled by pedestrian signals on the receiving lane is not included in the measurement of the distance. However if the nearest pedestrian crossing line is 40 feet or more from the extension of the farthest edge of the farthest conflicting traffic lane, then the distance should be measured to the nearest pedestrian crossing line.

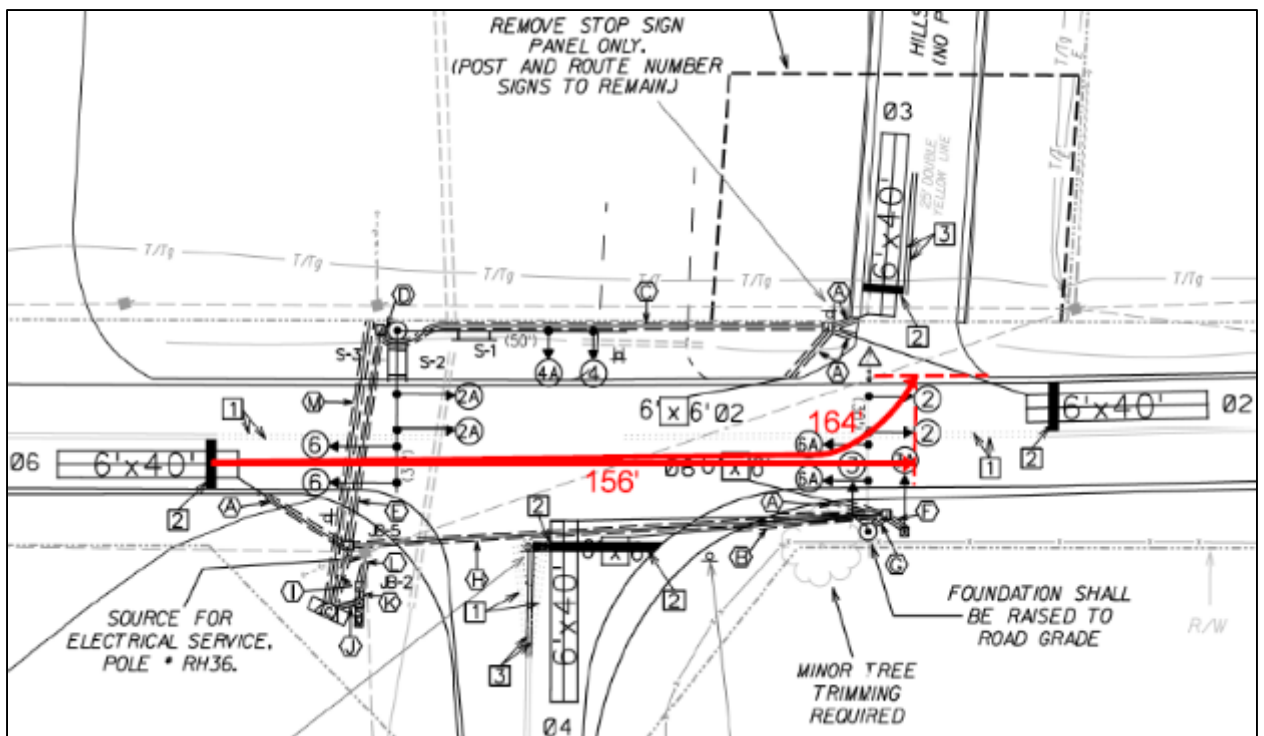
Examples of measurements for atypical intersections are shown below.

Example for Atypical Intersection: Intersection Width of 186' selected for Phase 8
 Considering the hypothetical case where Phase 4 follows Phase 8 in the phase sequence, if no demand exists on the Phase 4 approach, then Phase 4 could be skipped and Phase 1 would follow Phase 8. Therefore, the longer measurement of 186' should be selected. However, if the phase sequencing is fixed and Phase 4 always follows Phase 8, the measurement of 70' may be used provided the engineering judgment behind this decision is documented.



Example of Measurements for Closely Spaced Intersection with Single Controller: For Phase 6, Selected 164' as the Longest Length Movement for the Phase.

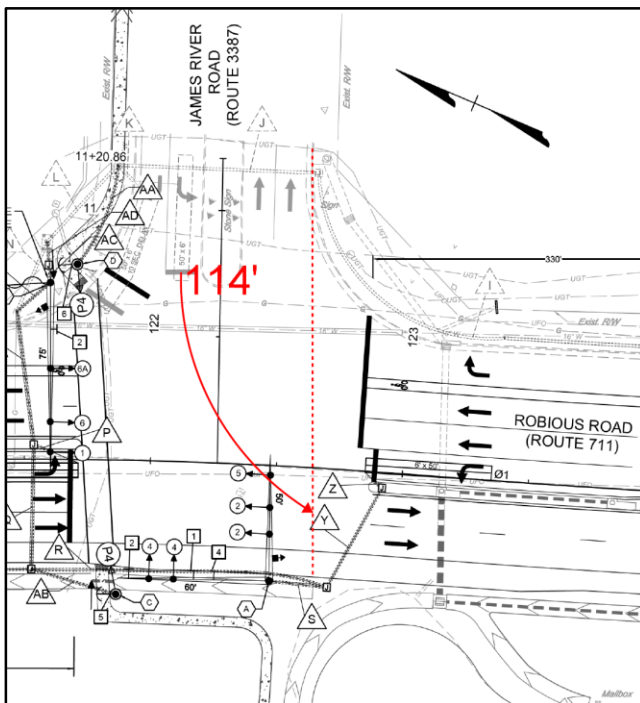
For a single offset intersection, specifically one that is configured with mainline stop bars only on the "outside" of both side street approaches, the measured distances should extend to the far side of the farthest side street approach. This assumes that the intersection is operated by a single controller, all movements operate as a singular phase, and overlaps and/or signal delays are not programmed into the controller. For two closely spaced intersections, where there are mainline stop bars to allow queuing in between side streets in both directions, the measured distances should span only the individual intersections (i.e. standard measurement procedures). Engineering judgment should be documented in the determination of yellow change and red clearance intervals for single offset intersections.



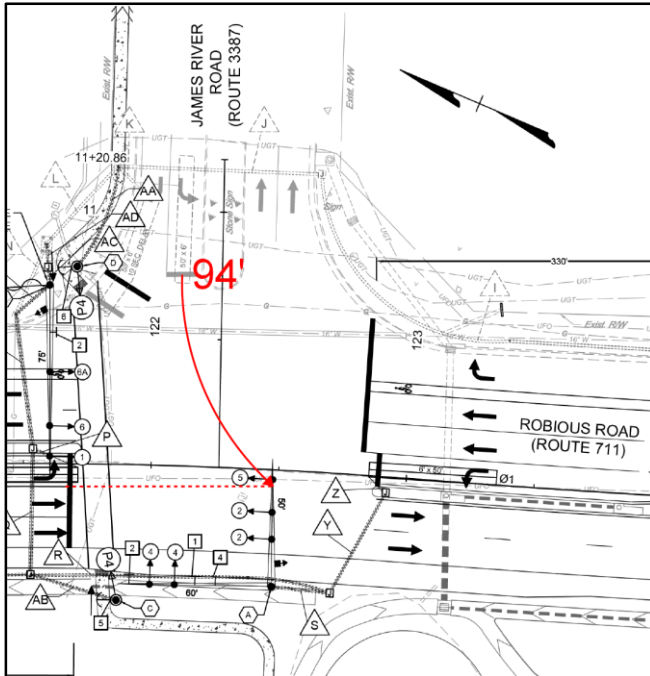
Examples of Measurements for stem of a T-intersection.

Below are three examples of measurements for left-turns from the stem of a T-intersection, all of which meet the intent of TE-306.1. Since the vehicle is turning into different potential paths of subsequent conflicting traffic, there is some room for engineering judgment in the decision for where to terminate the measurement. The engineer should determine the most appropriate end point for the measurement of left-turning distance based on the intersection's geometry, the phasing, and sequencing.

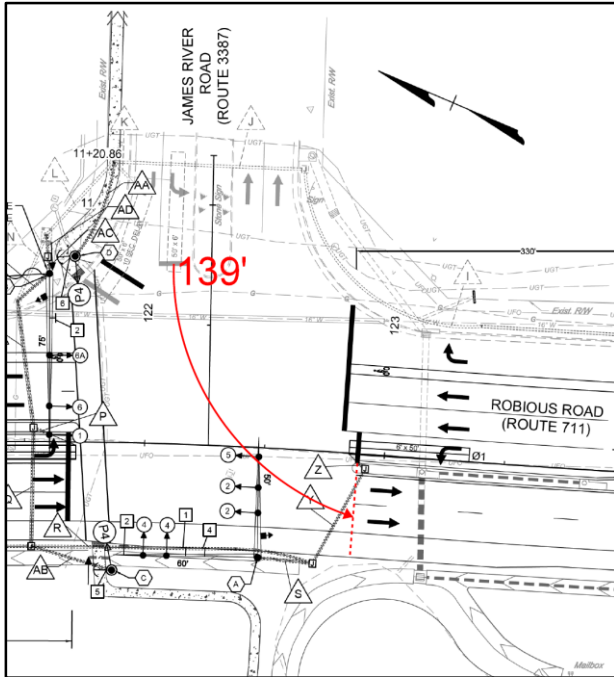
- TE-306.1 indicates that the intersection width, w , for turn movements should be measured to the “farthest edge as defined by the extension of the curb line or outside edge of the farthest travel lane.” In the case of a T-intersection, the far-side curb extension does not exist as there is no 4th leg on the far side. The example below measures to the extension of the near-side curb line extension as a “virtual” extension of what would have been the 4th leg.



- *The example below measures to the near edge of the far-side through travel lanes into which the turning traffic is entering. Depending on the intersection, some may consider the next set of moving vehicles that would likely be “in conflict” with the turning movement as the near-side through travel lanes (NB) and the far-side left turn lane. So in this example the “w” represents the vehicle clearing those potentially conflicting movements. Under this scenario, the engineer is assessing that once the turning vehicle is in view of and in alignment with the far-side through lanes (SB) that are proceeding in the same general direction as the turn movement, that no such conflict exists.*



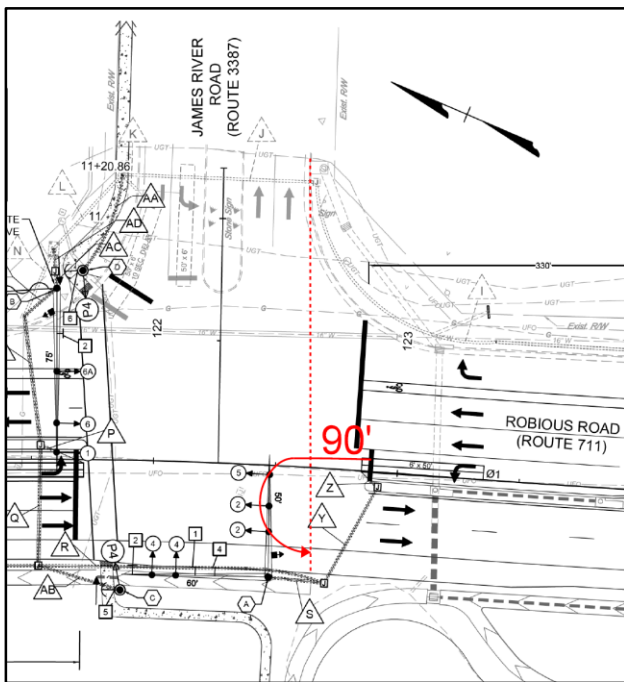
- *The example below measures to the extension of the stop bar on the destination leg. This is the more conservative measurement that could reasonably be used.*



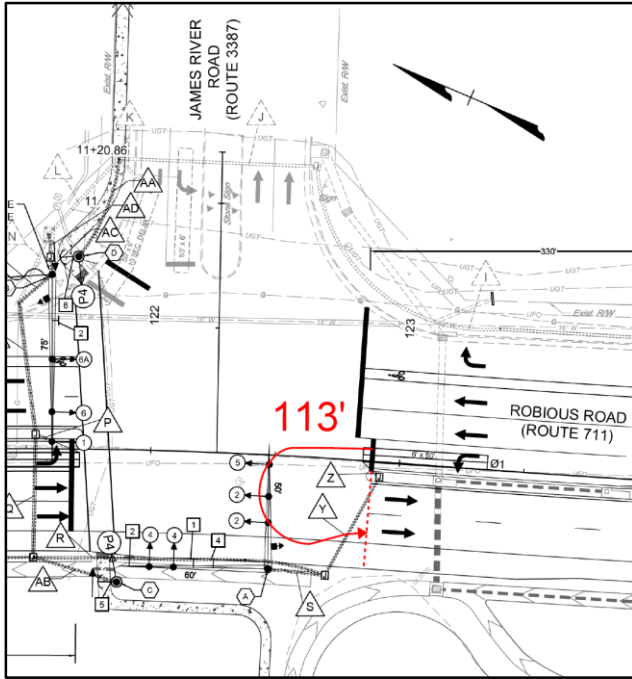
Examples of Measurements for an exclusive U-turn movement.

Below are two examples of measurements for U-turns made from an exclusive U-turn lane where there is no option to make a left-turn. Similar to left-turns from the stem of a T-intersection, there is some room for engineering judgment in the decision for where to terminate the distance measurement. The engineer should determine the most appropriate end point for the measurement based on the intersection's geometry, the phasing, and sequencing.

- TE-306.1 indicates that the intersection width, w , for turn movements should be measured to the “farthest edge as defined by the extension of the curb line or outside edge of the farthest travel lane.” In the case of a T-intersection, the far-side curb extension does not exist as there is no 4th leg on the far side. The example below measures to the extension of the near-side curb line extension as a “virtual” extension of what would have been the 4th leg.



- *The example below measures to the extension of the median nose on the destination leg. This is the most conservative measurement that could reasonably be used.*



VEHICLE LENGTH

16) When is it appropriate to use a longer vehicle length in calculating the red clearance interval?

TE-306.1 utilizes a vehicle length of 20 feet for calculation of the red clearance interval. No change to that length is recommended for typical situations. In the most recent national study of clearance and change intervals (NCHRP-731), the length of the vehicle used in the calculation of the red clearance interval typically ranged from 15 feet to 20 feet. At the time of that research, AASHTO specified a design passenger car as 19 feet. Arguments have been made to consider larger vehicles in the red clearance interval calculations, such as single-unit trucks (30 feet) or intermediate semitrailers (55 feet).

Using a longer vehicle length in the equation would increase the duration of the red clearance interval. However, conflicting vehicular traffic is obligated to yield the right-of-way to other vehicles legally in the intersection, which would include larger vehicles. Additionally, large vehicles in the intersection are typically fully visible to stopped vehicles about to receive a green indication and initiating movement.

When considering longer vehicle lengths, the practitioner may perform a screening on-site review to determine the actual time it takes for vehicles to clear the intersection. If it is determined based on the field observations that the calculated interval does not provide adequate time, then adjustments to the red clearance interval calculation parameters (speed and/or vehicle length) should be considered. For speed determination methods, refer to FAQ No. 3. For information about determining red clearance intervals based on travel time, see FAQ No. 9. For classification studies refer to FAQ No. 17.

17) What is the most cost-effective method to conduct a classification study?

TE-306.1 provides the option to utilize a longer vehicle length when a classification study is performed. Although it is typically not necessary, should engineering judgment determine that a longer vehicle length is desired, a classification count should be performed utilizing the FHWA vehicle classifications and average lengths.

Guidance regarding how to interpret the results of this study for clearance interval applications is not available at this time. If a classification study is performed for this purpose, engineering judgment should be applied to interpret the results of the study in order to determine if a longer vehicle length is appropriate for use in the red clearance interval equation.

PHASING CONSIDERATIONS

18) Can the application of yellow change and red clearance intervals differ from the policy for lagging protected left-turns and split phases without shared signal faces?

For both scenarios described in the question, TE-306.1 indicates the intervals shall be implemented as calculated and the related phases do not have to end concurrently with adjacent or opposing phases. This results in the shortest reasonable values. There has been some preference to provide concurrent termination. If it is decided through engineering judgment that the phases should still end concurrently, then this is an acceptable situation to apply engineering judgment and select the longer of the intervals instead of using the values as calculated. The rationale should be documented (see FAQ No. 19).

The engineer should consider the impacts of signal operations when selecting the longer yellow change and/or red clearance intervals as a result of concurrent termination.

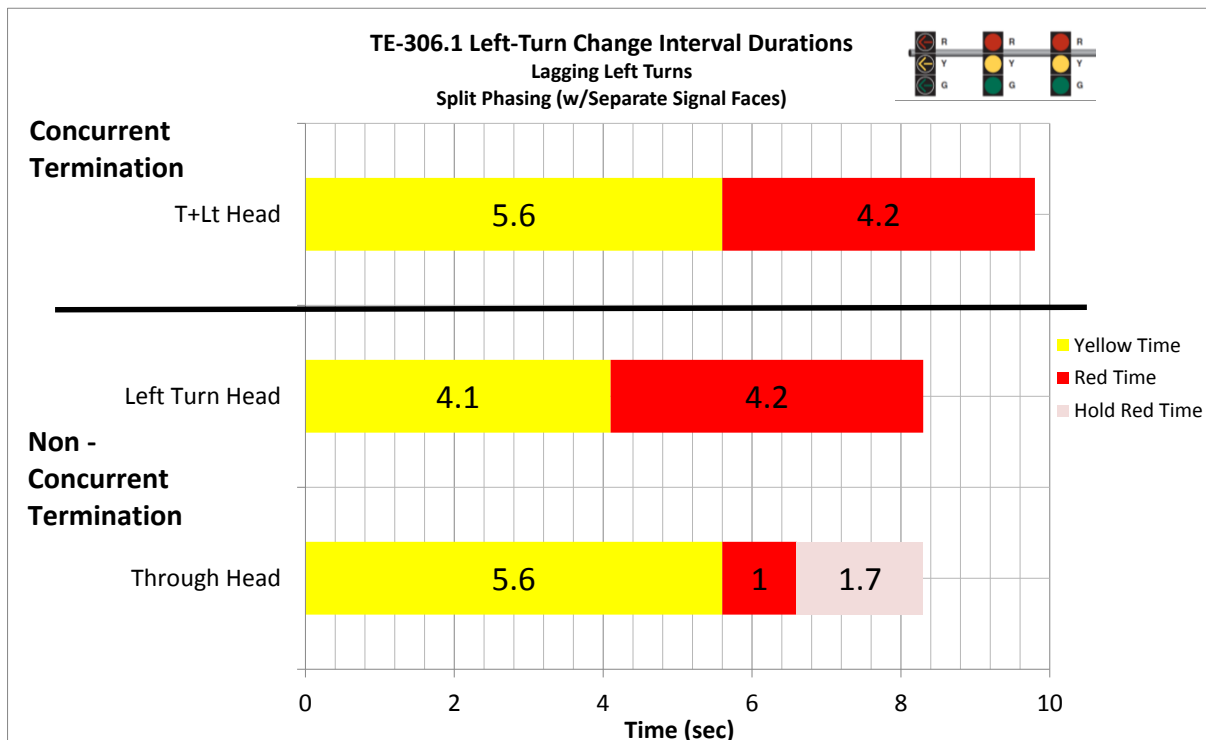
The example on the next page shows how concurrent termination can affect the total yellow and red time.

Example of Timing Impact of Concurrent and Non-Concurrent Signal Termination for Lagging Left-Turn

- **Calculated Yellow Change and Red Clearance Intervals**

Movement	Yellow Change Interval (sec)	Red Clearance Interval (sec)
Through	5.6	1
Left-Turn	4.1	4.2

- **Phasing Considerations for Non-Concurrent Termination (policy default):** apply the calculated through and left-turn yellow change and red clearance intervals. For the left-turn movement the total time is 8.3 seconds, and for the through movement the total time is 6.6 seconds (note that a 1.7 second red hold is shown for the through movement as applied by many controllers in this situation to assure both the left-turn and through movement phases cross the barrier simultaneously).
- **Phasing Considerations for Concurrent Termination:** apply the longer of the calculated through / left-turn movement yellow change (5.6 second) and red clearance (4.2 second) interval for a total time of 9.8 seconds.
- **Discussion:** Applying non-concurrent termination in this specific situation results in 1.5 seconds less time applied to the total yellow change and red clearance interval time, while still providing appropriate intervals for each movement. See figure below.



ENGINEERING JUDGMENT

19) What is the appropriate level of documentation when engineering judgment is applied?

TE-306.1 requires all applications of engineering judgment to be documented and maintained with the signed and sealed document. This information is invaluable during reviews and when engineers return to the document in the future.

In all cases, the appropriate level of documentation is a localized choice. Documentation of every decision and variable is not needed. Additional documentation may be required based on local or regional preferences.

Documentation of engineering judgment should explain the parameter to which the engineering judgment is being applied, the rationale behind the decision (factors considered), and the conclusion. More detailed engineering judgment documentation is more important for atypical situations. There is no set length that can define the appropriate level of documentation. Figures, plan mark-ups and field notes are effective examples of methods to document many decisions.

Sample documentation of engineering judgment is included below:

Grade – Although TE-306.1 requires measuring grade 400 feet in advance of the stop bar, site-specific considerations may include horizontal geometry and side street configuration. When a grade other than that taken at 400 feet is used, documentation is required to support the engineering judgment. See image below.

Speed – At times there are unique geometric configurations on approaches to intersections that may deserve consideration of an approach speed different from the posted or statutory speed limits, and a formal speed study at all of these locations may not be practical. Examples of such operational and geometric situations include: service roadways on the minor approach with a stop condition prior to approaching the main stop bar or approaches with sharp turns just prior to the intersection thereby affecting travel speed. For such conditions, engineering judgment, field observations, and field driving observations are the primary tools to determine approach speed. Documentation of findings and rationale behind the engineering judgment is important.

Intersection Width – The travel distance measurement is important to document for atypical intersection configurations or if the points from which measurements were taken are different from TE-306.1 guidelines. Sometimes a graphic is helpful in the documentation if words alone cannot sufficiently define the situation. Pursuant to the policy, it is not necessary to document every distance measurement; however individual regions may prefer to have this documentation included. If the engineer

finds an atypical situation where the distance chosen differs from the TE-306.1 guidelines, then it should be documented. See FAQ No. 10 for additional information.

Example of Engineering Judgment Documentation – Grade

This documentation could also be supported by Google Earth graphics as shown in the example in FAQ No. 13.

Additional Notes: (1) Grade measurements were made using Google Earth elevation measurements between stop bar and 400-ft upstream for Phases 1, 2, 5, and 6. (2) Grade measurements for all possible sidestreet approach movements were made using Google Earth elevation measurements between stop bar and 90-ft to 150-ft upstream for Phases 4 and 8. The most conservative grade of all approach movements was used for Phase 4 and Phase 8.

Example of Engineering Documentation – Speed

Additional Notes: Engineering Judgment was applied to the red clearance intervals for Phases 3 and 4. Field observations were performed to determine the actual travel time for left-turn vehicles to pass through the intersection. For each approach, an observer used a stopwatch to determine the amount of time from when the front of the vehicle crossed the stop bar until the rear of the vehicle was clear of conflicting traffic. The distance traveled is equivalent to the distance $w + L$ in TE-306.1 using each vehicle's actual travel path and length. A total of 40 samples per approach were collected in the field. Since the red clearance time formula in TE-306.1 takes an approximation of travel time (derived from distance traveled and speed) and subtracts one second to obtain the red clearance interval, one second was subtracted from the travel time observed in the field to obtain the clearance intervals shown in Phases 3 and 4 above. The 15th percentile travel time used to determine the clearance intervals since speed and travel time are inversely related and the 85th percentile speed is used for clearance interval calculations in TE-306.1 and the NCHRP report that supports the memo. A minimum of 35 samples are required in order to obtain a statistically valid result of the 15th percentile travel time. Since 40 samples were collected in the field, the result can be considered statistically valid. The 15th percentile travel time for Phase 3 was 5.73 seconds, and for Phase 4 was 5.85 seconds. After rounding up and subtracting one second, the resultant all red clearance times for Phases 3 and 4 are 4.8 seconds and 4.9 seconds, respectively. The raw travel time data collected in the field is included as an attachment to this document.

Example of Engineering Judgment Documentation – Intersection Width

For Phase 8 left-turn, vehicle paths were first identified using turn template in CAD. The phasing and sequencing are fixed such that Phase 8 is always followed by Phase 4. (Special phase sequences, such as preemption, were also checked). The path to clear Phase 8 lefts from traffic entering from the Phase 4 approach is 70'. Therefore 70' is used in the Phase 8 left-turn red clearance interval calculation.

