EFFECT OF EACH PID VARIABLE

The PID algorithm is dependent on utilizing the cross track error (CTE) (the distance the car is from the intended trajectory or center of the lane/track in this case) to calculate a steering angle based a combination of the current CTE (P roportional), the change in the CTE (D erivative) and the total CTE over time (I ntergral).

The coefficient on the current CTE (P) steers the car back to the center as it drifts away either due to the lane turning or the car just drifting due to its current trajectory. This gets it moving towards the center, however; it will continue turning towards the center all the way until it reaches it without shallowing out its trajectory to continue straight down the lane. As a result, the car ends up oscillating back and forth about the center of the lane.

The coefficient on the change in the CTE (D) helps reduce the steering angle as the car approaches the center (in addition to helping to steer it back to the center as it drifts away). Working to counter P as it approaches the center, in a properly aligned car with a properly tuned D for the CTE will result in the car gently its trajectory and continuing in a straight line as long as the lane stays straight.

If the alignment on the car is off, creating a bias in the steering, the car will need to be off-center in order for the previous two influences (P and D) to steer the car in a straight line. For example, if the car wanted to steer right, the car would need to be right of center so that the P influence would offset the tendency right. To correct this the sum of the CTE (I) is tracked. As the car stays to the right of center, the sum of the CTE continues to accumulate. As it accumulates, the coefficient on the I term will increase the amount that the car steers to counteract the initial tendency. Once it has found its center, the sum will vary about this number as the car drifts but will this will stay roughly even over time as long as the alignment stays constant, continuing to counter the tendency towards one direction, centering the car, and freeing P and D to correct short term drifts, re-centering the car on turns and sending down the road in hopefully smooth curves and straight lines.

CHOSING PARAMETERS

The hyperparameters were chosen through a process that included initial manual tuning to find a combination of p, I, and d parameters that made it all the way around followed by fine-tuning with twiddle for best results.

For manual tuning, the I parameter could be ignored as there wasn't a strong bias either direction. P and D were adjusted in tandem as P needed to be large enough to make it around the sharp curves but without a strong D to cancel out some of the oscillations, it would drive itself off the road before it even reached those curves. I was able to quickly find a ratio between P and D that worked (approximately 1 to 5) for balancing the oscillations and scaled P up from there until it was able to handle the sharpest curves. The manual tune had me at 0.13 for P's coefficient and 0.75 for D's coefficient. This was at a throttle of 0.3 which ended up with a constant speed around 36mph.

For twiddle, the initial coefficients were used along with a set number of messages (called steps from here on out) from the simulator that would complete one full lap. Twiddle used the sum of the squared CTE for all steps after the first 100 (gave it some time to get on track) normalized by the amount of steps taken to decide whether there was an improvement over past iterations and the new coefficients should be kept with adjustment happening around these new best values. The root of this number could have been used as well to give a slightly more meaningful value but ultimately the outcome would be the same.

In addition to adjusting the parameters when the full cycle was complete, the simulator would also reset early when the cross track error was too high signaling that the car had gone off the road. There was a limit to how low this could go as there seems to be a few bad numbers thrown in (two easy to spot ones are right as the car gets to the bridge and near the end of the bridge you will see the tires twitch for seemingly no reason) throughout the course. I was tempted to use an average for a few steps or just filter out bad numbers to limit the impact of this but ended up keeping all the numbers in and calculations done on the most recent one. Limiting the max CTE This sped up the optimizing at what appeared to be a small additional chance of getting stuck in a local minima. To counter this, the threshold that was used was quite small to give it time to adjust slowly if needed. Initially the seeded change for all variables was the same, however; the best coefficients were saved after each improvement and after some time finding the best parameters, twiddle was reset with those parameters as well as change rates more proportional to the magnitude of the number. Without this change, some of the parameters would be challenged to fine tune before the threshold was met. The coefficient for the integral was particularly sensitive to even the smallest change while the coefficient for the derivative required larger changes.

This twiddle process was repeated often as anytime the behavior of the car or sim changed (ideal throttle/speed change, addition of dynamic target speed, simulator resolution and quality change) , the coefficients needed to be optimized. As long as the change was small, the old coefficients still worked as a beginning place for twiddle but sometimes there was additional manual tuning that needed to be done before twiddling.

The twiddle process can be seen if you run the most recent code from the twiddle branch on the github repo for the project.

Also, the numbers utilized in hear for manual tuning are not very reflective of the final result as they were done with beautiful and 640 x 480 setting for the sim. Ultimately, I settled on a quality of fastest and screen resolution of 1152 x 864, which gave substantially higher P and D values as well as a lower P/D ratio. The effect is most pronounced in the D term as the time steps are happening quicker so your CTE change over that faster time step is smaller, requiring a larger D value and a larger D value relative to the P coefficient. P also went up substantially, likely as the result of faster time steps and a larger d being able to smooth out a higher P more quickly. All this means a smoother ride and tighter turns.

The final numbers were:

P = 0.31051
I = 0.000938289
D = 4.22214