Theoretical Safe Following Distance

***Abstract*— Filler Text**

I. Theoretical Safe Following Distance

For any platooning vehicle (v2), its Theoretical Safe Following Distance (TSFD) from its preceding vehicle (v1) can be computed based on the observed velocities of the vehicles, the estimated maximum deceleration rates of v1 and v2, and the delay between when v1 begins to decelerate and v2 begins to decelerate. This delay may be caused by some combination of detection delay, such as computing the preceding vehicle's current acceleration and determining whether it has breached a safety threshold, and physical factors, such as the time it takes to actuate v2's brakes.

If we define a safe following distance as one in which v2 does not collide with v1 in an emergency braking scenario, then such safe following distance can be derived by combining the stopping distance calculations for both vehicles and is given by the following equation:

$$d = v_2 * delay - \frac{v_2^2}{2a_2} + \frac{v_1^2}{2a_1} \tag{1}$$

In Equation 1, d is the TSFD, v is the initial velocity of vehicle 1 or 2, and a is the deceleration rate of vehicle 1 or 2.

We can see from this equation that with the ideal scenario of homogeneous vehicles, the same initial velocities, and no delay in v2's braking, that we require no following distance at all. This is shown in Figure I

However, the ideal scenario is not very practical. At a minimum, even with homogeneous vehicles, we will have some delay between when v1 initiates an attack and when v2 is able to respond to it. Figures I, I, and I show that the following distance increases linearly with this delay. The absolute increase in TSFD depends on this delay and the initial velocity of the platooning vehicles. For instance, a 20 millisecond delay at 29 meters per second will only increase the required following distance by 0.54 meters, while a 0.25 second delay will increase it by 7.25 meters alone.

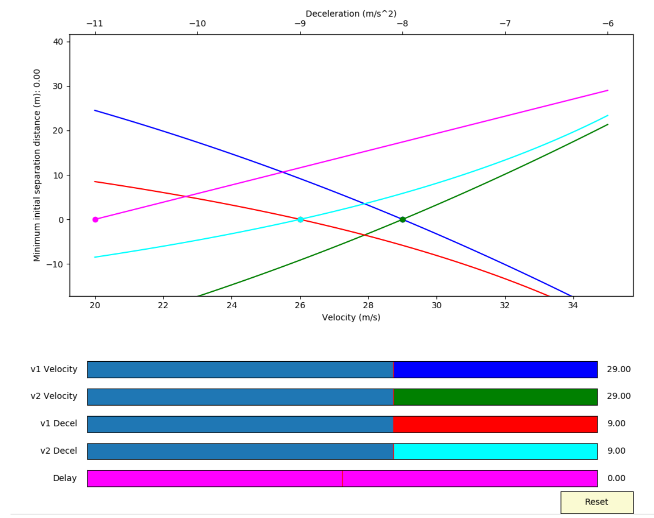

Fig. 1. Ideal scenario. No following distance required.

However, accounting for such a delay is not sufficient in and of itself to realistically predict the TSFD. In practice, due to environmental factors, differences in vehicle types, or even differences in maintenance among identical vehicles, vehicle 1 and vehicle 2 are not guaranteed to decelerate at the same rate. Consequently, we should include in the TSFD a factor of safety and assume that the leading vehicle (v1) can decelerate more quickly than the following vehicle (v2). Using an assumed 50 milliseconds of delay, the results of a 10% factor of safety are shown in Figure I and the results of a 20% factor of safety are shown in Figure I. Figure I shows a 20% factor of safety at a higher absolute deceleration rate for both vehicles. Interestingly, higher absolute deceleration rates appear to lead to lower TSFDs, depite the deceleration ratio remaining constant.

Finally, our TSFD will depend on the initial velocity of both vehicles, and should be adjusted in

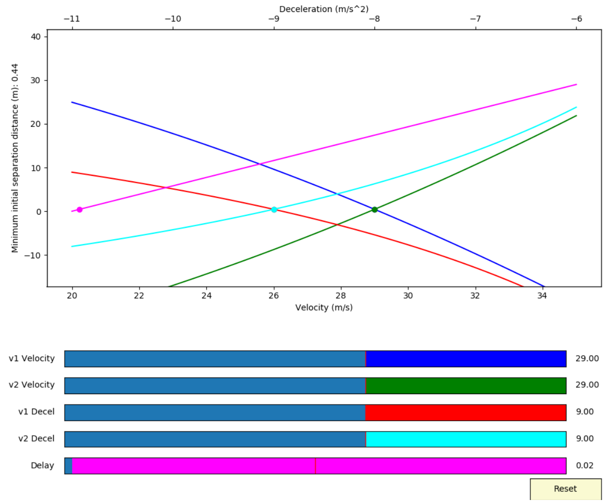

Fig. 2. Delay of 20 milliseconds

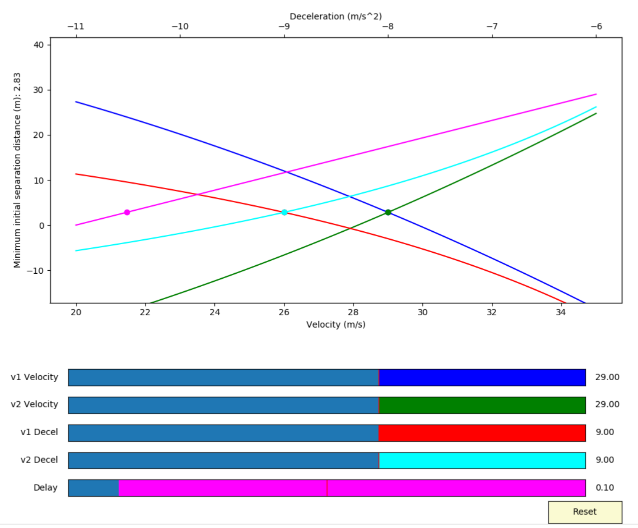

Fig. 3. Delay of 100 milliseconds

real-time with the platoon's current parameters. As we decrease the platoon's initial velocity from 29 m/s to 27.77 m/s (100 km/h), the TSFD decreases correspondingly. This is shown in Figure I.

Calculator Link[1]

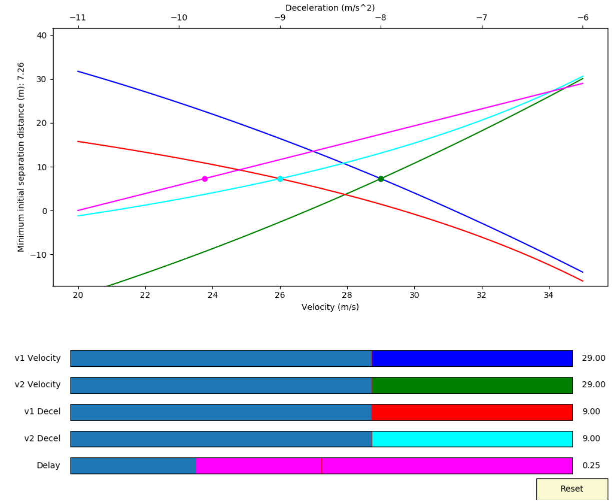

Fig. 4. Delay of 250 milliseconds

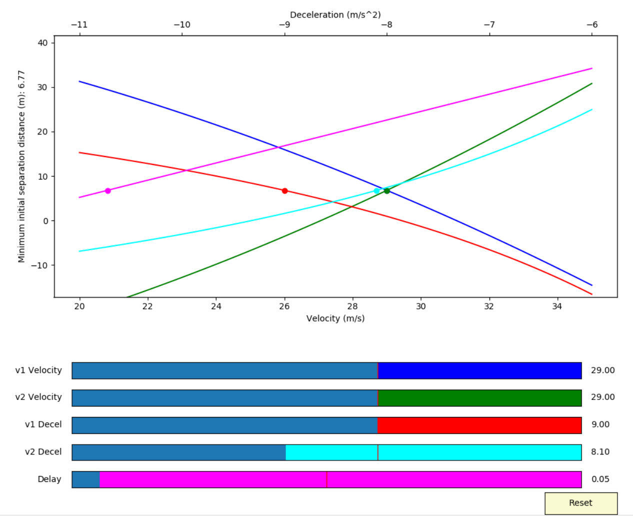

Fig. 5. Delay of 50 milliseconds and a 10% factor of safety.

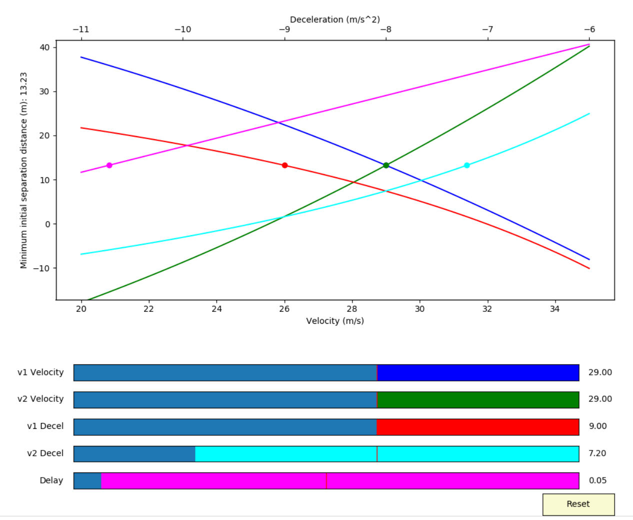

Fig. 6. Delay of 50 milliseconds and a 20% factor of safety.

[1]Safe Following Distance calculator at https://github.com/jericks-umich/platoonfollowingdistance

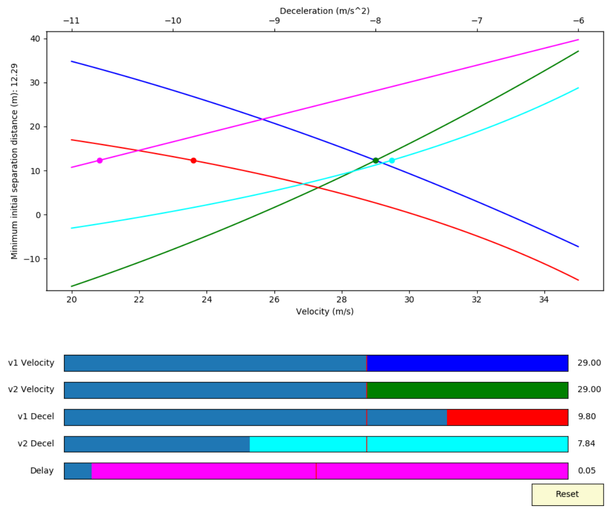

Fig. 7. Delay of 50 milliseconds and a 20% factor of safety with higher deceleration rates.

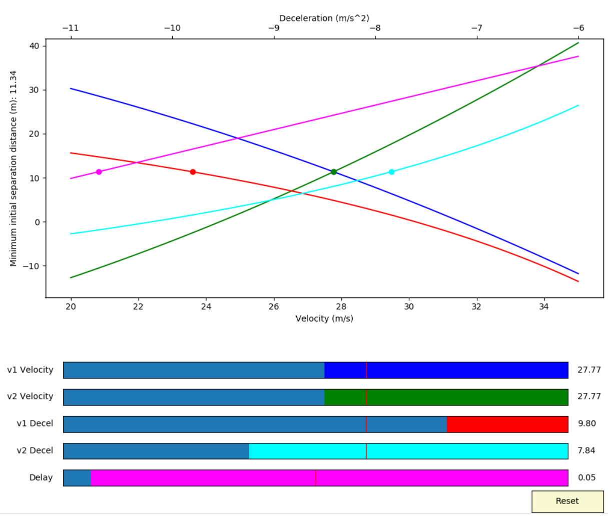

Fig. 8. Delay of 50 milliseconds, a 20% factor of safety, and a reduced initial velocity.