INFRASTRUCTURE TO FACILITATE AUTOMATED AND ASSISTED DRIVING

Ken Smith, Tom Hedblom, James Snyder,
James Howard, Jane Peterson, Travis Potts, Kris Hansen
3M Center, 235-3W-52, St. Paul, MN 55144
klsmith@mmm.com; tphedblom1@mmm.com; kjhansen@mmm.com & jkpeterson@mmm.com

ABSTRACT

Over 1 million people die on the road each year, a death rate equivalent to five jumbo jets crashing every day. Of these deaths, 94% have been attributed to human driving error (1). Improved road safety is just one of the many benefits associated with the advent of assisted- and automated-driving systems. Automobile innovators are developing video cameras, lidar-, radar-, and ultrasonic-sensors to equip cars with the tools necessary to safely and efficiently navigate the roads.

To help fully deliver on the promise of autonomous driving, 3M is developing innovative solutions for road way infrastructure. These innovations are built on over 75 years of history of developing safe, robust solutions for conventional driving and on the technical and regulatory expertise that comes with industry leadership.

3M is working with automakers, government agencies and regulatory bodies to develop infrastructure solutions that provide consistent, reliable tools to communicate effectively with both automated and non-automated vehicles. These infrastructure solutions are designed to interact with sensor and sensor fusion systems, providing a back-up solution should one system fail. For example, pavement markings with higher contrast provide improved lane detection to humans and to cars equipped with camera systems. Next generation lane markings can be detected even when covered with snow or during heavy rains. According to auto manufacturers and designers, a high degree of robustness and detectability in pavement marking is needed to ensure consistent performance of the automated vehicle (2).

In addition to pavement markings, 3M is developing innovative solutions in signing that increase detectability by sensor systems and have the potential to deliver more information to the vehicle...information that can warn the vehicle and driver of changing road conditions, of obstacles that may impede traffic flow or of specific safety risks that arise. This leap in technology can be encoded within existing sign formats so that human drivers experience no degradation of information.

3M has begun testing prototype systems on test tracks and highway corridors in United States. These "real world" testing environments have provided insights into prototype successes and future development needs.

INTRODUCTION

The Society for Automotive Engineers (SAE) has designated 6 levels of driving automation from Level 0 (no automation) to Level 5 (fully autonomous) (3). Today, vehicles with the highest degree of autonomy are in Level 2, where two critical functions (e.g. lane keep, adaptive cruise control) are automated and in control of the vehicle at the same time.

Much of the popular press associated with automation in driving has focused on developments on the vehicle and the sensor systems. There is consensus in the industry that multiple different cameras and sensors will be required to support the higher levels of automation. This "belt and suspenders" approach has been fundamental in the aerospace industry where any one system can fail and the vehicle is designed to continue to operate safely.

Even so, the solution to providing the safest possible driving environment that meets the needs of automated and non-automated vehicles does not rest entirely with the vehicle and associated sensors. Driving infrastructure, pavement markings, road signs, and traffic control materials, for example, can be foundational in creating and managing a connected and automated driving environment. Advanced infrastructure can be built to be sensed by discreet detectors, to help locate a vehicle in space and to transmit information dynamically, providing immediate feedback on current or upcoming conditions. Like vehicles, roadways could be certified as capable of supporting different levels of automation. A Level 2 certified road may have pavement markings that meet a certain standard of visibility to ensure that lane guidance systems have the tools necessary to perform in concert with a current state-of-the-art optical camera. A Level 5 certified road may require that pavement markings have detectability to several different types of sensor systems (beyond optical) so as to provide detection and one or two levels of redundant verification to the vehicle re: position on the roadway to within centimeter accuracy. A roadway classification system would allow municipalities to engage thoughtfully and efficiently in their road design and investment decisions and drivers to clearly understand the limits and capabilities of a particular stretch of roadway.

SOLUTIONS IN PAVEMENT MARKINGS

Concepts

3M's first products designed for detection by optical camera systems is 3M™ Stamark™ 380 All Weather Durable Tape and 3M™ Stamark™ 710 Removable Tape, both of which provide reflectivity both day and night, wet or dry. With the understanding that infrastructure on today's roads needs to meet the needs of both a human and automated driver, Stamark™ 380 and Stamark™ 710 maximize the return of reflected light to the vehicle. Historically, pavement markings have included ceramic beads with a refractive index between 1.8-1.9. These beads effectively reflect light back towards the vehicle when dry but are not retroreflective when wet. The Stamark™ 380 and 710 products incorporate a modified version of the ceramic beads that have a refractive index closer to 2.4-2.5. This slight change results in effective retroreflection when the beads are wet. By using a combination of the two types of ceramic beads, the pavement marking are visible to human eyes and optical cameras in both wet and dry conditions. Figure 1 shows a side by side comparison of different parts of a roadway in Michigan, USA, with and without pavement markings that include both types of ceramic beads.

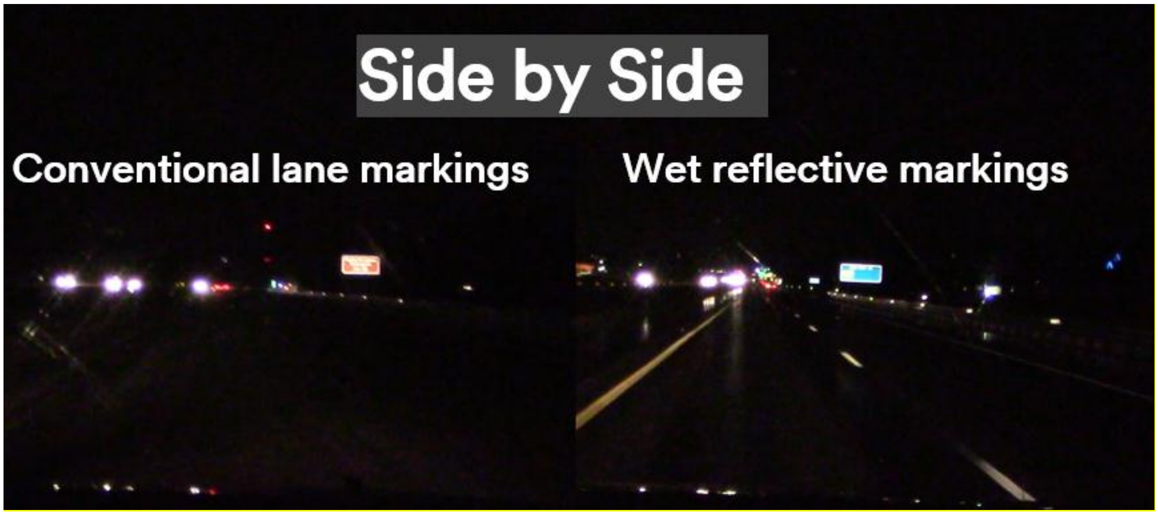

FIGURE 1 Side by side comparison of wet pavement markings on a roadway at night; the left side has markings that only include ceramic beads that effectively retroreflect in dry conditions while the right side images wet pavement markings that include both types of ceramic beads

The wet retroreflective properties of these products provide a bright line during wet or dry conditions, facilitating lane guidance and lane keep even during nighttime. We are working on the next generation pavement markings which will retain a high level of dry and wet retroreflectivity and have even brighter daytime luminance, provide higher contrast between the pavement marking and the background, and have improved durability to extend the lifetime of the marking. We believe these characteristics will help the detectability of the markings in glare conditions and on cement roadways. We are currently evaluating these products on test facilities and highway corridors in anticipation of a 2018 launch.

In addition to retroreflectivity, variables such as line width (4" vs 6"), contrast ratio and pavement marking detectability in adverse weather conditions, including fog, are being evaluated in on-going studies.

Corridor Study, New Orleans, LA (USA)

A study was conducted by 3M on a highway test deck in New Orleans, LA (USA) during which the wet recovery retroreflectivity of the test deck edgeline was measured for both 3M's Stamark™ 380-AW and for a patterned tape with dry optics only (4). At the time of installation, the wet recovery (30 meter) coefficient of retrorefelcted luminance for 380-AW was just over 500 MCD/M^2/LX, approximately double that of the patterned tape. After 24 months on the test deck, the wet recovery coefficient of retroreflected luminance for the patterned tape was approximately 80 MCD/M^2/LX compared to > 250 MCD/M^2/LX for the 380-AW, higher than the highest retroreflectivity standard for pavement markings (5).

In the US, currently standards for pavement markings do not reflect the capabilities of sensor systems in automated vehicles. With the understanding that most lane keep/lane guidance sensor systems are based on optical cameras, we assume that greater luminance provides better detectability by optical camera-based sensors. Preliminary data published by the Texas Transportation Institute suggests that daytime conditions may pose a bigger challenge for camera-based sensor systems than night time conditions. This is especially true on concrete road surfaces in the sun where glare may make the pavement markings almost invisible. In this case, a pavement marking designed to maximize contrast between the background and the line may be better suited for detection by optical sensor systems. The preliminary data from TTI also suggests that roadway lighting does not play a significant role in night time visibility and that speed (50-65mph) has little impact on detectability (6).

SOLUTIONS IN SIGNING

3M has long been a lead innovator in sign sheeting. 3M's Diamond Grade (DG^3) sheeting material returns 58% of light to the source. This high retroreflectivity is due, in part, to tiny "cube corner" structures in the sheeting that reflects light very efficiently back towards the source. Relative to more conventional sheeting, the high retrorefelctivity makes the signs easier to see, especially at night. Although, in the US, the requirement that traffic signs be retroreflective was established in 1935, a minimum standard for retroreflectivity was not established until 1993. The standards, which have continued to evolve, make many assumptions about the age and position (relative to the light source) of the driver, the size and position of the vehicle and head lamps and the vehicle orientation on the road, with the key measurement, luminance, being difficult to measure quantitatively (7).

Automated vehicles do little to solve this problem and for the time being, we assume that surfaces with higher luminance that are easier for a human to read will also be better read by an optical camera.

In general, humans are good at deciphering the meaning of a known sign (~95%) even if the sign is partially obscured by traffic or weather. Machine vision systems designed to read road signs exist, but they currently lack the accuracy of a human reader. This deficiency is especially true if the full sign is not visible (8).

Looking ahead to next generation sensor systems, 3M is evaluating prototype signs that contain a 2D barcode (3M Smart code) designed to communicate directly with the vehicle. While the codes can be configured to communicate exactly what the sign indicates to a human driver, the digital message can be both more detailed and dynamic. For example, a sign that reads "Work Zone Ahead" to a human driver, can be configured to provide that same message to the vehicle, along with details about what else the driver can expect, such as distance to construction, upcoming obstacles and whether workers are present. The codes can provide location verification to the vehicle and can indicate installation date, for example, to help infrastructure owner/operators determine when the signs need to be replaced. An example of a visible Smart code is show in Figure 2, below.

FIGURE 2 Example of visible 3M 2D barcode

3M's Smart codes are designed to communicate robustly to the vehicle even if the sign becomes partially obscured by traffic, graffiti or snow, for example. This degree of digital certainty is critical in allowing the vehicle to properly interpret the complete meaning of the sign.

Corridor Study, Highway I-75 in Michigan, USA

3M is testing prototype signing concepts, including the 2D barcode, on Highway I-75 in Michigan, USA. The test corridor includes a ~4km stretch of roadway that is part of Phase 2 of the Michigan Department of Transportation's (MDOT) 10year construction plan. Testing occurred between May - September 2017; 3M worked with MDOT to have 15 Smart code signs installed along the test corridor. 3M installed replicate signs at the 3M Test Track in Cottage Grove, MN, USA. A suitable camera and sensor system was developed and installed in the test vehicle at both locations; data were collected on a laptop computer in the test vehicle.

A variety of different signs were printed on different color backgrounds. Examples are shown in Figure 3, below.

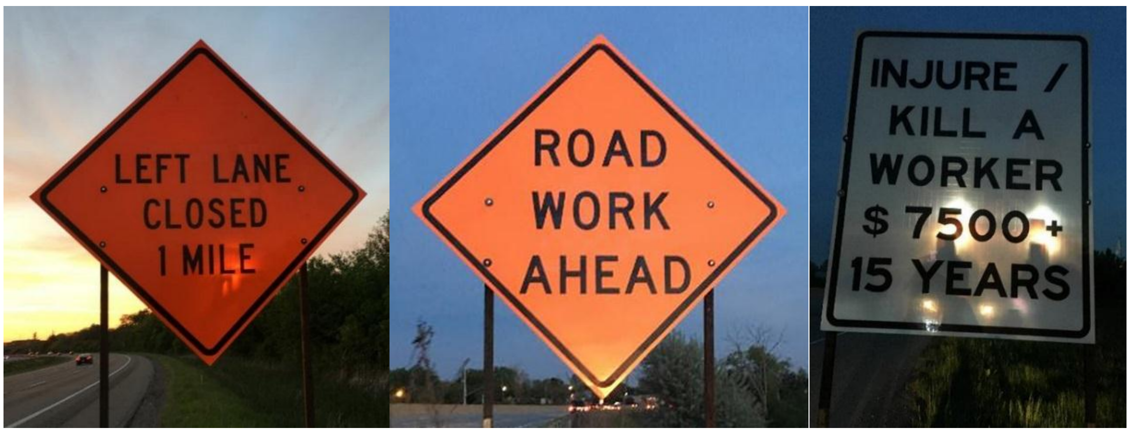

FIGURE 3 Road Signs with 3M Smart codes installed on I-75 Corridor in Michigan, USA

Read distance was recorded from the moving vehicle with data collected from either the center or right lane of traffic at speeds of 35-90kph. Some differences in read distance were noted depending on which lane the car was driving in relative to the sign. Further optimization of the code and sign placement are needed but preliminary data are promising. Read distance was fairly consistent from sign to sign and did not seem to depend on the message or background color of the sign. On 3M's closed test track, with nearly 1000 data points, the average read distance of the Smart code was 39+/- 18 meters. On the I-75 corridor in Michigan, USA, the average read distance calculated from over 200 data points was 34+/-18 meters.

This was the first test of the 3M Smart code and associated sensors on a public highway; subsequent work will focus on increasing the read distance or on increasing the information density readable at highway speeds.

SOLUTIONS IN TEMPORARY TRAFFIC CONTROL

Although not demonstrated on the I-75 corridor in Michigan, USA, the materials and software solutions developed for signs have been adapted to mark barrels and cones inside construction work zone. As with the signs, the high visibility imparted to the infrastructure by 3M DG^3 sheeting material should provide better detectability to forward facing optical camera sensor systems. The ability to encode each barrel or cone with a unique identifier increases the potential to continue improving safety and mobility through the work zone.

CONCLUSION

As the needs and capabilities of automated vehicle sensor systems continue to develop, so too with the characteristics of transportation infrastructure. Roadside infrastructure is not a static element of the world's roadway systems, but instead, an integral component of the overall solution set for connected and automated vehicles. Using a combination of material- and digital-solutions, 3M is position to work closely with road authorities, sensor makers and AOEMs to design solutions that deliver on the promise of improved safety associated with next generation roadways.

REFERENCES

1) Dr. Mark Rosekind, administrator of the U.S. National Highway Traffic Safety Administration (NHTSA).
2) 01 Feb 2017, Ludwig Willisch, President and Chief Executive Officer of BMW of North America;http://transportation.house.gov/calendar/eventsingle.aspx?EventID=401047,
3) SAE Standard J3016
4) Tom Hedblom, 3M TSD, St. Paul, MN (USA), unpublished data
5) https://safety.fhwa.dot.gov/roadway_dept/night_visib/fhwasa10015/
6) Road Markings for Machine Vision NCHRP Project 20-102(6), Paul Carlson, TAMMU Technology Conference, Bryn, TX, May 2017
7) https://www.fhwa.dot.gov/publications/research/safety/03081/03081.pdf
8) Stallkamp, J., Schlipsing, M., Salmen, J., and Igel, C.: 'Man vs. computer: Benchmarking machine learning algorithms for traffic sign recognition', Neural Networks, 2012, 32, pp. 323-332