Application of the ITE Change and Clearance Interval Formulas in North Carolina

DURING 2005, THE NORTH CAROLINA SECTION OF ITE CONVENED A TASK FORCE TO INVESTIGATE AND RECOMMEND A PRACTICE FOR DETERMINING YELLOW CHANGE AND RED CLEARANCE INTERVALS. THIS FEATURE BRIEFLY SUMMARIZES KEY DELIBERATIONS AND DECISIONS OF THAT TASK FORCE. THE METHODOLOGY AS IMPLEMENTED BY THE NORTH CAROLINA DEPARTMENT OF TRANSPORTATION ALSO IS PRESENTED ALONG WITH SAMPLE YELLOW AND RED TIMES RESULTING FROM ITS APPLICATION.

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INTRODUCTION

In December 2004, in response to a formal request by the North Carolina Department of Transportation (NCDOT), the Traffic Engineering Council of the North Carolina Section of the Institute of Transportation Engineers (NCSITE) announced a task force to investigate and recommend a practice for determining yellow change and red clearance intervals at signalized intersections in North Carolina. The purposes of this feature are to briefly summarize key deliberations of that task force and present the resulting methodology as implemented by NCDOT.

BACKGROUND

One issue in determining appropriate yellow and red intervals is that, despite the existence of several well-recognized guidance documents, there is no national standard. The *Manual on Uniform Traffic Control Devices* (MUTCD), which typically provides prescriptions for device operation, does not stipulate the manner in which yellow or red intervals should be determined. It does, however, require the use of a yellow interval; require that the duration of the yellow and red intervals be predetermined; and suggest durations of 3 to 6 seconds for yellow and, at most, 6 seconds for red.[1]

Calculation methods are available in the *Traffic Engineering Handbook* and other sources.[2] A recent survey by ITE suggests that, by far, the most common method in use today is based on what is termed the "ITE formula," shown below:[3]

$$Y + R = t + \frac{v}{2a + 2Gg} + \frac{w + l}{v} \qquad (1)^4$$

where:
Y = yellow change interval (seconds [sec.])
R = red clearance interval (sec.)
t = perception-reaction time (sec.)
v = design velocity (feet/sec.)
a = deceleration rate (feet/sec.^{2})
G = acceleration due to gravity (32.2 feet/sec.^{2})
g = grade in decimal form (1 percent = 0.01)
w = clearance distance (feet)
l = vehicle length (feet)

In discussion of the yellow and red intervals, the *Traffic Engineering Handbook* goes on to suggest a typical application of the first two terms to determine the yellow and the last term to determine the red.

The ITE formula has been published, with timely revisions, since the first edition of the *Traffic Engineering Handbook* in 1941. Beginning in 1965, the formula appeared in its present form, although without the effect of grade. In this same year, ITE suggested the use of a red interval under certain conditions. The inclusion of the effect of grade on the yellow and red intervals appeared in 1982. In all, the formula has been updated eight times since 1941.[5] Still, the *Traffic Engineering Handbook* has not accrued any legal status.

Although the NCDOT documentation covers only the more recent practices for calculation of yellow and red, it gives clear evidence of its desire to provide both safe and efficient operation. One source, from February 1990, summarizes a meeting NCDOT hosted to discuss change and clearance intervals, involve traffic engineers from across the state and examine current practice. At the time of the meeting, NCDOT and most other state agencies were using the ITE formula as the foundation of their practice.[6]

More recently, NCDOT has worked to improve signal design consistency through publication of the *Traffic Management and Signal Systems Unit Design Manual.*[7] The purpose of the manual is to highlight standards of practice in signal design and operation. Although all the design manual editions have required the use of the ITE formula, specific division of the resulting total clearance into yellow and red times has not been consistent over the last 15 years and has been, at varying levels, left to the discretion of the design engineer.

The result is inconsistent yellow and red timing throughout the state.

The resulting inconsistencies, differing preferences among designers and a general consensus among NCDOT design and field personnel that these intervals are becoming too long all were factors in the decision to request a recommendation from NCSITE.

THE NCSITE TASK FORCE

In December 2004, a call went out for volunteers for the NCSITE Task Force. The NCSITE mailing list offered a representative pool of traffic engineering professionals from all over North Carolina, with a wide cross-section of relevant experience and knowledge. The resulting volunteer membership included:

- municipal engineers: 11
- consulting engineers:10
- NCDOT engineers—central office: 7
- NCDOT engineers—field forces: 2
- non-profit organizations: 1
- research organizations: 1
- students: 1

The full NCSITE Task Force met a total of four times between January and June 2005 and divided into subcommittees to help meet the prescribed 6-month deadline. During the first task force meeting, a discussion and brainstorming session provided a list of issues to be addressed. Subcommittees held teleconferences and in-person meetings to discuss their topics and conducted data collection and reduction efforts in support of their tasks.

Issues Addressed by the Task Force

For purposes of organization, the issues tackled by the task force are presented in the sequence that they would be encountered using the methodology, beginning with text from the written recommendation and ending with summaries of key issues.

The ITE formula for the calculation of the total change plus clearance interval should be the basis for NCDOT practice. Both NCDOT's long history and the recent ITE surveys suggested the ITE formula was the logical starting point for use in the methodology.

Calculation of the yellow change and all-red clearance intervals should not vary based on the presence or absence of enforcement devices. At this time, NCDOT does not operate or intend to operate automated enforcement devices (such as red-light cameras); however, individual municipalities can petition the state legislature for the authority to install such devices. The recommended practice should result in safe and efficient intervals, independent of enforcement.

RECENTLY, NCDOT HAS WORKED TO IMPROVE SIGNAL DESIGN CONSISTENCY THROUGH PUBLICATION OF THE *TRAFFIC MANAGEMENT AND SIGNAL SYSTEMS UNIT DESIGN MANUAL.*

The NCSITE Task Force also discussed the option of including a grace period at automated enforcement locations, but it decided to leave such choices to the operating agency. NCDOT does recommend a break-in period to allow drivers to become accustomed to any changes made as a result of the new practice.

Separate practices should not exist for different regions of the state, unique vehicle streams (such as a high percentage of heavy vehicles), or left-turning vehicles versus through vehicles. Because one of the primary motivations for the task force was consistency, there was little discussion of this issue. The recommended practice should result in safe and efficient intervals, independent of region, stream, or movement.

Calculation of the yellow change interval should be performed using the first two terms of the ITE formula, with the result rounded up to the next 0.1 sec.

$$Y = t + \frac{v}{2a + 2Gg} \quad (2)$$

The yellow and red intervals serve different functions; therefore, the calculation should be made as independently as possible. In past practices, time might be shifted from the red to yellow, but not in the new practice. Independent calculations are needed to help prevent excessive yellow time from contributing to disrespect of the yellow change interval.

The 2001 constants from the American Association of State Highway and Transportation Officials (AASHTO) for deceleration (11.2 feet/sec.^{2}) and perception/reaction time (1.5 sec.) are sound. The longer perception/reaction time responds both to the aging driver population and to the increasing number of distractions in the driving environment. At higher speeds, the higher deceleration rate does help offset the additional perception/reaction time.

The NCSITE Task Force also looked into the performance characteristics of trucks. Although no specific information could be found related to "comfortable" stops, AASHTO constants were within the expected performance capabilities of trucks.

The effect of positive grade should be factored into the yellow calculation. In past practice, NCDOT included the detrimental effects of negative grades but ignored the beneficial impacts of positive grades. None of the ITE publications suggests that positive grades should be ignored in calculations, and the Federal Highway Administration's *Signalized Intersections: Informational Guide* clearly indicates that positive grades can be used.[8]

The minimum value for yellow should be 3.0 sec. Not only does MUTCD recommend this minimum value, it also is required by the National Electrical Manufacturers Association Standards Publication.[9] Note that when the calculated yellow is less than 3.0 sec., the time difference is not shifted from red: In other words, the yellow increases without a change in the red.

Current practice in the Signals and Geometrics Section for selection of vehicle speeds, "v", was reviewed and retained in this application. For through movements, current practice uses the posted speed limit as the design speed unless a speed study has been specifically performed. When provided, the design speed will be taken as the 85th-percentile speed, up to a maximum of 10 mph above the posted limit. Because NCDOT does not signalize facilities with

Site	Left Turn Angle	Single or Dual	Collection Method*	Sample Size	Speed					
					Min	15%	Avg	StDev	85%	Max
1	125	Dual	All	39	14	15.0	**18.9**	**3.4**	21.3	30
2	110	Single	All	40	11	12.0	**15.6**	**2.7**	18.0	24
3	120	Single	All	71	12	16.0	**18.4**	**2.9**	21.0	26
4	110	Single	Sample	120	14	16.0	**18.1**	**2.1**	20.0	23
5	100	Single	Sample	120	9	11.0	**13.6**	**2.2**	16.0	20
6	100	Dual	End Car	80	14	17.0	**19.0**	**1.8**	21.0	23
7	70	Dual	End Car	160	10	13.0	**14.6**	**1.6**	16.0	20
8	115	Dual	End Car	80	13	16.0	**18.7**	**2.3**	21.0	26
9	130	Dual	End Car	156	14	17.0	**19.3**	**2.3**	22.0	25
10	85	Single	End Car	160	12	15.0	**17.2**	**2.0**	19.0	23
11	90	Dual	End Car	80	13	16.0	**17.4**	**1.8**	19.2	21
ALL	-	-	-	**1106**	**9**	**14.0**	**17.1**	**2.9**	**20.0**	**30**

*** Collection Methods:**
All = Speed recorded for all vehicles making the left turn
Sample = Speed recorded for an initial vehicle, a mid-queue vehicle, and an end-of-green vehicle
End Car = Speed recorded for the last vehicle using the phase each cycle

Figure 1. Left-turn speed data.

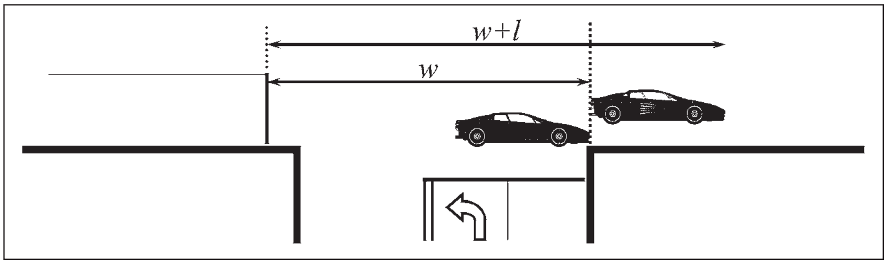

Figure 2. Effect of removing "l" from red calculations.

speed limits greater than 55 mph, the highest allowable design speed is 65 mph.

For left-turn movements, past editions of the *Traffic Management and Signal Systems Unit Design Manual* suggested a speed between 20 and 30 mph, with 20 mph the almost universal selection. Many expressed concern that 20 mph was overly conservative and led to excessive red intervals, so a field investigation was conducted. Unexpectedly, the study results, shown in Figure 1, indicated typical speeds slightly lower than 20 mph but not low enough for the task force to justify changing current practice.

Calculation of the all-red clearance interval should be based on the third term of the ITE formula, but with the following modification: The vehicle length should be removed from the all-red formula, and the result rounded up to the next 0.1 sec.

$$R = \frac{w}{v} \qquad (3)$$

Unlike MUTCD, which does not require the use of a red interval, the North Carolina Supplement to the MUTCD does.[10] As noted above, NCDOT design and field personnel shared the belief that reds were becoming too long, and NC-SITE Task Force discussions showed this sentiment was shared by both municipal and consulting engineers within the state.

The culprits: increasing intersection widths and the need to provide protected phases for left turns. The causes: increasing corner curve radii standards; the separation of crosswalks with two handicapped ramps on each corner; and increasing facility size in terms of number of lanes. To be clear, neither accident nor ticketing issues had developed to draw public attention to the problem; however, the task force members wished to correct any problems before such statistics evolved.

As modified, the red interval serves to carry the front bumper of a last-instant legal intersection entry to the far edge of the conflict zone. Originally, any vehicle equal to or shorter than the assumed length would be carried past the conflict zone. The resulting difference is shown in Figure 2.

The obvious advantage to removing the assumed vehicle length is a reduction in the red interval. Past NCDOT practice used 20 feet as the assumed vehicle length. Removing this results in a 0.7-sec. reduction at 20 mph; 0.4-sec. at 35 mph; and 0.2 sec. at 55 mph.

Despite this anticipated reduction, the formula still allows the red to increase without bound. Left-turn clearance distances of 200 ft. currently exist, resulting in red intervals of 6.9 sec., much longer than acceptable to the task force.

If the initial calculation results in an all-red clearance interval greater than 3.0 sec., the all-red clearance interval should be recalculated as follows:

$$R = \frac{1}{2}\left(\frac{w}{v} - 3\right) + 3 \qquad (4)$$

Discussion of reducing excessive red times consumed a large portion of the NC-SITE Task Force effort. The recommended method was determined to best balance competing concerns related to overly short and overly long red times. The result of this mitigation was that all of the first 3 sec. calculated for the red interval are used, but only half of the portion above that. So, if the initial calculation resulted in 4.0 sec. of red, the mitigation will reduce it to 3.5 sec. As with the other calculations, the result is rounded up to the next tenth.

The only other method receiving serious consideration was the reduction of red time based on expected time to conflict point. Although a preliminary field study looked positive, investigation of current literature, notably Muller et al., provided only minimal adjustments.[11] Faced with minimal benefits and questions about proper application, the task force discontinued its investigation into this option.

The clearance distance should be measured to the far side of an exclusive right-turn lane.

- *In the presence of a crosswalk with pedestrian signals, the clearance distance should be taken to the near side of the crosswalk*
- *A crosswalk without pedestrian signals should not be considered when determining clearance distance.*

These recommendations did not represent a change from past practice. This includes clearance distance measurements using the "straight line" method rather than a vehicle turning arc. A preliminary comparison of the straight line method to an outside wheel arc method resulted in an average difference of +2.2 feet, only +0.07 sec. at 20 mph. The task force agreed to continue using the straight-line method.

Past practice left consideration of crosswalks to the discretion of the design engineer. The task force felt it was important to always consider crosswalks with pedestrian signals when determining clearance distance. The decision to not consider crosswalks without signals was based on two factors: unsignalized crosswalks typically have insignificant pedestrian volume; and unsignalized crossings provide no guidance, so pedestrians cannot be expected to cross during any particular interval, reducing the probability of providing protection.

The *Traffic Management and Signal Systems Unit Design Manual* gives specific guidance for calculating clearance distances, shown in Figure 3.

The minimum value for all-red clearance intervals should be 1.0 sec. Prior practice suggested at least 1.0 sec., so this was not a significant change.

The proposed implementation of a yellow change interval longer than 6.0 sec. or a red clearance interval longer than 4.0 sec. is cause for a "stakeholder discussion" to provide advance notification and involvement to stakeholders and provide an opportunity to consider possible countermeasures.

Field personnel should be involved in developing and applying the practice. Stakeholder discussions help ensure these personnel are not surprised by new installation of long intervals.

Although countermeasures for reducing the yellow are difficult, typically involving the reduction in grade over the stopping distance or making geometric and enforcement changes to reduce travel speed, identification of excessive yellow at an intersection can provide an opportunity for present or future mitigation.

The opportunity for reducing the red is more likely, with lower cost solutions such as reduced median widths, positive offset left turns and channelized right-turn lanes.

For a "shared clearance" phase (when a phase serves multiple movements needing different yellow change and all-red clearance intervals), the following procedure should be applied:

- *Calculate each movement's change plus clearance intervals as if it had a dedicated phase.*
- *Use the largest yellow value; then subtract this yellow value from the largest total change plus clearance to determine red.*

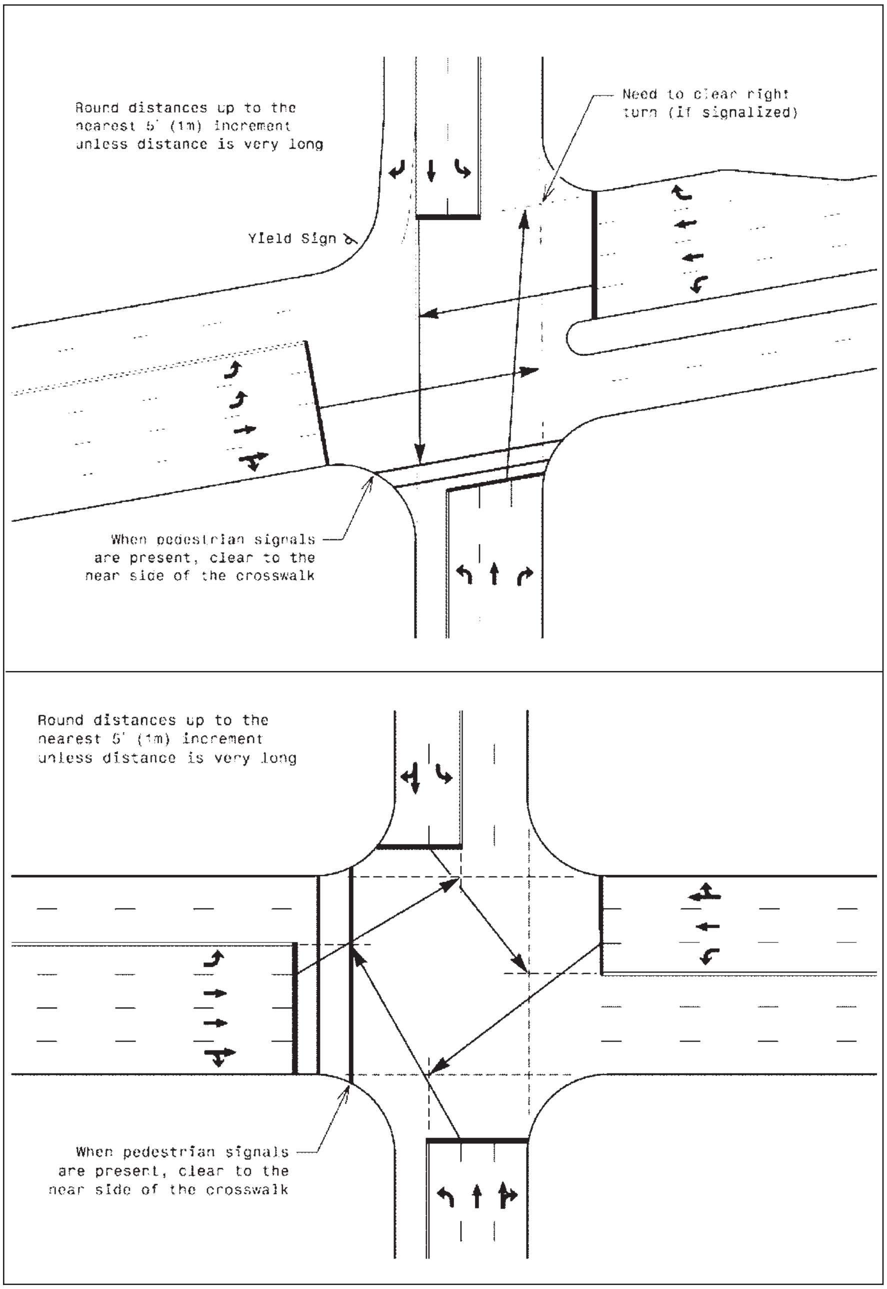

Figure 3. Measuring clearance distances.

Although this is not a change from past NCDOT practice, this confirms that mitigation of excessive red clearance intervals will take place for each movement before the shared change plus clearance is determined.

The Task Force considered but rejected both the use of the longest yellow change with the longest red clearance interval and the use of the yellow change and red clearance interval associated with the longest total clearance. The former option was rejected because it was incompatible with the goal of reducing interval length; the latter was rejected to ensure that every movement received sufficient yellow change time.

CONCLUSION

After receipt of the NCSITE Task Force recommendations, Greg A. Fuller, P.E., of the Intelligent Transportation Systems and Signals Unit of NCDOT, officially adopted the revised methodology, and the *Traffic Management and Signal Systems Unit Design Manual* was revised accordingly. The resulting methodology is presented in full in Figure 4, and a sample set of yellow and red intervals is presented in Figure 5.

Determination of Yellow Change and Red Clearance Intervals

Yellow Change Interval

Yellow interval = $t + \frac{v}{2a + 64.4g}$

t = perception reaction time, typically 1.5 seconds
v = design speed*, in ft/s
a = deceleration rate, typically 11.2 ft/s_2
g = grade

Round up to nearest 0.1 second.

Minimum yellow change interval is 3.0 seconds.

Hold stakeholder discussion** when calculated yellow change interval is longer than 6.0 seconds.

Red Clearance Interval

Red interval = $\frac{w}{v}$ w = width of intersection, in feet; v = design speed*, in ft/s

If the initial calculation results in an all red time longer than 3.0 seconds, recalculate the red time as follows:

Recalculated red interval = $\frac{1}{2}(\frac{w}{v} - 3) + 3$

Round up to nearest 0.1 second.

Minimum red clearance interval is 1.0 seconds.

Hold stakeholder discussion** when recalculated red clearance interval is longer than 4.0 seconds.

Notes

* Design speed is the speed limit unless a speed study determines that the 85th percentile speed is faster or intersection geometrics compel vehicles to traverse the intersection slower.

** The purpose of a stakeholder discussion is to provide advance notification and involvement to stakeholders and provide an opportunity to consider possible countermeasures.

For most left turn lanes, assume a speed of 20 mph (32 kph) to 30 mph (48 kph). For locations with unusual conditions a higher or lower speed may be appropriate.

For separate left turn phases, calculate yellow and red intervals.

For left turns without a separate phase, calculate yellow and red times for both the through movement and the left turn movement. Use the highest yellow and enough red to equal the highest total time.

Where existing times are higher than calculated times, use the calculated values unless there is a documented history of the need for higher times. If approach is high speed and existing times are significantly higher than the calculated times, use the calculated values but consider adding a note to the plan to direct field forces to reduce the time incrementally. Include in the note how much and how often to reduce time until the final value is reached. (Ex. Existing Yellow Change Interval for phase 2 may be decreased by 0.2 seconds per week until the required value is reached.)

Where revising a location or adding a new signal along a corridor, consider comparing clearance times at adjacent intersections to new calculations to meet driver expectations.

Sources:
Traffic Engineering Handbook, Fifth Edition, Institute of Transportation Engineers, 1999.
A Policy on Geometric Design of Highways and Streets, Fourth Edition, American Association of State Highway and Transportation Officials, 2001.

Change and Clearance Intervals
SIGNALS & GEOMETRICS SECTION
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Figure 4. The revised methodology, as adopted.

Speed		Grade				
mph	fps	-6%	-3%	0%	3%	6%
20	29.3	3.1	3.0	2.9*	2.8*	2.7*
25	36.7	3.5	3.3	3.2	3.1	2.9*
30	44.0	3.9	3.7	3.5	3.4	3.2
35	51.3	4.3	4.1	3.8	3.7	3.5
45	66.0	5.1	4.8	4.5	4.3	4.1
55	80.7	5.9	5.5	5.2	4.9	4.6
65	95.3	6.7+	6.2+	5.8	5.5	5.2

* Less than 3.0 second minimum, increase yellow time to 3.0
\+ Greater than 6.0 sec threshold, requires stakeholder meeting prior to approval

Speed		Clearance Distance (feet)						
mph	fps	50	75	100	125	150	175	200
20	29.3	1.8	2.6	**3.3**	**3.7**	**4.1+**	**4.5+**	**5.0+**
25	36.7	1.4	2.1	2.8	**3.3**	**3.6**	**3.9**	**4.3+**
30	44.0	1.2	1.8	2.3	2.9	**3.3**	**3.5**	**3.8**
35	51.3	1.0	1.5	2.0	2.5	3.0	**3.3**	**3.5**
45	66.0	0.8*	1.2	1.6	1.9	2.3	2.7	**3.1**
55	80.7	0.7*	1.0	1.3	1.6	1.9	2.2	2.5
65	95.3	0.6*	0.8*	1.1	1.4	1.6	1.9	2.1

Shaded cells indicate mitigated red intervals
* Less than 1.0 second minimum, increase all red time to 1.0
\+ Greater than 4.0 sec threshold, requires stakeholder meeting prior to approval

Figure 5. Sample yellow and red intervals.

With the adoption of this practice, NCDOT has established a consistent method for calculating yellow and red intervals that will provide safe and efficient operation. Because of the prohibitive cost associated with an immediate statewide change, the new practice will be used for new signals and phased into existing signals as they require other revisions, with a review of closely spaced signals to help promote the desired consistency. ■

References

1. *Manual on Uniform Traffic Control Devices for Streets and Highways*. Washington, DC: Federal Highway Administration (FHWA), November, 2004.

2. *Traffic Engineering Handbook, Fifth Edition*. Pline, J.L. (ed.). Washington, DC: Institute of Transportation Engineers (ITE), 1999.

3. Tarnoff, Philip J. and J. Ordonez. *Signal Timing Practice and Procedures: State of the Practice*. Washington, DC: ITE, 2004.

4. *Traffic Engineering Handbook*, note 2 above.

5. Eccles, K.A. and H.W. McGee. *A History of the Yellow and All-Red Intervals for Traffic Signals*. Washington, DC: ITE, 2001.

6. North Carolina Statewide Stakeholder Meeting on Clearance Intervals. Unpublished Meeting Minutes, 1990.

7. *Traffic Management and Signal Systems Unit Design Manual*. North Carolina Department of Transportation (NCDOT), 2004. Note: The former Traffic Management and Signal Systems Unit since has been renamed the ITS and Signals Unit, and the manual has been renamed the accordingly.

8. *Signalized Intersections: Informational Guide* (FHWA-HRT-04-091). Washington, DC: FHWA, 2004. Accessible via www.tfhrc.gov/safety/pubs/04091.

9. *NEMA Standards Publication TS 2-1998: Traffic Controller Assemblies with NTCIP Requirements*. National Electrical Manufacturers Association, 1998.

10. *2004 North Carolina Supplement to the Manual on Uniform Traffic Control Devices*. NCDOT, 2004.

11. Muller, T.H.J., T. Dijker and P.G. Furth. "Red Clearance Intervals: Theory and Practice." *Transportation Research Record,* No. 1867 (2004): 132–143.

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