Article

Public Works Management & Policy
2014, Vol. 19(2) 180–197

DOI: 10.1177/1087724X13500944
pwm.sagepub.com

Performance Evaluation of Wet Pavement Markings in Ohio

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Abstract

Snow plowable raised pavement markers (RPMs) have been used in Ohio for the past four decades to provide visual guidance to motorists under inclement weather conditions. In recent years, rare incidents have occurred where the aged pavement surface failed to provide adequate support to the RPM castings. As a result, the Ohio Department of Transportation (ODOT) initiated this study to evaluate the performance of alternative pavement marking materials and determine whether they can provide equivalent or better delineation than the existing system. These materials included all weather paint (AWP) and wet retroreflective (WR) durable tape. Both materials exhibited high initial WR. However, their wet night performance was significantly compromised within a relatively short period of time due to traffic and snow plowing activities. Therefore, it was concluded that given the harsh environmental conditions in Ohio, it will not be cost-effective to use AWP or WR durable tape as a replacement for RPMs.

Keywords

pavement markings, dry retro-reflectivity, wet retro-reflectivity, daytime color, and durability

Introduction

Pavement markings play an important role in providing visual guidance to motorists. They are used to delineate the intended travel path and guide drivers regarding their location on the road (Migletz, Fish, & Graham, 1994; Federal Highway Administration

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[FHWA], 2009). To function properly, pavement markings must be visible under all weather conditions. In general, most pavement markings provide satisfactory performance under dry conditions. However, under wet night conditions, the visibility of these materials degrades significantly (Migletz & Graham, 2002). This is because the marking surface becomes flooded with water, which leads to partial or complete disappearance of the marking. There are two primary reasons for this incident (Pike, Hawkins, & Carlson, 2007). First, the accumulated water over the pavement marking scatters the light away before it reaches the marking surface, which results in a specular reflection rather than retro-reflection. Second, this accumulated layer of water changes the efficiency of the reflective media in the pavement markings resulting in a shorter detection distance for the drivers. Therefore, under the wet night conditions, driving becomes more challenging because less guidance is provided to the drivers by the pavement markings.

Snow plowable raised pavement markers (RPMs) are typically used in Ohio to provide visual guidance to road users under inclement weather conditions. In recent years, due to the extended pavement resurfacing cycle used by the ODOT, several incidents have occurred where the aged pavement surface failed to provide adequate support to the RPM castings. As a result, ODOT adopted a rigorous plan to identify and replace loose RPMs. In addition, ODOT initiated this study to evaluate the performance of other alternative materials and determine whether they can provide equivalent or better delineation than the existing system. This paper presents a summary of the performance evaluation procedure and comments on the periodic evaluation results.

Objectives

The main objectives of this study are to evaluate the wet night performance of several wet pavement markings and determine the feasibility of using them as a replacement for RPMs in Ohio.

Literature Review

Over the past two decades, several research studies have been conducted to evaluate the performance of pavement markings (Aktan & Schnell, 2004; Carlson, Miles, Pike, & Park, 2007; Carlson, Miles, Pratt, & Pike, 2005; Craig, Sitzabee, Rasdorf, & Hummer, 2007; Fu & Wilmot, 2013; Gibbons, Andersen, & Hankey, 2005; Gibbons & Hankey, 2007; Higgins et al., 2009; Lindly & Narci, 2009; Sasidharan, Karwa, & Donnell, 2009; Robertson, Sarasua, Johnson, & Davis, 2012; Schnell, Aktan, & Lee, 2003; Sitzabee, White, & Dowining, 2013). Most of these studies focused on the dry performance of these materials. However, in recent years, concerns about the effectiveness of pavement markings under wet conditions have gained increased attention leading to many studies on this topic. This section offers a brief summary of some of these studies and highlights their findings.

Schnell et al. (2003) evaluated the performance of three pavement markings under different weather conditions. These materials included preformed flat tape, patterned tape, and wet-weather tape. The evaluation took place on a test track in Cottage Grove, Minnesota, that had a road section equipped with spray nozzles capable of simulating a 1-inch-per-hour rain event. Testing was conducted under dry, simulated rain, and recovery (45 s after rain cessation) conditions. Eighteen participants (11 women and 7 men) drove along the test track and reported the earliest point they could see the end of the pavement marking. This information was used to determine the pavement marking detection distance. Eye movement data was also collected and analyzed to determine the drivers' level of comfort while driving around the test track. In addition, pavement marking retro-reflectivity was measured with handheld retro reflectometers in accordance with American Society for Testing and Materials (ASTM) E1710 (dry), ASTM E2177 (wet recovery), and ASTM E2176 (continuous wetting). It was found that under dry conditions, all three pavement markings provided long detection distances. However, under wet conditions, the wet-weather tape had the longest detection distance, followed by the patterned tape and the flat tape. Furthermore, for the wet-weather tape, the eye fixations were more concentrated, which was interpreted as a gain in the visual search comfort by the participants. Good correlation was reported between the detection distances under continuous rain and retro-reflectivity values measured using ASTM E2176 and between the detection distances under recovery conditions and retro-reflectivity values measured using ASTM E2177. It was emphasized, however, that retro-reflectivity measurements from ASTM E2176 and ASTM E2177 are not interchangeable. Hence, ASTM E2177 cannot be used to determine the effectiveness of pavement markings under continuous rain, and ASTM E2176 cannot be used to determine the effectiveness of pavement markings after rain cessation.

In a follow-up study by Aktan and Schnell (2004), the nighttime visibility of a large-beaded permanent pavement marking was compared with two patterned tapes (one with high-index beads and the other with mixed high-index beads) under dry, wet, and simulated rain conditions. The evaluation was conducted on the same test track mentioned earlier and using the same evaluation techniques. Most participants from the previous study also participated in the evaluations. It was found that the patterned tape with mixed high-index beads performed best under all three weather conditions. The permanent pavement marking with large beads was comparable with the tape with high-index beads under wet and rainy conditions. However, under dry conditions, the permanent pavement marking with large beads performed the worst.

In a study funded by the Texas Department of Transportation (TxDOT), Carlson et al. (2005, 2007) evaluated the performance of a wide range of pavement markings under dry and wet conditions. In addition to RPMs, these materials included waterborne traffic paint, thermoplastic, durable tapes, epoxy, polyurea, and methyl methacrylate. This study also looked into the effects of increasing the pavement marking width (from 4 to 6 inches) and rumble strip markings on the wet visibility performance. The evaluation was conducted on a 1,600 ft. long test track with rain tunnel located at the Texas A&M University's Riverside Campus. The pavement markings were placed along the rain tunnel in 8 ft. strips. Three rainfall rates were used in the evaluation. These rates included 0.28, 0.52, and 0.87 inches per hour representing low, medium, and high rainfall rates, respectively. Thirty-four participants drove through the rain tunnel and reported the beginning of the pavement markings, which was used to determine their detection distance. In addition, retro-reflectivity was measured under dry, continuous rain, and wet recovery conditions using ASTM E1710, ASTM E2176, and ASTM E2177, respectively. This study found no correlation between dry and wet retro-reflectivity measurements or between retro-reflectivity measurements obtained using ASTM E2176 and ASTM E2177. However, a moderate correlation was reported between the visual observations for all rainfall levels and ASTM E2176 and ASTM E2177 retro-reflectivity measurements with an R^2 value of 0.619 and 0.595, respectively. An average wet night detection distance of over 550 ft. was reported for the RPMs, which was 200 ft. greater than any of the other materials tested. The tapes were also found to perform better than the rest of the materials, with the exception of the RPMs. In addition, the 6-inch wide lines were observed to have 30% longer detection distances than the corresponding 4-inch lines.

Gibbons et al. (2005) evaluated the performance of six pavement marking treatments under different weather conditions. These treatments included standard latex paint and glass beads with RPMs, standard latex paint and glass beads, standard latex paint with large glass beads (visibeads), profiled thermoplastic (drop-on line), wet retro-reflective (WR) tape, and semi-WR tape. The experiment was conducted at the Virginia Smart Road facility, where participants were subjected to a simulated rain event of 0.8 inch of rain per hour and a simulated recovery (10 min after rain cessation). The participants rated the visibility of the pavement markings under dry, continuous rain, and recovery period by counting the number of skip lines visible from a stationary vehicle (static experiment). The continuous rain evaluation indicated that all pavement markings performed better under dry conditions than under wet conditions, with the exception of the RPMs that performed the same under both conditions. The recovery evaluation showed that the time required for the visual performance of a pavement marking to recover from rain is significantly higher for paints and bead products than for profiled, wet, and semi-wet pavement markings. The visual observations from continuous rain and wet recovery were also compared with retro-reflectivity measurements obtained using ASTM E2176 and ASTM E2177. A high degree of correlation was reported. However, a definitive level of retro-reflectivity required to meet drivers' needs in wet night conditions was not found.

In a subsequent study by the same research group (Gibbons & Hankey, 2007), the performance evaluation was conducted under continuous rain (0.8 inch per hour) while driving a vehicle on a closed test track (dynamic experiment). Four pavement markings were evaluated. These materials included standard latex paint and glass beads, standard latex paint with large glass beads (visibeads), profiled thermoplastic (drop-on line), and WR tape. The performance evaluation was conducted under variable lighting conditions in the presence and absence of glare. It consisted of determining the detection distance of the start or end point of a white 4-inch edge line. This study found that the WR tape had the longest wet visibility distance, followed by the profiled thermoplastic and the standard latex paint with large glass beads, and the standard latex paint and glass beads. However, it was concluded that none of the materials tested provided adequate visibility distance at speeds greater than 45 mph.

In a study funded by the FHWA Highways for LIFE Technology Partnerships Program, Higgins et al. (2009) evaluated the performance of several temporary pavement markings for work-zone projects. Three experimental optics-on-paint marking systems incorporating high refractive index dual-optics drop-on elements, specially designed to provide good visibility in dry and wet conditions, and two commercially available temporary markings (one glass beads-on-paint system and one wet-reflective removable tape) were evaluated under dry, wet-recovery (just after rainfall), and simulated rain conditions (0.5 inch/hr). Thirty participants drove through simulated work zones on a closed test track and viewed the pavement markings at night under all three weather conditions. Each driver was asked to identify the direction of work-zone lane shift tapers delineated by the markings. This study found that all three experimental marking systems and the wet-reflective tape retained 50% to 70% of their average dry detection distances under simulated rain and 60% to 80% of their average dry detection distances under wet recovery. Meanwhile, the average wet-recovery and rain-detection distances for the conventional glass beads-on-paint system dropped to 28% and 17% of its dry detection distance, respectively. Furthermore, it was reported that participants failed to detect the conventional glass beads-on-paint system in nearly half of the observations in the rain condition.

Lindly and Narci (2009) conducted a study to evaluate the performance of double-drop glass beads edge lines in Alabama and compared them with standard thermoplastic, rumble stripes, and profiled pavement marking, in terms of service life, lifecycle cost, and dry and wet retro-reflectivity. The double-drop glass beads edge lines were found to have the highest dry retro-reflectivity followed by the rumble stripes, then the standard thermoplastic, and finally the profiled pavement marking. As for the wet retro-reflectivity, the double-drop glass beads edge lines had the highest retro-reflectivity values, followed by the profiled pavement marking and the rumble stripes. The standard thermoplastic had the lowest wet retro-reflectivity values. This study also indicated that the double-drop glass beads edge lines are expected to have the longest service life, followed by the rumble stripes, the standard thermoplastic, and the profiled pavement marking.

The previous studies revealed valuable information about the wet night performance of pavement markings and the methods used to characterize their performance. However, most of these studies focused on the initial performance, which is not necessarily indicative of the long-term performance of these materials. In addition, none of these studies accounted for the effect of snow plowing on the wet night performance of the evaluated materials. Therefore, results from these studies are not applicable to the state of Ohio.

Test Site

This study was conducted in Licking County, Ohio, along Interstate 70 at a location where the interstate has two lanes per direction. The average annual daily traffic (AADT) at the test site is approximately 44,000 vehicles per day, equally divided between the eastbound and westbound directions, with about 30% truck traffic. This region of Ohio receives an average annual snow fall of 20 to 30 inches. Snow removal practices involve using deicing salt and front-mounted snow plows. ODOT uses a bare pavement surface policy in its snow-removal activities, where the plow blade runs on the pavement surface, leaving little to no snow/ice behind.

Pavement Marking Materials

Three pavement markings were evaluated in this study. These materials included AWP, WR durable tape, and extruded thermoplastic. The AWP consisted of a traditional fast dry waterborne traffic paint mixed with standard glass beads and wet-reflective elements. Each element comprises a silicon core topped with microcrystalline ceramic beads. The ceramic beads are a mixture of 80% wet reflective beads, with a refraction index of 2.4, and 20% dry reflective beads, with a refraction index of 1.9. The 2.4 refraction index ceramic beads are not effective under dry conditions. However, in the presence of water that has a refraction index of 1.33, the overall refraction of the element-water system becomes ideal for pavement marking retro-reflectivity. The WR durable tape consisted of a base bead-filled pliant polymer layer topped with polyurethane coating intermixed with microcrystalline ceramic beads. It uses specially designed optics to improve wet-night visibility. In addition, it has a patterned structure with raised near-vertical surfaces to improve retro-reflectivity under wet weather conditions. The extruded thermoplastic was the standard alkyd thermoplastic that is commonly used by ODOT on new asphalt surfaces.

As can be seen in Table 1, these materials were applied in six different treatments. All materials were installed on a new asphalt surface, that is, following an asphalt-resurfacing project. The AWP was installed on rumble strips and on the surface, while the WR durable tape and the extruded thermoplastic were installed in groove and on the surface. The AWP was applied at a thickness of 20-mil (0.51 mm), the WR durable tape was about 90-mil (2.3 mm) thick at the raised profile, and the extruded thermoplastic was applied at a thickness of 125-mil (3.2 mm). Where applicable, a groove depth of 90 ± 10-mil was used for the WR durable tape, and a groove depth of 125 ± 10-mil was used for the extruded thermoplastic. The groove depth was selected the same as the pavement marking thickness to protect them from snow plowing during winter. In addition, RPMs were installed on the lane lines where AWP and extruded thermoplastic were used but not where the WR durable tape was used.

Performance Evaluation

The performance of the pavement markings was evaluated on a semi-annual basis for a period of 1.5 years. The performance evaluations were conducted in September 2008, April 2009, September 2009, and April 2010. This allowed for evaluating the performance of these materials for two winter seasons. All evaluations were conducted at night between midnight and dawn. Each treatment was evaluated in two locations. Key performance attributes that were taken into consideration include dry and wet retro-reflectivity (ASTM E1710 and ASTM E2177, respectively), durability, daytime

Table 1. Pavement Marking Materials and Experimental Design.

Treatment No.	Mile marker	Line type	Treatment type
1[a]	138-139 (EB)	Yellow edge line	AWP on rumple strips
		White lane line	AWP on surface
		White edge line	AWP on rumple strips
2[b]	139-140 (EB)	Yellow edge line	WR durable tape on surface
		White lane line	WR durable tape on surface
		White edge line	WR durable tape on surface
3[b]	140-141 (EB)	Yellow edge line	WR durable tape in groove
		White lane line	WR durable tape in groove
		White edge line	WR durable tape in groove
4[a]	141-142 (EB)	Yellow edge line	Thermoplastic in groove
		White lane line	Thermoplastic in groove
		White edge line	Thermoplastic in groove
5[a]	142-143 (EB)	Yellow edge line	AWP on surface
		White lane line	Thermoplastic on surface
		White edge line	AWP on surface
Control[a]	138-143 (WB)	Yellow edge line	Thermoplastic on surface
		White lane line	Thermoplastic on surface
		White edge line	Thermoplastic on surface

Note. EB = east bound; AWP = all weather paint; WR = wet retro-reflective; RPM = raised pavement marker; WB = west bound.
[a]RPMs were installed at 120 ft. along the lane line.
[b]No RPMs were used.

color, and wet night visibility. In general, six to eight evaluators were present during the evaluations. The evaluation team consisted primarily of engineers from ODOT District 5 and ODOT Central Office, who were familiar with the performance evaluation procedures.

Retro-Reflectivity

The dry and wet retro-reflectivity of the pavement markings were measured in accordance with ASTM E1710 and ASTM E2177, respectively, using a Delta LTL-X handheld retro-reflectometer. This device uses the 30-m geometry in simulating the roadway being illuminated by the headlights of a car. This device was calibrated prior to taking any retro-reflectivity measurements and outfitted with a base plate and two wet night feet before being used to measure WR. At each location, an effort was made to collect 10 dry and 5 wet retro-reflectivity readings per line per evaluation.

The dry and wet retro-reflectivity measurements were made by placing the LTL-X device on the surface of the pavement marking in a stationary mode. For rumble stripes, the device was placed 14 inches away from the highest point on the rumble strip to take the reading. Wet retro-reflectivity measurements were made 45 ± 5 s after two to five liters of water were applied to the surface. This waiting period allows some water to drain leaving a surface in a wet condition.

Durability

In this evaluation, a group of experienced evaluators visually judged the percentage of pavement marking remaining on a 10 ft. line segment. This evaluation was conducted in the most deteriorated location for each treatment. The durability rating was reported as an integer on a scale of 0 to 10, where a rating of 0 indicates that the marking material is completely lost and a rating of 10 indicates that 100% of the marking material is remaining.

Daytime Color

Daytime color was measured using a MiniScan XE Plus (Model 4500L) spectrocolorimeter. This model uses the 45°/0° geometry in measuring daytime color, where the system illuminates the sample at an angle of 45° and measures its color at an angle of 0° (perpendicular to the surface). This model has a relatively large view area, over which color is measured, with 31.8 mm measurement port. Color readings are provided in the Commission Internationale de l'Eclairage (CIE) xyY color units, where x indicates the red quality of the color, y indicates the green quality of the color, and Y describes how bright or luminous the object is. In this study, color was measured every 6 months. An effort was made to collect five color readings per line per evaluation.

Wet Night Visibility

Wet night visibility was evaluated at night during a rain event. It involved observing the pavement markings as well as the RPMs from a moving vehicle under low-beam headlight illumination to determine the longest visible distance. The distance was estimated by counting the number of RPMs that were visible and multiplying by 120 ft. (the distance between two consecutive RPMs in Ohio) or by counting the number of lane lines that were visible and multiplying by 40 ft. (the distance between the midpoints of two consecutive lane lines).

Results and Discussion

This section offers a summary of the periodic evolution results. As mentioned earlier, these results were collected on a semi-annual basis for a period of 1.5 years.

Retro-Reflectivity

Figures 1 and 2 present the average dry and wet retro-reflectivity values, respectively, obtained during the periodic evaluations for all six treatments. A minimum acceptable retro-reflectivity value of 100 mcd/m^2/lux is represented as a dashed line in these

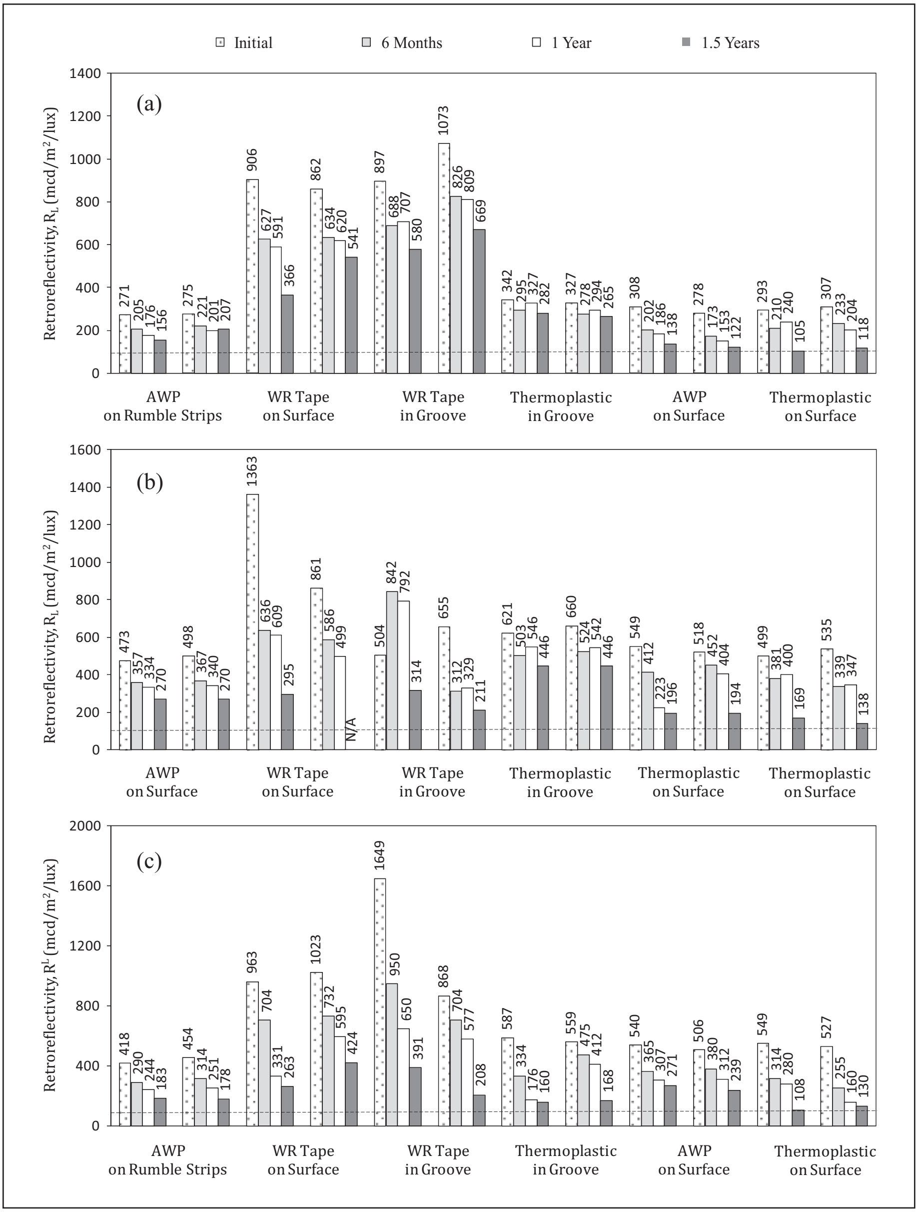

Figure 1. Dry retro-reflectivity: (a) yellow edge line, (b) white lane line, and (c) white edge line.
Note. AWP = all weather paint; WR = wet retroreflective.

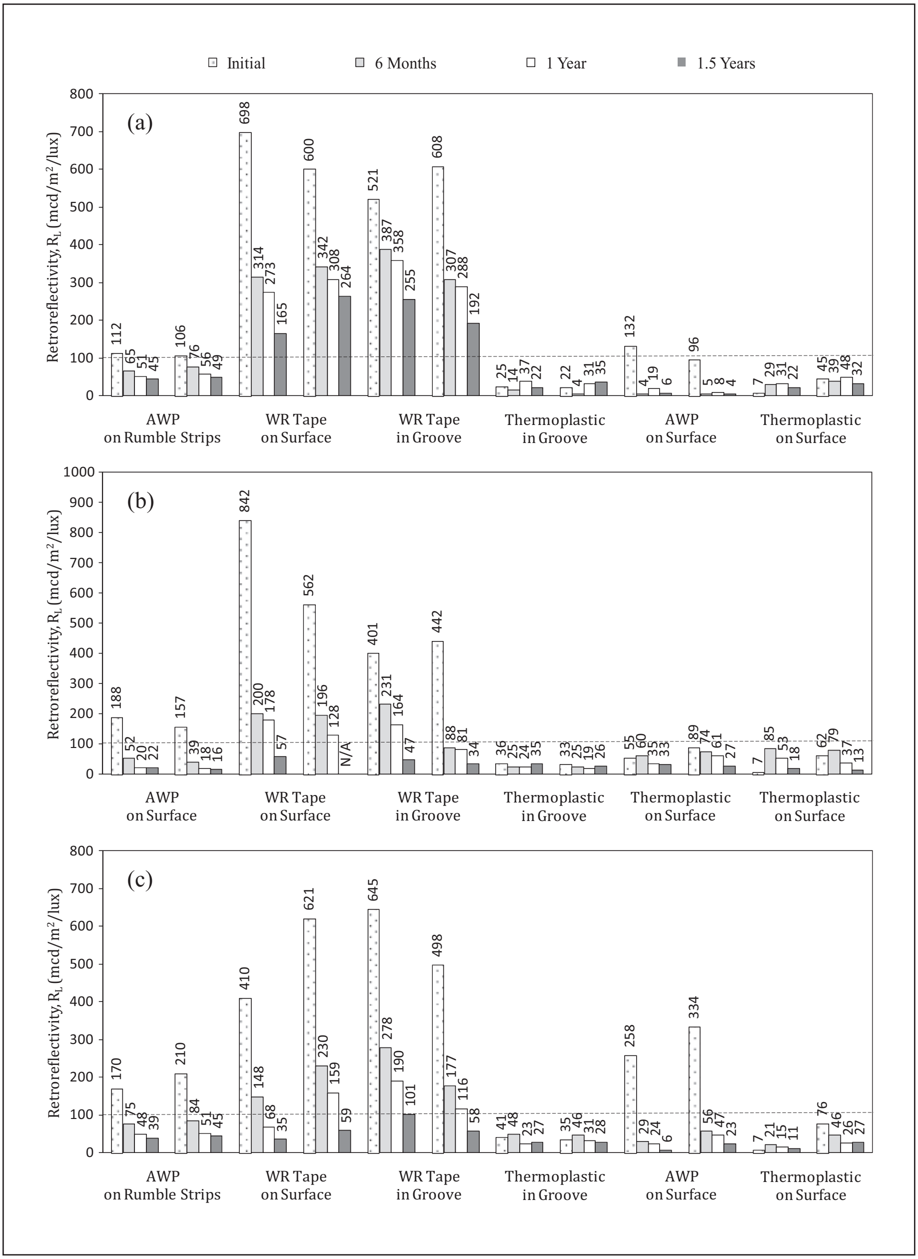

Figure 2. Wet retro-reflectivity (a) yellow edge line, (b) white lane line, and (c) white edge line.

Note. AWP = all weather paint; WR = wet retro-reflective.

figures. As can be seen from these figures, the WR durable tape had the highest initial dry and wet retro-reflectivity values. This was expected because these tapes contain specially designed optics to improve their dry and wet performance. This material also had the highest retained dry and wet retro-reflectivity values after 1.5 years. Nevertheless, the WR of this material dropped significantly during the first and second winter seasons, especially on the right edge and lane lines that are typically subjected to higher traffic volumes. In addition, when installed on the surface, this material was caught by snowplows, which explains the lack of dry and wet retro-reflectivity data after 1.5 years for the lane line in Treatment 2. Aside from this issue, the performance of the WR durable tape in groove was comparable with that on the surface.

The initial dry retro-reflectivity of the AWP was comparable with that of the extruded thermoplastic. However, the AWP had significantly higher initial WR, which was anticipated because this material contains wet-reflective elements to improve their wet visibility. Similar to the WR durable tape, the WR of the AWP dropped significantly during the winter. This material lost most of its WR though during the first winter season, which was the case for AWP installed on rumble strips and on the surface.

The extruded thermoplastic had moderately high dry retro-reflectivity, with the lowest retro-reflectivity deterioration rate (year-to-year drop in retro-reflectivity). This was especially the case for the lines that were installed in groove, which probably had a better glass bead retention.

This material, however, had the lowest wet retro-reflectivity values of all materials. This was expected because this material uses standard glass beads that are not designed for wet conditions. The extruded thermoplastic installed on the surface showed higher WR values than those installed in groove. This was attributed to the ability of the surface-installed extruded thermoplastic to better drain water off its surface.

Durability

Almost all materials performed satisfactory throughout the 1st year of evaluation. The only material that showed a drop in durability was the AWP installed on the rumble strips. This was probably due to higher abrasion from traffic at the peaks of these rumble strips.

After the second winter season, the WR durable tape installed on the surface was caught by snowplows in many locations and was striped with fast dry traffic paint in the following summer. Therefore, this material must be installed in groove to protect it from snow plowing activities when used in harsh winter environments.

Daytime Color

The daytime color readings—obtained using the MiniScan XE Plus colorimeter—were compared with ODOT color specifications for yellow and white markings. A set of formulas were developed in Microsoft Excel to determine whether the readings met these specifications. This was visually verified by superimposing the color readings and the specifications on a CIE color chromaticity diagram. Figure 3 presents an example of such figures. As can be seen from this figure, the AWP met ODOT color specifications for white markings at all times as well as yellow markings for initial and 6-month evaluations. However, it did not meet ODOT color specifications for yellow markings after 1 and 1.5 years. The rest of the materials met ODOT color specifications for white and yellow markings at all times.

Wet Night Visibility

Figures 4 and 5 present the wet night visibility distances obtained during the periodic evaluations for the pavement markings and the RPMs, respectively. As can be observed from these figures, the RPMs exhibited the longest wet night visibility distance, followed by the AWP on rumble strips, then the AWP on the surface, and finally the extruded thermoplastic. The RPMs had an initial wet night visibility distance of 600 ft., which dropped to 360 ft. after 1.5 years. The WR durable tape had an initial wet night visibility distance of 240 to 420 ft., which dropped to 120 to 160 ft. after 1.5 years. The AWP had an initial wet night visibility distance of 240 to 420 ft., which dropped to 40 to 80 ft. on the surface and 240 ft. on the rumble strips after 1.5 years. Meanwhile, the extruded thermoplastic had an initial wet night visibility distance of 50 to 240 ft., which dropped to 40 to 120 ft. after 1.5 years.

It is noted that in some instances, the wet visibility distance of some of the pavement markings increased rather than decreased over time. These variations are expected because ratings are subjective and may vary from one person to another. Another factor that might have contributed to such variations is the rainfall intensity during the evaluations. This study was not conducted under a controlled environment. Therefore, it was not possible to apply the same rainfall rate during the evaluations.

Pavement Marking Service life

Pavement marking service life is generally defined as the time required for retro-reflectivity to drop below a threshold value where the pavement marking is no longer considered effective as a delineation system. Over the past two decades, several research studies have been conducted to establish a minimum retro-reflectivity requirement for pavement markings. However, no consensus has been reached among researchers on the minimum retro-reflectivity level required to meet the driver's visibility needs at night. While a range of values have been suggested for minimum retro-reflectivity, the most common threshold values used in the literature are 150 mcd/m^2/lux for white and 100 mcd/m^2/lux for yellow (Abbas, Mohi, & Butterfield, 2009).

The service life of the pavement markings was estimated by fitting an exponential model to the dry retro-reflectivity and WR data collected during the evaluation and solving for the time required for retro-reflectivity to reach the threshold value. Table 2 presents the predicted service lives for all materials. As can be noticed from this table, a longer service life was obtained for yellow edge lines and white lane lines than for white edge lines, which indicates that the white edge lines were subjected to greater

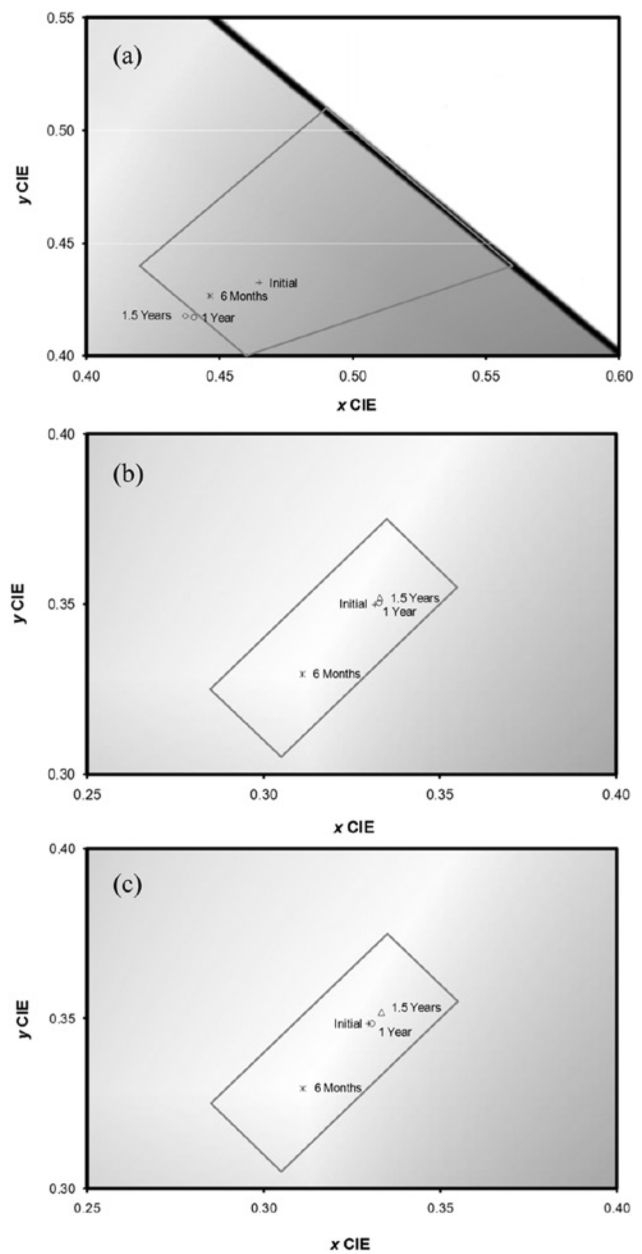

Figure 3. Comparison between AWP daytime color readings and ODOT color specifications (a) yellow edge line, (b) white lane line, and (c) white edge line.
Note. AWP = all weather paint; ODOT = Ohio Department of Transportation; CIE = Commission Internationale de l'Eclairage.

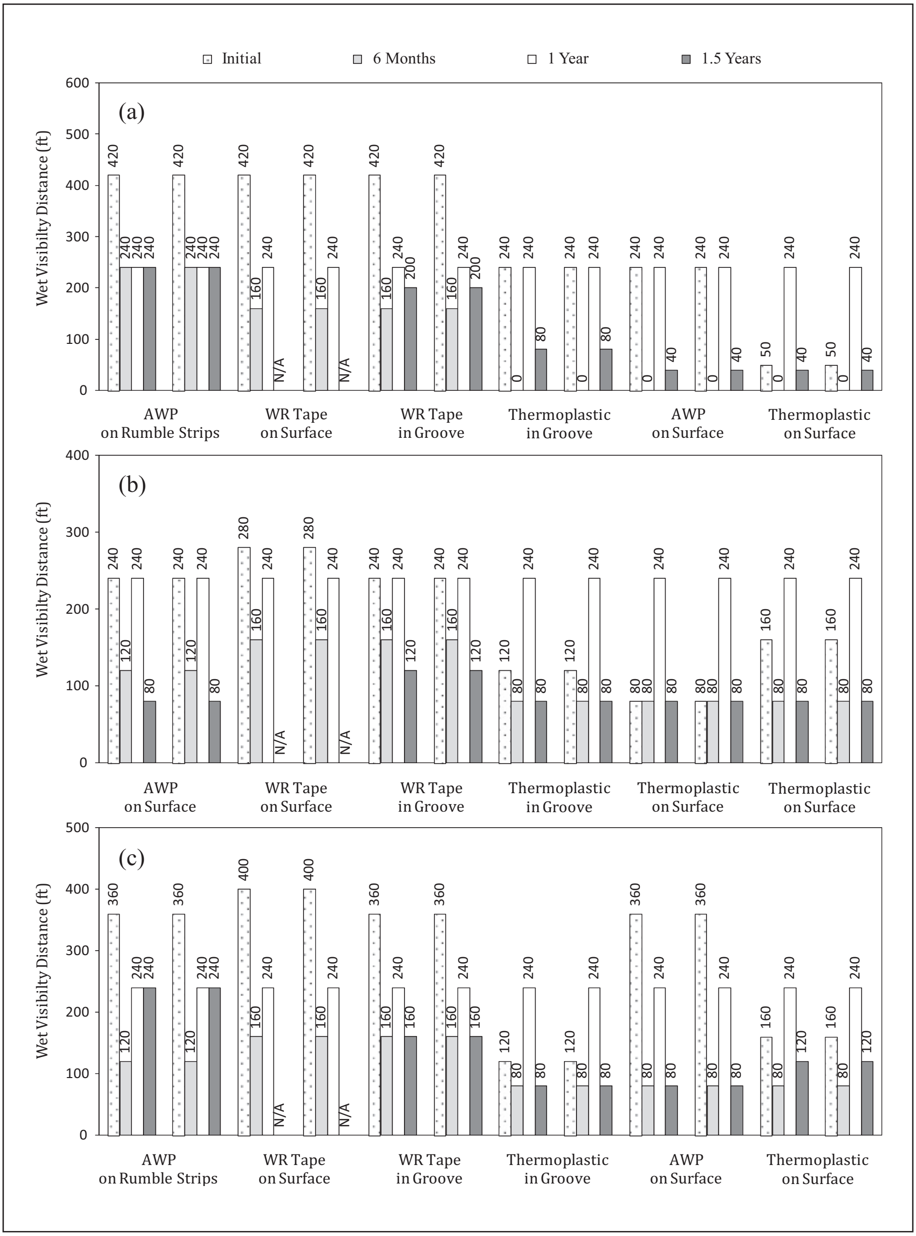

Figure 4. Pavement marking wet night visibility distance (a) yellow edge line, (b) white lane line, and (c) white edge line.
Note. AWP = all weather paint; WR = wet retro-reflective.

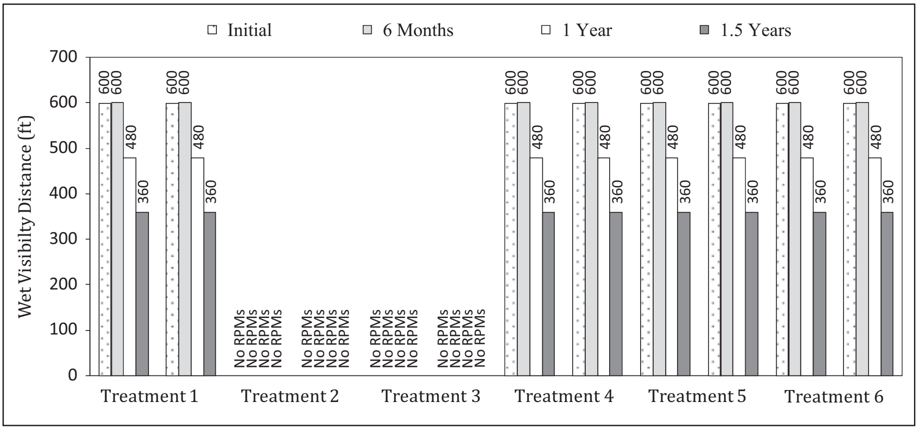

Figure 5. Wet night visibility distance for RPMs along the white lane line.
Note. RPM = raised pavement marker.

Table 2. Predicted Pavement-Marking Service Life.

Treatment No.	Line type	Treatment type	Service life (Years) Dry	Service life (Years) Wet
1[a]	Yellow edge line	AWP on rumple strips	3.3	<0.5
	White lane line	AWP on surface	3.1	<0.5
	White edge line	AWP on rumple strips	2.8	<0.5
2[b]	Yellow edge line	WR durable tape on surface	6	2.4
	White lane line	WR durable tape on surface	2.7	0.9
	White edge line	WR durable tape on surface	2.6	0.6
3[b]	Yellow edge line	WR durable tape in groove	7.7	2.3
	White lane line	WR durable tape in groove	4	0.6
	White edge line	WR durable tape in groove	2	0.8
4[a]	Yellow edge line	Thermoplastic in groove	10.8	<0.5
	White lane line	Thermoplastic in groove	6.5	<0.5
	White edge line	Thermoplastic in groove	1.9	<0.5
5[a]	Yellow edge line	AWP on surface	2.8	<0.5
	White lane line	Thermoplastic on surface	1.8	<0.5
	White edge line	AWP on surface	3.3	<0.5
Control[a]	Yellow edge line	Thermoplastic on surface	1.6	<0.5
	White lane line	Thermoplastic on surface	1.8	<0.5
	White edge line	Thermoplastic on surface	1.1	<0.5

Note. AWP = all weather paint; WR = wet retro-reflective; RPM = raised pavement marker.
[a]RPMs were installed at 120 ft. along the lane line.
[b]No RPMs were used.

Table 3. Installation Cost of Pavement Markings and RPMs.

Material type	Installation cost ($/line mile) Grooving	Edge line	Lane line	Installation cost[a] ($/roadway mile)
AWP	N/A	1,990	1,290	5,270
WR durable tape (without grooving)	N/A	12,702	4,607	30,011
WR durable tape (with grooving)	4,478	12,702	4,607	43,445
Extruded thermoplastic (without grooving)	N/A	1,680	850	4,210
Extruded thermoplastic (with grooving)	4,478	1,680	850	17,644
RPMs	N/A	N/A	1,023	1,023

Note. RPM = raised pavement marker; AWP = all weather paint; WR = wet retro-reflective; N/A = not applicable.
[a]The total installation cost for roadway mile includes two edge lines, one lane line, and grooving, if applicable.

wear from traffic and snow plowing activities. It can also be noticed that, under wet conditions, none of the materials on the white edge lines was effective for more than 1 year. Overall, the WR durable tape had the longest service life of all materials under dry and wet conditions. The AWP performed relatively well under dry conditions. However, it had a low service life under wet conditions. Furthermore, the extruded thermoplastic was unable to meet the minimum retro-reflectivity value under wet conditions at any point during the evaluation.

Cost Comparison

Table 3 presents the installation cost of the pavement markings and RPMs as awarded for this project. As can be seen from this table, WR durable tape had the highest installation cost especially with grooving followed by AWP and extruded thermoplastic. It can also be noticed from this table that the cost of installation for RPMs is much lower than the longitudinal pavement markings. Given that RPMs are less expensive than pavement markings, have a relatively long service life of approximately 6 to 8 years, and consistently provide better wet night visibility, they are more cost-effective than the pavement marking materials investigated in this project. It should be noted that because the focus of this paper is on wet night performance, it was not reasonable to compare the pavement markings based on lifecycle cost because of the relatively short service life predicted for these materials under wet conditions.

Conclusion

Based on the performance evaluation results and the subsequent analyses findings, the following conclusions were made:

- The AWP had a relatively high initial dry and wet retro-reflectivity. However, it lost most of its WR during the first winter season. This was the case for AWP installed on the surface and on the rumble strips. Therefore, this product would require regular restriping to maintain a reasonable level of wet visibility, which would not be cost-effective.
- The WR durable tape lost most of its wet visibility during the first and second winter seasons. Therefore, it will not be cost-effective to use this relatively expensive material as a replacement for RPMs to guide motorists under inclement weather conditions.
- When installed on the surface, the WR durable tape was caught by snowplows. Therefore, this material must be installed in groove to protect it from snowplowing activities.
- RPMs consistently provided better wet night visibility than AWP and WR durable tape. Therefore, it is recommended to continue to use RPMs in Ohio to provide wet night visibility. It is also advised to continue to check the condition of the RPMs from time to time, especially on aged asphalt pavements, to ensure proper adhesion to the pavement surface.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This study was sponsored by the Ohio Department of Transportation (ODOT) and the Federal Highway Administration (FHWA) under State Job Number 134563.

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