Project Title: Safe and efficient automated freeway traffic control

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- Ohio Department of Transportation

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Project Description:

Shockwaves are a naturally emerging phenomena in freeway traffic, but they represent one of the largest safety risks on freeways. Freeway drivers do not expect to encounter abrupt drops in speed or stopped traffic, as a result, shockwaves sharply increase the accident rates, particularly in the context of rear end collisions. For example, US interstate highways in 2021 saw the following rear-end collision numbers: Fatality 985, Injury-Only 71,408, Property-Damage-Only 152,011. Rear end collision severity is directly related to the relative speed between the involved vehicles, shockwaves increase these relative speeds, and thus, they also increase accident severity. Shockwaves also reduce freeway capacity and have a detrimental impact on fuel consumption and emissions because accelerating engines are less efficient than when cruising. Connected and autonomous vehicles (CAV) hold the promise to attenuate and eliminate shockwaves (and thus, also reduce the severity and number of accidents), but only if the system is explicitly designed to do so. The very factors that give rise shockwaves in human driven vehicles (HDV) will also do so in CAV. While CAV offer new ways to manage traffic dynamics, an automated freeway will still be subject to traffic dynamics. For example, even with perfectly driven CAV, trucks and cars behave differently and the ever-changing mix of different vehicle types will give rise to rapidly varying bottleneck capacity. The real challenge is designing the CAV system so that it ensures the safest possible operation, and then within those bounds, the greatest operational efficiency (maximizing capacity, minimizing delays, etc.). This research will approach CAV traffic control by first establishing the desired macroscopic traffic states along a freeway corridor and will use a rolling horizon to continually update the desired states in response to perturbations in the macroscopic traffic stream. Under this macroscopic framework, the CAV will know what behavior they should take simply by knowing where they are in space relative to the set of desired states. The main objective of the macro to micro control scheme is that the system can efficiently anticipate and respond to disturbances over large distances. It is this macroscopic look-ahead that will allow the system to detect and attenuate shockwaves. Although communications bandwidth is not the focus of this work, the macro to micro control scheme also has the potential to greatly reduce the necessary communication bandwidth to control the freeway traffic. For this initial project the focus will be on detecting and dissipating large shockwaves after they have formed and begun propagating. The research will include developing the macroscopic framework to anticipate, detect and respond to shockwaves; developing the means to convey the macro to micro control scheme for the CAV to realize the macroscopic traffic states; and finally demonstrating the methodology using microscopic vehicle trajectory data from real shockwaves as both the initial conditions and bounding constraints of how the system can respond. If successful, it is anticipated that future research will explore mitigating shockwaves at the source- accommodating the variable bottleneck capacity and other unstable traffic dynamics.

Outputs:

It is anticipated that the quantifiable outputs of this research will include one Master's Thesis and several scholarly publications. While harder to quantify, we believe the goal-oriented approach of, "What do we want

CAV to do and how do we get there?" will help the work achieve impactful results. As discussed in the body, we seek to move from simply addressing disturbances as they arise to proscribing the target traffic state over time and space to prevent the disturbances from arising, which will address the primary objective of improving safety (eliminating unexpected speed drops), while also leading to secondary benefits of reducing emissions and fuel consumption (avoiding unnecessary accelerations), and increasing throughput (stable traffic has a higher capacity than fluctuating traffic states).

Outcomes/Impacts:

Since the earliest autonomous vehicle research the focus has primarily been the very challenging task of making the technology work. While the fact that automated vehicles would benefit operations was taken as self-evident. To date, these priorities were well placed, but now that we are at the cusp of finally deploying safe and reliable CAV, it is important to take a step back and critically assess exactly how CAV can and should impact operations. Much of the past motivation was built on the recognition that CAV can maintain tighter headways, which increases vehicle throughput locally. This research seeks to take a step back from such a point perspective, moving to a proactive corridor perspective. Freeway operations are ultimately constrained by a few links that either have the lowest capacity or highest demand. Away from these bottlenecks is excess local capacity that we plan to use to optimize the flow of traffic through the bottlenecks. This research seeks work outward from bottlenecks to both supply demand to meet (potentially dynamic) capacity and manage any excess demand in stable manner where the waiting vehicles do not give rise to shockwaves. By mitigating shockwaves, it will improve safety, increase throughput, and reduce emissions.