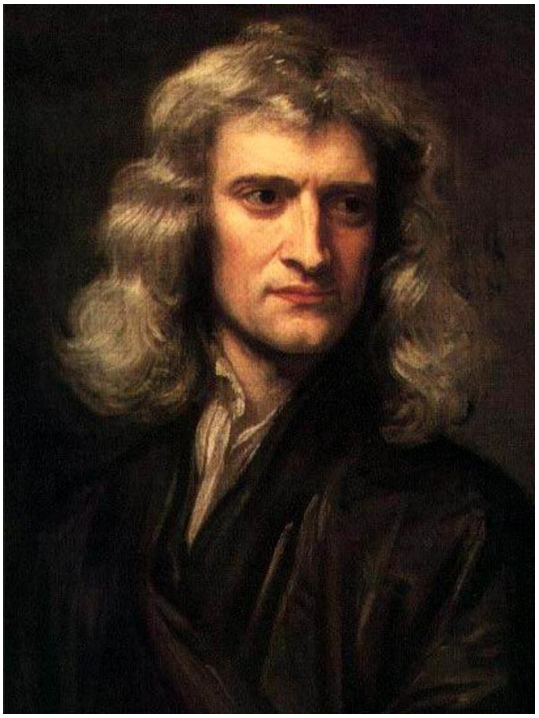
2012

Isaac Newton vs. Red Light Cameras



Approach Speed vs. Speed Limit

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Table of Contents

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In my other papers, I have not been concerned with the difference between approach speed and speed limit. Whether one sets *v* to the speed limit or to the approach speed does not matter in a discussion of basic physics. What matters is that the yellow light interval formula is a function of speed, and that the formula makes an error regardless of which kind of speed one plugs in. Whether one plugs in an approach speed or plugs in the speed limit, the formula still outputs yellow times less than required by the laws of motion. Inadequacy is a matter of degree.

This paper is not about the inadequacy of the formula, but about which speed the formula requires for input. There is a difference between approach speed and speed limit and traffic engineers often use the wrong one.

Definition of Speed Limit

The speed limit is the posted speed on the highway signs. Engineers are supposed to set the speed limit according to the 85th Percentile Rule. 85% of the vehicles travel slower than this speed. 15% travel faster. The engineer's speed limit varies on when and where the engineer takes speed measurements. As you can see, engineers do not share the same definition of speed limit with the law. It is an incompatibility speed cameras and red light cameras exploit.

Definition of Approach Speed

To the traffic engineer, the approach speed is the speed of a vehicle as it *approaches* the intersection. That is an imprecision definition. But that is what traffic engineers use. Unknown to the engineer is the fact that the approach speed of a vehicle is the free-flowing *initial speed* of a vehicle *at the critical distance from the intersection*[1]. In a flat landscape like the Town of Cary, most of the time the approach speed is the speed limit. But when the critical distance is a point on an even longer hill, vehicles approaching the intersection are most likely going faster than the speed limit. Therefore,

$$v_{approach} \geq v_{speed\ limit}$$

Traffic engineers must use $v_{approach}$ in the yellow light formula.

$v_{approach} >= v_{speed\ limit}$ is mandatory when setting the yellow light duration. A traffic engineer cannot do otherwise lest he forbids drivers from going the legal speed. When the engineer enters a speed less than the speed limit into the formula, the formula does not provide the required distance necessary for a legally moving driver to stop before the light turns red. That entraps drivers to run red lights. See *Short Yellows and Turns* for a mathematical treatise.

The Present World-Wide Problem

Presently for left turn traffic, traffic engineers all over the world force drivers to run red lights by doing exactly what they are not supposed to do. They set the approach speed to less than the speed limit. For left turn yellow arrows, they routinely set

$$v_{approach} < v_{speed\ limit}$$

When asking one of Town of Cary's traffic engineers,

"Why do you set the left turn lane yellow to 3.0 seconds while the straight-thru yellow is 4.5 seconds?"

The engineer replied, "We feel that vehicles go slower in the left lane." The engineer is simply following the advice of the Institute of Transportation Engineers[2]. ITE gives the engineer two pieces of bad advice . 1) Use the average of the speed limit and the intersection speed as the approach speed, and 2) Use the yellow light formula.

While going slower is not a problem for drivers who have been waiting in a queue, it is a problem for drivers who have not been waiting. Trouble brews for any driver who travels unimpeded down the left turn lane at the legal speed limit with a green arrow in front of him. Any driver, who has passed the safe stopping distance and is thus committed to proceed through the intersection, can easily have that green light change to yellow then to red before he enters the intersection.

The Town of Cary has penalized drivers $4,000,000.00 for going the legal speed limit down the left turn lane.

After talking to dozens of traffic engineers, I have come to one conclusion. Engineers use these equations without knowing the physical meaning of the terms. In this case, the traffic engineer does not know what an *approach segment* is, that his very own yellow light formula makes it necessary for him to establish one, and that he must use its entry point as the location to compute the approach speed using the 85th Percentile Rule.

The Definition of the Approach Segment

The yellow light formula affects all drivers travelling within the safe stopping distance. The approach segment, therefore, is the span of road from the intersection to a point at the safe stopping distance preceding the intersection. The safe stopping distance is the entrance point of the approach segment.

The computation of the length of the approach segment comes in 4 steps.

1. Find the location of the safe stopping distance from the intersection. From here you first measure the 85th percentile speed. From the *Derivation of the Yellow Light Interval Equation*, we know that the length of the approach segment and the safe stopping distance S are . . .

$$S = v_0(t_p + v/2(a_b + 32.2g))$$

   Where . . .

   v_0 = speed of the vehicle at the safe stopping distance
   t_p = perception time
   a = deceleration due to braking
   g = grade of the road, where $g < 0$ is a decline.

   S = distance from the intersection = the length of the approach segment = the critical distance.

2. If vehicles at distance S from the intersection are going at most the speed limit, then you are done. S is the length of the approach segment. The approach speed = speed limit.

3. But if vehicles enter the approach segment at S at a speed faster than the speed limit, then you have to compute a new S using that speed.

   For example, if you are on a hill and the speed limit is 35 mph, and the computed S for that speed is 250 feet, you cannot have an approach segment starting at 250 feet when vehicles are entering the approach segment at 45 mph. You must recompute S using 45 mph.

In the end, the approach speed is the speed of vehicles at distance S from the intersection. The approach speed is the speed of vehicles when they *enter* the approach segment.

Approach Speed and the Short Left-Turn Yellow

Engineers apply the bad advice from ITE setting the left-turn lane to the average of the speed limit and the intersection entry speed. In most cases, he sets the speed to 22.9 mph yielding a 3.0 second yellow light. The engineer is not aware of the consequences of setting a 22.9 mph approach speed.

The formula speed is the speed at the critical distance. By setting a 22.9 mph approach speed, the engineer shorts the yellow. Drivers travelling down the lane at the legal speed will not have the distance to safely stop. The engineer will force them all to run a red light.

The Formula Always Makes Turning Drivers Run Reds

Even when engineers establish the left turn yellow duration using the correct approach speed, they still force a great deal of unimpeded left-turning drivers to run red lights. That is because the yellow light formula never gives drivers adequate yellow time to *slow down and proceed* through the intersection. The formula only allows drivers *going the speed limit or more* to proceed through the intersection. In the last moments of the approach, drivers decelerate to execute a left turn. Deceleration exhausts the clock. The yellow time runs out. Drivers run a red light. See *Short Yellows and Turns*.

Approach Speed and the Intersection on a Hill

Here is an example of how Raleigh forces drivers to run red lights by miscomputing the approach speed for a hill.

Click here to see the intersection of Peace Street and West. As you can see, Peace Street goes down a hill. The hill has a 6% decline. Peace Street is 35 mph. The red light camera is on Peace Street, facing downhill toward the intersection at West St.

I travel down Peace Street often. My destination is Krispy Kreme donuts. There is a long hill before the intersection at West St. Every time I travel down the hill, gravity increases my speed by just over 10 mph. When I enter the approach segment, I am going slightly over 45 mph.

The road levels out 60 feet before the intersection.

Although the grade and approach speed of the road at the critical distance is 6% and 45 mph respectively, the City of Raleigh's traffic signal plan says that the grade of the entire approach is 0% and the approach speed is 35 mph. Using 0% grade and 35 mph, Raleigh's engineer set the yellow light to 3.8 seconds. This is why there's a red light camera at this intersection.

Raleigh's engineer miscomputed the yellow light duration by considering a 60 foot long approach segment. The approach segment for a 6% downhill 45 mph approach speed starts at 334 feet, not 60 feet. That places the entrance to the approach segment well upon that 6% decline. Given the actual approach speed and grade of road, according to the own formula, the engineer should have set the yellow light duration to 5.1 seconds.

So far the City of Raleigh has made $400,000.00 off this one intersection.

All-Red Clearance Interval

Definition

After the last yellow light facing one direction ends its phase, comes the all-red clearance interval. The all-red clearance interval is the length of time that all drivers from all directions see red. The purpose of the all-red clearance interval is to give drivers who had just entered the intersection just when the light turns red enough time to traverse the intersection before cross traffic gets a green.

The formula for the all-red clearance time is:

$$R = \frac{W + L}{v}$$

where:

W = the width of the intersection

L = the length of your vehicle, and

v = speed of slowest vehicle inside intersection, usually the left-turning vehicle.

The speed of the vehicle, that an engineer should use to determine the all-red clearance interval, is the speed of the slowest vehicles moving within the intersection. Those vehicles would be the left-turning drivers.

You need to give the slowest vehicles enough time to clear intersection. By using the speed of the slowest vehicles, you take care of the faster moving vehicles moving straight.

Common Screw Ups using Approach Speed

Since engineers do not know what their equations mean, they often erroneously interchange the speeds they use to compute yellow durations with speeds they use to compute the all-red clearance interval.

Note that the speed of the vehicle an engineer should use for all-red intervals has nothing to do with the approach speed. Approach speed is for approaches, not for vehicles that are inside the intersection. Vehicles inside the intersection have already "approached."

Here are some common screw ups:

1. In computing an all-red clearance interval, engineers will set v = approach speed and in doing so not give turning drivers a chance to clear the intersection. Engineers kill drivers turning left. To set an all-red clearance, *v* must be set to the slowest moving vehicle in the intersection. Consider a turning school bus. A turning school bus is not going to make a 90 degree turn at 45 mph.

2. In one of the biggest screw ups, the Institute of Transportation Engineers tells traffic engineers to take the average of the initial speed and the intersection entry speed and use that for the approach speed[2] for turning vehicles. That shorts yellow lights for all turning drivers, exacerbating an already short yellow caused by the fact than one cannot apply the formula to turn lanes to begin with. See Short Yellows and Turns. This two-fold engineering mistake is why you see red light cameras at any approach with a high volume of turning traffic.

3. Many jurisdictions, like the State of Washington, do not have a separate all-red interval. That means that as soon as your light turns red, drivers on the cross street see green. This is an obsolete way of programming signals, but it is still used in many places.

   Washington engineers combine the yellow light equation with the all-red equation[3] to form one equation for the yellow interval:

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

   Engineers see this equation, but not knowing what the terms physically mean, assume that the two instances of "v" are the same "v". They think that both instances of "v" are the approach speed. That assumption works for unimpeded straight-thru movement, not for turning movement. (Unimpeded straight-thru movement is the only case where the formula applies[4].) The "v" in the first term is the approach speed. The "v" is the second term in the speed of the vehicles as they turn within the intersection. Approach speed and turn execution speed are apples and oranges.

85th Percentile Rule

Generally speaking, I do not mention the 85th percentile rule or approach speed in my papers. I just say speed limit. My usual readers understand speed limit without elaboration. And besides, neither 85th percentile rule nor approach speed are germane in a discussion pointing out the faults in the formula.

Nonetheless the 85th percentile rule is the method by which traffic engineers establish an appropriate speed limit. Traffic engineers measure the speed of freely flowing traffic. 85% of the vehicles travel slower the proposed speed limit. 15% travel faster.

Traffic engineers are supposed to establish speed limits based on road geometry and on normal natural human behavior. Engineers won't post a 20 mph speed limit sign on an Interstate because it is unnatural for a driver to go 20 mph on an Interstate. 85% of the people travelling on the Interstate are not going 20 mph or less, but rather 65 mph or less. (Usually more!) Engineers are supposed to accommodate human behavior, not impose artificial limits.

Traffic engineers are conservative in establishing speed limits, opting to set speed limits less than the 85^{th} Percentile Rule. Time of day adds unjustness to the computation. Traffic engineers measure the speeds at a specific time of day usually during peak traffic. Measuring speeds during peak traffic is going to be less than measuring speeds at midnight. While the 85^{th} percentile speed during peak traffic is 30 mph, at midnight the speed is 50 mph.

When it comes to setting the legal speed limit, traffic engineers are confined to a can of paint. The number they'll paint on the sign is that speed measured during peak traffic where the road is level. Then engineers will usually round down the number to the nearest 5mph.

It this practice unfair to midnight drivers? Yes.

Do policemen take that into consideration? The good ones do.

Do speed cameras, red light cameras or industrious police officers take that into consideration? No. They exploit the incompatibility.

Even a decrease of 2 to 3 mph in from the real approach speed to the speed limit decreases the yellow duration by 2 – 3 tenths of a second. That 2 – 3 tenths of a second decrease doubles the number of drivers running red lights[5].

Summary

Approach speeds, though not pertinent to the thrust of my papers, is important enough for me to address even if I only address it for self-defense. Many engineers think in terms of approach speeds, and upon reading my papers where they see that I repeatedly write v = speed limit without mention of approach speed, seem to think me a moron.

The fact remains. Not that I am a moron, but despite their misgivings, they missed my entire point, a basic fact of physics. The bogusness of the ITE's Yellow Light Change Interval screws up any yellow time with whatever speed you plug into it, whether you stick in the speed limit or the approach speed. The formula always yields garbage out.

This paper is necessary to reveal some of the common ways traffic engineers miscompute the approach speed. These miscomputations contribute to red light running, crashes and fatalities.

References

[1] Gazis, Herman, and Maradudin, GM Research Labs *The Problem of the Amber Signal Light in Traffic Flow*, Institute for Operations Research and the Management Sciences, Vol 8, No. 1, p. 113, 1960 (V_0 is the speed of the vehicle at the critical distance.)

[2] Institute of Transportation Engineers, *Determining Vehicle Signal Change and Clearance* Intervals, Publication IT-073, 1994, p. 4

[3] Institute of Traffic Engineers, *Traffic Engineering Handbook*, 3rd Edition, 1965, p. 407.

[4] Gazis, Herman, and Maradudin, GM Research Labs *The Problem of the Amber Signal Light in Traffic Flow*, Institute for Operations Research and the Management Sciences, Vol 8, No. 1, p. 113, 1960

[5] Town of Cary, Brian Ceccarelli, Graphs of Cary Camera Data, website http://redlightrobber.com visited on February 29, 2012