RESEARCH SUMMARY

JULY 2024

Pavement Markings to Support Automated Vehicles

Automated vehicles (AVs) using advanced driver assistance systems depend on pavement markings to accurately track roadway lanes. While MnDOT continues to ensure human drivers easily and effectively detect and interpret various pavement markings, the agency also wanted to understand marking designs and characteristics that support AV functions. Field observations in different locations and during the day and at night using different data collection methods allowed researchers to evaluate the impact of various pavement marking properties on AV lane-keeping functions. Results support MnDOT in producing pavement marking guidance that is responsive to changing needs.

What Was the Need?

While AVs have significant safety potential to reduce crashes caused by human error, the vehicles need supporting infrastructure to fully function. Lane position and navigation features, including adaptive cruise control, blind spot monitoring and lane departure warnings, operate with real-time sensors (such as cameras and radar) and computer software supplemented with mapping or other information. In addition to guiding human drivers, well-maintained pavement markings keep AVs appropriately positioned on the road.

Pavement marking style and patterns have largely been designed based on human vision. MnDOT is completing a human factors study on pavement marking variations, analyzing responses to different skip line patterns and widths, marking contrast and quality, and dotted line extensions. The differences between what AVs and human drivers need, however, are unclear. To complement the human factors study, MnDOT wanted to know how the characteristics and configurations of pavement markings impact AV functioning on the road.

What Did We Do?

A review of federal policies, current state policies and practices, and previous studies of pavement markings and AV functionality found research lacking in several areas, including the impacts of contrast pavement markings, broken line width and cycle pattern changes.

"As automated vehicle technologies continue to advance, MnDOT wants to be ready to optimize potential safety benefits. This study will help us ensure our pavement marking standards support automated driving systems."

—ETHAN PETERSON, STATE PAVEMENT MARKING AND CRASHWORTHY ENGINEER, MnDOT OFFICE OF TRAFFIC ENGINEERING

A field study included data collected through various methods from test corridors in Minnesota and Texas during daytime and nighttime driving. A closed course at Texas A&M University allowed researchers to observe how marking width, quality and the ratio of broken line markings to gap length impacted automated driving functions. A vehicle equipped with a camera-based data acquisition system that measured relative tracking performance of different pavement markings was driven on a roadway with 10-foot-long skip markings at 30- or 40-foot gaps and 4- or 6-inch-wide markings.

On an open road outside of Houston, researchers used the same vehicle-camera combination to determine if different contrast markings improved the tracking ability of the camera system. Researchers observed AV functions on 4- and 6-inch white markings followed by black, and white markings with a black border with and without sun glare.

In Minnesota, an aftermarket sensor system commonly used in AVs, in addition to four test vehicles with varying degrees of automatic and driver assist functions, provided lane-tracking performance information of different pavement markings. A pavement marking test area evaluation included skip line configurations with varying line, gap and cycle length. Markings of different widths and contrast, lane line configurations and line extensions across ramps and turn lanes were then evaluated across the Minneapolis area.

What Did We Learn?

After analyzing the data collected with the camera systems, researchers found that the camera systems adequately detected most markings. Detection performance was better at night, with longer stripes but shorter gaps than the current MnDOT practice and white markings followed by black contrast.

Data collected with the four vehicle sensor systems, however, indicated only whether markings provided adequate lane tracking guidance (the systems either functioned properly or not). There was no evidence that the line stripe to gap ratio, line width or contrast patterns affected performance. The systems had some loss of tracking with lower-quality markings. Turn lanes or highway ramps without dotted line extensions often caused unintended lane shifts.

Study results led to the following recommendations for MnDOT:

- Change 10-foot-long skip marks with 40-foot gaps to 12.5-foot-long marks with 37.5-foot gaps.
- Consider using 6-inch-wide markings in striping.
- Implement dotted line extensions on off-ramps and turn lanes.
- Maintain pavement markings in good condition.
- Use contrast markings (white followed by black) on lighter-colored pavement where contrast with white markings is low.

What's Next?

Together with results from the human factors study, this project will support MnDOT in updating pavement marking policies to support AV functionality. Changes can be made cost-effectively over time. Re-striping to change the skip mark-to-gap ratio, for example, can be implemented without pavement resurfacing as the striping cycle length remains at 50 feet.

About This Project

REPORT 2024-16
"Assessing Pavement Markings for Automated Vehicle Readiness."
Find it at mdl.mndot.gov.

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