Pavement Marking Application: A Bead Gun Evaluation Study Using a High-Speed Camera

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Abstract

The Iowa Department of Transportation (DOT) relies heavily on the performance of waterborne pavement markings in providing guidance to motorists. Waterborne markings are installed by DOT crews at the district level and cover roughly 95 percent of the state maintained system. The DOT is continually seeking opportunities to improve crew-applied waterborne marking performance in terms of durability and retroreflectivity. Specific to night-time performance, proper placement of the glass beads, within the waterborne paint, is critical to maximizing retroreflectivity (visibility back to the driver). One of the ways the DOT improved retroreflectivity was to improve bead placement through slowing their trucks down from around 14 mph down to 8 mph. With a limited painting season, and slower truck speeds, the DOT found it difficult to achieve their desired annual paint coverage. In an effort to increase application speed and yet achieve good bead placement (and resulting retroreflectivity) the DOT investigated the option of using a new style of bead gun. This paper presents the findings of a field study using two different (higher application speed) bead guns and reports on the contrast between the two devices in terms of bead delivery versus application speed.
INTRODUCTION

The Iowa Department of Transportation (DOT) relies heavily on the performance of waterborne pavement markings in providing guidance to motorists. Waterborne markings are installed by DOT crews at the district level and cover roughly 95 percent of the state maintained system of 9,000 center line miles. Paint operations within each of the six DOT districts include both long-line and curb marking crews and equipment.

The DOT is continually seeking opportunities to improve crew-applied waterborne marking performance in terms of durability and retroreflectivity. Specific to night-time performance, proper placement (proper embedment, good distribution, and no or minimum bead roll) of the glass beads, within the waterborne paint, is critical to maximizing retroreflectivity (visibility back to the driver). One of the ways the DOT improved retroreflectivity was to improve bead placement through slowing their trucks down from around 14 mph down to 8 mph. With a limited painting season, and slower truck speeds, the DOT found it difficult to achieve their desired annual paint coverage. In an effort to increase application speed and yet achieve good bead placement (and resulting retroreflectivity) the DOT investigated the option of using a new style of bead gun. This paper presents the findings of a field study which contrasted the use of two different (higher application speed) bead guns and reports on their overall effectiveness in balancing proper bead placement over various application speeds from 8 to 14 miles per hour. To contrast the different bead delivery systems, the use of a high speed video camera was utilized.

BACKGROUND

Characteristics that affect retroreflectivity include the distribution of beads across the marking, the level of bead embedment, and the amount of bead roll which occurs during initial placement. Beads must be distributed across the marking and should be embedded into the marking material without being completely buried. Distribution can be explained by the number of beads and the uniformity of the beads throughout the stripe. Embedment is the partial submersion of the glass bead into the marking material (waterborne paint). Ideally, the glass beads submerge part way into the binder, becoming suspended as the binder dries and cures around them. Inefficiencies, and even failure, can occur when these beads are either over or under embedded. Bead roll occurs during the delivery of glass beads onto the wet paint surface. As the bead contacts the wet paint surface it has a tendency to roll and this can cover the bead surface with paint material, thus preventing light from entering the bead resulting in a reduction in retroreflectivity. These attributes are controlled by the speed of the striping truck, type and settings of the bead guns, and characteristics of the paint.

LITERATURE REVIEW

According to NCHRP Synthesis 306 (1), the total value spent in pavement markings by the 50 states, 13 Canadian provinces and territories, US counties, and US cities was $1.5 billion annually on 3.8 million centerline miles. Iowa reported pavement marking expenditures of $3.2 million on just over 11 thousand miles of centerline in 2000. The Manual on Uniform Traffic Control Devices (MUTCD) provides specifications for the placement of road markings. Longitudinal pavement markings provide delineation of the traveled way as well as communicate messages to drivers such as lines indicating passing or no
passing zones. However, the MUTCD does not specify the material to be used for the markings. Materials are chosen based on an agency’s pavement marking specifications (2). Sixteen different materials are currently used for longitudinal pavement markings (1). Although material selection specifications are based on several factors, the two most common materials are waterborne and thermoplastic paint. Waterborne paint became more popular after the Environmental Protection Agency (EPA) established standards on volatile organic compounds (VOC) in 1995 (3).

Previous research of retroreflective elements show the characteristics evaluated in this study are important for maximizing pavement marking performance. Pavement markings guide drivers on the roadway whether it is during daylight or non-daylight conditions. Pavement markings perform effectively during non-daylight hours by providing retroreflectivity. This characteristic is either provided as a matrix or a glass bead applied to the surface of the marking during application. Retroreflectivity represents the amount of light that is reflected back to the source. Reflection gives drivers appropriate information at a safe distance to give the driver sufficient reaction time. Light from the headlamp enters the glass bead and is reflected back to the driver’s eye. Proper bead placement is necessary to reflect light back to the driver at the appropriate angle. Improper placement causes the light to scatter making it difficult for the driver to see the marking. Bead roll also causes a loss in retroreflectivity because paint covering the glass bead prevents light from entering the sphere. These attributes contribute to the delineation of pavement markings during nighttime conditions.

The Texas DOT developed a pavement marking handbook to assist pavement marking personnel with marking material selection, installation, and inspection (3). The handbook discusses installation and inspection that includes bead application properties. The two most important field-controlled properties are the amount and dispersion of exposed beads across a line and the depth of bead embedment (4).

Highway safety has been linked to several attributes of the roadway. Several transportation officials and researchers have attempted to relate visibility and retroreflectivity to safety. Transportation agencies continue to look for ways to accommodate the rise in the average age of drivers on the roadway. The Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for User (SAFETEA-LU) contains provisions that include improving pavement markings in all States, specifically targeted at older drivers (5). The article supports bigger and brighter signs, more conspicuous signals and wider pavement marking in an attempt to make highways safer for older drivers. The University of Iowa completed a study in 2003, Enhancing Pavement Markings Visibility for Older Drivers, to determine the effects of increasing the width and retroreflectivity of pavement markings (6). The study was trying to determine an effective method to increase the detection distance and found that distances are driven by retroreflectivity rather than width.

Run-off-the-road crashes are one of the most common types of crashes on rural facilities. One study attempted to find a relationship between retroreflectivity and crashes on rural facilities. The research proposed that lower retroreflectivity values were a contributing factor in crashes (7). The study managed to identify a statistically significant relationship between low pavement marking retroreflectivity and safety performance (7).
FIELD STUDY

Equipment

Currently, the DOT uses two different bead guns in their pavement marking practices. The most widely used is the Binks™ Model 30. Some districts are using Potters Industries Visigun™. This study evaluated two different bead guns as described below.

SpeedBeadertm

Potters Industries started manufacturing the SpeedBeadertm to improve pavement marking efficiency. The gun allows application speeds in excess of 8 mph which saves time and resources. The gun is designed to be used with different bead sizes and can be easily adjusted with the single-knob flow adjustment. An air injection system is designed to reduce bead roll at speeds over 8 mph and to provide for a more uniform bead distribution, which reduces waste and increases the bead concentration on the line (8). Figure 1 shows the SpeedBeadertm device which is considered to be an off-the-shelf item even though slight adjustments were made to the internal components of the tested unit.

Figure 1. SpeedBeadertm bead dispenser.
Zero-Velocity™ Bead Gun

The Zero-Velocity™ bead gun is not currently on the market and is considered to be a prototype bead gun as developed by EZ-Liner Industries. This device delivers beads through two “rollers” whose velocity matches the speed of the truck. This concept attempts to deliver the beads at near zero horizontal velocity. A speed dial allows for adjustment of the rollers velocity to match the speed of the truck or it can be set on automatic. The Zero-Velocity™ prototype is pictured in Figure 2.

Figure 2. Zero-Velocity™ prototype bead dispenser.

Equipment Setup

Experimentation took place on in-service roadways using DOT long-line marking crews within both Districts 1 and 6. Operations for each style of bead gun were contrasted through documenting the distribution of glass beads across the marking sample, bead roll, initial retroreflectivity, and the analysis of bead trajectory using high-speed video. The bead guns were evaluated at speeds of 8, 10, 12, and 14 miles per hour.
Data collection took place on the side of the roadway as the striping truck passed by. A Photron Fastcam® SA-1 High-Speed Camera and appropriate lighting was set up along the roadway to capture bead trajectory. The camera is capable of capturing high-speed video with mega pixel resolution at 5,000 frames per second. The camera was set up perpendicular to the direction of the truck to obtain footage that would allow the subjective evaluation of horizontal and vertical velocity of the glass beads. Additional video captured at an angle that showed the distribution of glass beads as they exit the bead gun. This video footage showed bead gun distribution across the width of the stripe before the beads reach the paint. Figure 3 shows the setup used. Notice the test panel in front of the camera that was collected for each run.

![High-speed camera setup on side of roadway.](image)

Aluminum test panels were placed where the video was captured. The 10”x24” plates were subsequently analyzed to examine the bead distribution, bead roll, and initial retroreflectivity. The experimentation of the SpeedBeadetm and Zero-Velocity™ bead guns used Type III glass beads.
ANALYSIS

The high-speed video and plates from each test run were used to analyze the different bead guns at various speeds (8, 10, 12, and 14 mph). The video enabled a subjective evaluation of the glass bead particles as they travel through the air displaying distribution and trajectory. The aluminum plates allowed the properties of bead distribution, bead roll, and initial retroreflectivity to be assessed. Bead embedment was not assessed since the experiment didn’t control the paint thickness for the two applications. Future experiments will investigate bead embedment and also bead loss utilizing similar field studies and equipment.

Bead Distribution

Bead distribution, bead roll, and initial retroreflectivity were analyzed by random sampling of the test panels. A 1”x1” sample was taken at four randomly selected locations on each plate (within the area of paint stripe). The random selections were photographed with a digital camera in digital macro zoom mode to view individual beads. Figure 4 shows a random sample taken from a 12 mile per hour pass with the SpeedBeadertm.

Figure 4. SpeedBeadertm (12 mph) 1” x 1” random sample.

The number of beads contained on each of the four samples were counted and an average value from the four samples was calculated. This average number of beads per 1”x1” sample was multiplied by the area of the stripe to obtain the number of expected beads per test panel. Figure 5 displays the results for the average distribution for the Zero-Velocity™ and SpeedBeadertm bead guns as applied at 8, 10, 12, and 14 mph. This graph shows the relationship between speed and the distribution of glass beads. As expected, the average distribution decreased with increasing speed. Note that the amount of bead distribution (bead rate) was not changed for the different speeds throughout the experiment.
As shown, the SpeedBeader™ was observed to dispense more beads than the Zero-Velocity™ at speeds up to 12 mph. At 14 mph, the bead distribution from the two guns was similar. The SpeedBeader™ was dialed in at 10 lbs/100 ft2 and the Zero-Velocity™ was set at 9 lbs/100 ft2 with the speed dial set on manual at 14 mph.

![Figure 5. Average distribution of SpeedBeader™ and Zero-Velocity™ bead guns.](image)

Bead Roll

Observed bead roll between the two guns was contrasted for the varying application speeds. The same four test plate samples were used to count the number of beads with an apparent roll. The beads that appeared to be partially covered with paint were considered to have roll since these beads do not provide retroreflectivity because the paint blocks light from entering the glass sphere. The number of beads rolling is expected to increase with increasing truck speed as shown in Figure 6. The graph displays the percentage of beads rolling per 1” x 1” sample. This was defined through dividing the average number of beads rolling by the average distribution. The number of beads counted in each sample is displayed on the graph. In contrast to the SpeedBeader™, the Zero-Velocity™ bead gun showed no bead roll at speeds less than 12 mph and minimal bead roll at 14 mph.
Initial Retroreflectivity

Most agencies use presence and retroreflectivity as key definitions of a pavement markings performance. The DOT uses initial retroreflectivity, taken between 2 and 8 minutes after applied, to provide feedback to the crew in making any needed adjustments. When readings are out of specification, or unexpected, the crew can quickly adjust without sacrificing a significant amount of time and material.

Retroreflectivity for this field evaluation was measured using the hand-held LTL-X Retrometer® as sampled using four random readings per test plate. The average value of four readings was reported as the initial retroreflectivity in Table 1. Note, these samples were removed from the roadway prior to any presence of vehicular traffic and all readings occurred 26 days after the panels were painted. To accommodate using the same long-line truck for both bead guns, the evaluation used white paint for the SpeedBeader™ and yellow paint for the Zero-Velocity™ bead gun. It is established that yellow paint produces lower retroreflectivity values than white. Some of the retroreflectivity values of the white paint were lower than the yellow, which may have been caused by differences in bead distribution or bead roll.

As observed in the distribution evaluation, the SpeedBeader™ delivered a much high number of beads at 8 mph as opposed to 10 mph. This change clearly impacts the retroreflectivity values as well. The large number of beads rolling above 8 mph could have also influenced the poor retroreflectivity of the SpeedBeader™ test panels. Figure 7 documents the

![Figure 6. Average distribution of SpeedBeader™ and Zero-Velocity™ bead guns.](image-url)
The overall trend that retroreflectivity decreases with increasing speed and also increasing bead roll (see % of rolled beads in Figure 7). Higher application speeds were shown to produce less distribution and more bead roll as represented by the percentages shown.

Table 1. Initial retroreflectivity values.

<table>
<thead>
<tr>
<th>Bead Gun</th>
<th>Speed (mph)</th>
<th>Paint Color</th>
<th>Reading 1</th>
<th>Reading 2</th>
<th>Reading 3</th>
<th>Reading 4</th>
<th>Initial Retroreflectivity (mcd/m²/lux)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SpeedBeader</td>
<td>8</td>
<td>White</td>
<td>289</td>
<td>302</td>
<td>354</td>
<td>341</td>
<td>322</td>
</tr>
<tr>
<td>SpeedBeader</td>
<td>10</td>
<td>White</td>
<td>187</td>
<td>179</td>
<td>189</td>
<td>195</td>
<td>188</td>
</tr>
<tr>
<td>SpeedBeader</td>
<td>12</td>
<td>White</td>
<td>172</td>
<td>170</td>
<td>168</td>
<td>164</td>
<td>169</td>
</tr>
<tr>
<td>SpeedBeader</td>
<td>14</td>
<td>White</td>
<td>148</td>
<td>150</td>
<td>173</td>
<td>186</td>
<td>164</td>
</tr>
<tr>
<td>Zero Velocity</td>
<td>8</td>
<td>Yellow</td>
<td>266</td>
<td>274</td>
<td>262</td>
<td>262</td>
<td>266</td>
</tr>
<tr>
<td>Zero Velocity</td>
<td>10</td>
<td>Yellow</td>
<td>305</td>
<td>326</td>
<td>319</td>
<td>308</td>
<td>315</td>
</tr>
<tr>
<td>Zero Velocity</td>
<td>12</td>
<td>Yellow</td>
<td>249</td>
<td>319</td>
<td>326</td>
<td>316</td>
<td>303</td>
</tr>
<tr>
<td>Zero Velocity</td>
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<td>Yellow</td>
<td>262</td>
<td>246</td>
<td>282</td>
<td>262</td>
<td>263</td>
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</tbody>
</table>

Figure 7. The relationship between initial retroreflectivity and striping truck speed.
Bead Trajectory

A high-speed camera was used to show how the speed of the truck affects the trajectory of the beads. The horizontal and vertical speed of the beads can be obtained from the footage, however, this study was limited to a subjective evaluation of bead trajectory and velocity. Watching the video at low frame rates of 5 to 15 frames per second showed bead interaction at the various application speeds. Figure 8 shows the Zero-Velocity™ bead delivery at 14 mph. Here the beads appear to be falling vertically with little or no horizontal velocity. The striping truck was moving from right to left in the image, but the beads appear to be moving from left to right.

Figure 8. Screenshot of Zero-Velocity™ bead gun video at 14 mph.

Video images of the large beads were also captured for the SpeedBeader™. The screenshot in Figure 9 shows the bead delivery at 8 mph. The truck is passing from left to right in the image. However, the beads appear to be reaching the paint surface with minimal horizontal velocity. The SpeedBeader™ effectively countered the velocity of the truck at 8 mph by dispensing glass beads in the opposite direction thus keeping bead roll to a minimum.
Figure 9. Screenshot of SpeedBeadertm bead gun video at 8 mph.

Figure 10 shows the bead delivery for the SpeedBeadertm at 14 mph. The truck is moving from left to right in this image and the beads were found to have significant bead roll.

The video information was also used to observe the distribution of glass beads as they left the tip of the bead guns. This was accomplished through setting up at a 45 degree angle rather than perpendicular to the test plate. Figure 11 shows the two bead guns at this angle. This footage was also used to observe bead collisions and loss (not hitting the line).

These images were used to show some of the footage that was captured. Although, the images do not do justice compared to what is seen in the videos. These images give an example of the bead cloud that is present as the striping truck passes over the wet pavement marking.
Figure 10. Screenshot of SpeedBeader™ bead gun video at 14 mph.

Figure 11. Screenshot of Zero-Velocity™ and SpeedBeader™ bead guns at 8 mph.
SUMMARY AND CONCLUSIONS

This evaluation uses high-speed video and long line test plates to help contrast the performance of two very different bead guns. With a goal of achieving good bead placement at speeds higher than 8 mph, the evaluation provided the DOT and industry with a starting point in documenting equipment performance and reasonableness in meeting the expectations of the above goal. It is clear that this analysis is limited to the field settings of the equipment. As an example, truck speed was easy to establish using low speed cruise control and long approach areas to align the truck with the test plates. In contrast, accurately establishing bead gun distribution rates was challenging even with the assistance of an experienced paint crew and the bead gun vendors on-site. This is one of the reasons that this evaluation set the speed for the Zero-Velocity™ bead gun at 14 mph for all test runs knowing that this would skew performance at lower speeds.

Based upon the findings in this study, the DOT will be using modified versions of each bead gun over the summer paint season to allow for a comparison of long term performance. Truck parameters and reflectivity over time will be used to further evaluate and modify each of these new products and to consider their utility to DOT paint operations.

REFERENCES


