Is the Yellow Light Long Enough?

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Anyone who has driven a car has been confronted with the following decision while approaching an intersection when the light is green: If the light turns yellow, should I go through the intersection or try to stop before it? While traveling down a steep hill towards a green light one day, we wondered whether the yellow light was longer to account for the hill. Our curiosity led us to do a survey of intersections and use simple equations of motion to see if yellow lights are in fact designed for a safe decision. We present here our results, and recommend this exercise as an enjoyable practical problem for a physics class.

We decided to use a very simple condition to determine the safety of an intersection: When the driver approaches an intersection driving the speed limit and the light turns yellow, she must be able to either stop before the intersection or pass through before the light turns red. Basically our criterion is that the driver should *not be in* the intersection when the light turns red. The law in California is less stringent and states only that the driver must not *enter* the intersection when the light is red.[1] We decided to use our safer condition and see how many intersections passed the test, particularly on steep hills.

The stopping distance d_s can be determined from the driver's reaction time, τ, and the coefficient of friction between the tires and the road, μ. During the driver's reaction time, the car travels a distance of $V_o\tau$, where V_o is the car's initial velocity. After the brakes are applied, the additional distance can be calculated, assuming constant acceleration, from the formula $V_f^2 = V_o^2+2as$. We want $V_f = 0$ under conditions that the acceleration is provided by a combination of downhill force and braking. The acceleration is: $a = g \sin\theta - \mu g \cos\theta$. Consequently,

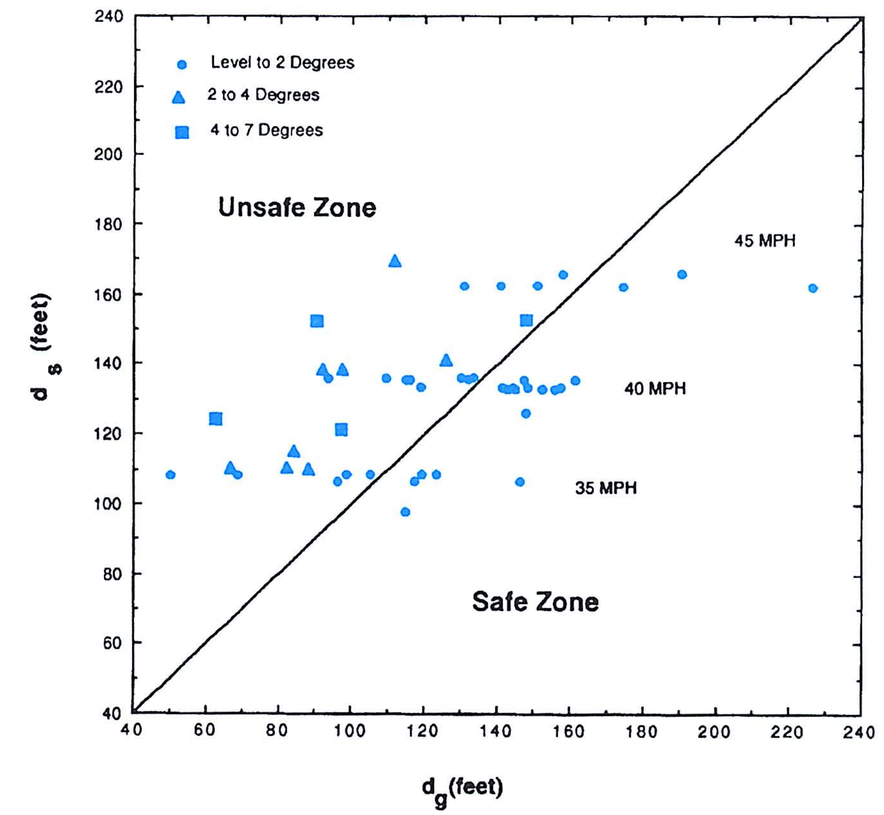

Fig. 1. Plot of d_s vs d_g [defined in Eqs. (1) and (2)] for various intersections in the Los Angeles area. If $d_g < d_s$, the driver might not be able to either stop in time or pass through the intersection before the light turns red. Thus intersections above the line $d_s = d_g$ are considered to be in the unsafe zone.

$$d_s = V_o\tau + \frac{V_o^2}{2g(\mu\cos\theta - \sin\theta)} \qquad (1)$$

where V_o is the car's initial velocity. From this equation we can see that the hill has two effects that make it more difficult to stop. *First* there is a component of the gravitational force, $mg \sin\theta$, which accelerates the car down the hill in the direction of the motion, and *second* the normal force is reduced by a factor of $\cos\theta$, which reduces the maximum frictional stopping force. The coefficient of friction and the reaction time can be calculated from the driver's handbook.[2,3] Using the California Division of Motor Vehicles handbook, we obtained values of 0.6 for μ and 0.75 sec for τ.

The maximum distance from the intersection the driver can be and still drive through before the light turns red is given as

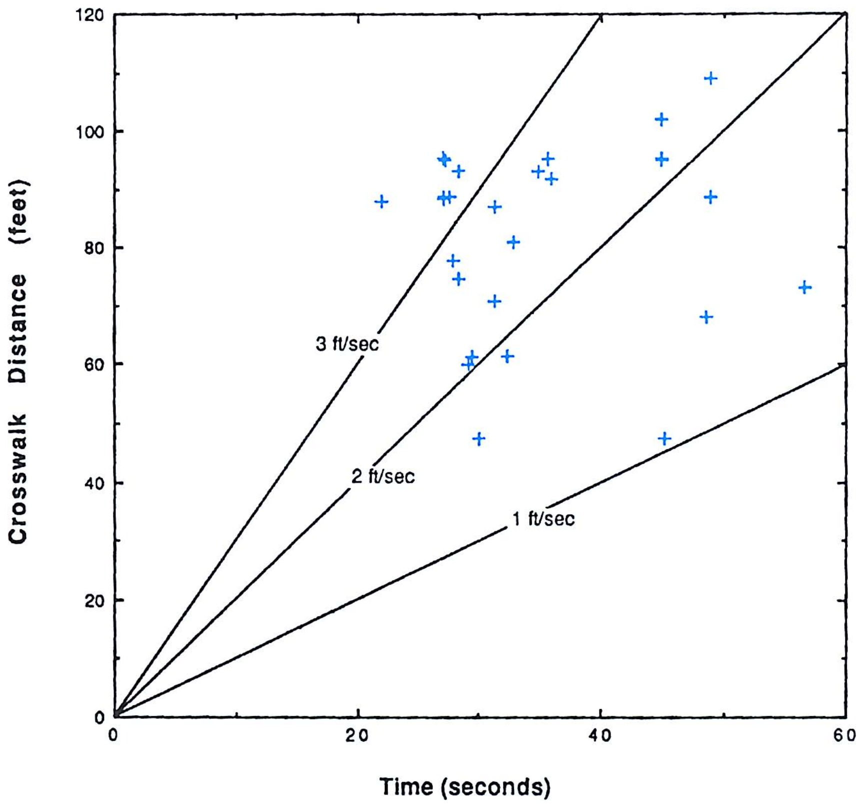

Fig. 2. Plot of crosswalk distance vs time allotted to cross when the walk button is pressed. The lines drawn correspond to speeds of 1 ft/sec, 2 ft/sec, and 3 ft/sec.

$$d_g = V_o t - l \qquad (2)$$

where l is the length of the intersection, and t is the time of the yellow light. Thus when the light turns yellow, if the car is less than d_g from the intersection, the driver can drive completely through before the light turns red. On the other hand, if the driver is greater than d_s from the intersection, she can safely stop in time. By the above criteria, an intersection in which $d_s \leq d_g$ is considered safe. The distance $d_g - d_s$ is the amount of safety zone available in which the driver can either go through the intersection or safely stop before it.

In Fig. 1 we display data from 50 intersections in the Los Angeles vicinity. We have plotted d_g vs d_s for intersections where the speed limit was either 35, 40, or 45 mph, and the angle of the hill was from level to 6 degrees. The straight line $d_s = d_g$ marks the boundary between safety and danger. To our surprise, most of the intersections we tested were unsafe by the above standards, and the yellow light was too short for all of the hills with an incline of 2° or greater. Notice in Fig. 1 that the distances d_s are quantized into three values or bands. This is because d_s mainly depends on τ and the speed limit; τ is fixed, and the speed limit is quantized at 35, 40, or 45 mph. The slight spreading of the bands is a result of different hill angles.

We discovered some other interesting things. The safety factor varied a lot from city to city. This is due to the flexibility, within standard criteria, that city traffic engineers have in setting the timing of the lights. In some cities, the time of the yellow light is the same throughout the city, independent of speed limit and intersection length! One of the longer yellow lights that we ran across was 4.4 sec for a speed limit of 40 mph and an intersection length of 106 ft. At the other extreme, in a different city, one of the shorter lights was for only 3.47 sec for the same speed limit (40 mph), same size intersection (106 ft), and a 2° downward incline! We should point out that all of the intersections tested were safe by California law. That is, in every case, the driver was able to get into the intersection safely before the light turned red. Also, for some intersections all lights were red for about half a second for extra safety.

We also checked out the pedestrian's situation by measuring the time allotted to walk across the intersection before the light turns red. We pressed the walk button and measured the time from the start of the green to the start of the red, as well as the distance across the intersection. In some cases it is absolutely necessary to press the walk button to have any chance of making it across the intersection. Our results for a few intersections are plotted in Fig. 2, along with lines corresponding to different walking speeds. The state of California recommends at least enough walking time for a speed of 4 ft/sec. We monitored a number of pedestrians and observed speeds ranging from as slow as 2 ft/sec to over 5 ft/sec. As can be seen, some intersections are considerate of the slow walker, and others are not.

The data-taking is a lot of fun and can be done with a bicycle and a stopwatch. The bicycle is used to measure the length of the intersection l by counting the number of revolutions of the front wheel as it is walked across the street. The bicycle is also useful in traveling from one intersection to the next, so the project can be incorporated into an after-school bike rally, with different teams measuring different intersections around the city.

We hope that your students will enjoy applying the laws of motion to an everyday situation, while checking to see how safe intersections are in your town. It might also improve some driving habits and lead to good discussions on ways to improve the safety of city driving.

References

1. State of California Vehicle Code 1991, Section 21453 (Department of Motor Vehicles, Sacramento, CA).
2. John W. Jewett, "DMV physics—The case of the disappearing time intervals," *Phys. Teach.* 29, 563 (1991).
3. B. Palatnick, "Kinematics and the driver," *Phys. Teach.* 12, 229 (1974).