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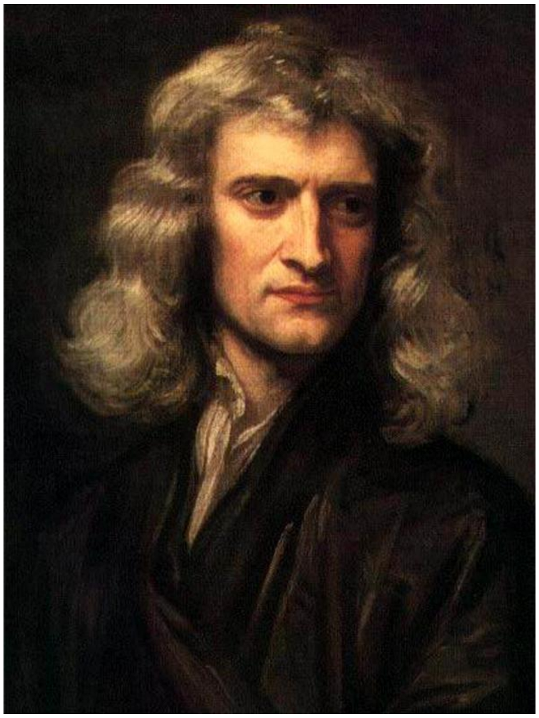
Isaac Newton vs. Red Light Cameras



Problems with the ITE Kinematic Formula for Yellow Light Intervals in a Nutshell

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Table of Contents

Problem

The federal standards used by traffic engineers force drivers to run red lights. The federal standards come in the form of applications of the ITE Yellow Light Change Interval formula. The formula, though it is the federal standard, violates the fundamental laws of physics. The formula forces turning drivers to run red lights. The formula forces drivers who need to decelerate before entering the intersection to run red lights. The formula makes drivers guess whether to stop or go, forcing them to run red lights.

ITE Kinematic Formula for Yellow Light Intervals

The yellow light interval equals the time it takes for a driver to perceive the light turning from green to yellow plus the time it takes for a driver to traverse the safe braking distance at the approach speed.[1] The approach speed >= speed limit.

Definition by Words

$$\boldsymbol{Yellow\ Interval = Perception\ Time + \frac{[Safe\ Braking\ Distance]}{Approach\ Speed}}$$

Definition by Math[4]

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

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

Variable	Description
t_p	perception time in seconds
v	vehicle's approach speed *at the critical distance*[6]
a	safe deceleration of car
G	acceleration due to Earth's gravity
g	grade of the road in %/100, downhill is negative grade
$Y = t_p + \frac{\left[\frac{v^2}{2a + 2Gg}\right]}{v}$	Numerator in 2nd term is for stopping vehicles Denominator in 2nd term is for vehicles going constant approach speed.
$b = \left[\frac{v^2}{2a + 2Gg}\right]$	Braking distance
$c = vY$ $c = v\,t_p + \left[\frac{v^2}{2a + 2Gg}\right]$	Critical Distance

Kinematic Formula Provision

Denos Gazis, the inventor of the ITE kinematic formula, designed his formula to work only under the confines of one specific traffic situation[2]. The formula works for stop and works for go *but with limitations*:

1. The kinematic formula allows a vehicle to stop without entering the intersection providing the driver starts decelerating before he crosses over an invisible line at distance *b* from the intersection.

2. The kinematic formula allows a vehicle to proceed into the intersection providing that the driver is closer to the intersection than distance *c*, and providing that the driver *does not decelerate below the approach speed at any time*.

3. The kinematic formula assumes that a vehicle can decelerate at a rate of at least *a*. The formula assumes that a driver can perceive a change in the traffic signal, absorb the traffic situation, make a decision, and react to the decision in time t_p or less.

Kinematic Formula Failure 1

The kinematic formula does *not* provide enough yellow time for any vehicle that both decelerates *and* enters the intersection[9]. The formula forces these drivers to run red lights:

1. Turning drivers.[9] Turning drivers need to slow down to execute a turn.
2. Drivers going straight who must slow down for vehicles in front of them.
3. Drivers going straight who must slow down for traffic waiting for the next intersection.[9]
4. Drivers going straight who must slow down for the stop sign or signal light at the next intersection after theirs. This situation is typical of downtown streets where the intersections are close together (within 400 feet).[9]

5. Drivers who must tap their brakes for other vehicles pulling into the road from business entrances.
6. Drivers who must tap their brakes to avoid colliding with an opposing left turning driver playing chicken.
7. Drivers who slow down for bumps in the road.
8. Drivers who slow down for pot holes in the road.
9. Drivers who slow down to go over railroad tracks.
10. Drivers who travel under the speed limit for any length of time. A driver does not have to tap his brakes for the formula to fail. All he has to do is travel under the approach speed for any length of time . . . even if he travels 1 mph under the speed limit for a $1/10^{th}$ of a second. That is enough to force him to run a red light.

    All these situations describe type I dilemma zones[5, 6]. The driver is faced with an unsolvable decision problem[7]. The driver cannot stop safely. The driver cannot proceed without running a red light.

The proper duration of turning yellows to cover any of the above situations is *greater* than the formula.

Consider turn lanes. Since ITE thinks this formula is the magic pill for every situation, ITE misapplies the formula to turn lanes[3]. But the formula does not accommodate turn lanes[9]. The formula is only for vehicles approaching and entering the intersection at a speed greater than or equal to the approach speed. It does now allow vehicles to decelerate to execute a turn. Because of the deceleration with intent to enter the intersection, a traffic engineer cannot use this formula in any part of a calculation. The result will never be adequate. I compute the adequate time below using the physical laws of motion.

By introducing pseudo-science in 1994[3] and repeating the mistake in the *Traffic Signal Timing Manual* [8], ITE misapplies their formula for turn lanes and introduces systematic errors forcing all turning drivers to run red lights. See *Short Yellows and Turns* for a complete description.

The only correct way to handle turning situations is to invoke a fundamental law of motion. From Isaac Newton:

$$a = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t}$$

$$\boldsymbol{t_{turn} = \frac{v_f - v_i}{a}}$$

$$\boldsymbol{Y = t_p + t_{turn}}$$

The only purpose the ITE kinematic formula could serve for a turn lane, is to compute the yellow's minimum duration. At the minimum duration, a driver (who intends to turn or not) will have the distance to stop. That is the sole purpose of the ITE formula. The moment the vehicle decelerates; however, the vehicle requires more time to traverse the critical distance than the formula provides.

Kinematic Formula Failure 2

Gazis never said that his formula eliminates the zone of indecision (a type II dilemma zone[5]) where when the light turns yellow, the driver does not *know* whether to stop or go. A yellow time according to Gazis' formula only means that a solution is possible, not that the driver knows what it is. Gazis' formula still forces people to *guess*. Is the solution to go? Is the solution to stop? When Gazis' formula is used as a mathematical equality, stop and go are mutually exclusive decisions. According to Gazis' formula, in order to choose stop or go correctly every time, drivers must know exactly where the critical distance is. A DOT could mark this distance on the road, but DOTs rather not and instead force drivers to guess. Sometimes drivers will slam on the brakes and face the possibility of a rear-end collision. Sometimes drivers proceed and enter the intersection before it turns red. Sometimes drivers proceed and enter the intersection and run the red light. Sometimes drivers accelerate to get to the intersection before the light turns red. Traffic engineers even expect drivers to accelerate[6]. The formula literally sets up a crap shoot.

Many engineers fervently believe the formula eliminates dilemma zones. Engineers fervently believe that the absence of the dilemma zone means that all drivers can now safely stop or safely go. Gazis never said that. Gazis' definition of dilemma zone is subject to the confines of his one traffic situation, his own assumptions of comfortable deceleration and his own measured *mean* perception/reaction times[10]. *Mean* implying that even in Gazis' measurements, "non-violators" are still being forced to run red lights.

By the way, Gazis' *mean* perception/reaction time is 1.14 seconds. ITE's uses 1.0 seconds. This *means* that Gazis assumption kills the slow-witted driver. ITE's assumption kills the average and the slow-witted driver.

Traffic engineers inappropriately set the yellow interval *equal* to the formula. When stopping is possible, drivers cannot go. When going is possible, drivers cannot stop. Looking at the formula as a mathematical equality does not provide a margin of error. Gazis' original formula[6] is an *inequality*. To compensate for the range of human behavior, Gazis and common sense dictate that yellow durations should be more than the formula. For 50 years traffic engineers have been using the formula as an equality, giving drivers the bare-bones minimum yellow time which means 1) drivers have no margin of error and 2) drivers must approach the intersection unimpeded and enter the intersection moving constantly at the speed limit or more.

Problems Misapplying the Formula

Just as engineers habitually misapply the formula for turn lanes, they also habitually enter the wrong velocity *v* into the formula. ITE made a mistake in 1965 when they sloppily did not copy the "naught" in v_0 from Gazis' paper. By miscopying the formula, ITE made a vacuum for the definition of *v*. Vanished was critical information embedded in the "naught" of v_0. Ever since 1965, traffic engineers have been filling that vacuum by capriciously devising unsuitable definitions for v, all of which force drivers to run red lights.

In the halls of physics and in Gazis' formula, v_0 is the *initial* velocity of the vehicle. v_0 is specifically the velocity of the vehicle at the critical distance from the intersection. Whatever velocity the engineer plugs into the formula, the resulting yellow duration provides just enough distance for drivers travelling at that velocity or less to stop safely. The velocity has to be at least the posted speed limit. If less than the speed limit, engineers prevent legally moving drivers from stopping safely, essentially reducing the legal speed limit without telling them.

Traffic engineers call *v* the "approach speed". To a traffic engineer, v can be the velocity at any random point along the approach or an average velocity thru the approach. That arbitrary definition opposes the precise physics definition inherent in the formula. The result is the forcing of drivers to run red lights. See *Approach Speed vs Speed Limit.*

The Solution

The Yellow Change Interval

The following formula works for all traffic situations. The following formula never forces a driver to run red lights. The following formula tells a driver he can always slow down at deceleration rate *a* without running a red light. The driver has the distance to stop. The driver has the time to proceed at the approach speed. The driver has the time to slow down and execute turns—to decelerate safely and enter the intersection.

$$Y = t_p + \frac{v_0}{a + G\sin(\tan^{-1} g)} \qquad \text{Equation 1}$$

Variable	Description
Y	Duration of Yellow Light
t_p	Perception Time. ITE gives 1.0 s. AASHTO gives an average of 1.5 seconds, saying that complicated intersections can take a driver up to 3.0 seconds to figure out what's going on.
v_0	Velocity of Vehicle Measured at $v_0^2/2[a + G\sin(\tan^{-1}(g))]$ from the Intersection $v_0 \geq$ Speed Limit
a	Safe Deceleration Assumes that all vehicles from motorcycles to 18-wheelers have brakes which can exert a force to decelerate the vehicle at the decelerate rate of ***a***. ***a*** could be less than 10 ft/s^2 if bumps or pot holes force the driver

	to decelerate more slowly.
G	Earth's Gravitational Constant
g	Grade of Road (rise over run, negative values are downhill)
$G\sin(\tan^{-1}(g))]$	Precise Expression When $g < 0.10$, $Gg \approx G\sin(\tan^{-1}(g))]$. See Derivation of the Yellow Light Interval Equation

All-Red Interval

The all-red formula gives enough time for any vehicle to fully clear the intersection before cross traffic gets a green light. Most jurisdictions apply the all-red interval to signal controllers which support displaying red on all approaches simultaneously. However for controllers that do not support all-red, jurisdictions add the all-red interval to the yellow change interval. Regardless of signal controller, the all-red interval must be:

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

Equation 2

Variable	Description
R	Duration of Time Where All Approaches See Red
W	Length of the Longest Vehicle Path Traversing the Intersection Usually the width of the intersection but could be the length of the path of a left turning driver.

L	Length of the Longest Vehicle
v_s	Velocity of the Slowest Vehicle while Traversing the Intersection Note that this velocity is not the same as the one used to compute the yellow duration. For example, turning vehicles traverse the intersection more slowly than straight-thru vehicles. Only for straight-thru movement does $v_0 = v_s$.

Spock to Captain Kirk

Equation 1 is the only solution to the problem. Spock would say, "There is no alternative Jim."

Physics does not yield. No justification warrants a change in Equation 1. Traffic engineers may feel that that's too much time, but that's too bad. Traffic engineers may feel that drivers will treat yellows as greens, but that's too bad. Physics does not yield to feelings. The moment the engineer establishes the deceleration constant "a", which he has done 50 years ago, the physical laws of motion uncompromisingly dictate the minimum requirements of every traffic situation. When an engineer shorts a light under Equation 1, he always forces a set of drivers to run red lights. Physics simply does not yield.

Engineers like to take the *mean* of this, the *average* of that and 85% of the other thing. But using statistics in cases where safety is at stake always jeopardizes drivers on the wrong side of the bell curve. When peoples' lives are at stake, engineers must first adhere to the dictums of physics then use values at the extremes to guarantee safety. Anything else is Russian roulette.

References

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[2] Denos Gazis, et. al, 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

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[5] Dr. Tom Urbanik, The University of Tennessee; Peter Koonce, Associate Engineer, Kittelson and Associates, "The Dilemma with Dilemma Zones"

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[8] Institute of Transportation Engineers, *Traffic Signal Timing Manual*, Publication TB-020, p. 5-13, 2009

[9] Denos Gazis, et. al, 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. 129, 1960

[10] Denos Gazis, et. al, 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. 130, 1960