# AVs vs. Infrastructure: How Infrastructure Can Impede Performance

**By Phil Magney**

Active safety and automated driving systems are as good as the infrastructure around them. For proof of this try engaging lane keep assist on a dirt road!

Pavement surface quality, lane geometry, lane markings, blend areas and intersections have a large impact on the performance of camera-based active safety and automated driving features. Physical infrastructure including signs, bridges and overpasses pose further challenges, especially for radar-based applications. These areas can even lead to safety concerns. For example, adaptive cruise control (ACC) and automatic emergency braking (AEB) systems can receive false positives leading to automatic braking action.

## The New ADAS

Active safety systems are the basis of automated driving systems available today. Level 2+ is the new standard and is even referred to as the new ADAS! What does this mean? These technologies are there to provide safety and comfort to the driver and passengers.

Series production cars increasingly offer automatic emergency braking (AEB), lane keep assist (LKA), blind spot detection (BSD), adaptive cruise control (ACC), and cross traffic alert (CTA). It's even becoming standard equipment!

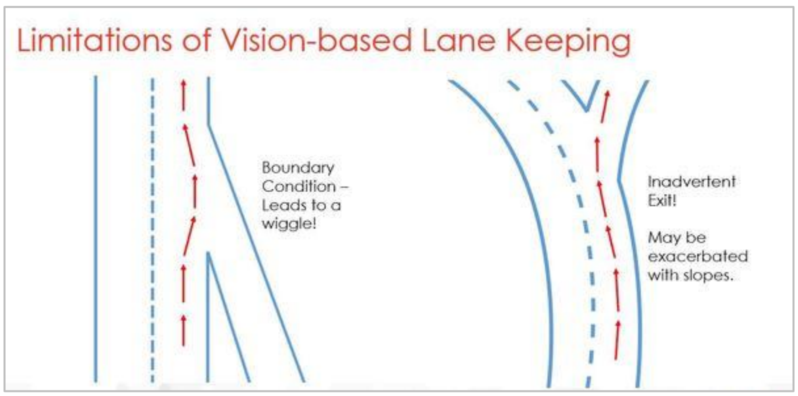
Built on top on these ADAS applications are automated driving systems that permit conditional automation. Some will be Level 2 that operate largely within a single lane. A more advanced version is "Level 2+" that are advanced enough to handle multilane operation and typically are map assisted.

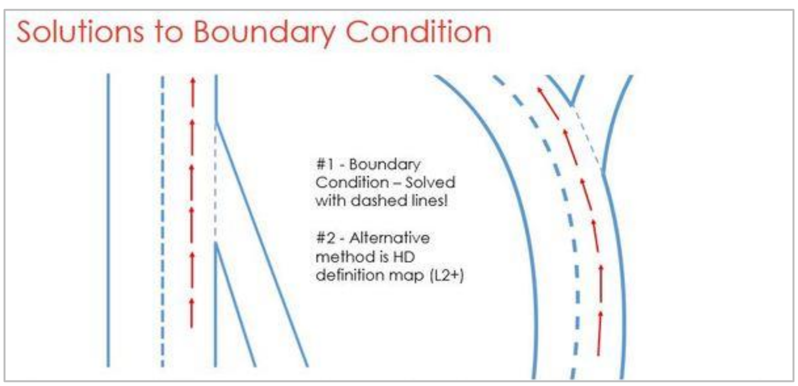
Today, most new cars are sold with some type of camera + radar systems for safety applications, the most common being lane keep assist and automated emergency braking (or mitigation). Although still an option, nearly every major OEM offers a Level 2 automated driving systems. The L2 systems are based on the same camera and radar systems though likely augmented with more sensors.

## Common Boundary Conditions

Boundary conditions happen when a camera-base lane keeping system make assumptions about where to position the vehicle within a lane. This often happens in blend areas where two lanes are merged into one. The resulting vehicle behavior can become erratic in these areas. Another example of a boundary condition is when the vehicle inadvertently exits from its intended path.

Boundary conditions are solvable in a couple of ways. A lane marking solution via dashed lines solves this problem. A more sophisticated method is through the vehicle's use of an HD map. Level 2+ systems typically apply these precision maps along with GNSS services to predict trajectories and path planning more accurately. The below charts visualize boundary conditions and associated vehicle behavior.



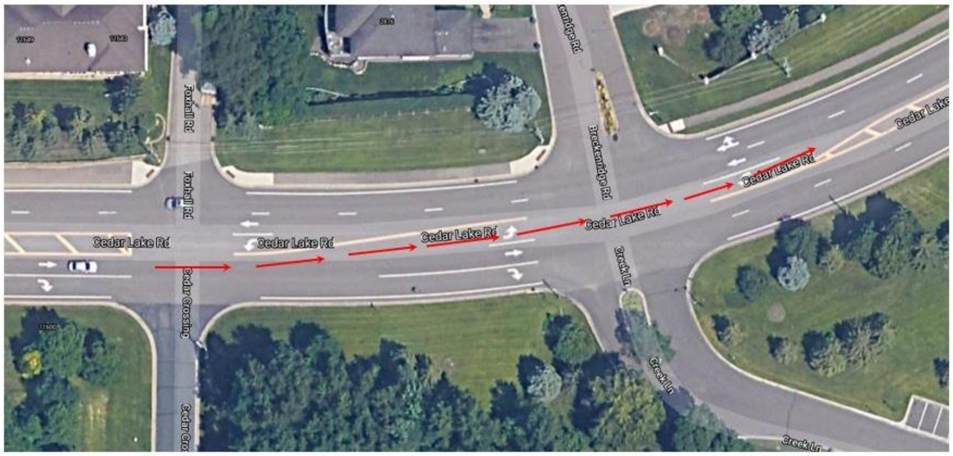

## Lane Geometry and Layout

Many lane keeping solutions and automated driving systems can be used on multilane highways within urban environments. These often involve intersections whereby additional exit lanes are added. Vision based lane keeping systems are often confused in these environments. In the below example a Tesla Model 3 on Autopilot inadvertently veered into the left exit lane and was heading into opposing traffic.

Fortunately, the driver was monitoring this situation and manually disengaged the system in time.

VSI does not recommend using an automated driving system within an urban environment like the one shown. But we often catch edge cases like this for purposes of understanding the limitation of the current technology.

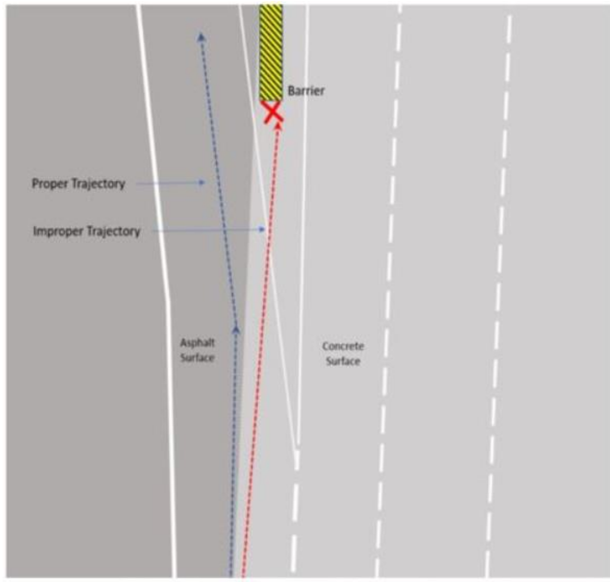
Intersection traversal is a complex task for any automated driving system, but especially for camera-only systems. The most effective method of managing intersection traversal is through HD maps. The Level 2+ solutions coming into the market utilize these maps which improves the performance and safety of these solutions.



## Gore Areas

Gore areas are problematic for LKS and automated driving when not properly marked. An automated driving system does not know the gore area is off limits unless their algorithms are trained to recognize the markings with the gore area.  Most advanced automated driving systems perform a drivable free space algorithm that does not automatically recognize this. However, we would expect AI-based solutions to increasingly be trained for these scenarios.

When unmarked a gore area can result in serious crashes as was the case with Tesla in Mountain View a few years ago. In the Tesla case the lane makings were worn and hard to detect. Furthermore, a difference in surface materials exacerbated the problem.  The vehicle misinterpreted the boundary of the surface materials as a lane line as shown below.




### Slopes, Hillcrests & Turns

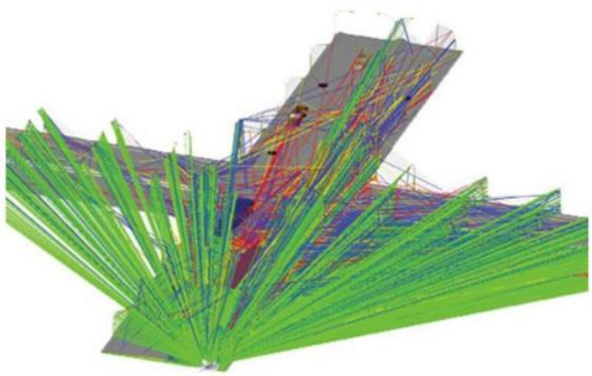
Hillcrests are problematic for LKS and automated driving applications. The vehicle cannot see beyond the crest.  Beyond shaving the hill little can be done from an infrastructure standpoint.  A tight bend or exit beyond the crest would cause confusion in the trajectory planner of a vision-based system.  The only practical method to cope with this is HD maps whereby the vehicle knows what is ahead.

The same problem happens with sharp bends, partially decreasing radius turns often used in highway exits.  While new AI-based algorithms are better than classical feature-based algorithms, decreasing radius turns are very challenging.  HD maps address with this tighter localization markers. Similarly, physical localization markers could be used if the vehicle were programmed to localize against them.  HD Maps are nearly required to handle interchanges for not only localization guidance but for speed control as well.  The speed metadata contained within the HD Map would automatically slow the vehicle to appropriate speeds.

### Phantom Braking

Phantom braking is caused by false radar detections. Objects such as signs and bridges typically cause this. Vehicles parked on the side of the road or in adjacent lanes may also cause this.  The vehicle is misclassifying an object as something in the roadway and either activates the brakes or worse case the automatic emergency brakes.

Radar is usually the culprit for phantom braking for a couple of reason. Radar is not very good at understanding lateral position so something on the side of the road may be interpreted as being in the drivable path. The second reason is radar is inherently noisy.  Radar return signatures are not precise enough to classify an object type.  All radar sees is a blob in its path. Lidar generally does not suffer from this problem because Lidar understands lateral positioning well and usually has enough resolution to classify object types. Lidar is still expensive and not fully proven in series production though.



## Conclusion

The interaction of ADAS and automated driving features and the surrounding infrastructure is constant battle. Lane lines and positioning, lane geometry, slopes and the presence of roadside infrastructure will never be perfect. V2X technologies have not been deployed yet so the ability to read the road ahead through wireless message sets is not an option.

Signal Phase and Timing (SPaT) is likely one of the first V2X deployments because most camera-based signal detectors are not accurate in all conditions. In all likelihood SPaT solutions will first appear in L4+ robotaxis operating in urban settings. For the rest of the market camera warning solutions will likely prevail.

To advance infrastructure to better accommodate automated driving it is important to understand the fundamental interaction between the automated vehicle and the surrounding infrastructure. Lane markings are an obvious high priority but need to be positioned in such a way that the automated vehicle can interpret them properly.

Lane geometry is another area that must be considered due to limitations in computer vision. Some technologies such as V2X and HD maps help close this gap but not all safety or automated driving systems can afford to use them.

Understanding the interaction of automated driving systems and the physical infrastructure is still in its infancy. We have begun to discover some of the edge cases that are more common but there are likely many more that have not been discovered. To advance this study VSI has optimized its data collection rigs to sample more area associated with the surrounding infrastructure. The goal of this study is twofold. First, VSI is constantly examining the performance of sensors and how they perform in diverse environments and scenarios. Our collected data sets can be used by industry who needs to test out their algorithms (or sensors) against these diverse environments. Our second task is to understand the interaction of the automated driving systems and the physical infrastructure. The goal here is to identify problematic infrastructure features so they can be known and considered to roadway improvements.

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## About VSI Labs

Established in 2014 by Phil Magney, VSI Labs is one of the industry's top advisors on AV technologies, supporting major automotive companies and suppliers worldwide. VSI's research and lab activities have fostered a comprehensive breakdown of the AV ecosystem through hands-on development of its own automated vehicle platform. VSI also conducts functional validation of critical enablers including sensors, domain controllers, and AV software development kits. Learn more about VSI Labs at https://vsi-labs.com/.

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