1. <u>The effect of each of the P, I, D components:</u>

- The proportional term P accounts for present values of the cross track error. If the cte is large and positive, then the steering angle will be proportionally large in order to reduce the current cte and bring the car closer to the desired trajectory. P tries to reduce the current cte. A high value for Kp results in a large steering response for a given cte. If the value for Kp is too high, the car can become unstable and if Kp is too low the steering response can be too small to reduce disturbances of the car.

- The integral term I accounts for the past cte values and integrates them over time. It measures the build-up of lane offsets over time caused by for example outside factors like bumps in the road. It responds to accumulated errors from the past and tries to eliminate them with a corrective steering command. The integral term I will be positive or negative if it spends more time on one side of the desired trajectory. If Ki is too large, the car can become unstable. If it is too small, the car can take too long to respond to these environmental changes.

- The derivative term D accounts for possible future trends of the cte, based on its current rate of change. It measures how fast we are moving away or in the direction of the desired trajectory. It aims to flatten the error trajectory and reduces overshoot. D predicts the cars behaviour and thus improves the stability of the car. Increasing Kd will increase the resistance the car is feeling to move too quickly towards the desired trajectory. If Kd is too low, the car will be underdamped and still oscillating. If Kd is too high, the car will be overdamped and will take too long to correct for offsets.

2. <u>Process of tuning each of the parameters:</u>

I applied the following manual tuning process:

1. Put the throttle on a low value 0.1
2. Set Ki and Kd to zero and gradually increase the value of Kp until the point where the car starts oscillating. Set Kp to half of this value. In my case the optimal Kp value is -0.5.
3. Repeat this process for Ki with Kd set to zero and Kp set to -0.5. For values above -0.001 the car crashed, so I took -0.001 as the optimal value for Ki.
4. Finally, we repeated the same process for the Kd parameter, while setting Kd and Ki to their optimised values. For Kd I found -25 to be the optimal value.
5. Finally, I increased the throttle up to the point the car crashed. The maximum throttle value without crashing was 0.7, resulting in a lap time of 43 seconds.
6. Finally, I manually tuned each of the 3 parameters based on observing the behaviour of the car at high speeds. My final set of tune parameters is: **Kp: -0.25, Ki: -0.004, Kd:-17.5**