Should I Stay or Should I Go?: The Infamous Issue of the Yellow Light Length

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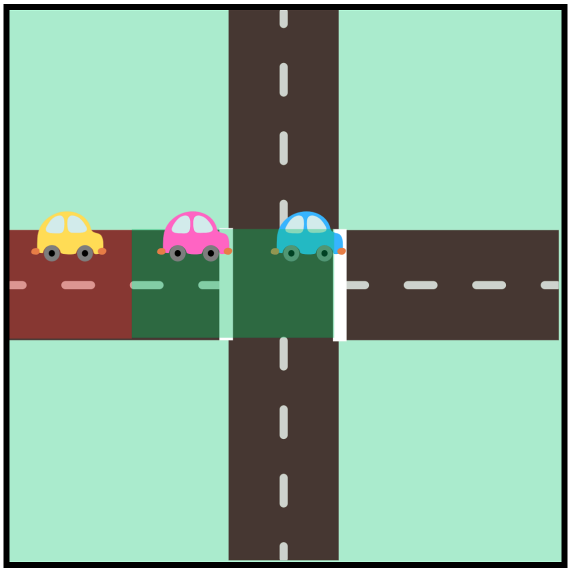
Problem Statement: When a car comes to an intersection, and the light turns yellow, it must either stop or go. If the car chooses to stop, it must be able to stop before the white line of the intersection. If it chooses to go, it must completely cross the intersection before the light turns red without accelerating. How long should the light stay yellow?

Process:

We started by thinking about what ideas would be important to understanding the problem, and came up with the follow ideas:

1. Any car that chooses to stop must be able to stop before the white line while going the speed limit.
2. Any car that cannot stop before the white line while going at the speed limit must fully cross the intersection.



For instance, in the diagram, the yellow car would stop since it can stop before the white line, while the pink and blue cars must go. The red represents the stop zone while the green represents the go zone. We started basing our ideas to solve the problem off of this.

Then, we defined some variables:

w = width of intersection

s = speed limit

a= deceleration of brakes if stopping

ΔX_{go} = maximum distance traveled during yellow

ΔX_{stop} = minimum distance to stop

l= length of car

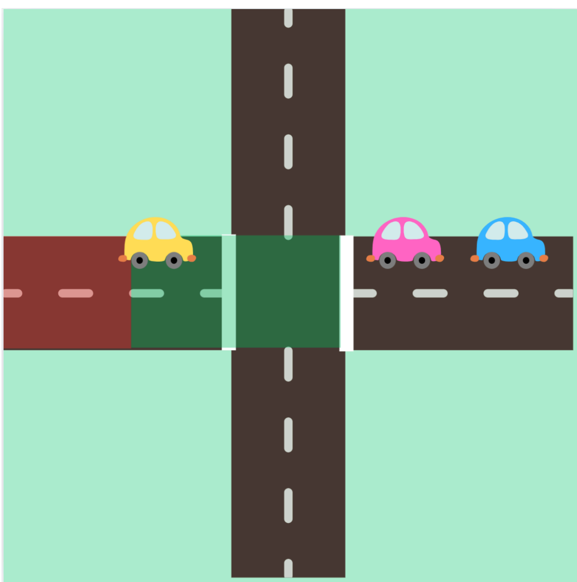
t_{stop} = time to stop (completely decelerate)

t_{go}= maximum go time

t_{rxn}= reaction time of driver

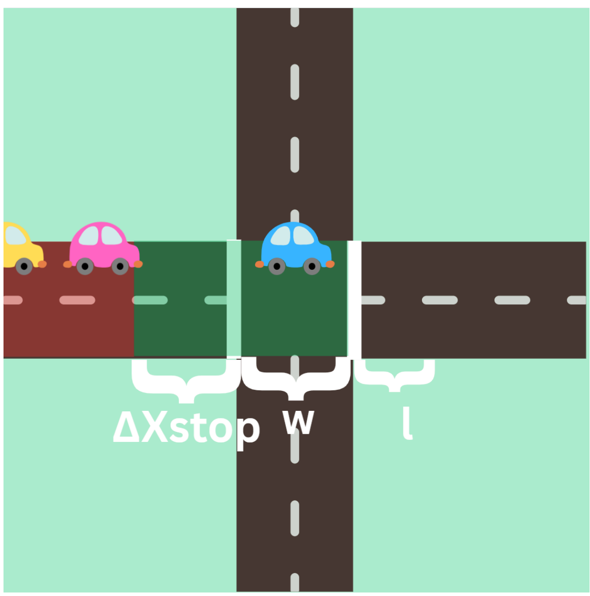
t_{buffer}= buffer time for extraneous conditions (bald tires, distracted driver, etc)

So, we decided to start by looking at the minimum distance needed to stop. We also found the time needed to stop, but then realized it was irrelevant. If it takes longer than the yellow light for a car to stop, it is fine, as the car would not be an obstacle in the intersection. As long as the car has sufficient distance, time is not an issue for cars that choose to stop.



In this scenario, the light has turned red. The pink and blue cars have fully crossed and are safe. Notice that the yellow car has not reached the white line even though the light is red, yet it is still not dangerous. Thus, the yellow light time is not dependent on the time it takes to stop the car, and is instead dependent on the longest amount of time needed for a car to fully and safely cross the intersection. We began looking into how to find this.

We realized any cars that did not have enough distance to stop must go. This means the maximum distance covered by a car would be the minimum stopping distance plus the width of the intersection plus the length of the car, since it would need to fully cross the intersection. Essentially, we thought that a car that was any amount over the edge of the stop zone must go, leading us to use the minimum distance as part of our formula for the total distance travelled.



For instance, the pink car does not have enough distance to stop, so it must cross the intersection. Thus, the yellow light must last long enough for the pink car to cross the minimum distance to stop, the width of the intersection, and the length of itself, since the back of the car needs to fully get across the intersection too.

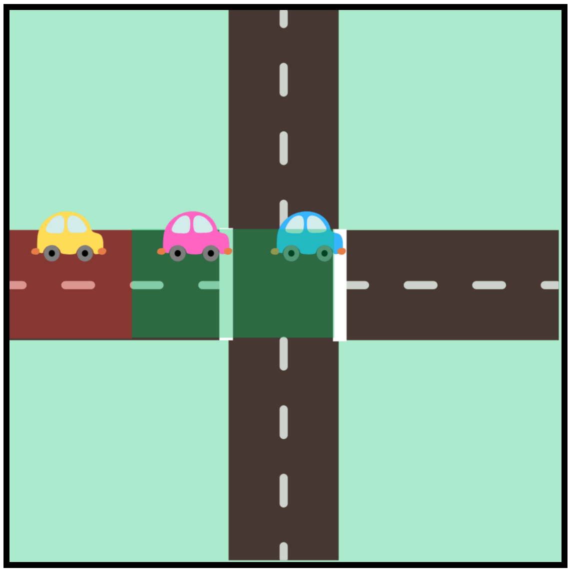
Then, we realized that some drivers would take time to realize the light had turned. This means that a driver could be in the stop zone, but by the time they react, they have moved into the go zone. Thus, the yellow light needs to accommodate reaction time. We also factored in buffer time given distracted drivers, braking in different vehicles, and weather conditions. Thus, the total time is shown below.

So, the minimum time for a yellow light for everyone to proceed safely is the longest distance you would need to travel (minimum stopping distance + width of intersection+ length of car) times the speed limit, plus reaction and buffer time. Note that this model may have an overlap between stop and go zones. The deciding factor is that once the front tires are past the stop line, you MUST go through the intersection.

Solution:

Assumptions:

1. Any car that chooses to stop must be able to stop before the white line while going the speed limit. b
2. Any car that cannot stop before the white line while going at the speed limit must fully cross the intersection.



For instance, in the diagram, the yellow car would stop since it can stop before the white line, while the pink and blue cars must go. The red represents the stop zone while the green represents the go zone.

Then, we defined some variables:

w = width of intersection

s = speed limit

a= deceleration of brakes if stopping

ΔX_{go} = maximum distance traveled during yellow

ΔX_{stop} = minimum distance to stop

l= length of car

t_{stop} = time to stop (completely decelerate)

t_{go}= maximum go time

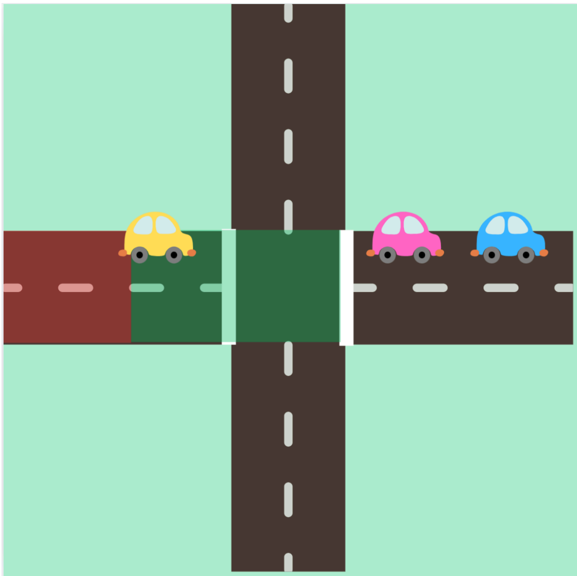
t_{rxn}= reaction time of driver

t_{buffer}= buffer time for extraneous conditions (bald tires, distracted driver, etc)

So, we decided to start by looking at the minimum distance needed to stop.

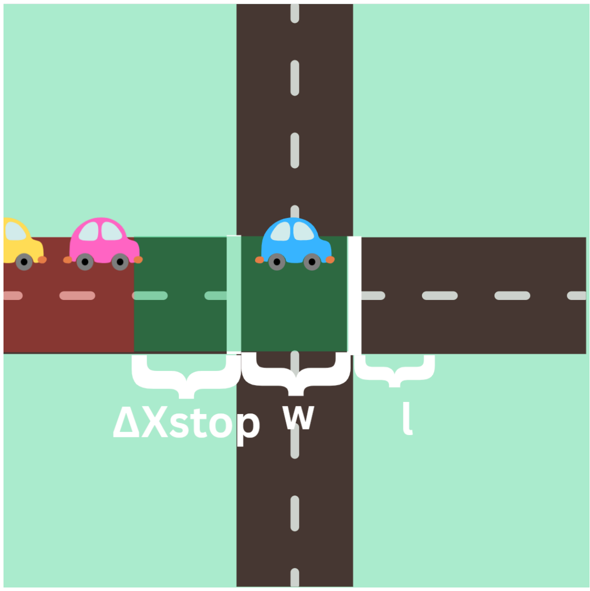
$$V_f^2 = V_i^2 + 2a\Delta x$$
$$0^2 = s^2 + 2a\Delta x_{stop}$$
$$\Delta x_{stop} = \frac{-s^2}{2a}$$

The time needed to stop is irrelevant. If it takes longer than the yellow light for a car to stop, it is fine, as the car would not be an obstacle in the intersection. As long as the car has sufficient distance, time is not an issue for cars that choose to stop.



In this scenario, the light has turned red. The pink and blue cars have fully crossed and are safe. Notice that the yellow car has not reached the white line even though the light is red, yet it is still not dangerous. Thus, the yellow light time is not dependent on the time it takes to stop the car.

We realized any cars that did not have enough distance to stop must go. This means the maximum distance covered by a car would be the minimum stopping distance plus the width of the intersection plus the length of the car, since it would need to fully cross the intersection.



For instance, the pink car does not have enough distance to stop, so it must cross the intersection. Thus, the yellow light must last long enough for the pink car to cross the minimum distance to stop, the width of the intersection, and the length of itself.

$$\Delta x_{go} = \Delta x_{stop} + w + l$$

$$\Delta x_{go} = vt = st_{go}$$

$$st_{go} = \Delta x_{stop} + w + l$$

$$st_{go} = -\frac{s^2}{2a} + w + l$$

$$t_{go} = \frac{\left(-\frac{s^2}{2a} + w + l\right)}{s}$$

$$t_{go} = \frac{-s}{2a} + \frac{w}{s} + \frac{l}{s}$$

Then, we realized that some drivers would take time to realize the light had turned. This means that a driver could be in the stop zone, but by the time they react, they have moved into the go zone. Thus, the yellow light needs to accommodate reaction time. We also factored in buffer time given distracted drivers, braking in different vehicles, and weather conditions. Thus, the total time is shown below.

$$t_{yellow} = t_{go} + t_{rxn} + t_{buffer}$$

$$t_{yellow} = \frac{-s}{2a} + \frac{w}{s} + \frac{l}{s} + t_{rxn} + t_{buffer}$$

So, this is the minimum time for a yellow light for everyone to proceed safely. Note that this model may have an overlap between stop and go zones. The deciding factor is that once the front tires are past the stop line, you MUST go through the intersection.

Discussion Questions:

a) What must be true about the STOP and GO zones in order for the intersection to be safe? Describe what happens at the intersection if the zones do not adhere to this rule.

    i) The distance it takes for the car to stop safely must be less than or equal to the distance of the GO zone. To be in the STOP zone, the distance it would take to stop the car must be less than the distance between the car and the white line. To be in the GO zone, you likely will not be able to stop behind the white line and must have enough time to cross the intersection. If you stop while in the GO zone, your vehicle will probably end up stopping somewhere in the middle of the intersection, putting you at risk of getting hit by oncoming cars. If you go while in the STOP zone, without acceleration, you will most likely cross while it is a red light and end up driving through the intersection while the oncoming cars are driving.

b) How would the following conditions affect the required yellow light time? Which zone would they affect? via which variable?

    i) Exceeding the speed limit

        1) It could take your vehicle less time to cross. Your car taking less time to cross would create a larger GO zone, affecting variables: t_{go} (maximum go time), and ΔX_{go} (maximum distance traveled during yellow). The GO zone would also be larger because more cars would not be able to stop before the white line.

        2) It could also take your vehicle a longer time to cross. Your car taking longer to stop would create a smaller STOP zone, affecting variables: t_{stop} (time to stop/completely decelerate), and ΔX_{stop} (minimum distance to stop). This means cars that cross the intersection must travel further during the yellow light, which could potentially take longer even at a higher speed.

    ii) Bald tires

        1) Bald tires would cause the vehicle to take a longer time to stop, affecting variables: t_{stop} (time to stop/completely decelerate), and ΔX_{stop} (minimum distance to stop). It would also increase t_{buffer}, a

variable dedicated to extraneous conditions, such as bald tires. Since less cars would be able to stop in time, the yellow light would need to be longer to accommodate cars crossing a larger distance during the light.

iii) Long vehicle such as semi truck

1) A longer vehicle size would take longer to cross the intersection, affecting variables: ΔX_{go} (maximum distance possible to travel during yellow). The truck would have to travel a greater distance than a car in order to position its back tires completely out of the intersection. This would affect the time the truck takes to cross the intersection, impacting the variable t_{go} (the maximum go time).

2) It would also take a bit longer to stop, as it has more kinetic energy, affecting variables: t_{stop} (time to stop) and ΔX_{stop} (minimum distance to stop). This also increases yellow light time, as more trucks need to travel further during the yellow light.

iv) Distracted driver

1) A distracted driver would have a longer reaction time. This would affect the variable t_{rxn} (reaction time of driver), and would also increase the t_{buffer} variable, which is a variable for extraneous conditions, overall increasing the necessary yellow light time.

c) Would it be a good idea to mark the stop and go zones on the road before the intersection? Why or why not?

i) While this is a good idea, the implementation wouldn't be consistent for all drivers. In a perfect world, such as the one in this problem, everyone is going exactly the speed limit and has either a car or a truck (one of two specific dimensions). However, in the real world, everyone is generally going at a different speed, and there are multiple other factors changing how people are driving, which would cause variability in stop and go zones for each car. In addition, each car has a unique shape, deceleration time, and upkeep of tires and brake pads. Similarly, everyone has different reaction times and levels of confidence in their driving skills.

d) In the 1960's traffic engineers piloted a system that would display a countdown timer to show how much time was left before the light would turn red. Why do you think the engineer decided against the idea?

i) We think the engineer decided against this idea because knowing how much time was left on the yellow light could lead to rash decisions from drivers. With a normal yellow light, there is no way to know how much longer is left, so many drivers stop to be cautious. However, if the amount of time is displayed, many people would likely try to speed up and make the light, as they believe they can cross in the amount of seconds left. This means people would be in the intersection when the light changes red, thereby endangering them and others. This is similar to how on walk signs that count down, people will still be crossing the road when the walk sign hits zero. Thus, the engineer decided against this because the nature of an untimed yellow light leads drivers to be more cautious rather than less, overall making intersections safer.