Signalized Intersections Prevent Travelling from Point A to B Legally

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Autonomous Vehicles Symposium, Michigan, October 25, 2017

How Much Do You Know About the Yellow Light?

There is an equation, called the "ITE formula", which calculates the duration of yellow lights:

$$Y = t_p + \frac{1}{2}\left[\frac{v}{a + Gg}\right]$$

Y = yellow change interval (yellow duration)
t_p = perception-reaction time
v = approach speed
a = deceleration
G = Grade of road
g = Earth's acceleration due to gravity

All traffic engineers in the world use this equation. Given the equation, the driver approaches the intersection at speed limit "v" and the light turns yellow . . .

Question 1. How long is the yellow light?

A. 50% of the time it takes a driver to stop
B. 100% of the time it takes a driver to stop
C. 150% of the time it takes a driver to stop

Question 2.

What kinds of traffic movement does the ITE formula apply thereby giving sufficient yellow time? (For other movements, the ITE formula computes too short of a yellow time.)

A. Turning traffic
B. Traffic moving toward and straight through the intersection
C. Unimpeded traffic approaching straight toward and going through an intersection at the constant speed of the speed limit, where the driver knows the exact location of the critical distance (The critical distance is the closest point upstream from the intersection where the driver can still react and stop comfortably.)
D. Traffic performing avoidance maneuvers
E. Commercial vehicle movements

Question 3.

The moment the driver no longer has the distance to comfortably stop, at what speed must he maintain in order to reach the stop bar (limit line) before the light turns red?

A. He must continue at the speed limit.
B. He can go faster than the speed limit (beat the light).
C. He can be cautious and go less than the speed limit.
D. He can decelerate (for example—in preparing to turn) into the intersection.

Question 4. To give the driver the distance to stop, what must be the minimum value for "v" for any traffic lane?

A. Speed limit or approach speed, whichever is greater
B. Half the speed limit
C. The approach speed
D. It does not matter. The yellow only needs to be the MUTCD 3.0 second minimum.

Question 5. Where is "v" supposed to be measured?

A. At the stop bar
B. At the critical distance
C. 600 feet upstream from the intersection
D. Depends on the traffic lane

Question 6. Where is "G", the grade of the road, supposed to be measured?

A. At the stop bar
B. At the critical distance
C. At the midpoint between the stop bar and the critical distance
D. It is the average grade of road through the critical distance.
E. 600 feet upstream from the intersection

Question 7. There is a "2" in the ITE formula. Where does the "2" come from?

Question 8. A driver approaches the intersection. The light turns yellow. What does the physics of the ITE formula require the driver to do?

Question 9. True or False? "If we increase the length of the yellow light, drivers will treat the yellow as a green light, drivers will disrespect the yellow and/or drivers will crash more."

Question 10. Because perception/reaction time, deceleration rate and road grade have known statistical errors and ranges, so does the resulting computation of the yellow change interval. The error in the yellow change interval can be computed by the technique of error propagation. What is the approximate *engineering error* of the yellow change interval when properly using the ITE formula?

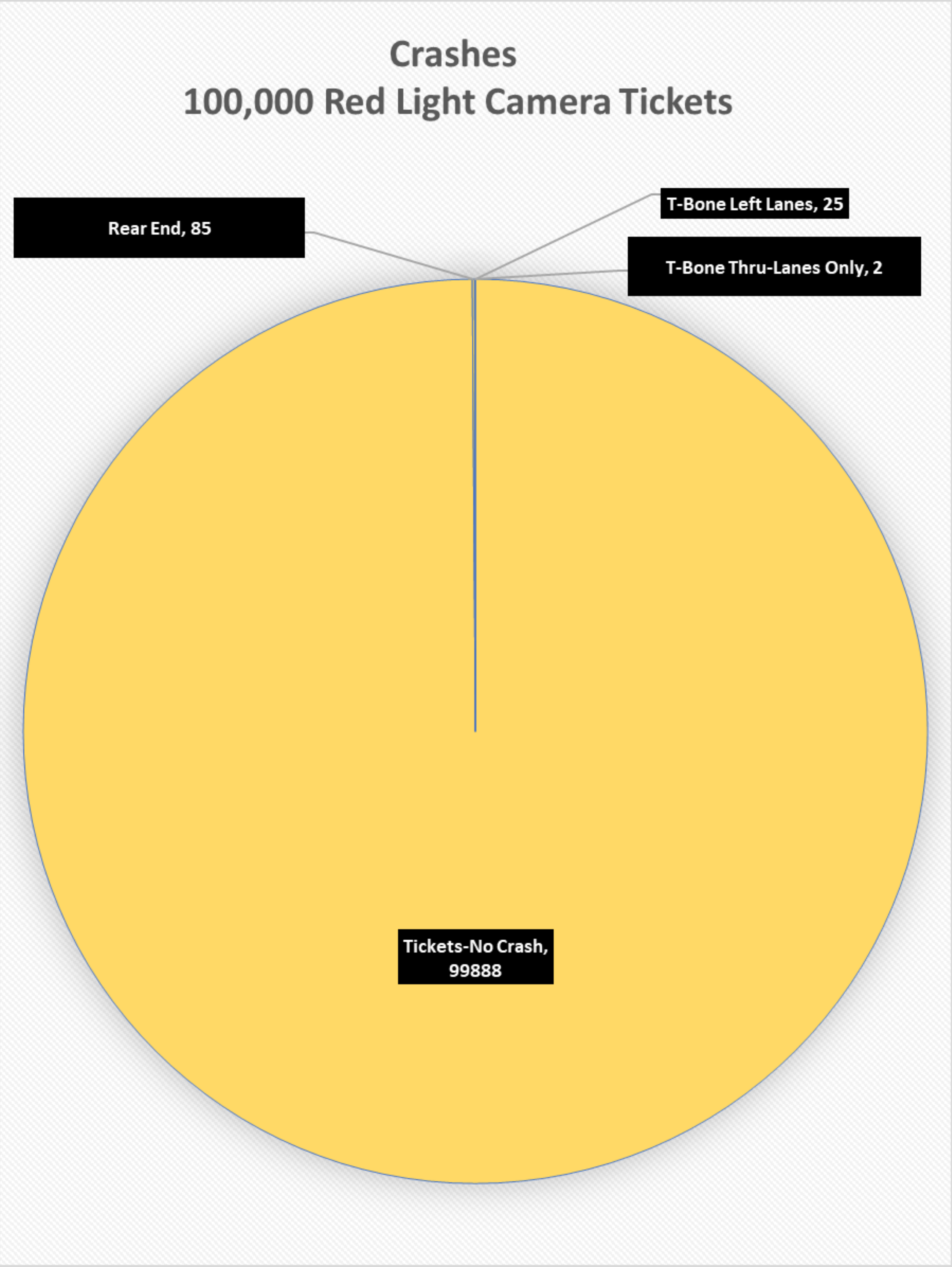
A. 0.0 seconds
B. 0.3 seconds
C. 3.0 seconds
D. 6.0 seconds

Question	Answer	Question	Answer
1	A	6	D
2	C	7	The 2 comes from the distance equation: $d = v^2/2a$. Where v is the velocity of the car at this distance where it starts decelerating at constant "a".
3	A and B	8	If the driver is farther from the intersection than the critical distance, then the driver has the distance to stop. He must stop. If the driver is closer to the intersection than the critical distance, he must proceed at the speed limit "v" or more toward and into the intersection.
4	A	9	False
5	B	10	C

Requirements

Can a manufacturer develop an AV which passes validation?

1. The AV shall travel safely.
2. The AV shall travel legally.
3. The AV shall travel efficiently.
4. The AV shall travel comfortably.



Suffolk County, New York

Red Light Camera Safety Report - 2015

Assumptions

Traffic engineers have designed signalized intersections so that a vehicle can always travel safely.

Traffic engineers have designed signalized intersections so that a vehicle can always travel legally.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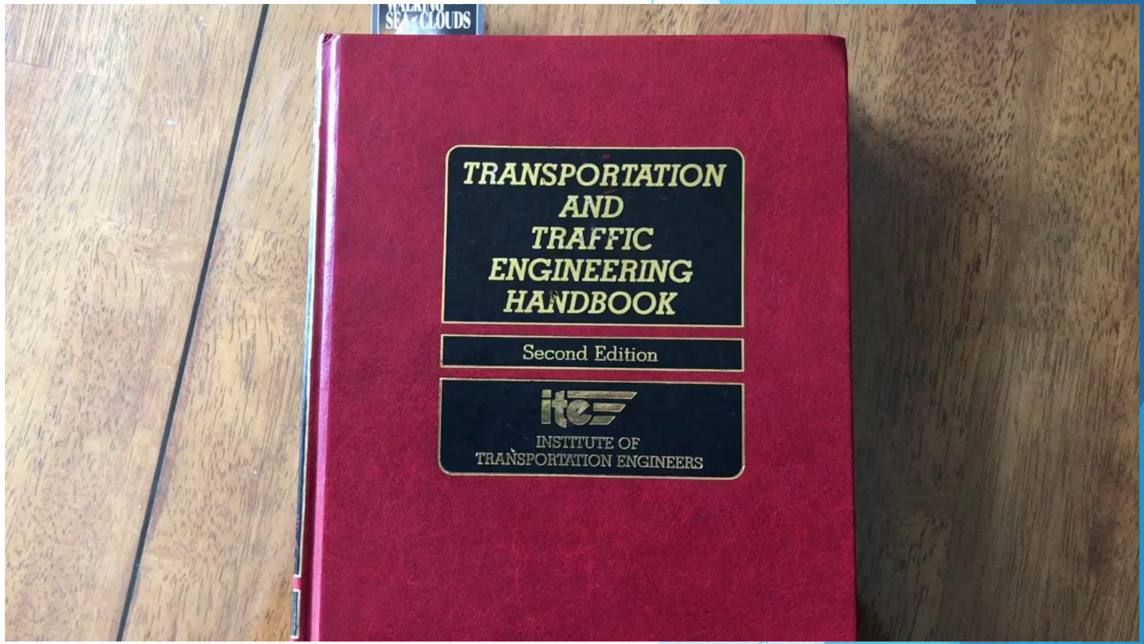
Yellow change and clearance intervals

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

Govt/RLC industry will punish AV manufacturers > $2 billion each year for systematic defects introduced by traffic engineers.

AV Manufacturers' Priorities

Traffic Engineers' Priorities

TxDOT Report 0-4372-2

The Yellow Change Interval Equation

1959

Yellow Change Interval Definition

Requirements:

1. Shall provide the distance to comfortably stop.
2. Shall be the amount of time the driver needs to reach and enter the intersection when he cannot comfortably stop.

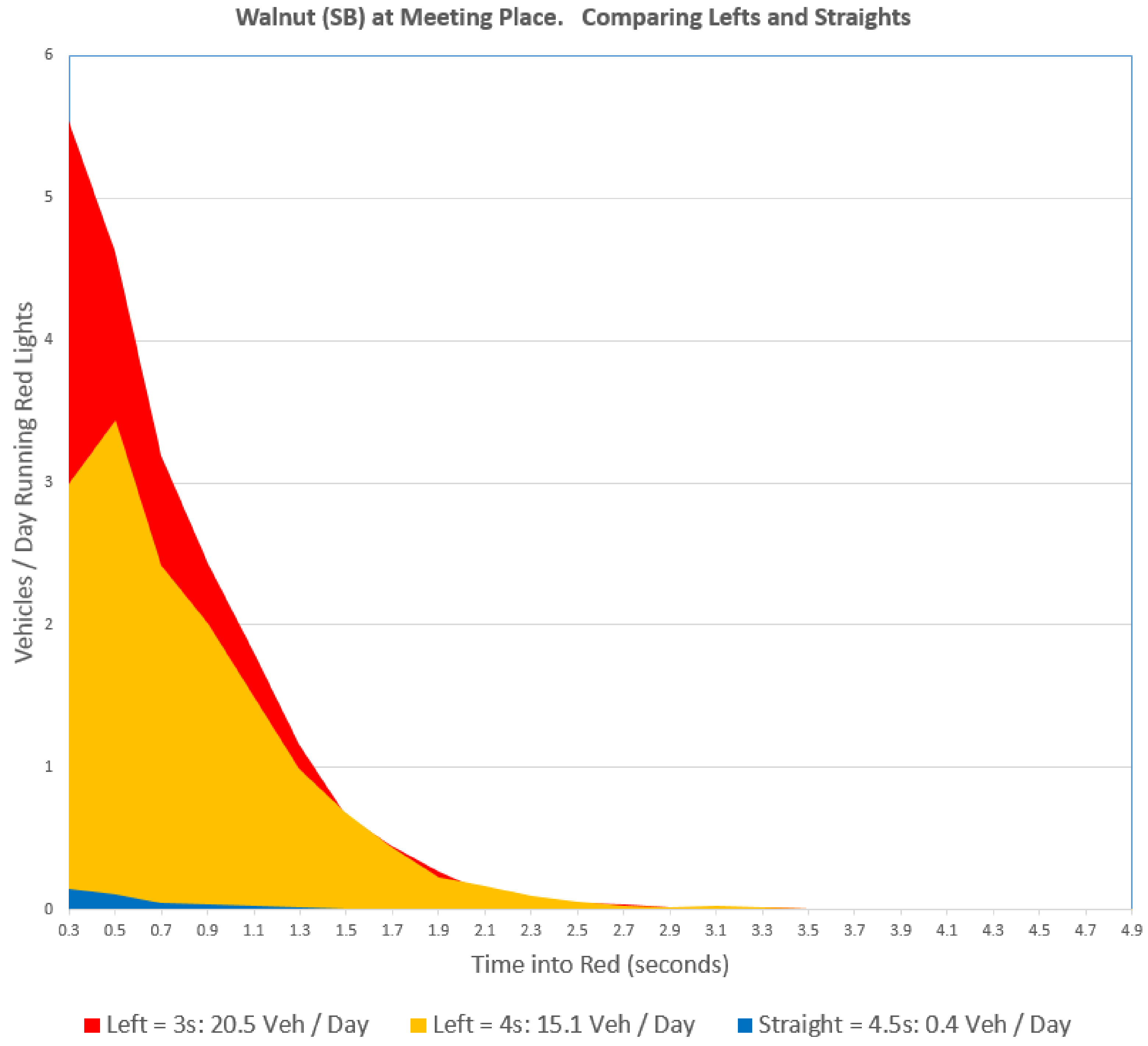
$$Y = t_p + \frac{v}{2(a + gG)}$$

Y	= yellow change interval
t_p	= perception-reaction time
v	= approach speed
a	= deceleration
g	= Earth's gravitational acceleration
G	= Grade of road (slope y/x where + is uphill)

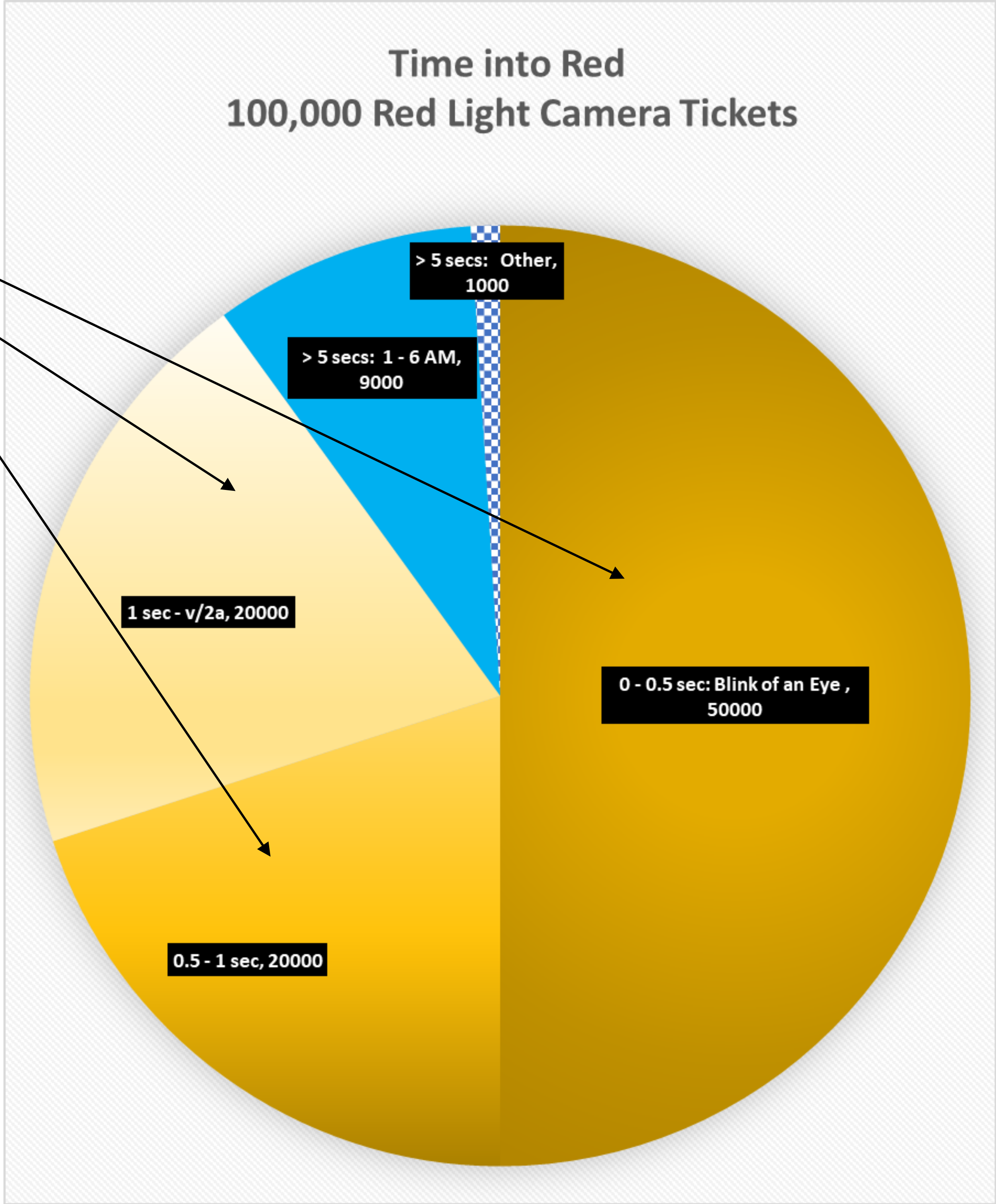
The equation works only for unimpeded straight-through movements given that driver and vehicle meet preconditions for t_p and a.

Errors and Omissions

1. **Wrong algebra** (Equation is special case but applied universally.)
2. **Wrong value for approach speed** (misunderstanding of physics)
3. **Wrong value for perception-reaction time** (misapplied stochastic method)
4. **Wrong value for deceleration rate** (misapplied stochastic method)
5. **Term gG wrong half the time.** (gG is an analytic solution, not a physical solution.)
6. **Omission of tolerances** (Drivers are punished for the error (uncertainty) in the yellow change interval calculation.

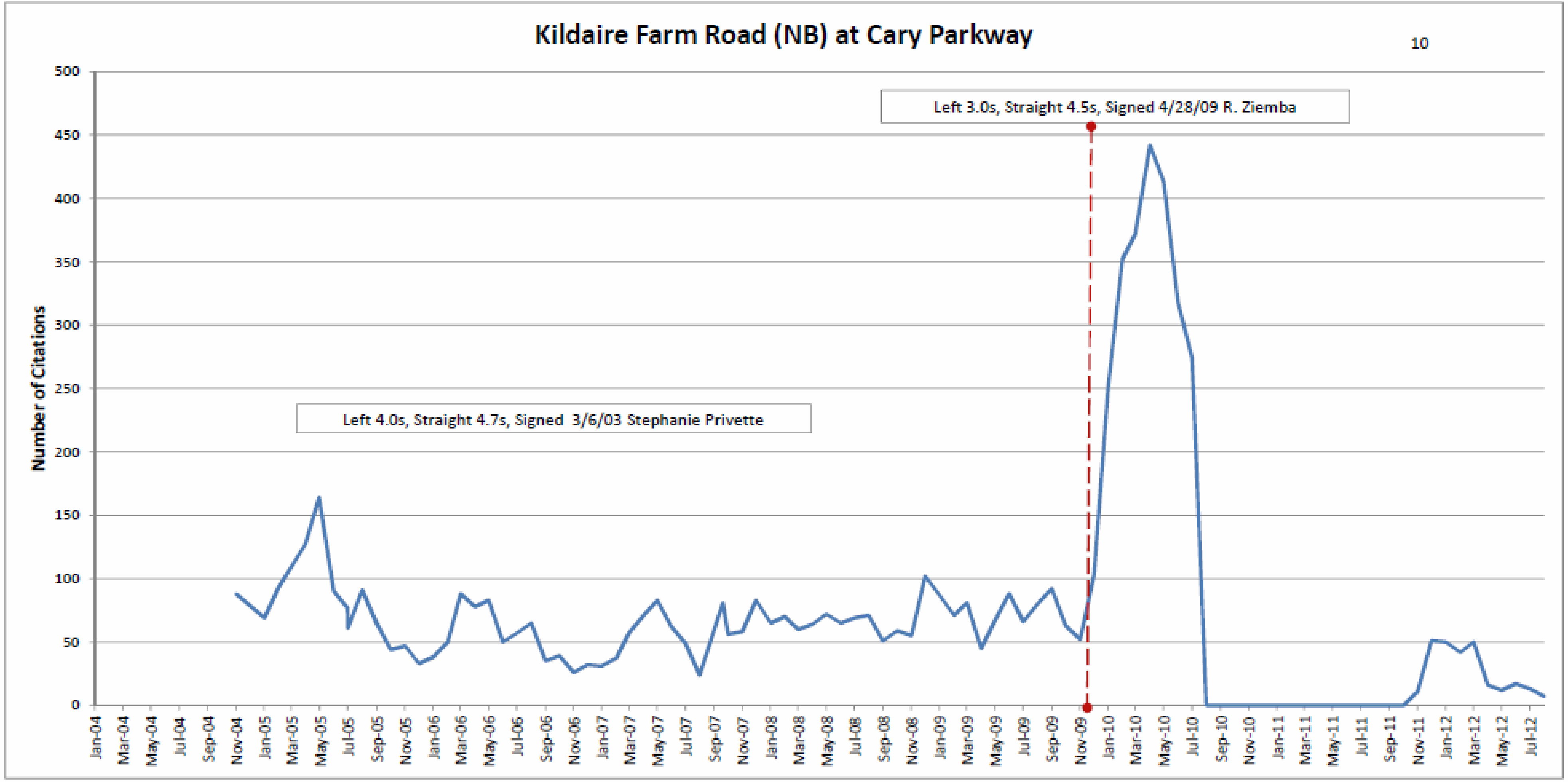

Walnut (SB) at Meeting Place. Comparing Lefts and Straights
Vehicles / Day Running Red Lights
0
1
2
3
4
5
6
0.3
0.5
0.7
0.9
1.1
1.3
1.5
1.7
1.9
2.1
2.3
2.5
2.7
2.9
3.1
3.3
3.5
3.7
3.9
4.1
4.3
4.5
4.7
4.9
Time into Red (seconds)
Left = 3s: 20.5 Veh / Day
Left = 4s: 15.1 Veh / Day
Straight = 4.5s: 0.4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

The misapplication of physics in the calculation of the yellow light duration is responsible for about 90% of all tickets and crashes.



Cary, North Carolina

Red Light Camera Data 2004 - 2012


Kildaire Farm Road (NB) at Cary Parkway
10
Left 3.0s, Straight 4.5s, Signed 4/28/09 R. Ziemba
Left 4.0s, Straight 4.7s, Signed 3/6/03 Stephanie Privette
Number of Citations
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
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Nov-09
Jan-10
Mar-10
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

Financial Problem

When the AI drives as manufacturer prescribes, manufacturers are legally culpable for consequences. Manufacturers will be punished with a $2 billion bill annually for systematic errors created by traffic engineers.

Legal

The traffic engineer, not the DOT or the City, is legally responsible for the injuries, both financial and physical, at intersections he designs. He is responsible to safeguard the life, health and property of the public by applying the physical and mathematical sciences to his designs.

The traffic engineer violates 23 CFR 655 part F, MUTCD 4D.26 (3).

TALUS SOFTWARE

http://talussoftware.com
http://redlightrobber.com

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Analysis of the Equation

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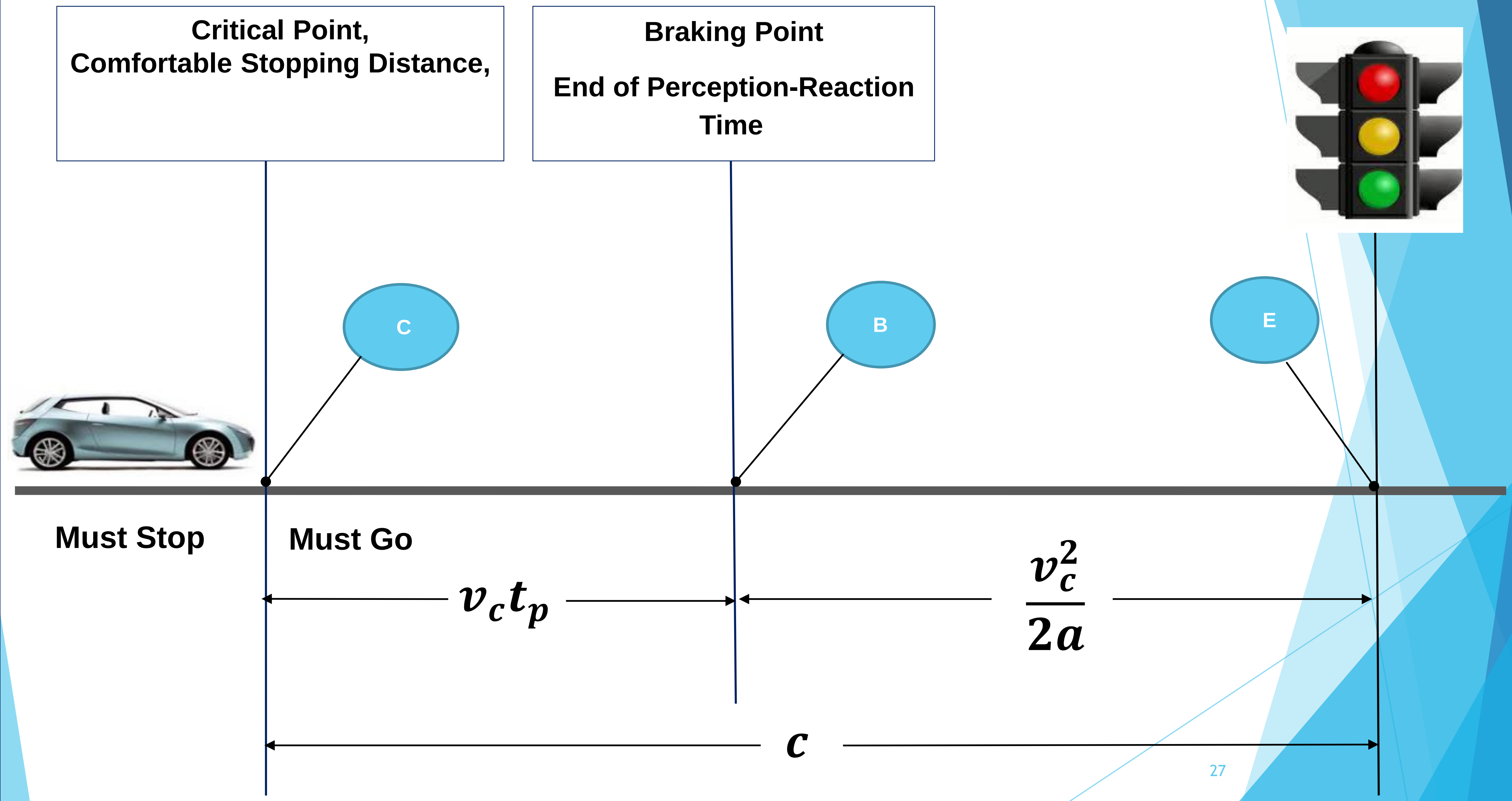

Critical Point,
Comfortable Stopping Distance,
Braking Point
End of Perception-Reaction Time
C
B
E
Must Stop
Must Go
$v_c t_p$
$\frac{v_c^2}{2a}$
c

$$Y_{min} = \frac{c}{v_{avg}} =$$

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

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

#1. Error. Wrong Algebra

Traffic engineers apply this algebra to all traffic movements.

BUT:

The equation works for only a special case.

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

#2. Error. V measured at wrong location

Some DOTs measure v *inside* the intersection. For turning lanes, some compute it as half the speed limit and intersection speed.

BUT:

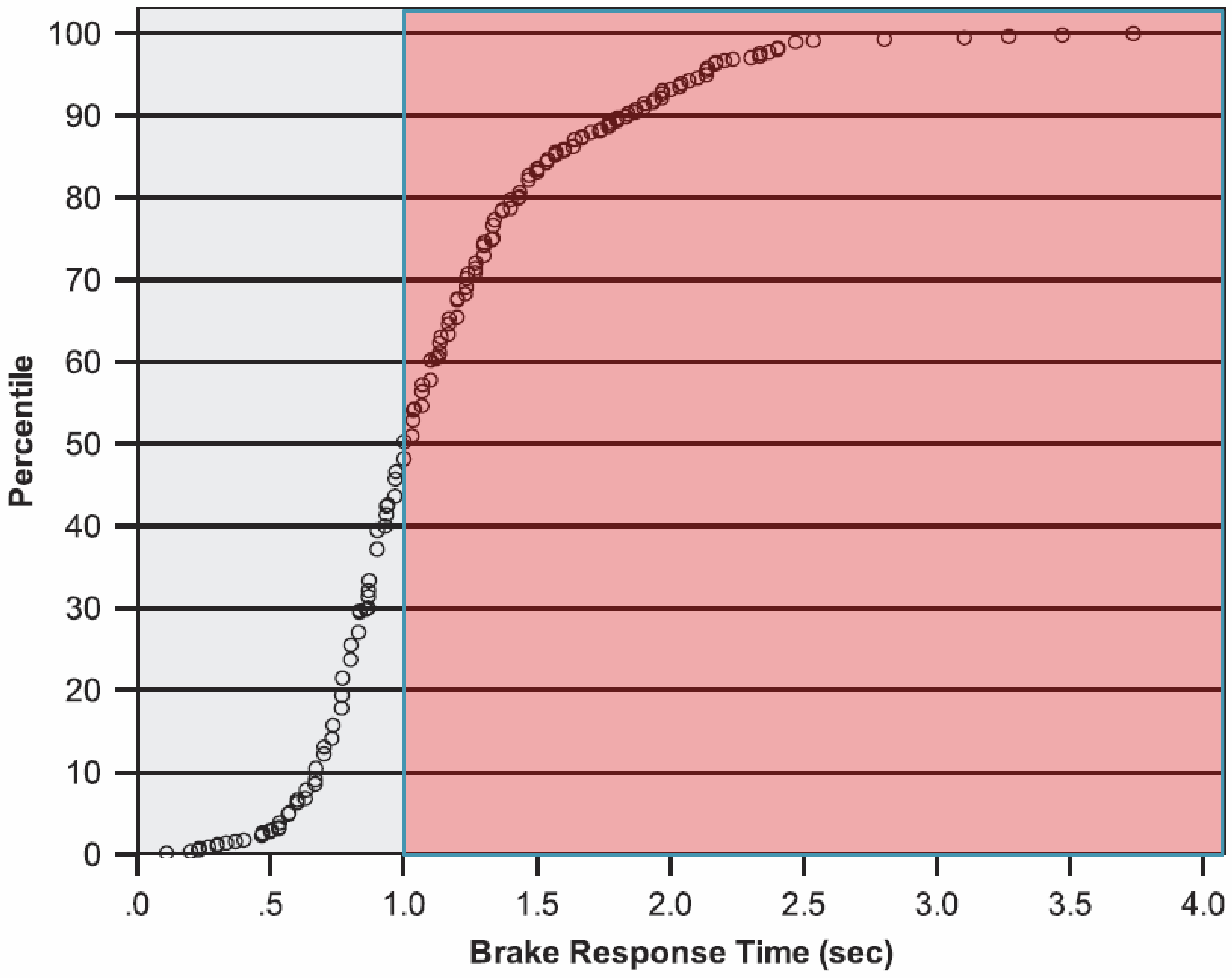
V must be measured at the critical distance upstream from the intersection.

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

#3, 4. Error. Traffic engineer misapply stochastic methods by calculating singular values, those being average values) for human perception-reaction time and vehicle deceleration

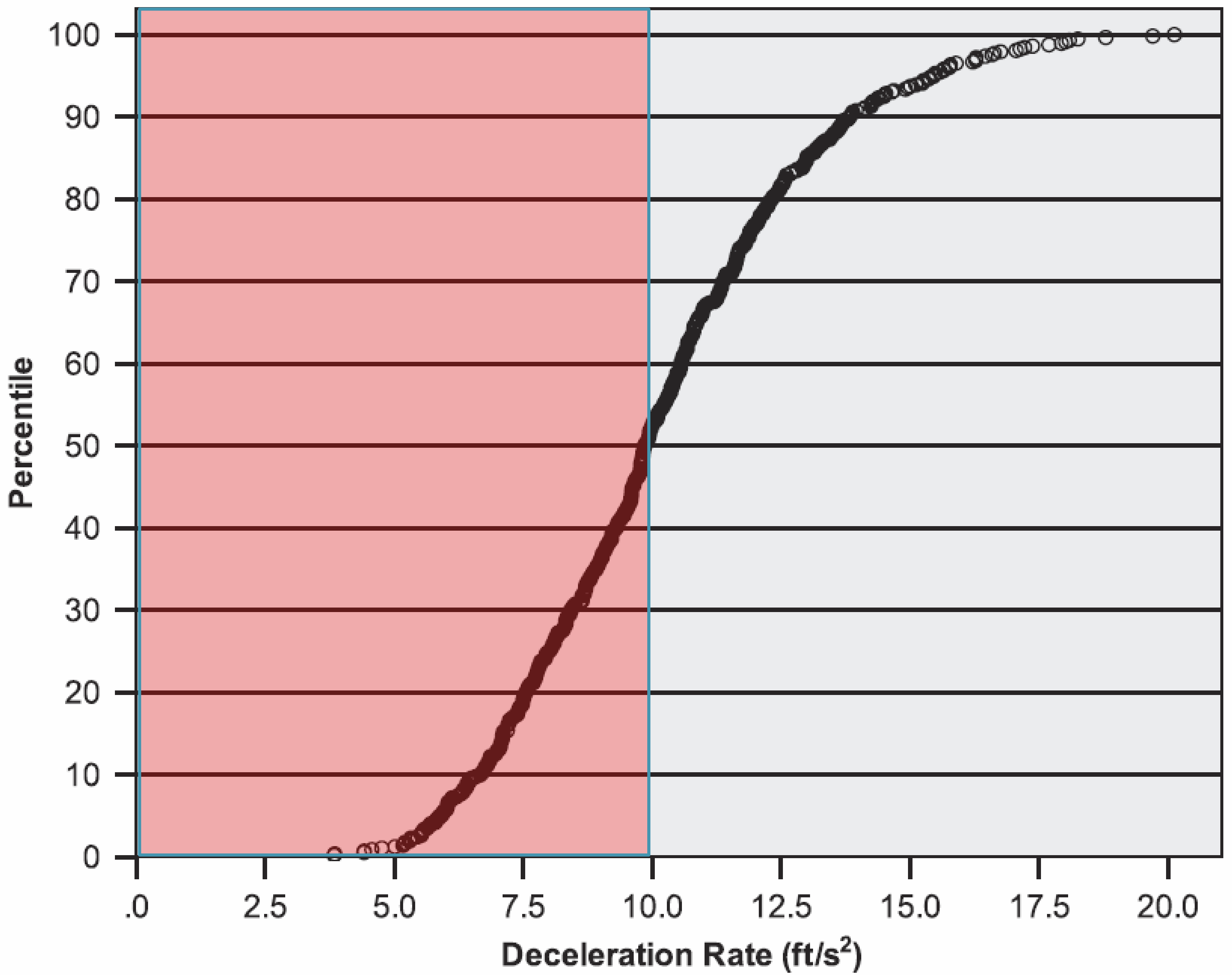
BUT:

“Average” vs “Allowable”. Perception-reaction time and deceleration are each *ranges* of valid values representing normal behavior. If a bridge engineer designed bridges like traffic engineers set yellows, then the bridge would only uphold the weight of the average passenger sedan, and yet allow school buses to go over it.



100
90
80
70
60
50
40
30
20
10
0
Percentile
.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/s^2)

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

#5. Error. gG - Misapplication of an Analytic Solution

gG was intended to be gravity's contribution to normal comfortable deceleration.

BUT

gG applies only to emergency stopping. The dynamics are different. gG only applies when the frictional force created between tire and pavement determines the maximum deceleration.

gG can be applied to yellow lights for vehicles going downhill for a different reason: It is not *comfortable* to press the brakes harder than normal.

gG cannot be applied uphill because drivers press the brake less in order to keep deceleration comfortable. Applying a negative gG shortens the yellow. Drivers actually need more time going uphill because when proceeding into the intersection, gravity slows them down through the critical distance.

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

#6. Omission of Tolerances

Straight Unimpeded Traffic:

$\Delta Y = \left|\frac{\partial Y}{\partial t_p}\Delta t_p\right| + \left|\frac{\partial Y}{\partial a}\Delta a\right| \approx$ 2 seconds on a 45 mph road.

Left Turning Traffic:

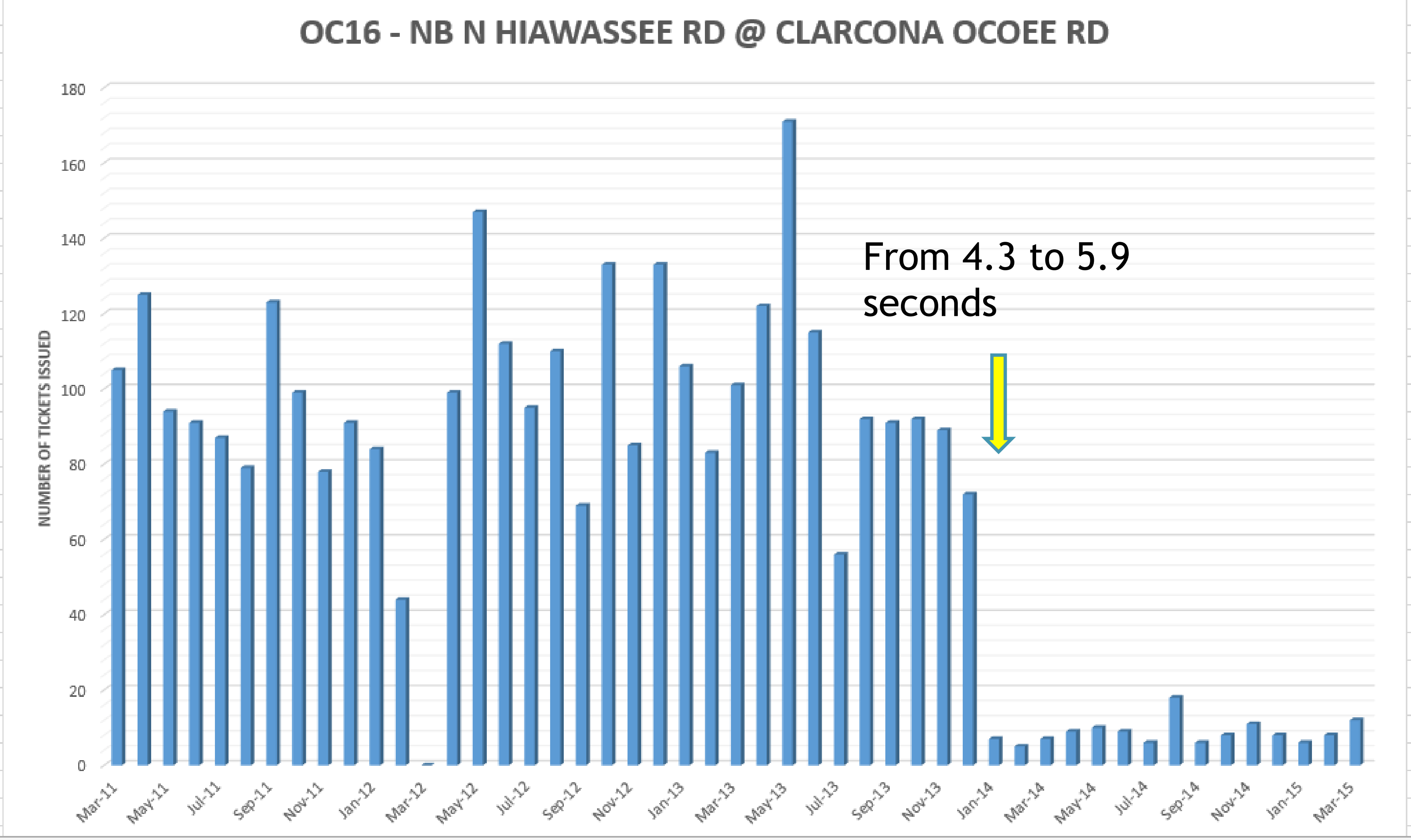
$\Delta Y = \left|\frac{\partial Y}{\partial t_p}\Delta t_p\right| + \left|\frac{\partial Y}{\partial a}\Delta a\right| + \left|\frac{\partial Y}{\partial v_i}\Delta v_i\right| = \left|\frac{2v_0}{v_0 + v_i}\Delta t_p\right| + \left|\frac{{v_0}^2}{a^2(v_0 + v_i)}\Delta a\right| + \left|\left(\frac{2v_0\left(t_p + \frac{v_0}{2a}\right)}{(v_0 + v_i)^2}\right)\Delta v_i\right| \approx$ 3 seconds.

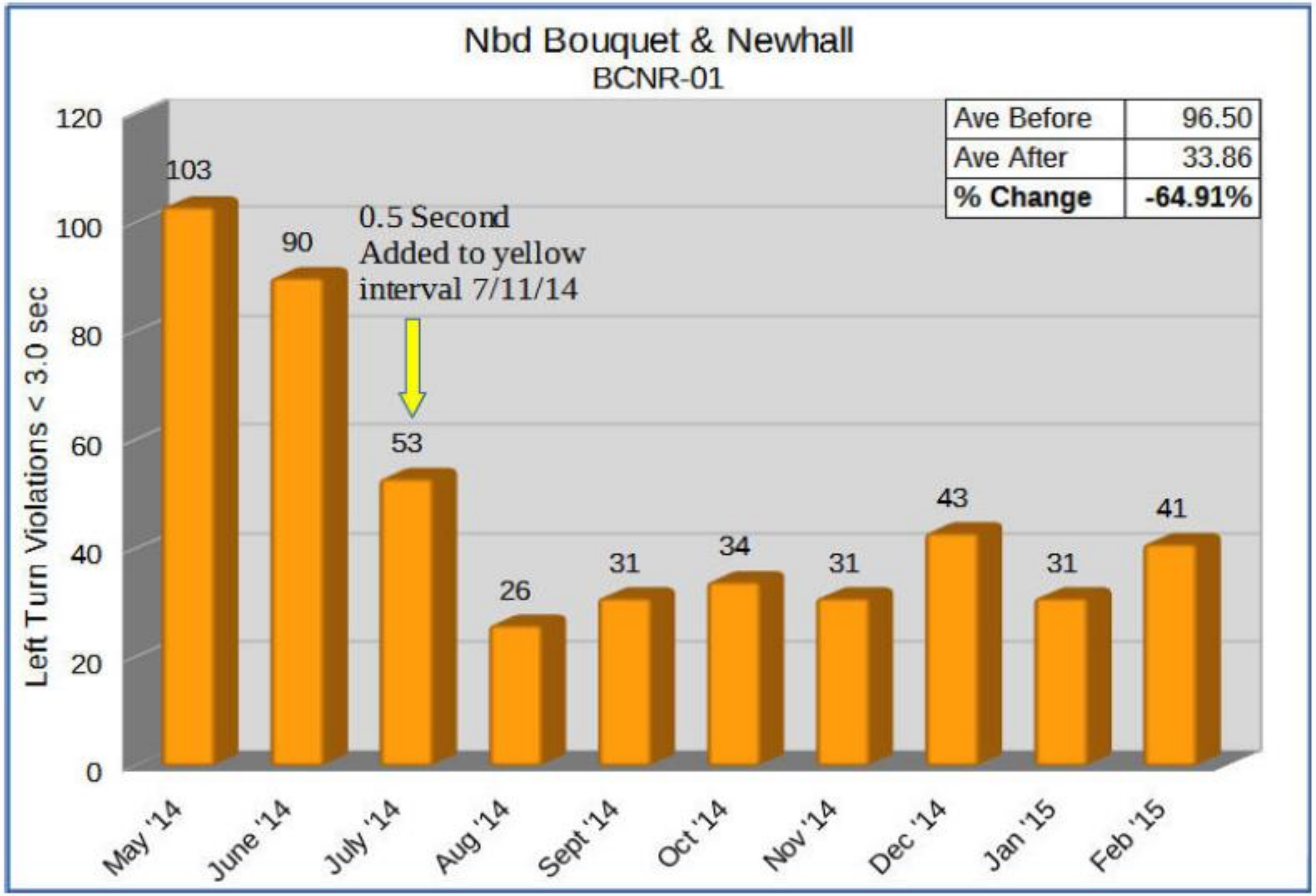
Average monthly # of tickets		
Oct 11 - Jul 12*	97	Yellow time 4.3
Aug 12 - Apr 13	105	**Yellow time 4.0 (below FDOT minimum for a 45 mph PSL)**
May 13 - Dec 13	97	Yellow time 4.3
Jan 14 - Mar 15	9	**Yellow time 5.9**

91% **Decrease in monthly ticket average for the period January 2014 - March 2015**

* March 2012 excluded due to camera offline

Month/Year	# of tickets	
Mar-11	105	Yellow time 4.3
Apr-11	125	
May-11	94	
Jun-11	91	
Jul-11	87	
Aug-11	79	
Sep-11	123	
Oct-11	99	
Nov-11	78	
Dec-11	91	
Jan-12	84	
Feb-12	44	
Mar-12	0	
Apr-12	99	
May-12	147	
Jun-12	112	
Jul-12	95	
Aug-12	110	**Yellow time 4.0**
Sep-12	69	
Oct-12	133	
Nov-12	85	
Dec-12	133	
Jan-13	106	
Feb-13	83	
Mar-13	101	
Apr-13	122	
May-13	171	Yellow time 4.3
Jun-13	115	
Jul-13	56	




Nbd Bouquet & Newhall
BCNR-01
Ave Before 96.50
Ave After 33.86
% Change -64.91%
0.5 Second
Added to yellow
interval 7/11/14
Left Turn Violations < 3.0 sec
120
100
80
60
40
20
0
103
90
53
26
31
34
31
43
31
41
May '14
June '14
July '14
Aug '14
Sept '14
Oct '14
Nov '14
Dec '14
Jan '15
Feb '15

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