TALUS SOFTWARE

PHYSICS OF THE YELLOW SIGNAL LIGHT

ITE'S FIRST RECOMMENDED PRACTICE

National Society of Professional Engineers, September 23, 2020

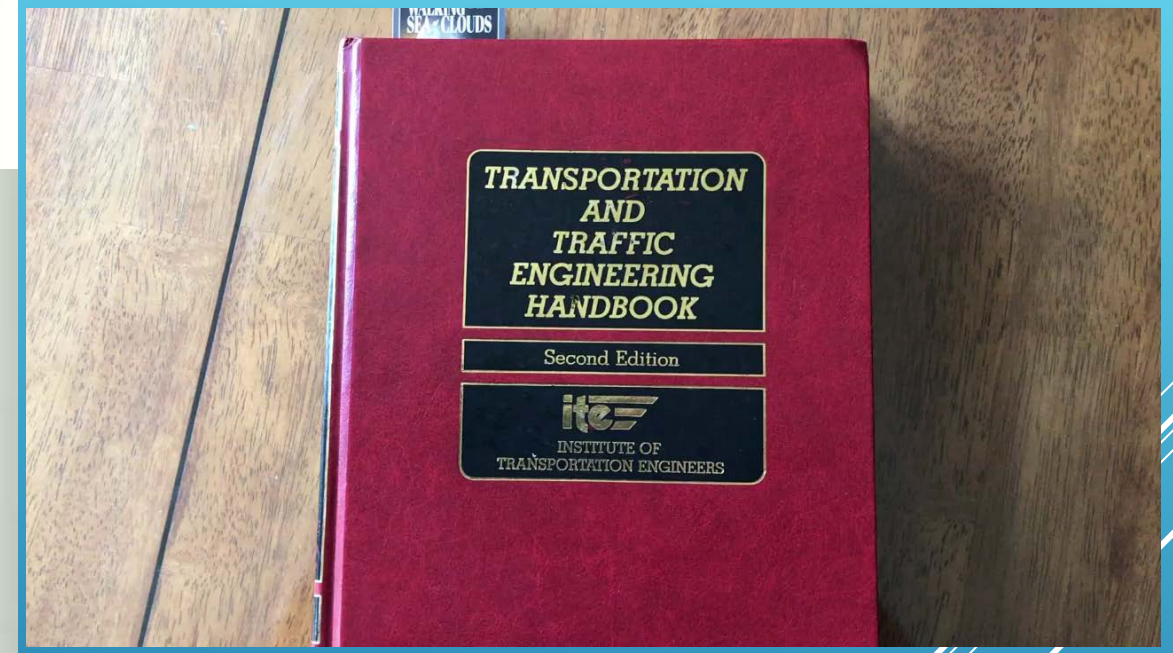
http://talussoftware.com/docs/nspe/nspe-nation.pptx

Brian Ceccarelli, P.E., M.NSPE

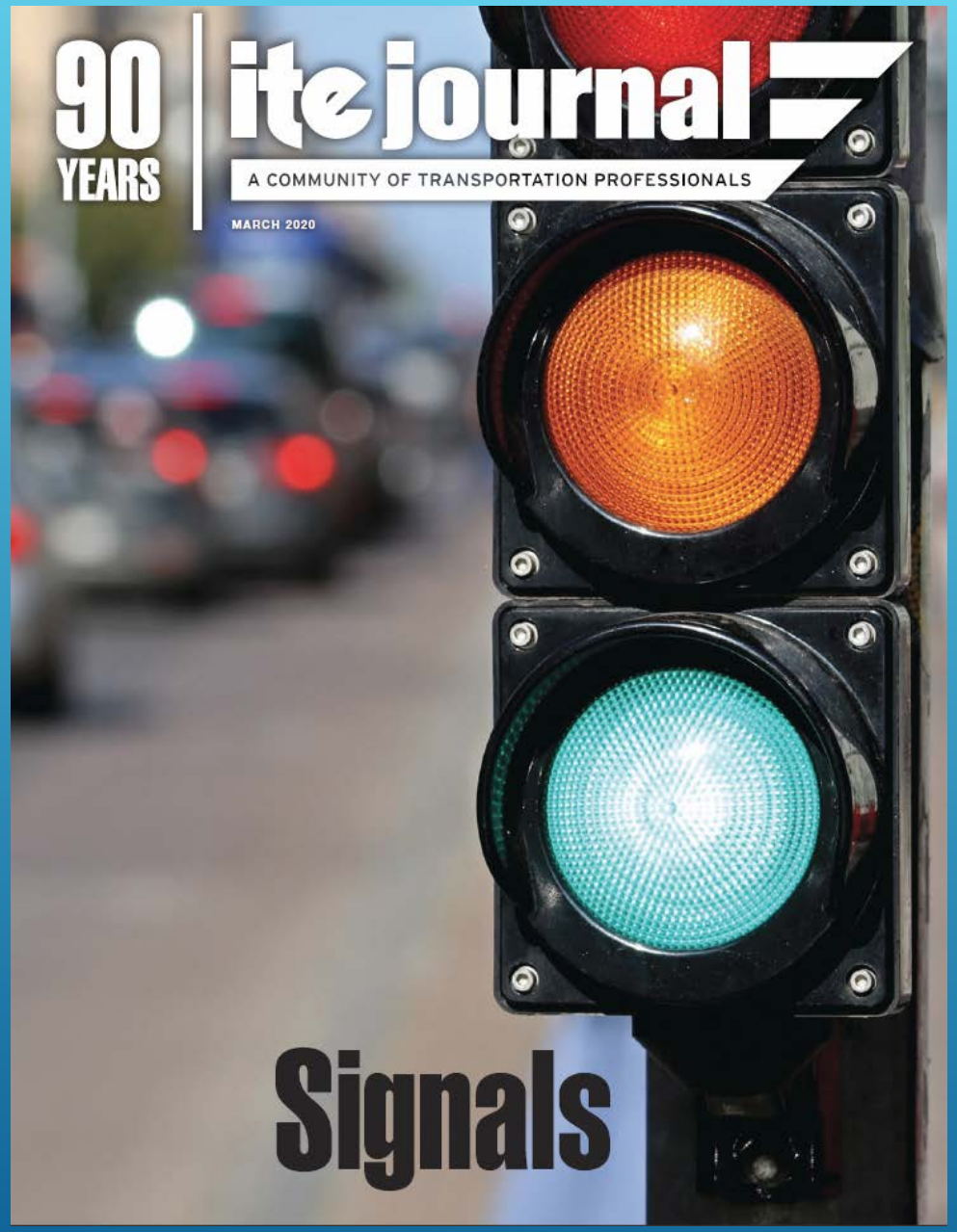
NSPE

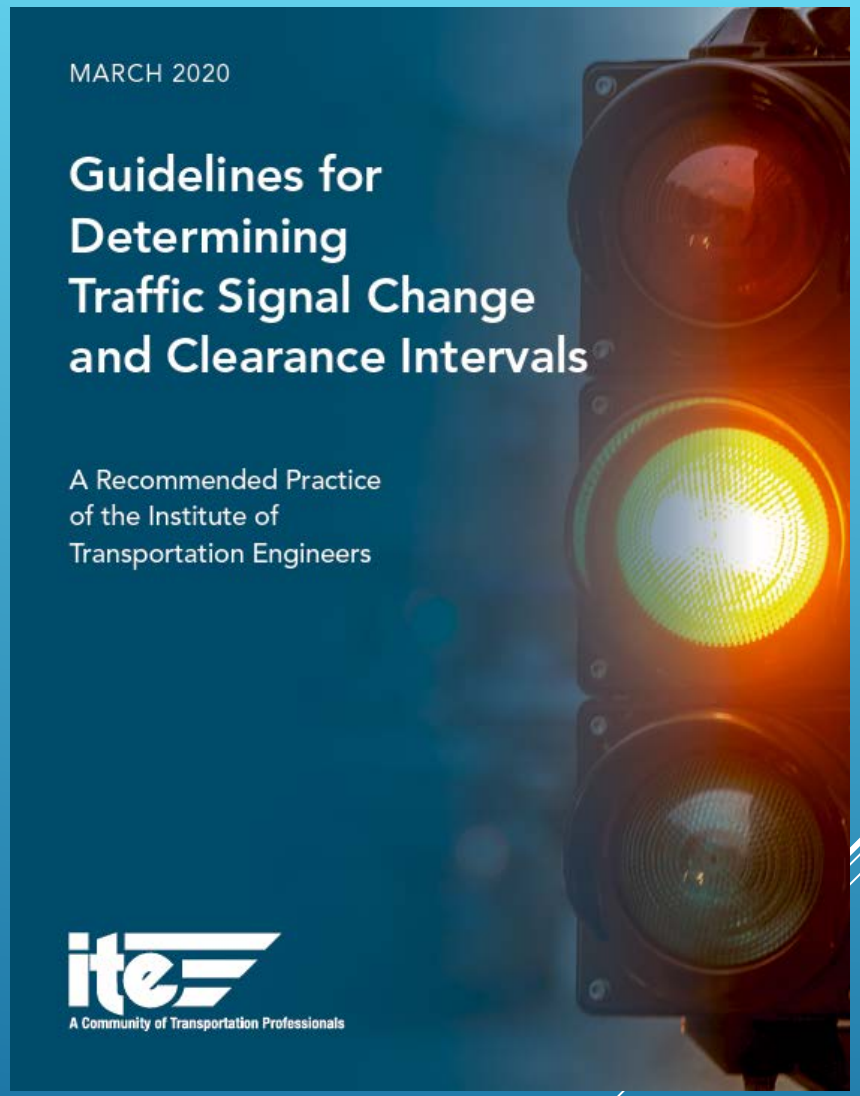
Yellow change and clearance intervals

At the termination of a green phase, motorists approaching a signalized intersection are advised by a yellow signal indication that the red interval is about to commence[35]. The speed and location of some approaching vehicles will be such that they can stop safely at the stop line; others will have to continue at their speed or even accelerate into or through the intersection. The minimum length of the clearance interval (which may include an all-red interval after the yellow indication) should accommodate both situations and eliminate the possibility of a dilemma zone in which a driver can neither stop safely nor legally proceed into or through the intersection. See Table 24-7.



Institute of Transportation Engineers,
Transportation and Traffic Engineering Handbook
1982


90 YEARS
ite journal
A COMMUNITY OF TRANSPORTATION PROFESSIONALS
MARCH 2020
Signals


MARCH 2020
Guidelines for Determining Traffic Signal Change and Clearance Intervals
A Recommended Practice of the Institute of Transportation Engineers
ite
A Community of Transportation Professionals

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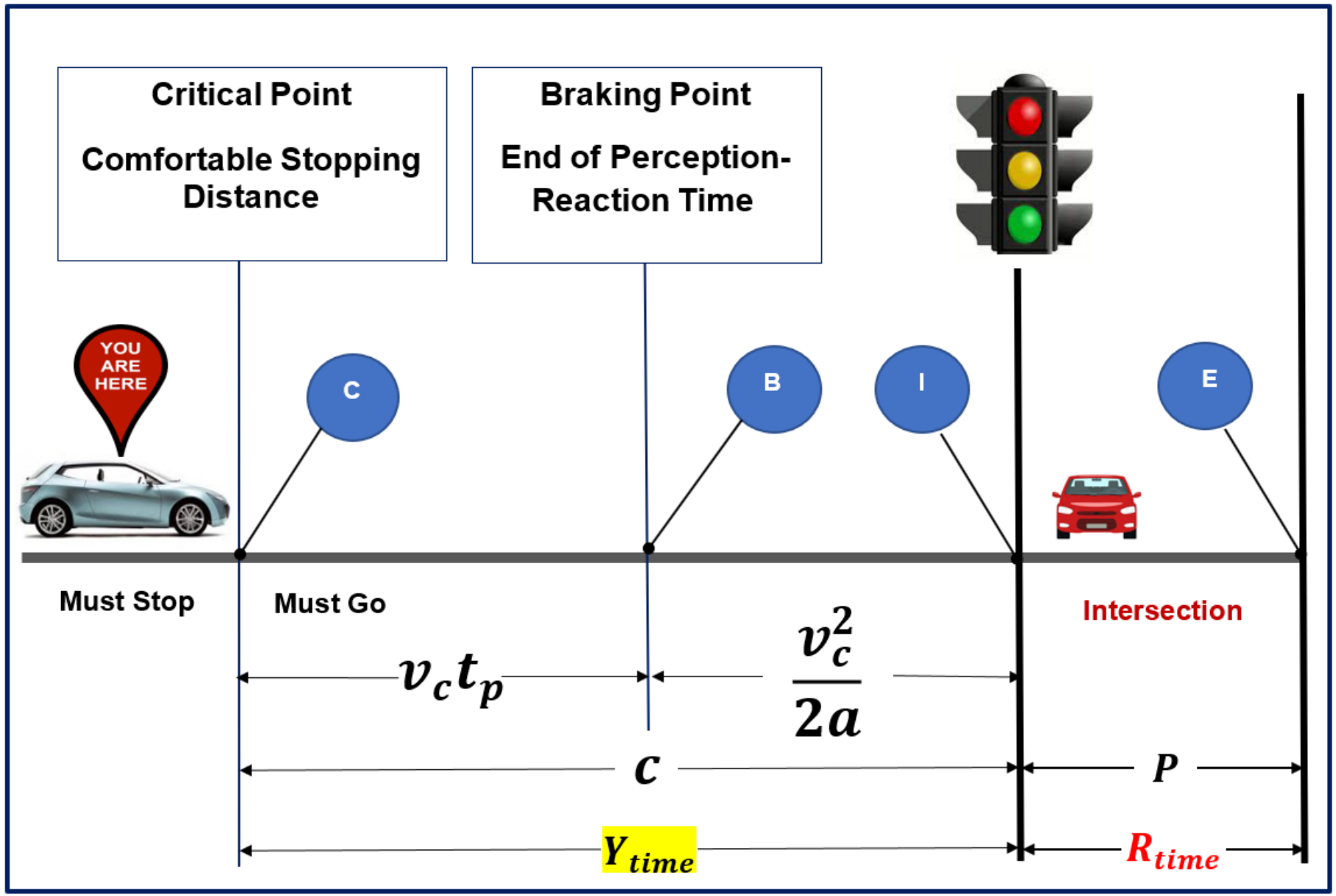
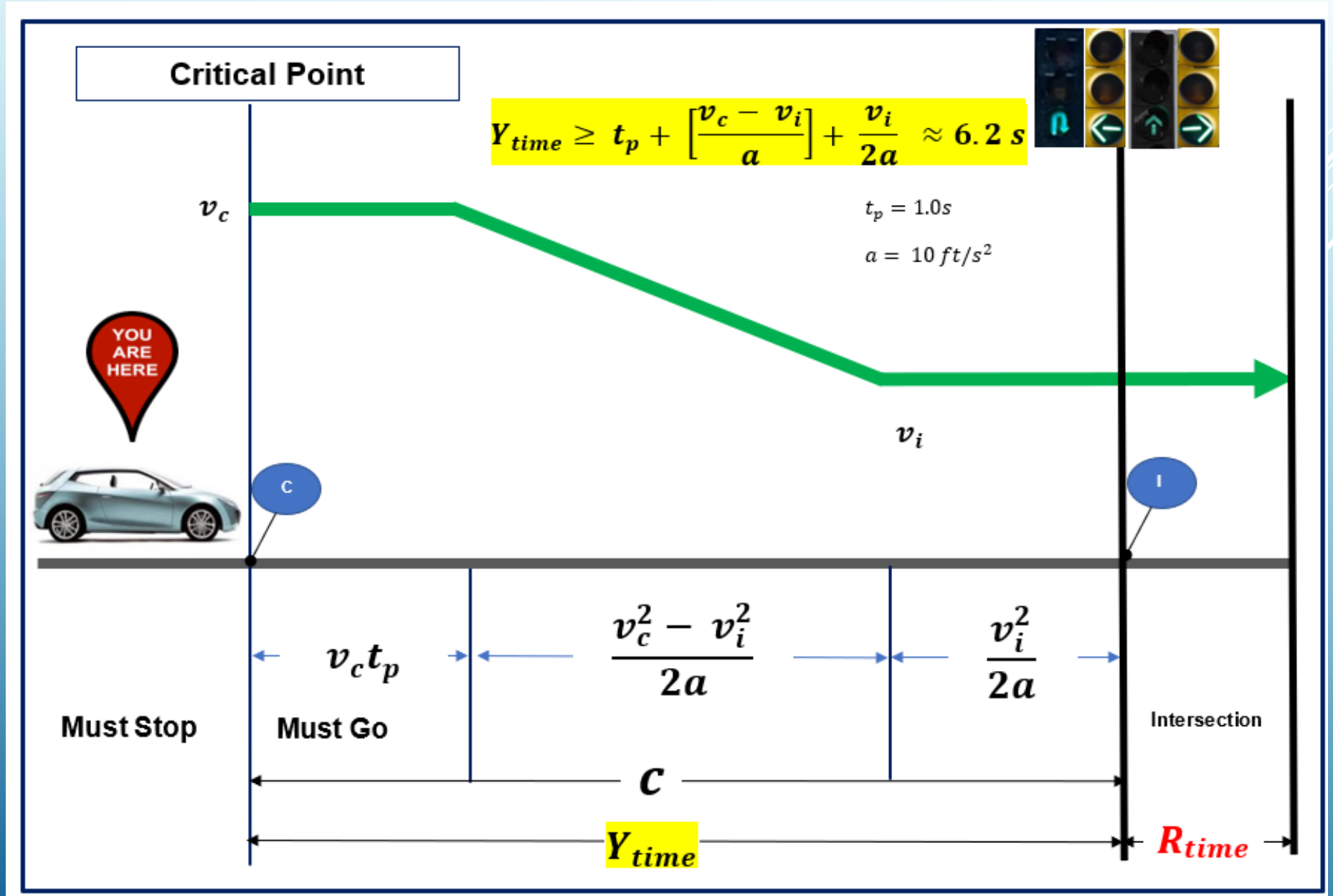
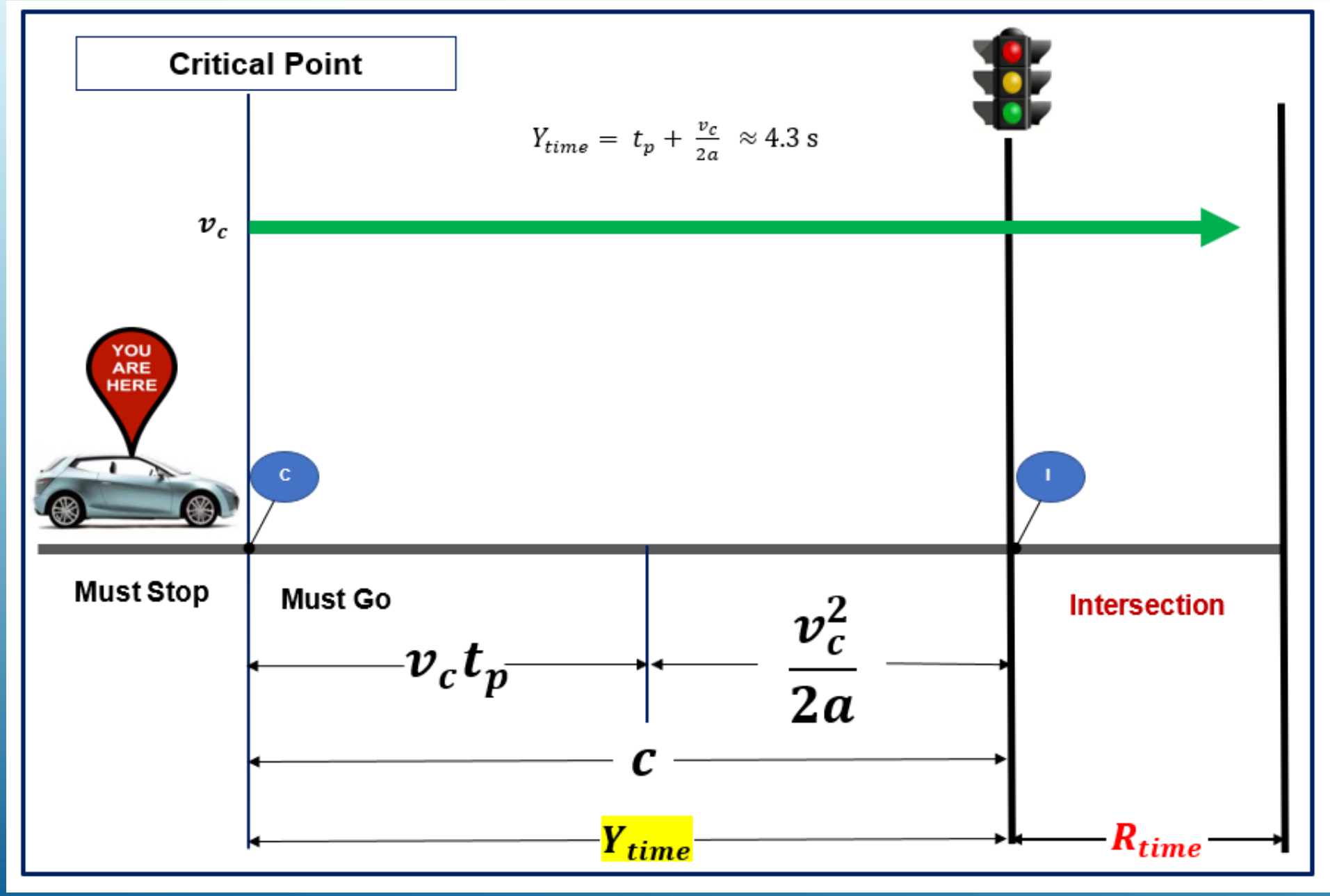
Critical Distance

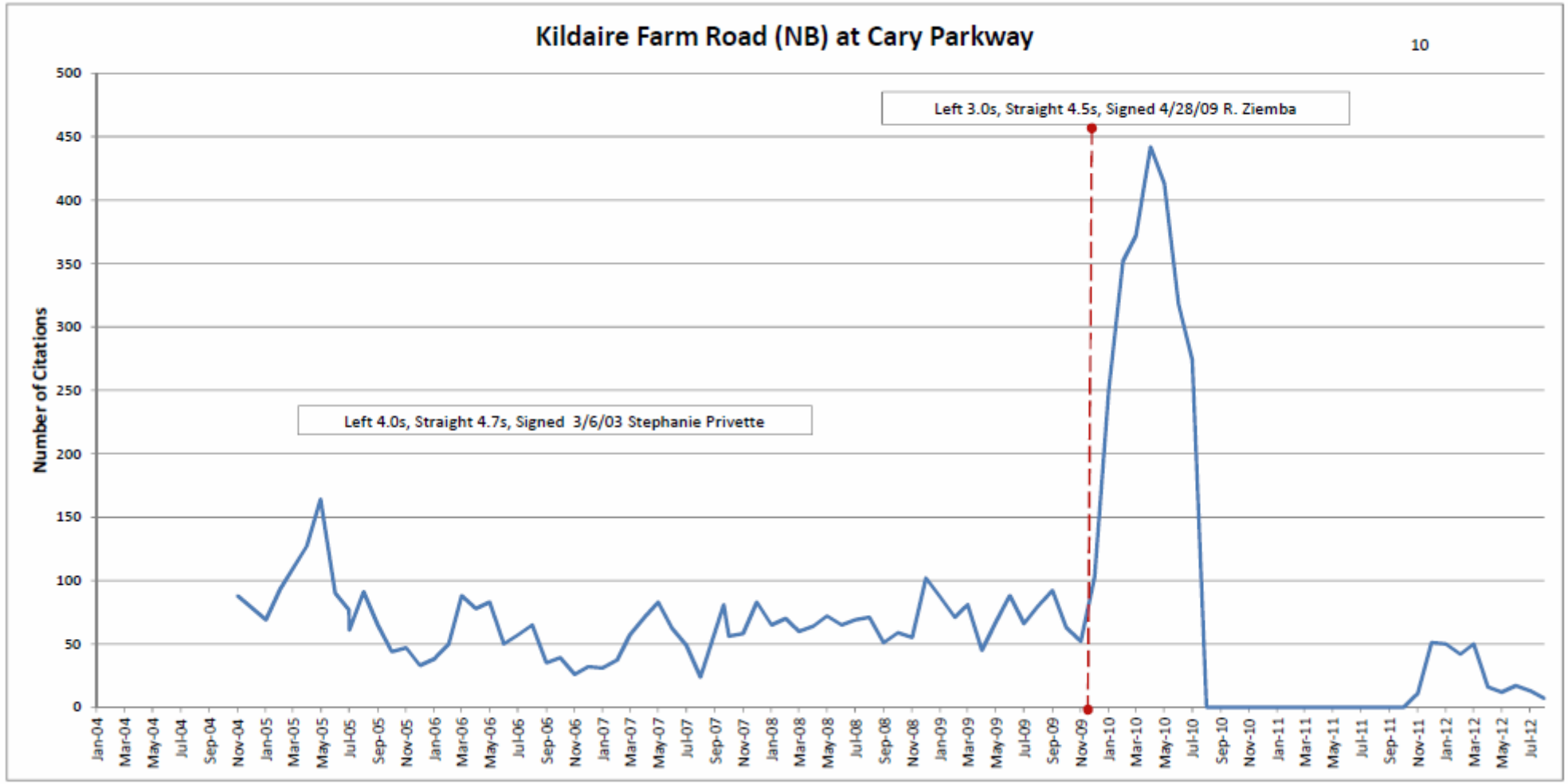


ITE Extended Kinematic Equation - First Recommended Practice (Järlström, 2016)



Constant Maximum Velocity – Old ITE Kinematic Equation (Gazis, Herman, Maradudin 1959)




Kildaire Farm Road (NB) at Cary Parkway
10
Number of Citations
Left 3.0s, Straight 4.5s, Signed 4/28/09 R. Ziemba
Left 4.0s, Straight 4.7s, Signed 3/6/03 Stephanie Privette
0
50
100
150
200
250
300
350
400
450
500
Jan-04
Mar-04
May-04
Jul-04
Sep-04
Nov-04
Jan-05
Mar-05
May-05
Jul-05
Sep-05
Nov-05
Jan-06
Mar-06
May-06
Jul-06
Sep-06
Nov-06
Jan-07
Mar-07
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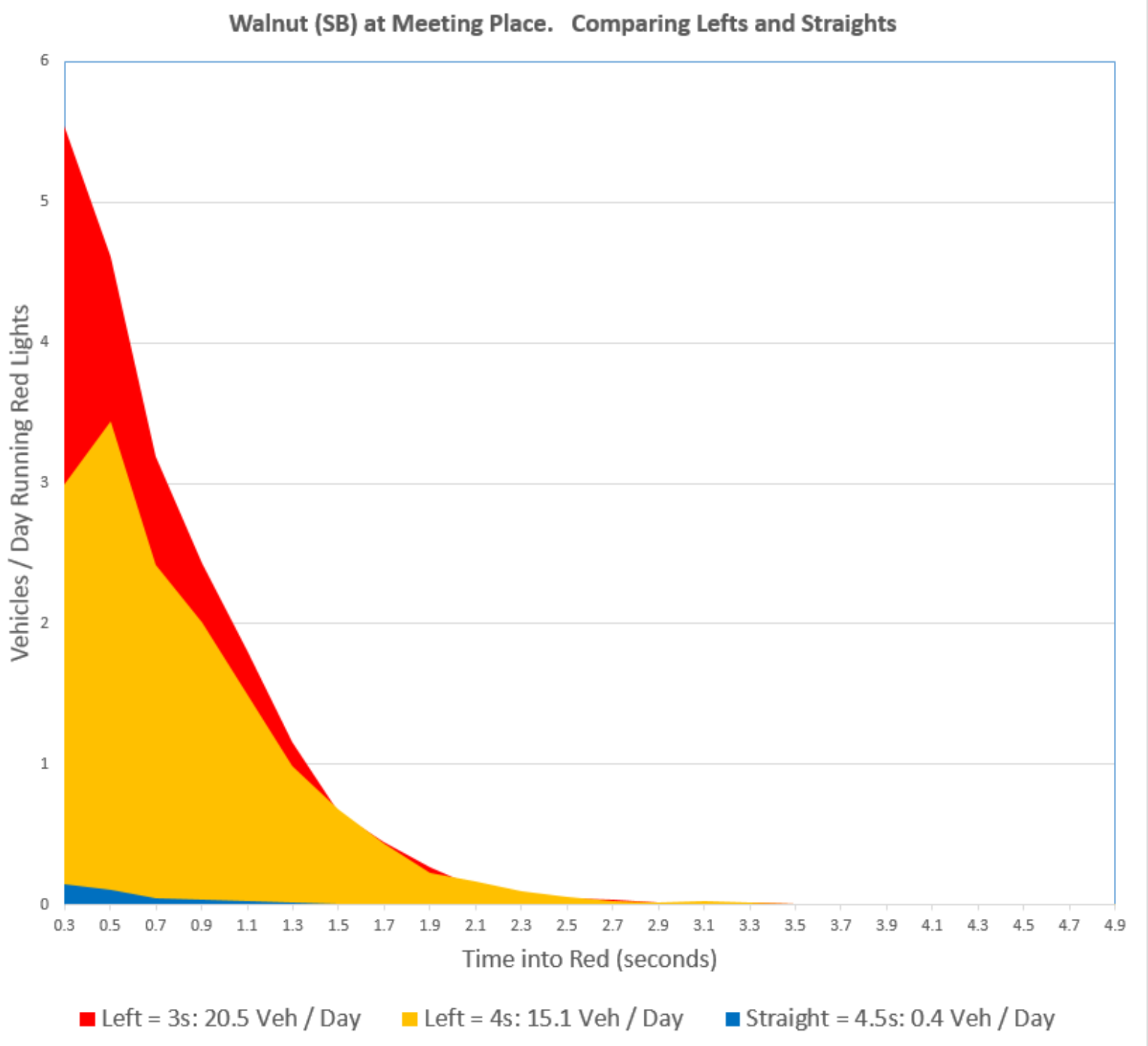
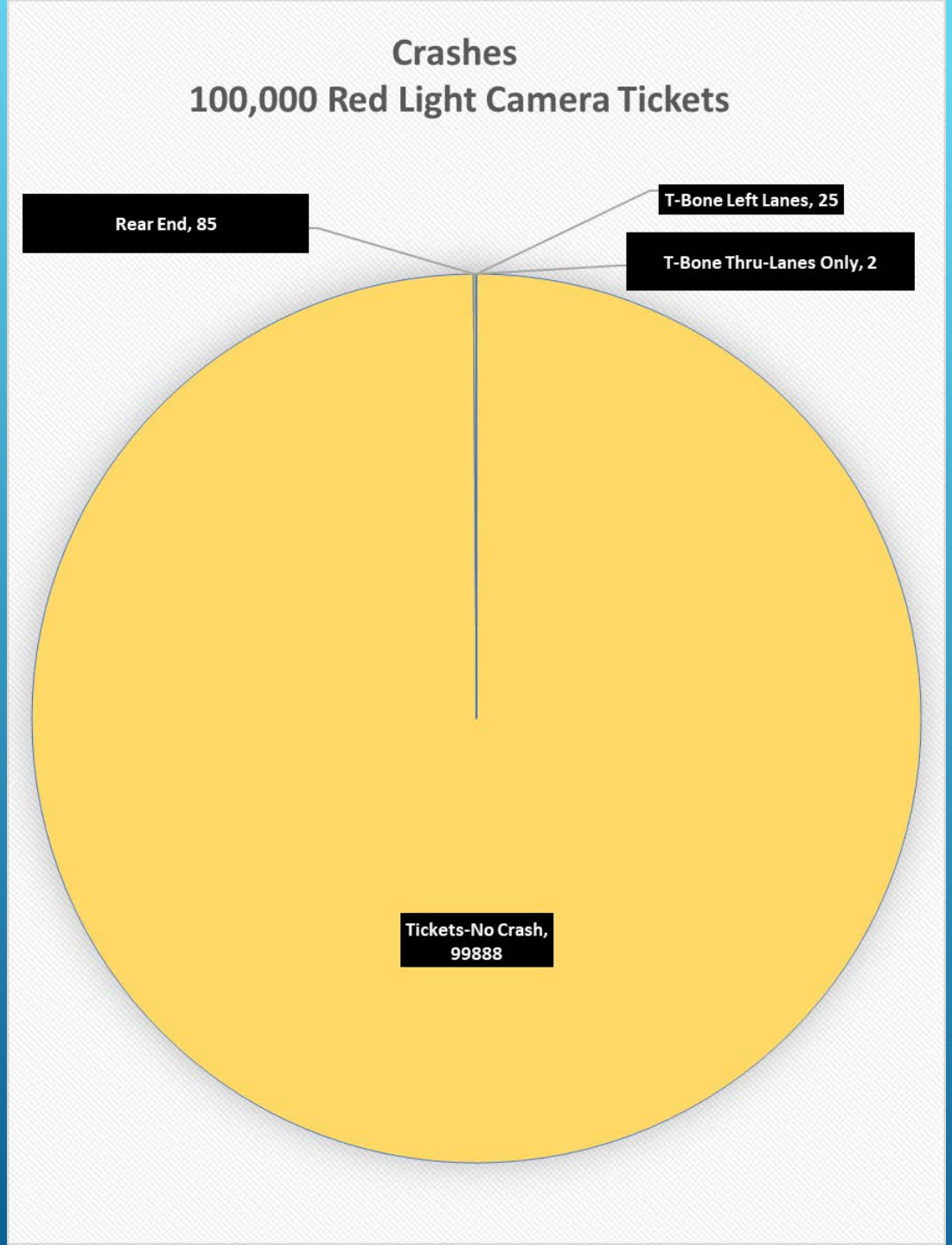
May-10
Jul-10
Sep-10
Nov-10
Jan-11
Mar-11
May-11
Jul-11
Sep-11
Nov-11
Jan-12
Mar-12
May-12
Jul-12


Walnut (SB) at Meeting Place. Comparing Lefts and Straights
Vehicles / Day Running Red Lights
0
1
2
3
4
5
6
0.3 0.5 0.7 0.9 1.1 1.3 1.5 1.7 1.9 2.1 2.3 2.5 2.7 2.9 3.1 3.3 3.5 3.7 3.9 4.1 4.3 4.5 4.7 4.9
Time into Red (seconds)
Left = 3s: 20.5 Veh / Day
Left = 4s: 15.1 Veh / Day
Straight = 4.5s: 0.4 Veh / Day

Suffolk County, New York

Red Light Camera Safety Report - 2015



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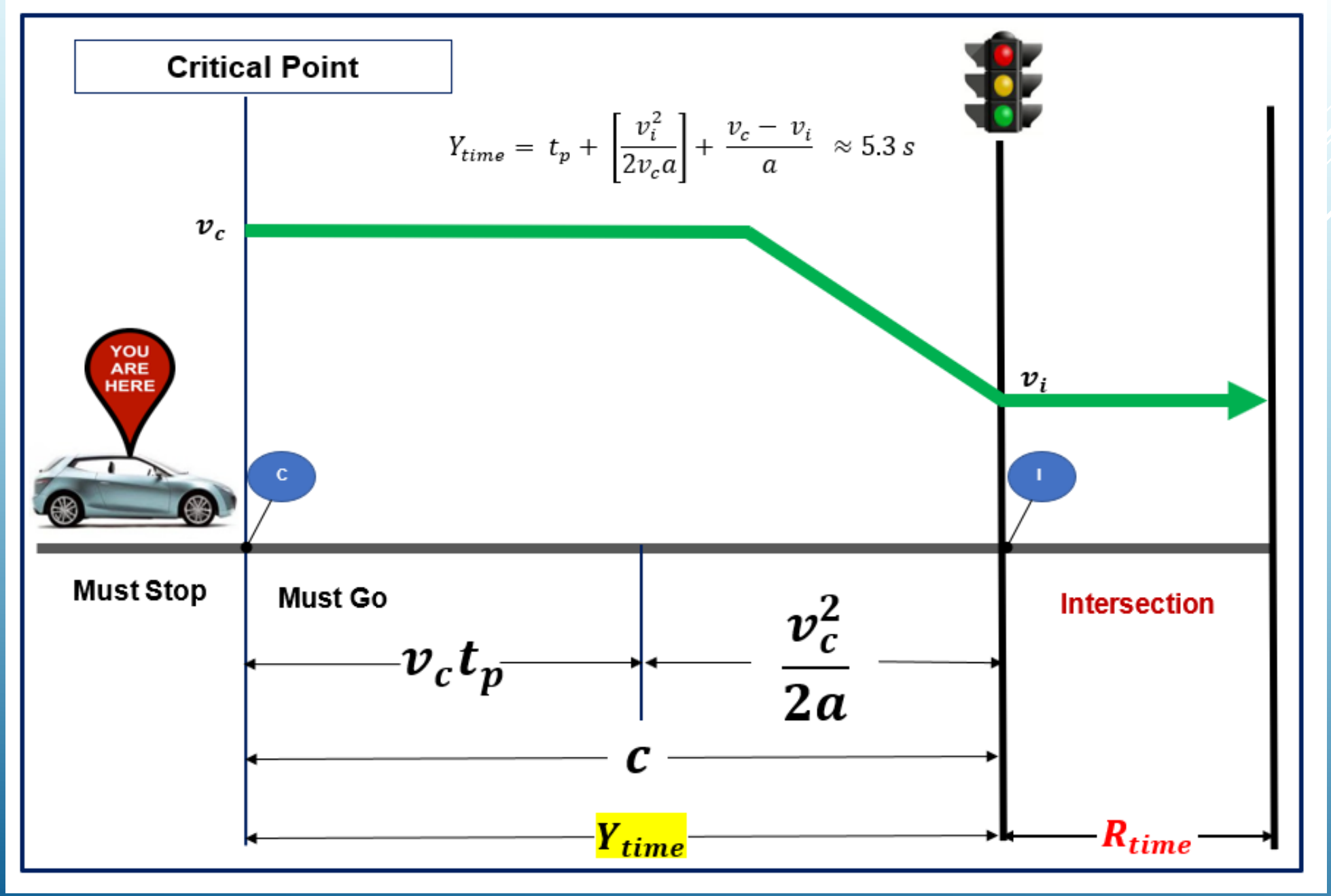
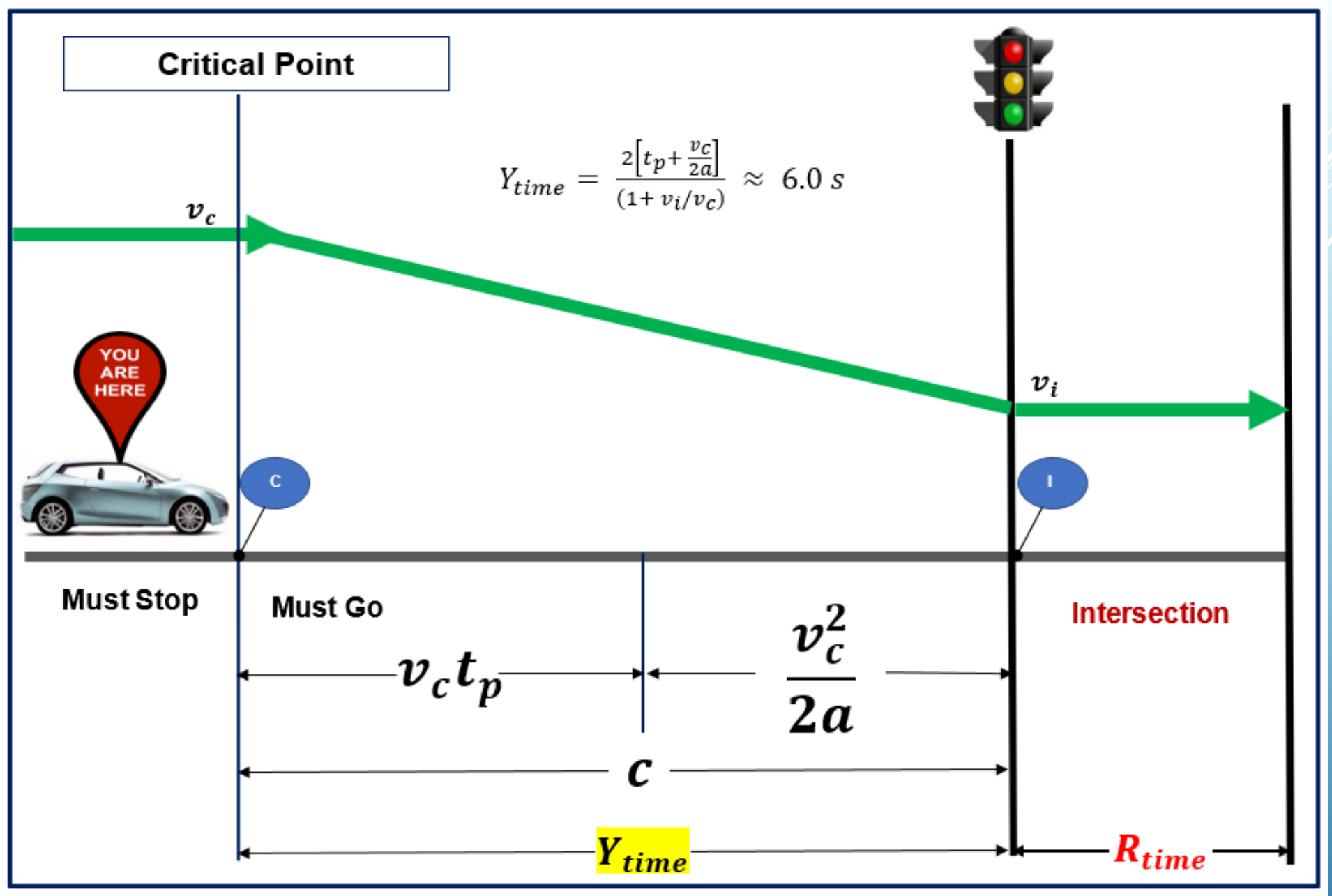
Suffolk County, NY 2017

Fastest Turn (Ceccarelli, 2010)



Turn with Constant Deceleration – Chiu Liu, 2002



Greenville, NC

NSPE

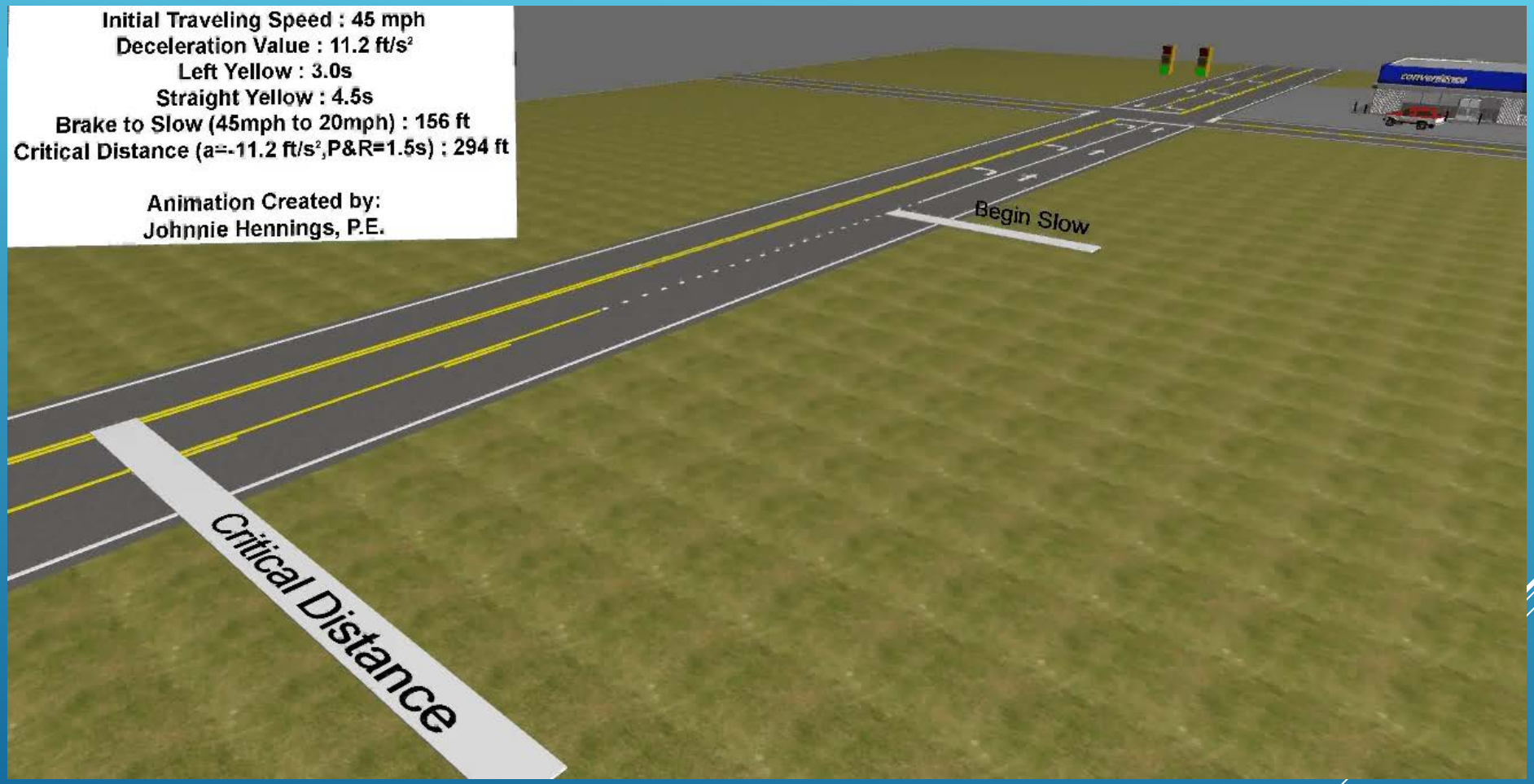
Wilmington, NC

NSPE

Omissions

Impeded Traffic

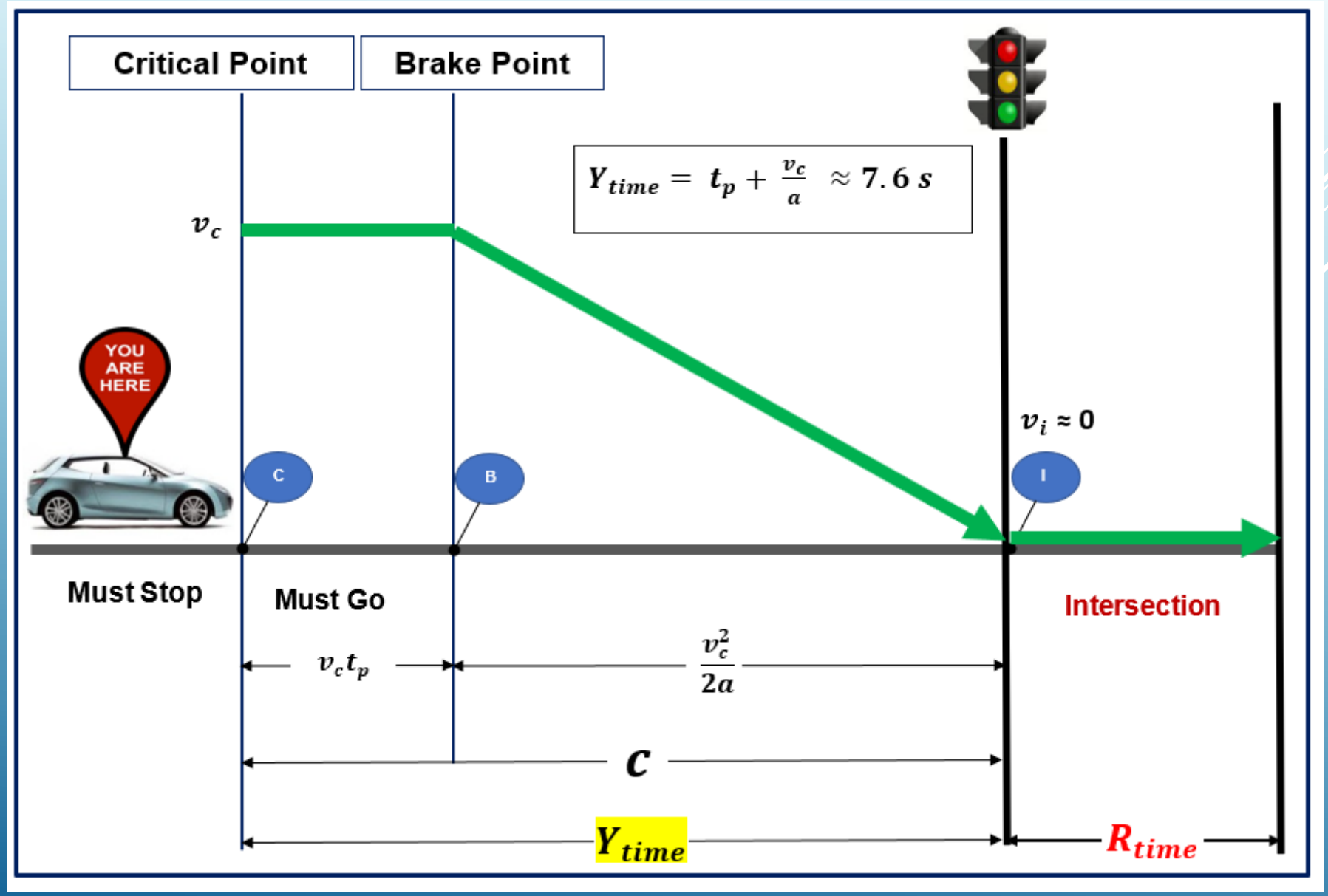
Vehicles Egressing/Entering Nearby Businesses



Close-By Intersections

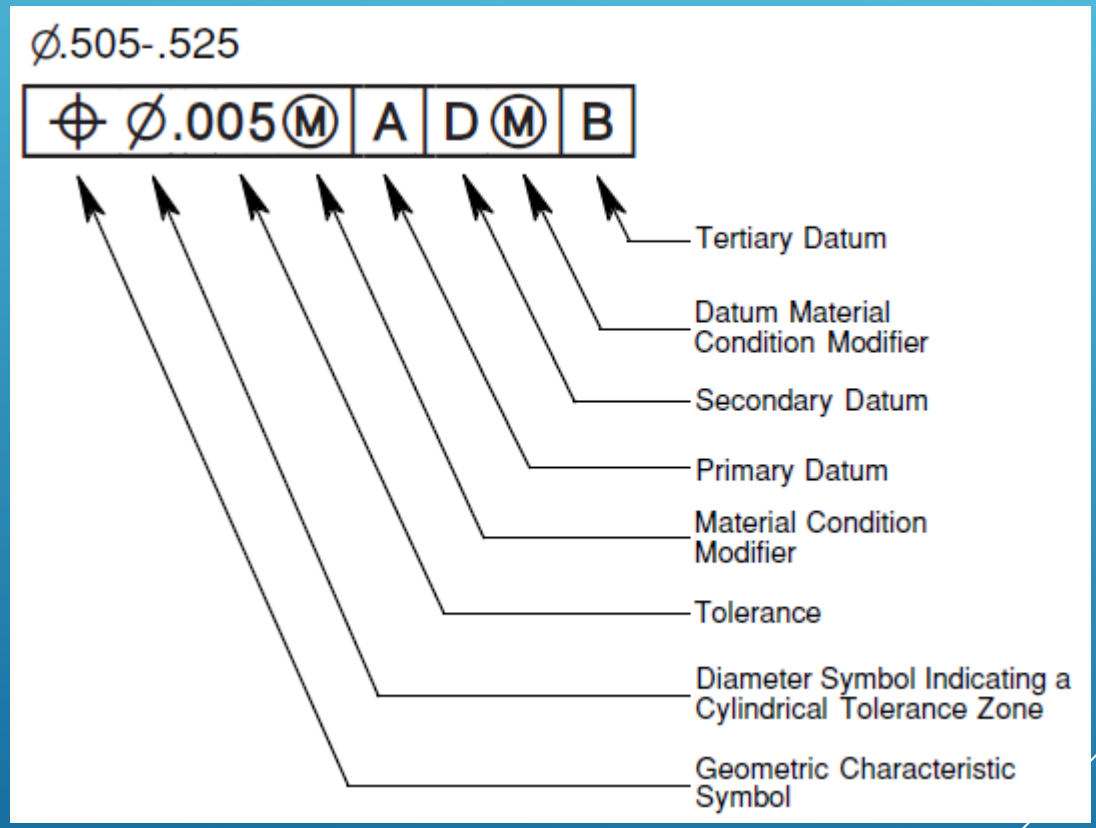
Solution – Includes Impeded Traffic @ Isolated Intersection

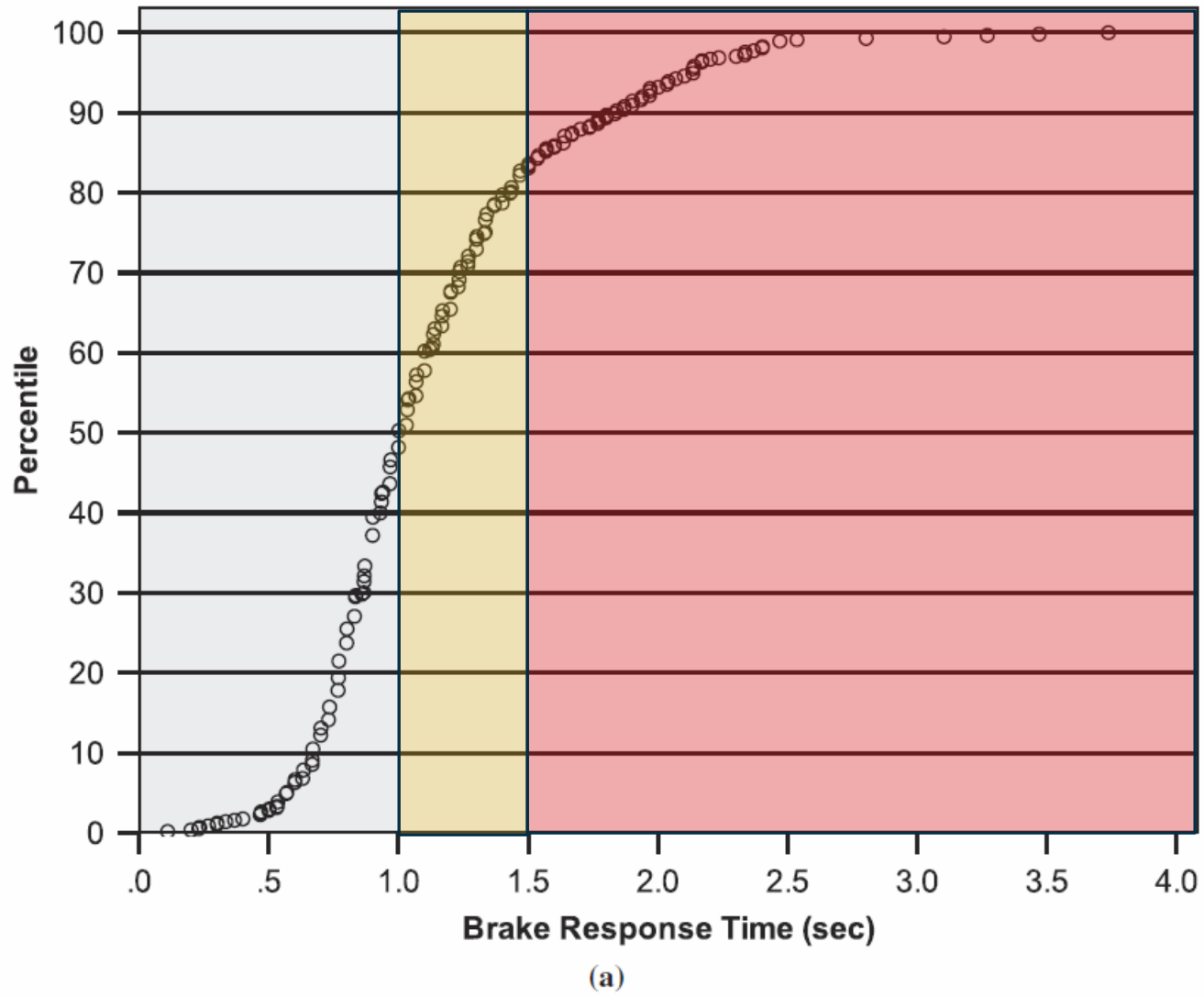
This changes the definition of a yellow light.



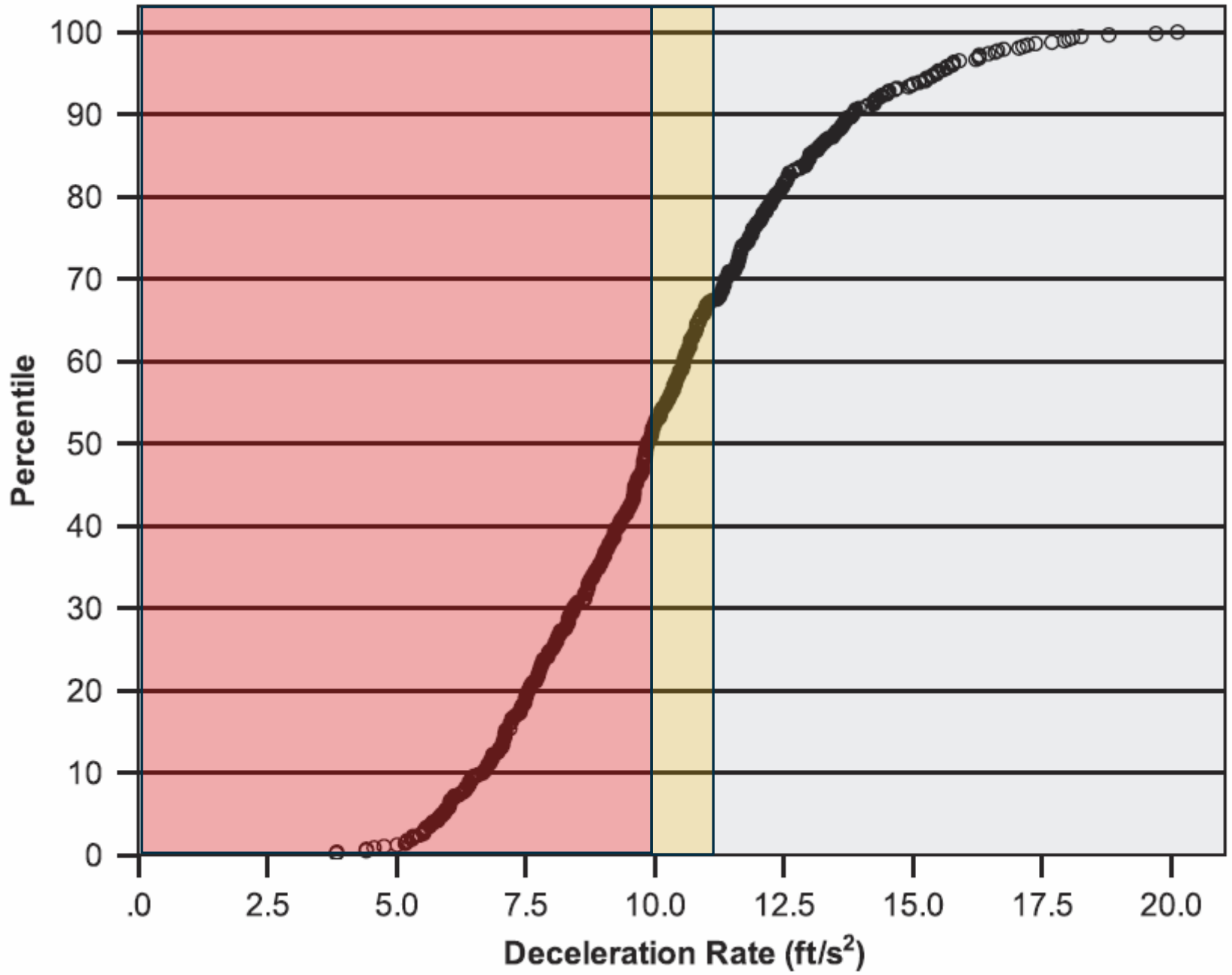
Tolerances

Type of Tolerance	Geometric Characteristics	Symbol
Form	STRAIGHTNESS	⏤
	FLATNESS	▱
	CIRCULARITY	○
	CYLINDRICITY	⌭
Profile	PROFILE OF A LINE	⌒
	PROFILE OF A SURFACE	⌓
Orientation	ANGULARITY	∠
	PERPENDICULARITY	⊥
	PARALLELISM	//
Location	POSITION	⌖
	CONCENTRICITY	◎
	SYMMETRY	⌯
Runout	CIRCULAR RUNOUT	↗
	TOTAL RUNOUT	⌰




Percentile
100
90
80
70
60
50
40
30
20
10
0
.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Brake Response Time (sec)

(a)


100
90
80
70
60
50
40
30
20
10
0
Percentile
.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
Deceleration Rate (ft/s²)

By Plugging In Boundary Values

Yellow Change Intervals using ITE Extended Kinematic Equation

	NCDOT	ITE	Boundary Value
Comfortable and Safe			
Perception-Reaction Time (s)	1.5	1.0	2.5
Decleration (ft/s2)	11.2	10.0	8.0

NCDOT (North Carolina Department of Transportation) uses the Emergency Stopping Values from the American Association o
ITE (Institute of Transportation Engineers) Perception-Reaction Time and Deceleration for the 50th Percentile Passenger Vehi
Boundary Values: Drivers exhibit a range of valid behavior. 2.5 s and 8.0 ft/s/s represent the maximum and minimum bound

Minimum Yellow Change Intervals
Going Staight at Constant Approach Speed
(Unimpeded Thru-Movements) Read Facts 4-9.

Mnimum Yellow Change Intervals
Turning or Impeded Thru-Movements
(Unimpeded Turning Movements) Read Facts 4-9.

Vo Approach Speed (mph)	Grade (%)	NCDOT Y (s)	ITE Y (s)	Boundary Value Y (s)	Red Light Camera Grace Period (s)	Ve Intersection Entry Speed (mph)	NCDOT Turn Y (s)	ITE Turn Y (s)	Boundary Value Turn Y (s)	Red Light Camera Turn Grace Period (s)	NCDOT Braking Time (s)
15	0	2.5	2.4	3.9	1.8	15	2.5	2.1	3.5	1.8	2.0
20	0	2.9	2.5	4.4	1.9	20	2.9	2.5	4.4	1.9	2.7
25	0	3.2	2.9	4.9	1.9	25	3.2	3.2	5.3	2.1	3.3
30	0	3.5	3.2	5.3	2.1	30	4.2	4.0	6.2	2.2	4.0
35	0	3.8	3.7	5.8	2.2	35	4.7	4.7	7.1	2.4	4.6
40	0	4.2	4.0	6.2	2.2	40	5.5	5.4	8.0	2.6	5.3
45	0	4.5	4.3	6.7	2.4	45	6.2	6.2	9.1	2.8	5.9
50	0	4.8	4.7	7.1	2.4	50	6.8	6.9	9.5	3.0	6.6
55	0	5.2	5.1	7.6	2.5	55	7.4	7.6	10.3	3.2	7.3
60	0	5.5	5.4	8.0	2.6	60	8.1	8.4	11.7	3.3	7.9
65	0	5.8	5.8	8.3	2.7	65	8.8	9.1	12.6	3.5	8.6

Facts

1. The yellow change interval, by definition, is the time it takes for a driver who intends to enter the intersection, to traverse the critical distance (columns P, T or X).
2. The critical distance is the safe and comfortable stopping distance upstream from the intersection stop bar. At the critical distance point and farther upstream from the intersection, the driver has the distanc
3. The critical distance is the same distance regardless of lane, and independent of the existence of a turning bay. The length of the turning bay is irrelevant because cars can just scoot over into the turning bay
4. Assumption. The main assumption of all the yellow change intevals above is the driver approaches unimpeded by other traffic. A vehicle that is unimpeded is one where there are NO obstacles, be it cars,
5. Example 1 of an Impeded Vehicle: Car A is approaching intersection and slows to turn right into a business or side-street. Because car B is travelling behind car A, car B has to slow down in order to avoid hitti
6. Example 2 of an Impeded Vehicle: Car A is approaching intersection and there is a railroad track. Car A has to decelerate otherwise he breaks his front suspension.
7. Example 3 of an Impeded Vehicle: Car A is approaching intersection and there is car B on the far side of the intersection pulling out of a gas station. Car must slow down to avoid hitting car A. Car A is inside
8. Example 4 of an Impeded Vehicle: Car A is approaching intersection and there is a pedestrian who just entered the intersection. Car A, who is inside critical distance, must slow down to avoid hitting pedestri
9. Any impeded motions require the yellow to be the stopping time (columns N, R or V). The driver must know that if he sees a yellow, that he can decelerate comfortably to a stop (Ve = 0) without running a re
10. Add to the perception-reaction time the time the signal head is not in line-of-sight to a driver within the critical distance.
11. Approach Speed >= Speed Limit. This must apply to thru and turning movements.
12. Approach Speed is meaured at the critical distance.
13. Grade = rise/run * 100.0. Grade is a percent. Negative grades are downhill. (Positive grades are uphill but the laws of physics forbid an uphill term.) Grade is the average between the critical distance poin
14. Turning and Impeded Thru-Movements when Vo > Ve. ITE Extended Kinematic Equation by Mats Jarlström, but ITE's equation includes term for uphill grade. Physical dynamics requires a 0 grade for uphill ac
15. The tolerance or red-light camera grace-period (aka, delay) is the Boundary value Yellow Change Interval - ITE Yellow Change Interval because commercial vehicles are the slowest vehicles allowed on the ro
16. In spite of the physics, ITE caps the yellow change interval at 7 seconds. Note that ITE's guideline cap is greater than the MUTCD's. In both cases, these are just guidelines, not standards. "Welcome aboar
17. The thru yellow change intevals (columns D, E, F) assume the vehicle maintains a constant speed through the critical distance.
18. The turning/impeded yellow change intervals (columns I, J, K) assume that the driver enters the intersection at speed Ve. (Ve = 0 is a U-turn, which is the time to stop.)
19. One must apply boundary values else the yellow change intervals work only for a subset of the driving population thereby not safeguarding the entire public.
20. For law enforcement purposes--*a compromise* when not using the boundary values--the NCDOT or ITE Y values require the traffic engineer to notify law enforcement to not ticket drivers when drivers run th
21. For law enforcements puroses, in the case of impeded traffic, one cannot fault a driver for needing the stopping time to enter the intersection. These drivers may enter the intersection up to R - E after the
22. If there is crash involving a commercial vehicle which would have been avoided had the engineer used the appropriate boundary value, then the engineer becomes responsible for the crash.
23. These yellow change intervals are shorter than what is required for two closely-spaced intersections. Crossing over the first intersection can leave you in a dilemma zone for the second intersection. More

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Talus Software PLLC
North Carolina Engineering Firm License: P1693

By Error Propagation

$$\Delta Y = \left|\frac{\partial Y}{\partial t_p}\Delta t_p\right| + \left|\frac{\partial Y}{\partial a}\Delta a\right| + \left|\frac{\partial Y}{\partial v_c}\Delta v_c\right| + \left|\frac{\partial Y}{\partial v_i}\Delta v_i\right|$$

$$= |\Delta t_p| + \left|\frac{(v_i - 2v_c)}{2a^2}\Delta a\right| + \left|\left(\frac{1}{a}\right)\Delta v_c\right| + \left|\left(\frac{1}{2a}\right)\Delta v_i\right| \approx \pm 3 \text{ sec}$$

for a 45 mph v_c and 20 v_i

TIMING CHART

2070N Controller

Phase	01	02	03	04	05	06	07	08
Minimum Green	7 sec	12 sec	7 sec	7 sec	7 sec	12 sec	7 sec	7 sec
Passage Gap	1.0 sec	2.0 sec	1.0 sec	2.0 sec	1.0 sec	2.0 sec	1.0 sec	2.0 sec
Max 1	25 sec	45 sec	20 sec	35 sec	25 sec	45 sec	20 sec	35 sec
Yellow Change Int.	6.2 sec	4.3 sec	6.2 sec	4.3 sec	6.2 sec	4.3 sec	6.2 sec	4.3 sec
Enforcement Delay*	2.8 sec	2.4 sec	2.8 sec	2.4 sec	2.8 sec	2.4 sec	2.8 sec	2.4 sec
Red Clearance	3.4 sec	2.1 sec	3.6 sec	1.3 sec	2.8 sec	2.1 sec	2.9 sec	1.4 sec
Recall Position	None	Min Recall	None	None	None	Min Recall	None	None
Vehl Call Memory	Nonlock	Lock	Nonlock	Nonlock	Nonlock	Lock	Nonlock	Nonlock
Walk	-	7 sec	-	7 sec	-	-	-	-
Flashing Don't Walk	-	29 sec	-	16 sec	-	-	-	-

*Enforcement Delay: Red-light camera delay/grace periods cannot be set to values less than this. Also the police cannot enforce red-light running until the driver enters the intersection after this length of time. Because the Yellow Change Int. is set for the average driver, good drivers (half the driving population is slower than average) may inadvertently run the red light up to this time into the red.

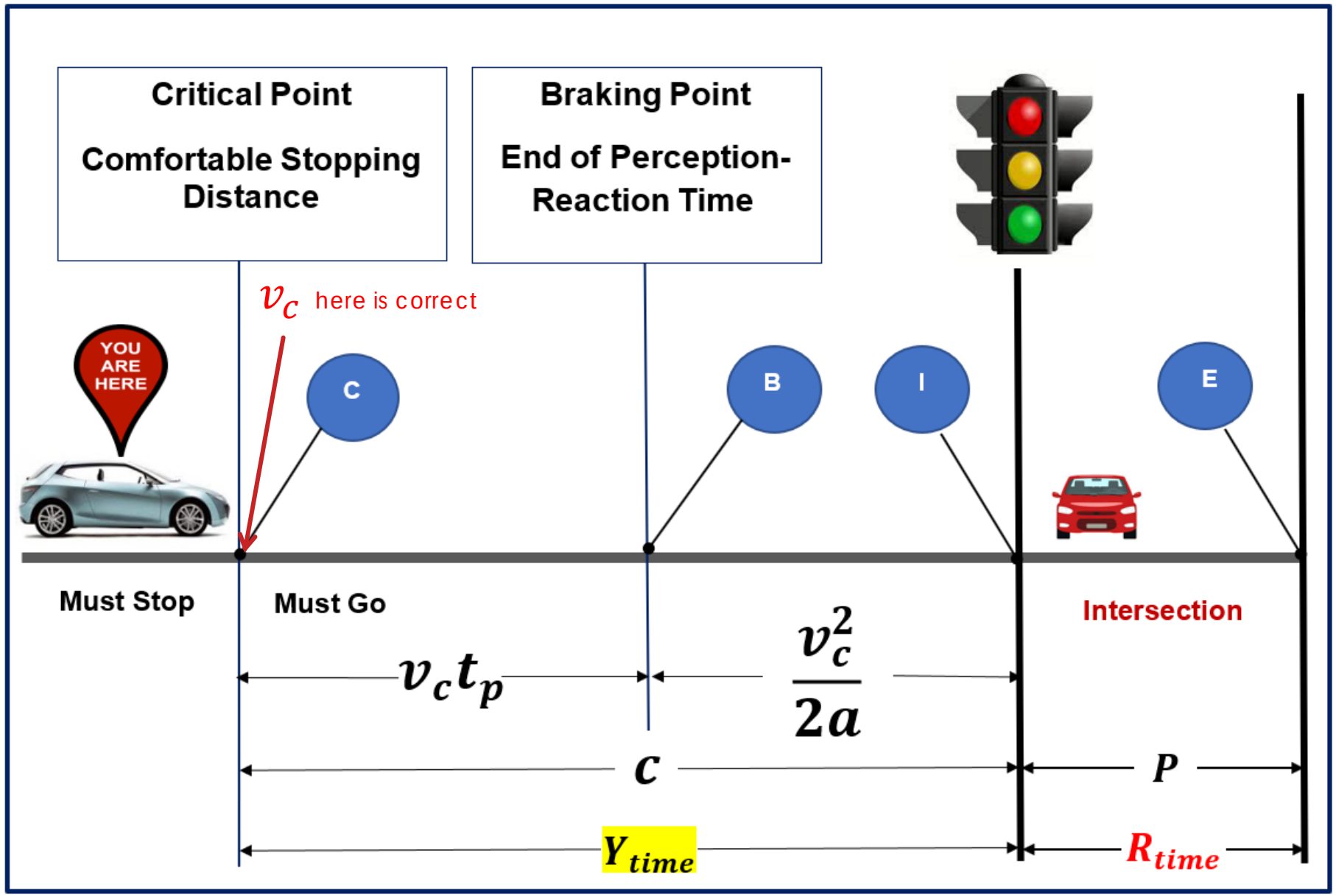
Perception-reaction time and deceleration are not constants. Good allowed drivers on the road exhibit a well-defined range of valid values. The curve of valid perception-reaction times has a range which tops at 2.6 seconds. The curve of deceleration has a range starting at 7.4 ft/s/s.

NSPE

Errors

Vc or Deceleration Measured at the Wrong Location

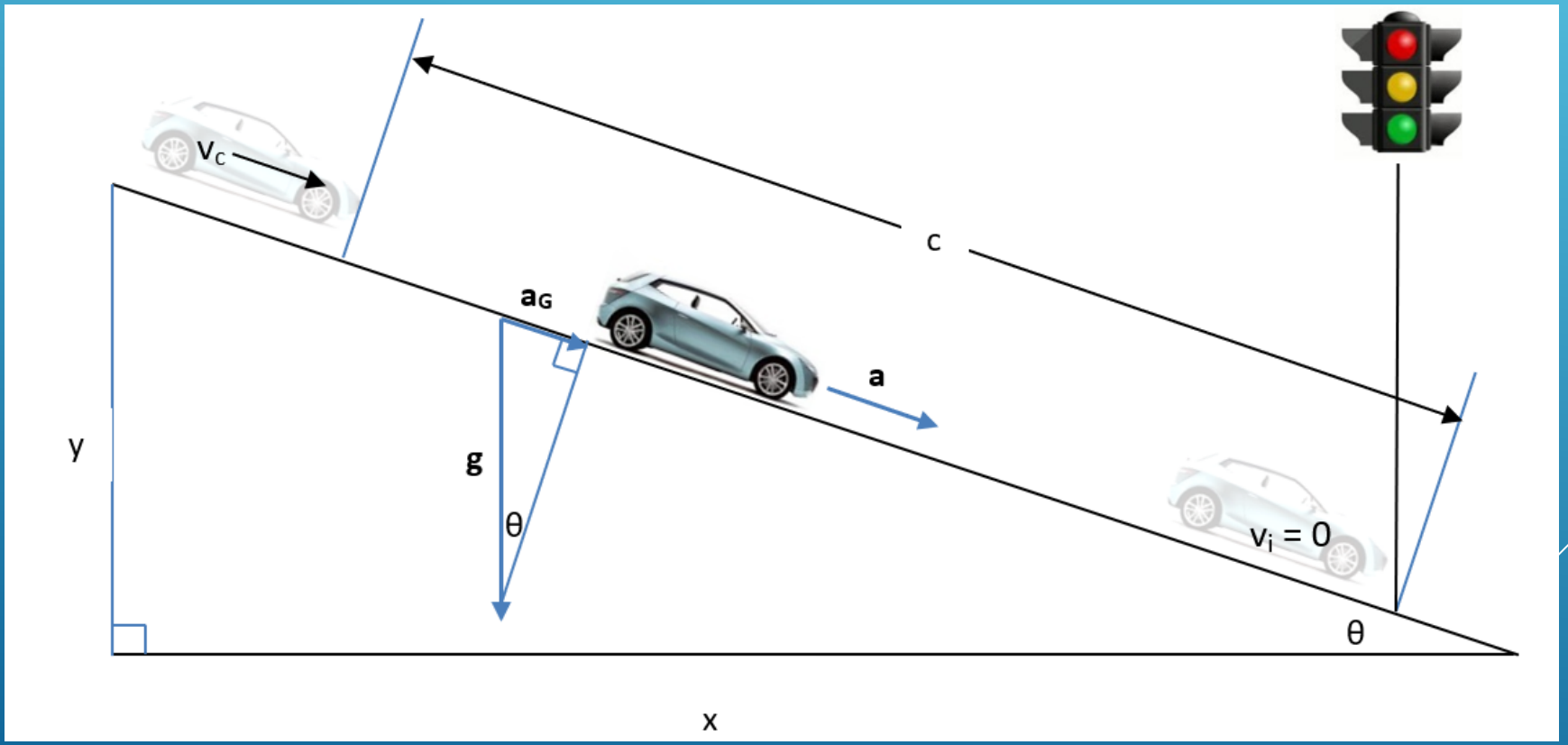
Critical Distance



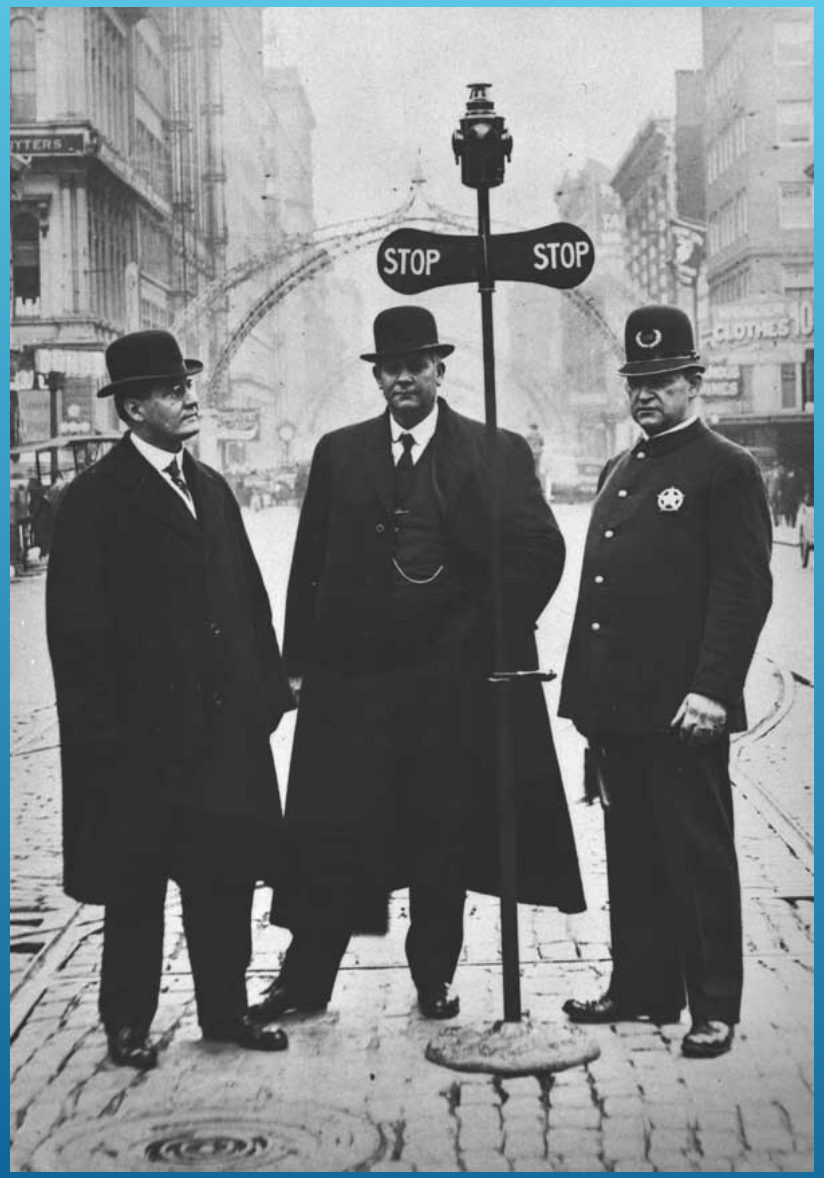
Dynamics of Emergency Stopping Misapplied to Comfortable Stopping

$$Y \geq t_p + \left[\frac{v_c - v_i}{a + Gg}\right] + \frac{v_i}{2(a + Gg)}$$

where G = y/x = grade and g = gravitational acceleration



History of the Yellow Light



1868

London, England

The First Red-Green
Traffic Light

J.P. Knight
1828 - 1886

William Potts
1883 – 1947
Detroit Policeman

1920

1921

Traffic “Towers”

Fifth Avenue
New York, NY

1923

Schenectady, NY

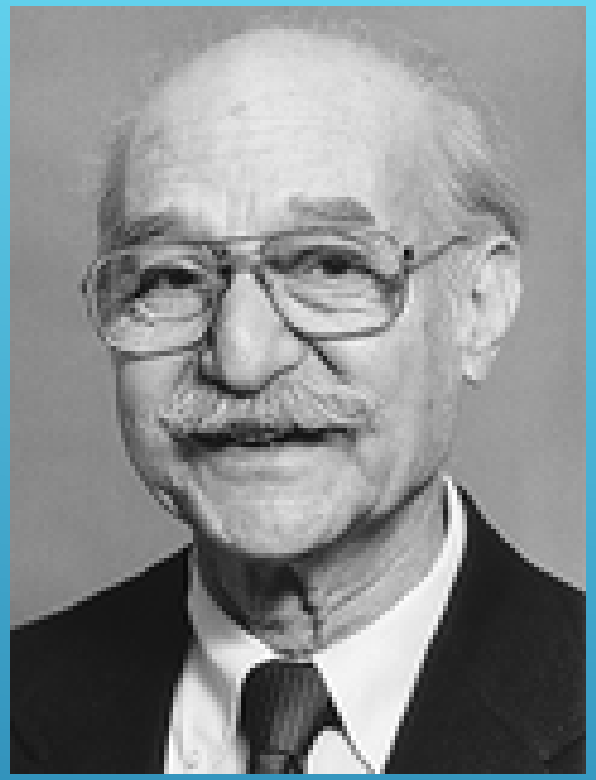
2017

The Henry Ford
Dearborn, MI

The Yellow Change Interval Formula

1959

Denos Gazis
1930 – 2004
Solid State Physicist and Traffic Scientist



Robert Herman
1914 – 1997
Physicist
Known for Research on Big Bang Theory: Microwave Radiation

Alexei Maradudin
1931 –
Physics Professor
UC Irvine

For vehicles traversing the critical distance at a constant speed which is the maximum allowable speed.

$$Y = t_p + \frac{v_c}{2a}$$

Institute of Transportation Engineers
The Yellow Change Interval Equation

1985

$$Y = t_p + \frac{v}{2(a + gG)}$$

Applied Universally

Mats Järlström
Beaverton, OR
2013

Brian Ceccarelli
Apex, NC
2009

Jay Beeber
Los Angeles, CA
2012

2020

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ITE'S FIRST RECOMMENDED PRACTICE

National Society of Professional Engineers, September 23, 2020

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