Establishing a Minimum Functional Reflectance for Raised Pavement Markers

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In this paper, the causes of reduction in reflectivity of reflective raised pavement marker (RPM) and reflective raised traffic button (RTB) systems, and a procedure to evaluate the effectiveness of these two types of marker systems, are discussed. All marker systems lose 95 percent of their reflectivity in the first 6 months after installation. Approximately one-half (50 percent) of their initial brightness is lost in the first 25,000 impacts and an additional 20 percent in the next 175,000 impacts. The major cause of loss of reflectivity in RPMs is the actual loss of the marker because of improper installation and the nature of the road surface on which the marker is placed. (Asphalt surfaces result in a greater loss of markers than portland cement concrete surfaces.) Those markers that remain on the roadway lose reflectivity because of abrasion and moisture seeping between the lens and the reflector. The major problem of ceramic markers is loss of reflectivity. Ceramic button markers generally are not dislodged from the pavement surface because of their shape. The major losses of reflectivity for ceramic marker systems result from the loss of reflector units and dirt accumulation on the reflectors. A method for the maintenance of marker systems is presented that uses reflectivity and loss of markers as evaluating criteria. The procedure and criteria are applicable both to centerlines and lane lines.

The primary problem addressed in this paper, and one of the major problems with reflective raised pavement marker (RPM) and reflective traffic button (RTB) systems, is the reduction in reflectivity. This reduction in reflectivity has many causes and is dependent on time.

Figure 1 shows the specific intensity degradation from a study conducted in Dallas, Texas *(1)*. All markers tested lost over 95 percent of their initial brightness in the first 6 months after installation. The results of an accelerated wear test conducted by the Signal Products Division of Amerace Corp. are shown in Figure 2 *(2)*. The validity of these data is not known. The data show that markers lose almost 25 percent of their initial reflectivity after 200,000 impacts. In wet conditions, the markers lose one-third of their initial brightness. The reduction is intensity is nonlinear, and the greatest loss of brightness occurs in the first few months after installation. Dry markers lose over 50 percent of their initial brightness in the first 25,000 impacts and an additional 20 percent in the next 175,000 impacts.

CAUSES OF REDUCTION IN REFLECTIVITY

Data in Table 1 relate the types of failure that result in reduction in reflectivity to the causes of those failures. The failure mode, percentage of all markers, and associated cause of the failure mode have been determined by inspection of both the RPMs and the RTBs at sites across Texas.

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PLASTIC MARKERS

Marker Location Pattern

One particular type of failure not related to the condition of the reflector is the physical loss of the marker. Over one-half of all RPMs are ineffective because of this type of failure. The major cause of this type of failure is the number of impacts that individual markers sustain. The numbers of impacts are related to the pattern of locations of the markers on the roadway. Markers placed too close (within 50 ft) to an intersection and those not protected by being located behind solid pavement marking lines are more susceptible to damage from impacts than those that are protected. Some patterns result in more impacts to the markers than do others. Markers in the transition zone between lanes used to channelize traffic into a single lane can be almost completely lost. Such a pattern is common on two-lane facilities that have turning lanes at intersections.

Improper Installation

Another cause of RPM loss is improper installation. Many markers can be dislodged because the epoxy has been improperly mixed or an improper ratio of resin to hardener has been used. The former condition causes the epoxy to be streaked in color; the latter affects the shade of the epoxy. When too much resin is used, the epoxy is light in color; when too much hardener is used, the epoxy is dark. Proper mixing and mixture ratios result in uniformly gray epoxy.

Missing Markers

The final cause of missing markers on asphalt is the nature of the asphalt itself. Many markers are missing because large portions of asphalt on which the markers must rest are dislodged from the roadway. Moisture and temperature contribute to this problem.

Factors directly related to reduction in reflectance properties of the markers are abrasions and accumulations of road dirt, tar, or moisture on the reflectors. These factors will be discussed in order.

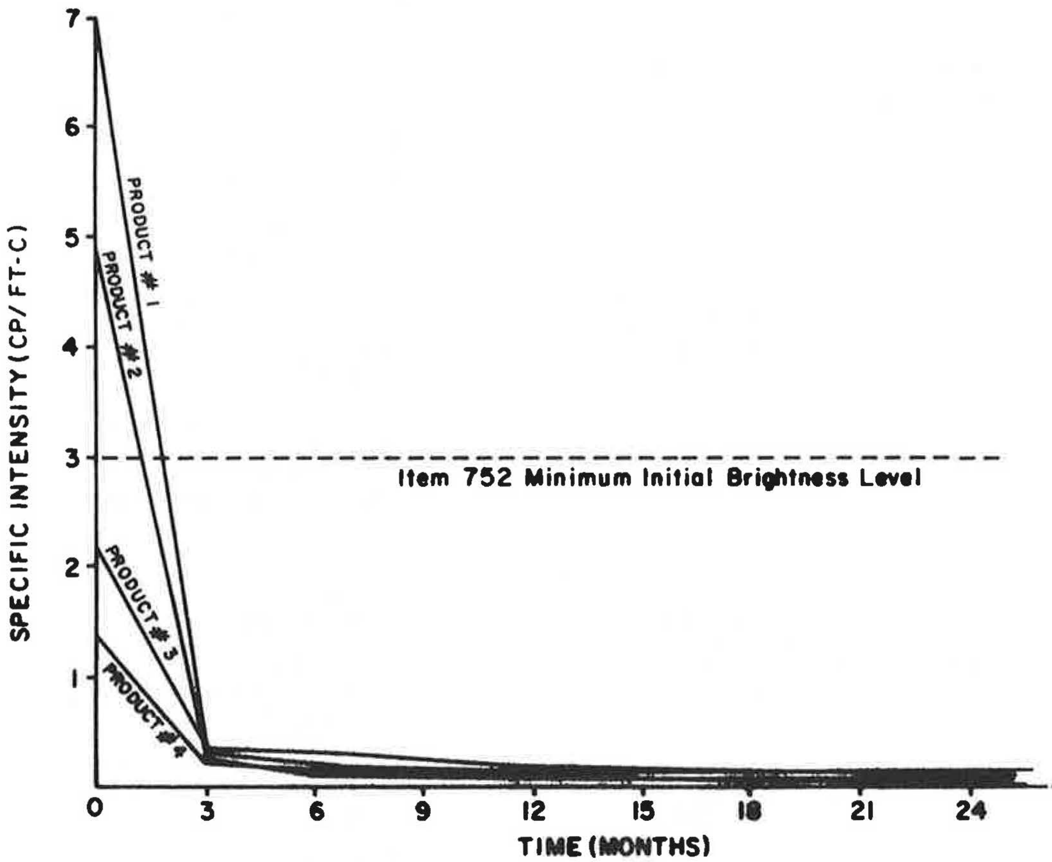

FIGURE 1 Specific intensity levels for four major suppliers of pavement markers by length of time.

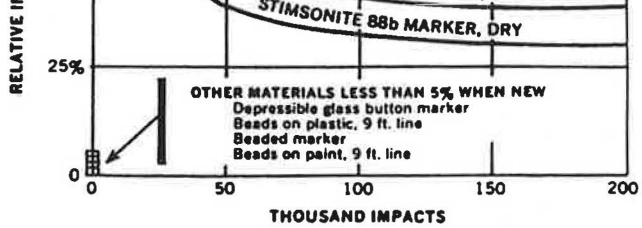

FIGURE 2 Accelerated wear test results.

Abrasion

The reflector face is abraded for several reasons. The most obvious reason is the number of impacts the marker sustains. The number of impacts depends on the pattern at the site and the location of the marker on the roadway. The material used to cover the marker is susceptible to scratches from these impacts. The plastic cover scratches easily on impact. After many thousands of impacts, the marker is abraded sufficiently to reduce its reflectivity. Amerace Corp. has tried to counteract this problem *(2)* by placing a piece of tempered glass on the face to reduce the scratching.

Road Dirt and Asphalt

Accumulations of road dirt and asphalt on the face of the marker reduce its reflectivity. A related problem is the effect of tire scuffing. The plastic material also discolors as a result of staining from road asphalt. Dirt accumulates near the base of the marker and on the bottom edge because of the scratches and entrapment by the epoxy and marker. Most of this dirt is eliminated by impact of the tire on the marker face. Because a portion of the reflective face is not struck upon impact, some dirt is not removed by vehicular impact, resulting in a reduction of reflectivity.

Water and Humidity

Roads that have insufficient drainage may accumulate water at the base of the markers. This water accumulation leaves a residue on the bottom of the marker that reduces the reflectivity. In areas of west Texas where there is little rainfall, the markers are not washed off, resulting in further lost reflectivity.

In areas where there is much rainfall or high humidity, moisture seeping between the reflector and the plastic cover is a serious problem. If the marker is properly installed and has structural integrity, this problem does not occur. In most instances, this problem results from improper epoxy installation.

TABLE 1 CAUSES OF REDUCTION IN REFLECTIVITY BY MARKER TYPE AND FAILURE TYPE

Marker Type	Failure Mode	Cause of Failure
Plastic RPMs	Missing Markers (56.2%)	Location of Marker Number of Hits Type of Pattern Improper Installation Weak Asphalt
	Abrasion to Reflector Face (14.0%)	Location of Markers Number of Impacts Material Used to Cover Reflector
	Accumulation of Road Dirt and Tar (8.4%)	Material Used to Cover Reflector Face Improper Drainage of Road Surface Scuffing by Tires
	Moisture Seeps Into Reflector (12.5%)	Marker Casing Failure Number of Impacts
Ceramic Button	Accumulation of Road Dirt and Tar (12.5%)	Ramp Design Improper Drainage of Road Surface Location of Marker
	Broken Reflector Rods (10.9%)	Weak Reflector Rod Impacts Not Protected By Ramp Faulty Rod Gluing
	Missing Ceramic Markers (6.3%)	Improper Installation Weak Asphalt Epoxy Service Life Exceeded
	Abrasion to Reflector Rod (4.7%)	Inadequate Ramp Protection

* Percentages Determined From Counts at Sites Studied in This Project.

If all four corners of a marker are not covered, so that a corner has a space between it and the pavement, the corner will break off after many impacts, providing a place for moisture to enter the marker's reflector system. A marker with a cracked plastic shell also allows moisture to enter.

CERAMIC BUTTONS

Ceramic buttons are characterized by the same types of failure in different proportions. Although the primary problem of plastic RPMs is keeping them on the road surface, that of RTBs is reflectivity. The magnitude of the RTBs' reflectivity problem is not as great as that of keeping the RPMs on the road.

Road Dirt and Asphalt

A problem with respect to reflectivity that the ceramic marker has is the accumulation of road dirt and asphalt on the reflector rod. The principal cause of this problem is the ramp design of the markers. The ramp allows dirt to accumulate against the reflector rod, decreasing the reflectivity. The ramp protects the reflector rod against impacts. When road surfaces do not drain properly, an abundance of road dirt and scum remains. This debris collects against the reflector rod because of the ramp design. Finally, the location of the marker contributes to the problem. Lane line markers do not accumulate as much debris as do centerline markers. Wind from passing vehicles removes the debris.

Broken Reflector Rods

Another problem with the ceramic marker is broken reflector rods. The major cause of the problem is improper gluing of the rod to the marker body. If the marker is not glued properly or if the glue is applied over glazing, the bond is inferior, resulting in missing reflector rods. In some instances, the reflector rod is partially missing because of weakness or the rods' being struck by a tire or a rock.

Missing Markers

Approximately 6 percent of all ceramic markers surveyed are lost, regardless of location. The same failure modes observed for plastic markers also apply to ceramic markers. For RTBs, exceeding the service life of the epoxy is an additional cause of missing markers. Because ceramic markers perform better on asphalt than do plastic markers, service life of the epoxy becomes a factor. The principal reason for the observed better performance is the shape of the RTB.

Abrasion

Abrasion of the reflector rod by tire scuffing is apparent in approximately 5 percent of all RTBs. The principal cause of this type of loss of reflectivity is improper ramp design. The ramp allows the tire to come into contact with the reflector rod in extreme acceleration and deceleration situations.

RESEARCH APPROACH USED TO ACHIEVE PROJECT OBJECTIVES

This paper relates the effectiveness of markers to both the number of missing markers and the reflectivity levels, using a subjective evaluation of markers by a team of experts who examined 35-mm slides.

Appropriate camera settings to use in the 35-mm slide evaluation were determined. Settings ranging from 1/250 sec, *f* 1.8 to time exposures of 10 sec by a Nikon 35-mm SLR camera with a 50-mm lens were used. Photographs of each site were taken from the driver's eye height and lateral position in the vehicle with no illumination other than ambient lighting and the vehicle's low and high beams.

Several slides that appeared to be visually representative of three sites were evaluated by a group of 23 subjects in Austin, Texas. On the basis of this evaluation, it was determined that 1/30 sec, *f* 1.8, and 1/60 sec, *f* 1.4, settings were appropriate when 35-mm ASA 400 film pushed two full stops was used. These three sites provided a representative cross section of all sites evaluated for effectiveness.

Research Methodology

Test Subjects

A total of 23 subjects were obtained from the Bryan/College Station and Austin, Texas, areas to participate in this study. The subjects were selected by age, sex, and visual acuity.

Test Equipment

The subjects were equally divided in two passenger vans. The 35-mm test slides were randomly placed on a slide viewer that was modified for use in the vans. The size of the light bulb was reduced so that the 35-mm slides projected approximately the same amount of light as the real-world environment with low beams on the van.

A tape recorder with taped messages was placed in each van. The tape recorder was used to present the instructions for both portions of this study to the subjects.

Test Sites

Four locations in Austin, Texas, were selected because of their accessibility to both the researchers and the study monitors. Table 2 presents the sites and the general information concerning each location.

Test Protocol

In this study, six 35-mm slides were randomly placed in sequence. In this way, the slides were not ordered from dark to light, nor were the subjects always able to select the same slide from its relative position. The sequencing at each site is given in Table 3.

TABLE 3 SLIDE SEQUENCING BY TEST SITE

Test Site	Sequence
1 a	P Z N M R S
1 b	R N P Z M S
2 a	Z T L P Y M
2 b	Y M L Z Y P
3 a	L M Z H T U
4 a	W Z T S Y N
4 b	N Y Z T W S

In Part I, the subjects evaluated various slides with the environment to determine the camera setting that resulted in the most accurate representation of the site. The objective of Part II was to determine which photograph best depicted the site. In Part II, the photographs were compared to the raised pavement markers to determine whether the panel of experts' evaluation

TABLE 2 SITES USED IN PHOTOGRAPHIC RELIABILITY STUDY

Location	Site#	Headlight Beams	Roadway Geometry	Roadway Lighting
U.S. 290	1	Low	Tangent	Rural
Texas 183 South	2	High	Curve	Rural
U.S. 71	3	Low	Curve	Urban
I-35	4	Low	Tangent	Urban

corresponded to that of the subjects. An evaluation of the quality of the photographs could then be made.

Statistical Analysis

Slide Validation Study

Table 4 presents the subjects' responses at each site. A χ^2 analysis was performed to determine whether any significant differences existed.

Two sites that showed a significant difference between the slides for camera settings of 1/60 sec, *f* 1.4, and 1/30 sec, *f* 1.8, were used. At those sites where there was no significant difference, the camera setting selected was 1/30 sec, *f* 1.8. On the basis of the results, it appeared that camera settings of 1/60 sec, *f* 1.4, or 1/30 sec, *f* 1.8, resulted in slides accurately representing sites with low ambient light levels.

Two different camera settings result in two slides that appear to the human eye as if they had been taken with the same setting. The two sets of comparable settings are

TABLE 4 SUBJECTS' RESPONSES FOR EACH SLIDE BY SITE

Site #	Subject Responses for Each Slide (f)					
1	M 7	N 12*	P 1	R 1	S 0	Z 3
2	L 3	M 4	P 3	T 8	Y 2	Z 4
3	H 1	L 11*	M 7	T 3	U 2	Z 0
4	N 6	S 3	T 8	W 4	Y 0	Z 3

* Chi-Square Showed Significance

1. 1/60, *f* 1.4, and 1/30, *f* 1.8; and
2. 1/30, *f* 1.4, and 1/15, *f* 1.8.

Table 5 presents the results of this study with these four settings combined into two comparable settings. With the settings combined into their comparable slides, the most accurate setting to use was 1/60 sec, *f* 1.4, or 1/30 sec, *f* 1.8.

The experts evaluated the different sites with respect to the effectiveness of the marker system in the environment in which the system existed. The evaluation team members were instructed to evaluate the marker system with respect to effectiveness in providing positive route guidance. The evaluators were also instructed to ignore as best they could existing pavement marking materials other than the markers. The following definitions were provided to the evaluators in making their evaluations:

1. Effective: A site was rated effective if (in the mind of the rater) the raised pavement marking system provided sufficient information to drivers without any maintenance needed at the site. The rater judged the effectiveness of the raised pavement marking system with respect to the number of missing markers, reflectivity of the markers, test conditions, color of the markers, spacing of the markers, and intended purpose of the pattern.
2. Semieffective: A site was rated semieffective if the site had to be maintained within the following 6 to 12 months for it to be effective. Accomplishment of the maintenance depends on the availability of funds and the placement of the site in the maintenance schedule. At the time the raters were rating the location, the raised pavement markers were considered to be providing sufficient information to drivers.
3. Ineffective: A site was rated ineffective if the raised pavement markers were not providing sufficient information to the driver and immediate maintenance was required. No other treatment except total maintenance of the site could be used to provide the required positive route guidance to drivers.

The judged effectiveness was related to the number of missing markers, length of time on road, and specific intensity.

TABLE 5 FREQUENCIES WITH EQUIVALENT SLIDES COMBINED

	Camera Settings			
Site #	1/60 f 1.8	1/60 & 1/30 f 1.4 f 1.8	1/30 & 1/15 f 1.4 f 1.8	1/15 f 1.4
1	M 7	N + R 13*	S + Z 3	P 1
2	Y 2	M + J 12*	H + U 7	L 3
3	Z 8	Z + N 9*	S + Y 3	U 4

* Chi-Square showed significance

Photograph Evaluation Study

At Sites 1 and 3, the subjects selected the photograph shown in Figure 3. This photograph was of a rural tangent roadway with lane lines and an edge line. The lane lines had reflective markers, whereas the edge line was painted. This arrangement was the exact duplication of Site 1 on U.S. 290 East. A χ^2 analysis was performed, and a significant difference was determined between evaluators that rated Site 1 as effective and those that rated it semieffective or ineffective. A χ^2 value of 14.25 was obtained for Site 1.

The subjects selected the photograph shown in Figure 4 as representative of Site 2. This photograph depicted a highly effective marker system on a rural multilane curved road. Both centerline and lane line markers were visible and highly effective. A χ^2 of 36.75, indicating a high degree of significance at this site with respect to the photographs, was obtained.

Site 4 had a greater spread of responses than both Sites 1 and 2. Fewer than 50 percent of the subjects selected the photograph shown in Figure 5 as most representative of the site. The site was classified as urban because of its traffic characteristics more than its lighting characteristics. The roadway was relatively dark, with little ambient lighting.

Maintenance Procedures

The maintenance standards described in this report are proposed to aid in evaluating RPM and RTB systems with respect to effectiveness and reflectivity. The following procedure is suggested to evaluate the effectiveness of the markers.

1. Photograph inventory. Sites to be evaluated should be photographically inventoried. This photographic inventory may be made from a vehicle. The appropriate camera setting to use should be either (a) 1/60 sec, *f* 1.4, or (b) 1/30 sec, *f* 1.8. A

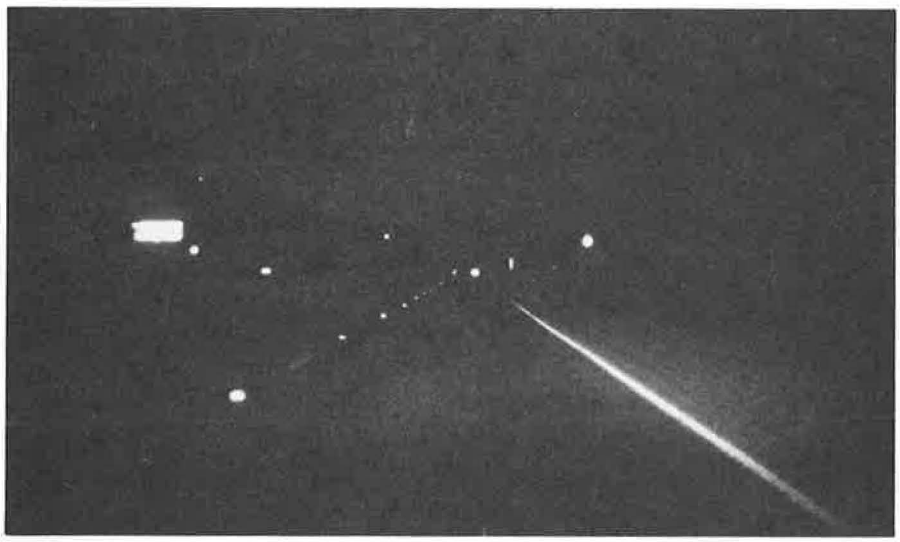

FIGURE 3 Photograph judged representative of Sites 1 and 3.

FIGURE 4 Photograph judged representative of Site 2.

FIGURE 5 Photograph judged representative of Site 4.

high-speed 35-mm film such as ASA 400 pushed two stops or a night 8-mm movie film such as Type G should be used.

2. Site evaluation. A panel of individuals, selected by Texas SDHPT district, may evaluate the photographs from the sites to be evaluated. This panel may consist of 5, 7, or 9 individuals. A panel consisting of one of these numbers is large enough to adequately evaluate a site but not so large that the members cannot adjust their schedules to evaluate the sites. The odd numbers prevent ties.

3. Effectiveness evaluation. The subject site will be evaluated with respect to its effectiveness. An acceptable rule of thumb is that if 50 percent of the markers are missing, the system is ineffective. A system is semieffective when 20 to 30 percent of the markers are missing. Markers become ineffective when their specific intensity is 0.05 candle power per foot-candle [cp/(ft-cd)] or less for 75 percent of the remaining markers. A system is semieffective when 75 percent of the remaining markers have a specific intensity between 0.2 and 0.05 cp/(ft-cd). At present, the only ways in which to determine the specific intensity of the markers are to (a) remove several randomly selected markers for analysis in a laboratory, or (b) use a photometric van. Figure 6 shows the reflective and retention properties of markers with different levels of effectiveness.

4. Maintenance photographs. When the panel cannot decide the effectiveness of the markers based on their physical properties, a set of maintenance slides can be used. A suggested procedure is for each member of the panel individually to view the slide of the site in question and to consider the set of maintenance standards. After each member has selected the most appropriate standard, the panel would reconvene. A decision may be reached by using the standard set of photographs.

5. Appropriate actions. If the site is judged to be semieffective or ineffective, the appropriate action would be taken; that is, the maintenance activity decided on by the evaluation panel would begin.

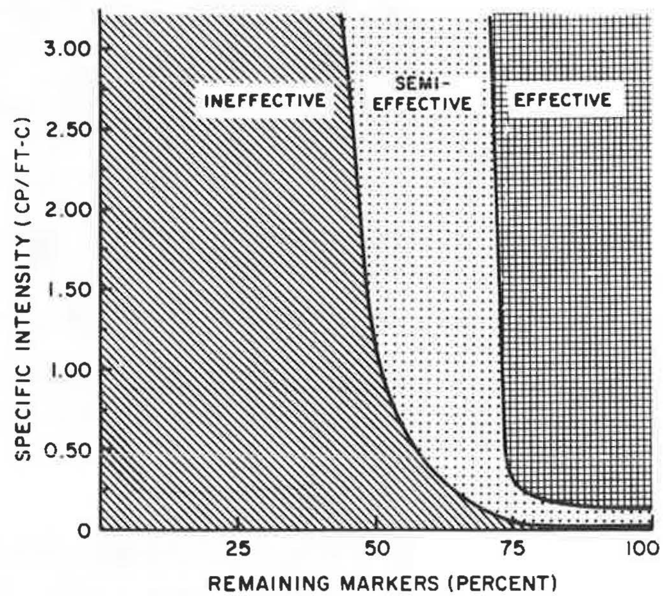

FIGURE 6 Relationship between specific intensity, remaining markers, and level of effectiveness.

REFERENCES

1. Texas State Department of Highways and Public Transportation. *Durability of Reflective Markers Under Traffic.* Report 3-03-76-079, 1979.
2. Amerace Corp. *Results of Accelerated Wear Testing.* Stimsonite Pavement Markers Model 88, Specification Sheet PN-2-3/76, 1976.