AFFIDAVIT

I, Brian N. Ceccarelli, first being duly sworn, depose and say:

1. Based on my education, training and work experience, I have knowledge of the facts hereinafter stated and am competent to testify as a sworn witness to the matters contained herein. I am over the age of 18 years.
2. I am licensed professional engineer in the State of North Carolina.
3. I received a B.Sc. in physics in 1983 from the University of Arizona.
4. The laws of physics are immutable, applicable everywhere, and at this level of physics, have been known with certainty for centuries.
5. My professional opinions of traffic engineers' signal timing practices, intersection geometrics, the empirical data provided by red light camera systems and the knowledge of federal and state engineering requirements, are based on a reasonable degree of engineering certainty.
6. I am the principal engineer at Talus Software PLLC.
7. I have been an expert witness in the field of the kinematics of traffic movements at signalized intersections in Wake County, North Carolina, and Suffolk County, New York.
8. The Institute of Transportation Engineers (ITE) recognized me as an expert in traffic signal timing.
9. I have been published by Traffic Technology International: "Defying the Laws of Physics – Misapplication of the Yellow Change Interval Formula."
10. I have presented the topic of traffic signal timing and red-light cameras at the Autonomous Vehicles Symposiums in Stuttgart, Germany and in Novi, Michigan, as well for the American Society of Civil Engineers.

11. **Preparation**

To prepare the affidavit, I did the following:

a. Reviewed relevant North Carolina General Statutes; relevant city and county ordinances and resolutions; and relevant federal regulations as referenced to herein;
b. Reviewed relevant engineering manuals and formulas as referenced to herein;

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c. Reviewed the traffic signal plans of record for Greenville's red-light camera intersections.
d. Reviewed American Traffic Solutions' red-light camera installation plans for Greenville's intersections.
e. Reviewed other red-light camera programs' policies, practices and engineering;
f. Reviewed copies of current Greenville red light camera citations, and watched an accompanying video showing the driver issued the citation as he proceeded through the intersection;
g. Visited each red-light camera intersection, observing traffic patterns, noting the geometrics of each intersection, measuring the signals' yellow change intervals, and measuring the distances between the advance warning signs, red light cameras and intersection stop bars.

12. **Abstract**

Greenville's red-light cameras do not comply with engineering standards and laws. NCGS 160A-300.1(c1) mandates that the yellow change intervals must conform to the Manual of Traffic Control Devices (MUTCD). The intervals do not. The MUTCD 4D.26(3) requires that traffic engineers determine the yellow change intervals using engineering practices. NCGS 89C-3(6)a defines engineering practice as the application of the physical and mathematical sciences. Traffic engineers do not determine the yellow change intervals using applications of the physical and mathematical sciences, but by *misapplications* of the physical and mathematical sciences. The misapplications create a systematic defect called dilemma zones subjecting every driver to inadvertently run red lights. My affidavit describes these misapplications.

Greenville red light cameras' advance warning signs do not comply with NCGS 160A-300.1(b1) and the MUTCD. NCGS 160A-300.1(b1) requires that advance warning signs be placed according to the MUTCD relative the photographic device. Greenville placed all the advance warning signs relative to the traffic signal instead. The signs are at least 100 feet too close to the intersection. My affidavit details this problem as well.

13. **North Carolina Red Light Camera Statute for Greenville NCGS 160A-300.1(c1)**

The duration of the yellow light change interval at intersections where traffic control photographic systems are in use shall be no less than the yellow light change interval duration specified on the traffic signal plan of record signed and sealed by a professional engineer, licensed in accordance with the provisions of Chapter 89C of the General Statutes, and shall comply with the provisions of the Manual on Uniform Traffic Control Devices.

14. **Federal Regulation Regarding Calculation of Yellow Change Interval**
23 CFR 655 Part F--Manual of Uniform Traffic Control Devices (MUTCD) 4D.26-3

Standard: The duration of the yellow change interval shall be determined using engineering practices.

It is important to understand that only "standard" statements in the MUTCD must be obeyed at all times (MUTCD 1A.13). I describe this more fully in paragraph 19.

15. **Engineering Practice - Defined**

NCGS 89C-3(6)a: Any service or creative work, the adequate performance of which requires engineering education, training, and experience, in the **application of special knowledge of the mathematical, physical, and engineering sciences** to such services or creative work as consultation, investigation, evaluation, planning, and design of engineering works and systems, planning the use of land and water, engineering surveys, and the observation of construction for the purposes of assuring compliance with drawings and specifications, including the consultation, investigation, evaluation, planning, and design for either private or public use, in connection with any utilities, structures, buildings, machines, equipment, processes, work systems, projects, and industrial or consumer products or equipment of a mechanical, electrical, hydraulic, pneumatic or thermal nature, insofar as they involve safeguarding life, health or property, and including such other professional services as may be necessary to the planning, progress and completion of any engineering services.

16. **ITE Yellow Change Interval Formula**

$$\boldsymbol{Y = t_p + \frac{1}{2}\left[\frac{v}{a + \mathrm{G}g}\right]}$$

The Institute of Transportation Engineers (ITE) yellow change interval formula is a math equation which calculates the duration of the yellow light for one special case of traffic movement. The flaw is not the formula itself. The flaw is that engineers apply the formula universally—to every case. Engineers apply the formula to motions the formula does not model. Engineers plug the wrong numbers into the formula. The result is that the yellow change interval is short by several seconds. The short yellow subjects all drivers to inadvertently run red lights, and predictably so according to laws of physics.

These misapplications create a systematic defect called dilemma zones. Systematic means that the defect is always present and that every driver is subjected by it. A dilemma zone

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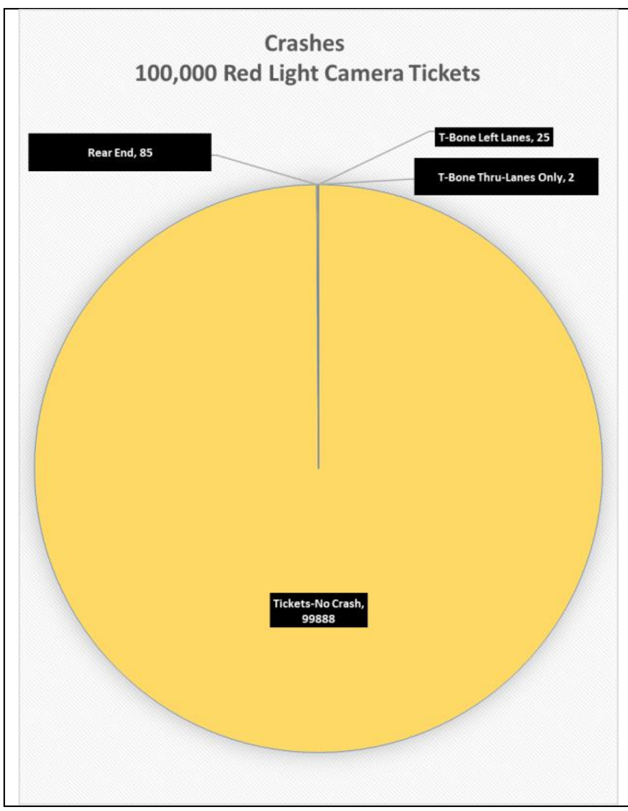
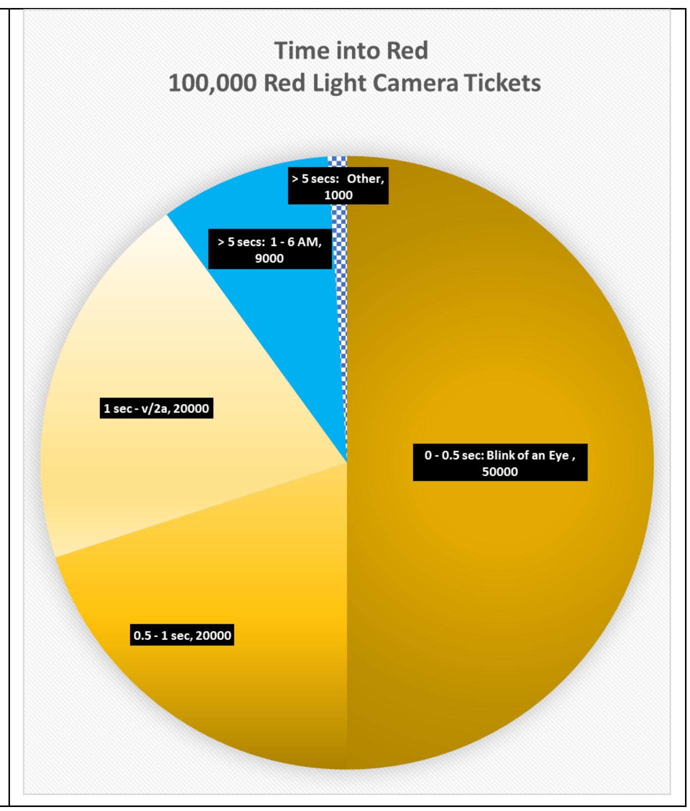
exists on every approach of every signalized intersection. There are no exceptions. When the driver so happens to be in a dilemma zone when the light turns yellow, he will run a red light inadvertently.

17. Here is some perspective on the magnitude of the systematic defect. Given the large volume of traffic passing through dilemma zones at the intersections, and given Greenville's current red-light camera citation statistics, it will take Greenville 18 months to issue as many citations as its population.

    Greenville advertises its program as the "Red Light Camera Safety Program." On the next page, the left chart reveals that the vast majority of the "violations" occur without crashes (yellow portion of pie). In contrast, the very thin sliver represents crashes. Though 0.002% of "violations" are the T-bone crashes, Greenville Police represent its program by just those T-bones videos. I, on the other hand, uploaded a representative cross section of "violation" videos on YouTube: https://youtu.be/N1Fle9TB8FE.





Crashes from Suffolk County, NY. Annual Report—2015

Time into Red from Cary, NC--2004-2012

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The right chart is a breakdown of citations by the amount of time drivers entered the intersection after the red light commenced. The chart shows half the drivers entered the intersection in a half second or less. A half second is so quick—the blink of an eye—that neither driver nor judge can focus on both vehicle and signal simultaneously and discern that the driver actually ran a red light.

The combined 3-shades-of-yellow slice represents drivers entering the intersection within the time it takes a driver to stop his car, that according to the laws of physics and verified by the associated RLR curves dropping to zero at v/2a in the RLC citation data. It is important to understand that the yellow is *half* the time it takes to decelerate to a stop. The blue slice is those vehicles that entered the intersection 5 seconds after red light commenced, during the time period from 1 AM to 6 AM in the morning. Drivers pull up to light. Light is stuck red. No one is coming. Driver goes. The remaining slice, the blue checkered slice, in the Town of Cary consisted mostly of drivers punished for broken traffic signals or malfunctioning red light cameras. There may be a few dozen in the blue checkered slice that are actually legitimate.

18. **Misapplications of the Formula**

Definition

Critical Distance. The critical distance is that point upstream from the intersection where the mandate to stop comfortably turns into the mandate to go full speed.

A	**Traffic engineers use the formula universally but the formula works only for one special case.** The formula works only for the special case of an unimpeded straight-through driver. When the light turns yellow, the driver either has the distance to stop comfortably, or he has the time to proceed into the intersection before the light turns red. It is important to understand that this case requires that when the driver proceeds, he must *go the speed limit or accelerate to beat the light*. He *cannot slow down* for any reason. He either stops or goes fast. There is nothing in between. This is the meaning of the physics behind the math; that is, the kinematics of the formula. The formula does not work for any motion which a driver slows down within the critical distance before entering the intersection. Slowing down requires more time to reach the intersection. There is not enough time in the yellow to slow down.

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	The formula fails at all of Greenville's left turn approaches, and all of Greenville's right-turn approaches. Greenville's cameras exploit the condition that drivers must slow down to do right or left turns. The difference between slowing from 45 to 20 mph to turn, and going straight at constant 45 mph, is over 1 second. The cameras additionally exploit that Greenville's right lanes are shared with straight-through traffic. For the drivers in the right lane, those going straight will have to slow down for cars turning right in front of them. These movements are called impeded movements. Traffic engineers neglect impeded movements. Impeded movements are gold mines for cameras. All of Greenville's red-light camera intersections exploit the presence of numerous businesses lining the highway. Drivers progressing into the intersection will have to slow down to avoid vehicles that enter or egress into and from these businesses.
B	**Traffic engineers plug the wrong approach speed into the equation.** Traffic engineers typically set "v" to the speed limit. If not, traffic engineers set v to that speed inside the intersection or pick some other arbitrary location. Physics is specific about where "v" must be measured. V must be measured at the critical distance upstream from the intersection. For a 45-mph level road, that is around 300 feet. The MUTCD guides that "v" should be the 85th percentile free-flowing speed. The local ordinances implicitly require that the approach speed must be at least the posted speed limit lest the engineer create a dilemma zone for legally-approaching traffic. Traffic engineers make a double error for protected turning movements. NCDOT traffic engineers not only misapply the equation, but also use 20 mph as the approach speed. Even when the posted speed limit is 45 mph, they still use 20 mph. "v" must be 45 mph or faster to give legally-moving traffic the distance to stop. Flaw A combined with B makes the yellow more than 2.5 seconds short when passenger cars slow to a 20 mph turn execution speed. The double error is the cause of about 94% of all T-bone crashes. The possibilities for a speed trap and red-light camera trap are readily apparent. The larger the difference between the free-flowing speed from the posted speed limit, the more incentive to set up a speed trap, or a red light running trap caused by the engineer inputting the lesser speed into the formula. The difference between daytime and nighttime approach speeds also traps drivers. North Carolina traffic engineers do not consider the difference. They set the yellow change interval using the slowest approach speed though that speed is not

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	representative at night. The slowest approach speed yields the shortest yellow lights. The yellow will be too short for those driving at night.
C	**Traffic engineers misapply stochastic methods.** One can only apply stochastic methods to random measurements when a determining a universal constant. Examples of stochastic methods are computing averages, medians and percentiles. Traffic engineers consider only the *average* driver. They calculate the median driver's perception-reaction time, the 65^{th} percentile deceleration and plug these into the formula (see paragraph 18). But the perception-reaction time of a human being is not a constant. Deceleration of a vehicle is not a constant. Not all drivers perceive and react in exactly 1.5 seconds. Not all vehicles decelerate at 11.2 ft/s^2. By using averages and percentiles for human factors, engineers misapply stochastic methods. An easy way to drive this point home is asking, "What would happen if an engineer designed his bridge to only uphold the weight of the average passenger car yet allowed school buses to traverse his bridge?" Perception-reaction time and deceleration are *ranges* of values, not universal constants. The range of human behavior and vehicle deceleration is well-defined. Dr. Timothy Gates wrote a paper showing the ranges: *Dilemma Zone Driver Behavior as a Function of Vehicle Type, Time of Day and Platooning*. *It is about comfort, not capability.* The engineer's frequent defense is that drivers "can" do it. It is true that a driver *can* slam on his brakes and have the air bag come out every time he sees a yellow light. But, the driver does not *expect* that. He expects to comfortably stop.
D	**Traffic engineers misapply an analytic solution to a physical solution.** In the equation appears Gg. "g" is gravity. G is the grade of the road. Gg is the contribution of gravity to the vehicle's deceleration. In the ITE formula, gG is an oxymoron. Traffic engineers apply Gg to uphill approaches, but Gg shorts the yellow by about 1 second for uphill approaches. Traffic engineers have misapplied the dynamics of emergency stopping to the dynamics of vehicles approaching a traffic signal--a non-emergency event. This error is called "misapplying an analytic solution." The math works but the math does not model the new physical conditions.

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	Gg comes from the stopping distance equation for *emergency* events. An emergency event is one when the driver slams on his brakes for an unexpected event; for example, a cow wandering into the middle of the road. At such times, the frictional force between tire and road determine the vehicle's stopping distance and gravity *directly* counters or contributes to that distance. The algebraic term expressing gravity's contribution is "gG". The dynamics for approaching a traffic signal are different. When going downhill, the limiting force is not friction but the driver's reluctance to press the brake uncomfortably harder. gG works downhill but for a different cause. Going uphill is different. The limiting force is neither friction nor pressing the brake. In order to maintain speed uphill, the driver presses the accelerator. Gravity works to slow his approach into the intersection. Slowing exacerbates flaw A. The driver needs the yellow to be longer than that at level grade. Engineers set it shorter than grade level. The yellow light is both about the driver having the distance to stop as well as the time it takes him to reach the intersection. Traffic engineers ignore the latter.
E	**Traffic engineers omit the calculation of the tolerance of the yellow change interval.** Engineers allow law enforcement to punish drivers to zero tolerance. A city typically sets the red-light camera grace period to 0.3 seconds but the tolerance for a properly-applied formula exceeds 2 seconds. The mathematical technique of error propagation computes such tolerances. For a 45 mph level grade approach: Correct straight-through unimpeded yellow: 5.3 ± 2.2 sec RLC Program: 4.5 ± 0.3 sec NCDOT: 4.5 ± 0.0 sec

19. **Misapplication of Physics Specific to North Carolina**

N1	**NCDOT engineers use an emergency deceleration value instead of a comfortable deceleration value.** NCDOT traffic engineers use the American Association of State Highway Traffic Officials (AASHTO) Green Book emergency stopping values for perception-reaction time and deceleration: 1.5 seconds and 11.2 ft/s^2 respectively. 11.2 ft/s^2 is the 90th percentile emergency stopping deceleration (Green Book, 2011, p3-3). Only 9 States in the USA

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	make this mistake. North Carolina is one of them. Other States use 10 ft/s^2 for deceleration. 10 ft/s^2 is the 50th percentile deceleration. Whether one uses 10 ft/s^2 or 11.2 ft/s^2 is still wrong. Either value remains a misapplication of stochastic methods. 11.2 ft/s^2 is the 65th percentile deceleration for comfortable stopping for passenger cars. 65% of the driving population decelerates *slower* than 11.2 ft/s^2 when approaching a traffic signal. The NCDOT neglects 65% of the driving population.
N2	**NCDOT traffic engineers use the wrong approach speed of 20 mph in a protected left turn lane for any posted speed limit.** NCDOT traffic engineers can no longer claim to adhere to the federal guidelines*. ITE raised the bar in December 2016 by lessening the magnitude of flaw B. The flaw is still there, but the new "guideline" invalidates NCDOT's claim.

*Engineers may invoke the name of the "federal guidelines" to justify using the ITE formula. The ITE formula, however, is neither a federal standard nor guideline. The formula is only an indirect reference of an option in the Manual of Uniform Traffic Control Devices. As an option, engineers use the formula at their own discretion and responsibility.

Engineers often justify any yellow change interval between 3 and 6 seconds because of MUTCD 4D.26(13). But the MUTCD does not tell the engineer to arbitrarily pick any value within that range, does not force the engineer to restrict yellow change intervals to this range, or mandates the engineer to even use 4D.26(13). 4D.26(13) is discretionary. 4D.26(13) is a MUTCD "guidance" statement. It is not a "standard" statement. The engineer applies guidance, option and support statements at his own discretion and responsibility. Also, by virtue that 4D.26(13) is *not* a standard, the statement *cannot* be applied universally. If the statement should be applied universally, then the MUTCD would elevate the statement to a standard. The MUTCD is written in the exacting vernacular of a System Requirements Specification (SRS) —a special type of engineering document. The MUTCD's standard, guidance, options and support statements must be interpreted in that context. Even the MUTCD describes itself this way (MUTCD 1A.13)

20. Other Engineering Error Common to all Yellow Change Intervals

SY	**The duration of the yellow change interval is always less than that on the signal plan of record. A violation of NCGS 160A-300.1(c1).** A. MUTCD 4D.26 (1) defines the yellow change interval as the *steady* yellow signal indication. This is the yellow change interval the driver experiences. B. The traffic signal plan defines the yellow change interval as the electrical circuit closed time for the yellow signal.

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	The definition of the yellow change interval in the MUTCD differs from that in the traffic signal plan. A is always less than B. The legal requirement of NCGS 160A-300.1(c1) is never satisfied. There is a delay between the time the electricity begins flowing through the circuit and the time the yellow light reaches a "steady yellow signal indication". That delay is about 0.2 seconds. Incandescent yellow light bulbs take about 0.2 seconds to warm up to become "steady". Even LED lights have a problem. LED traffic signals require a rectifier which requires ± 0.2 seconds to send sufficient current to the LEDs to light them up. 0.2 seconds does not sound like much but those first 0.2 seconds is 25% of the money harvested from red light cameras. Those 0.2 seconds mean millions of dollars to the City of Greenville.

21. **Greenville Red Light Camera Intersections**

Greenville and American Traffic Solutions chose to place red light cameras at the following intersections. All these intersections have errors and omissions as defined in Paragraph 18: A, B, C, E; Paragraph 19: N1, N2 and Paragraph 20:SY. Error Paragraph 18:D resides at all uphill approaches. The "**Features**" at these particular intersections are the reason why the red-light cameras are there. The "**Additional Deficiencies**" column lists additional intersection problems as defined in Paragraph 22.

Jason P. Galloway, P.E. (license 029904) signed and sealed all Greenville's red-light camera intersections.

#	Intersection	Features	Additional Deficiencies
1	SB Charles Blvd at East 14th St.	Train trestle obstructing view of intersection. Shared straight/right-turn lane. A long downhill slope followed by a speed limit decrease just before the intersection. Road goes uphill into intersection.	G1a, G2, G3, G4, G5, G7,

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2	SB Charles Blvd at East First Tower Rd.	Long and wide approach unimpeded by business entrances and side-streets where the free-flowing exceeds speed limit, then just before the intersection, there are suddenly many nearby businesses. Massive congestion due to timing signal cycle error. Shared straight/right-turn lane.	G1a, G2, G5, G7, G8
3	WB Fire Tower Rd. at Arlington Blvd.	Lots of surrounding businesses + traffic signal synchronization problem between Charles Blvd and Arlington. Insufficient left-turn bay causing back-up in straight-through lane. Shared straight/right-turn lane.	G1a, G2, G6, G7, G8
4	NB Arlington Blvd. at Greenville Blvd. SB Arlington Blvd. at Greenville Blvd.	Greenville Mall is here causing drivers to slow down when entering the intersection. At night the approach speed will be faster than 35 mph. Shared straight/right-turn lane.	G1a, G1b, G5, G7
5	NB Arlington Blvd. at Memorial Dr. WB Memorial Dr. at Arlington Blvd.	The northbound approach has a stop bar set up such that drivers turning right have to pass over the stop bar in order to see oncoming east-bound traffic. As drivers approach, they see enough to know that it is safe to pass over the stop bar, but that is technically a red-light violation. This scenario provides typical red-light camera trap.	G1a, G1b, G5, G7

		Shared straight/right-turn lane in WB direction.	

22. **Design Deficiencies Specific to Greenville Intersections**

G1a	Misplacement of advance warning sign "photo-enforced" in violation of NCGS 160A-300.1(b1). Any traffic control photographic system installed on a street or highway must be identified by appropriate advance warning signs conspicuously posted not more than 300 feet from the location of the traffic control photographic system. All advance warning signs shall be consistent with a statewide standard adopted by the Department of Transportation in conjunction with local governments authorized to install traffic control photographic systems. The "statewide standard adopted by the NCDOT" for the placement of advance warning signs is the MUTCD. On a 45-mph road, the MUTCD Section 2C.05 requires placement of advance warning signs to be farther than 175 feet from the device. NCGS 160A-300.1(b1) states that device is the "traffic control photographic system". The sign is 75 feet from the photographic device, not 175 feet as required by the MUTCD. Greenville assumed the distance was from the sign to the traffic signal and thus planted the sign 175 feet from the traffic signal. The photographic device is 100 feet from the intersection.
G1b	Misplacement of advanced warning sign "photo-enforced." NCGS 160A-300.1(b1) caps the distance from sign to photographic device to 300 feet. The sign is 308 feet from the photographic device.
G2	Faded stop bar. Lack of clear intersection boundaries. Drivers cannot see where the intersection begins, especially from a distance. The visual problem causes a driver to unknowingly enter the intersection on red.
G3	Train trestle blocks view of intersection. The visual problem causes a driver to not see the start of the yellow phase when he needs to see the start of the yellow phase. The driver does not get fair warning. The yellow change interval does not compensate for the duration of the visual block. The driver inadvertently enters the intersection on red.

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G4	Last minute change of speed limit, and the change occurs at the bottom of a hill, before arriving at the intersection. This common type of speed trap also allows the traffic engineer to short the yellow light by using the wrong approach speed. The driver does not expect the yellow to be so short, and so inadvertently runs a red light.
G5	No signal back plates. There is no contrast between the traffic signal and the background clutter. The traffic signal is not conspicuous. The visual problem causes the driver to inadvertently run a red light.
G6	No signal back plates on an East-West road. This engineering omission is especially problematic for drivers during the day when the Sun is behind the traffic signal. The glare is so bad that the driver cannot see the signal indication until it is too late. The driver inadvertently runs a red light.
G7	Traffic signals suspended from a span wire instead of fastened to a mast. This engineering limitation is problematic for drivers when the wind blows or ice causes the signal head to point in the wrong direction. The FHWA recommends mast arms. (FHWA, Signalized Intersections Information Guide FHWA-HRT-04-09, 2004, p. 77)
G8	There is a problem with traffic signal cycle length or its synchronization with downstream signals causing intolerable congestion. Drivers do not tolerate the engineering failures and may decide to run the red by platooning. Platooning occurs when vehicles close the distance between them unnaturally. Platooning vehicles looks like the children's game of crack-the-whip.

23. Yellow Change versus All-Red Clearance Intervals, Legal versus Safe Motion of Traffic

When there is a safety problem at a signalized intersection, the first thing a traffic engineer does is lengthen the all-red clearance interval. The all-red clearance interval is that time after the yellow light ends when all drivers facing the intersection see a red light. The all-red gives time for vehicles inside the intersection to clear the intersection before opposing traffic gets the green. Lengthening the all-red clearance interval is very effective at increasing safety.

The all-red, however, does nothing to ameliorate the vulnerability of the innocent driver to a citation. In early 2010 at the intersection of Cary Parkway and Kildaire Farms Rd in Cary, NC, a traffic engineer shortened the yellow from 4 to 3 seconds. That caused a permanent six-fold increase in red light camera citations. The 3 second yellow increased the number of crashes as well. Because of the crash rate increase, a few months later an engineer lengthened the all-red clearance interval. He lengthened the all-red by one half-second but kept the yellow at 3 seconds. The crash rate returned to its prior level but the citation rate remained at its elevated six-fold level.

Why didn't engineer revert back to the old 4 second yellow? The reason is to satisfy the engineer's top design priority. It is all about increasing traffic flow. Shortening the yellow by 1 second and increasing the all-red by one half-second decreases the overall "clearance time" by one half-second. That means that in a given signal cycle, the green light can be greener for one half-second longer. More green means an increase in traffic flow through an intersection.

An important insight into the traffic engineering profession is to know its design goals. Engineers have 3 disparate goals. Flow, safe motion and legal motion. In that order.

This is 5th day of February, 2018.

Brian N. Ceccarelli, P.E.

NORTH CAROLINA PROFESSIONAL SEAL 043760 ENGINEER BRIAN N. CECCARELLI

State of North Carolina
County of Wake
Sworn to and subscribed before
me this 5th day of February 2018.

Susan Garrott
Notary Public
My Commission Expires: 12/2/2019

Susan Garrott Notary Public Wake County, NC

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