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16. Abstract

This report is the second in a series of four and it presents the methodology and results of two studies investigating the reflectivity of raised pavement markers and raised traffic buttons. A suggested maintenance procedure to assure positive route guidance is thoroughly described and discussed. The study points out that markers lose approximately ninety percent of their initial reflectance within the first year. Markers remain effective with as little as .15 candlepower/foot-candle when at least eighty percent of the markers remain other parameters such as headlamps, trucks, and color of markers are discussed.

The other reports in this series are:

Research Report 322-1: "State-of-the-Art and Objectives of Reflective Raised Pavement Markers".

Research Report 322-3: "Retention of Raised Reflective Pavement Markers".

Research Report 322-4: "Executive Summary, Significant Results and Assorted Tests and Procedures for Reflective Raised Pavement Markers".

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REFLECTIVITY RETENTION OF REFLECTIVE RAISED PAVEMENT MARKERS

by

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and

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Research Report 322-2
Study Number 2-18-322-2

Sponsored by

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October 1986

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843

METRIC CONVERSION FACTORS

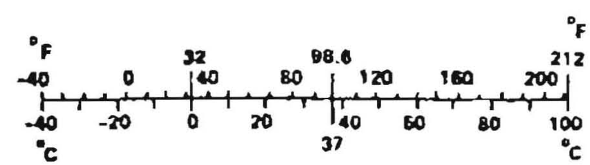
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



SUMMARY OF RESULTS

This report is the second in a series of four, and it presents the methodology and results of two studies regarding the reflectivity of Raised Pavement Markers (RPMs) and Raised Traffic Buttons (RTBs). Additionally, it presents a maintenance procedure suggested for use by the Texas State Department of Highways and Public Transportation (SDHPT) to assure the markers provide positive route guidance. One of the two reflectivity studies used a panel of experts to rate the effectiveness of the markers at several sites across the state. These effectiveness rating were used to evaluate the effect several factors had on the RPMs and RTBs. The second study was conducted to validate (1) the accuracy of the photographs in representing the sites and (2) the ratings of the panel of experts. The maintenance guidelines present a step-by-step procedure each district could use to obtain consistent maintenance procedures across the state. The maintenance procedures include a set of standards which should be used to evaluate the markers.

The results of the effectiveness study indicate that the markers lose over ninety-percent of their initial brightness within the first two years of service. All markers, regardless of type, are approximately at the same brightness level within one year. Markers remain effective for positive route guidance with reflectivity levels as low as .15 (CP/FT-C) and at least 80 percent of the markers remain. A suggested initial brightness level of 2.0 (CP/FT-C) is recommended based on the results of this study. Headlight beams increase the effectiveness of markers. When markers are in a transitionary state between levels of effectiveness, the use of bright lights increases the markers effectiveness. After markers have been washed, or during a rain, the level of reflectivity will increase 20-50 percent. Trucks have a greater impact on the number of missing markers than on the loss of reflectivity. The forces exerted on the RPMs by the trucks affect the failure of the asphalt more than the markers. The exception to this generality is when markers have been improperly installed and the corner of the marker breaks. The color of the marker has a significant effect on their effectiveness. Yellow markers required specific intensity (S.I.) values consistently higher than crystal markers for the same level of effectiveness.

The results of the validity study indicated that camera settings of 1/60 of a second with a f-stop of 1.4 and 1/30 of a second with a f-stop of 1.8 are proper settings to use with low ambient light levels. It should be emphasized that these settings were used with 400 ASA film pushed two-stops during development. Any other film or development technique will result in the use of other camera settings. The only negative effect of using this procedure is color balance. The color inbalance was not enough to affect the test subjects evaluation at each site. The test subjects evaluation at each site, with the aid of the maintenance standard photographs, agreed with the panel of experts. The photographic technique and maintenance procedure described in this report are valuable aids in maintenance to provide an excellent positive route guidance system using both reflective raised pavement markers and reflective raised traffic buttons.

The other reports in this series are:

Research Report 322-1 -- State-of-the-Art, Research Methodology and Annotated Bibliography of Reflective Raised Pavement Markers.

Research Report 322-3 -- Retention of Reflective Raised Pavement Markers.

Research Report 322-4 -- Executive Summary, Significant Results, and Assorted Tests and Procedures for Reflective Raised Pavement Markers.

Implementation

Due to the severity of the problems associated with the reflectivity of raised pavement markers, the results of these studies should be implemented as soon as possible. Markers lose a significant amount of initial reflectivity within 6-12 months after installation. They remain effective for positive route guidance at extremely low levels of reflectivity (.15 CP/FT-C). Therefore a initial brightness level of 2.0 (CP/FT-C) is recommended. A set of photographic standards may be used to assist in suggesting when maintenance may be performed.

The results presented in this report suggest that modification of existing Department practices and procedures would increase the operational efficiency of the markers on Texas roads and reduce driver confusion. These results, if implemented, have the potential to substantially reduce cost and save lives in the states.

Disclaimer

Acknowledgement

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The authors also wish to acknowledge the members of the technical advisory committee for their overall support and supervision. Special appreciation is extended to Messers Raymond Stotzer (District 15), Lawrence Jester (District 19), Franklin Young (District 20) and Carol Ziegler (District 17) for their support in the field and general interest in the project. Thanks are also extended to the staff of the Texas Transportation Institute for their assistance in conducting the studies and data reduction for these studies.

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BACKGROUND OF RESEARCH

INTRODUCTION

The primary problem addressed in this report and one of the major problems with reflective raised pavement markers (RPM) and reflective traffic buttons (RTB) is the reduction in reflectivity. This reduction of reflectivity has many causes and is time dependent.

Loss of Reflectivity

Figure 1 presents the specific intensity degradation from the Dallas Study (1). This figure indicates that all markers tested lost over 95% of their initial brightness in the first six months after installation. The result an of accelerated wear test conducted by the Signal Products Division of Amerace Corporation are presented in Figure 2 (2). The validity of these data is not known. These data show markers lose almost 25% of their initial reflectivity after 200,000 impacts. In wet conditions, the markers lose one third of their initial brightness. The reduction in intensity is non-linear and the greatest loss of brightness occurs in the first few months after installation. Dry markers lose over 50% of their initial brightness in the first 25,000 impacts and an additional 20% in the next 175,000 impacts.

CAUSES OF REDUCTION IN REFLECTIVITY

Table 1 relates the types of failures resulting in the reduction in reflectivity to the causes of those failures. The failure mode, their percentage of all markers, and the associated cause of that failure mode have been determined by inspection of both RPMs and RTBs at sites across Texas by the researchers as a part of this study.

PLASTIC MARKERS

One particular type of failure not related to the reflector is the physical loss of the marker. Over half of all RPMs are ineffective due to this type of failure. The major cause of this failure is the number of impacts an individual marker sustains. The number of impacts are also related to the location of the marker on the roadway and the type of pattern. Markers

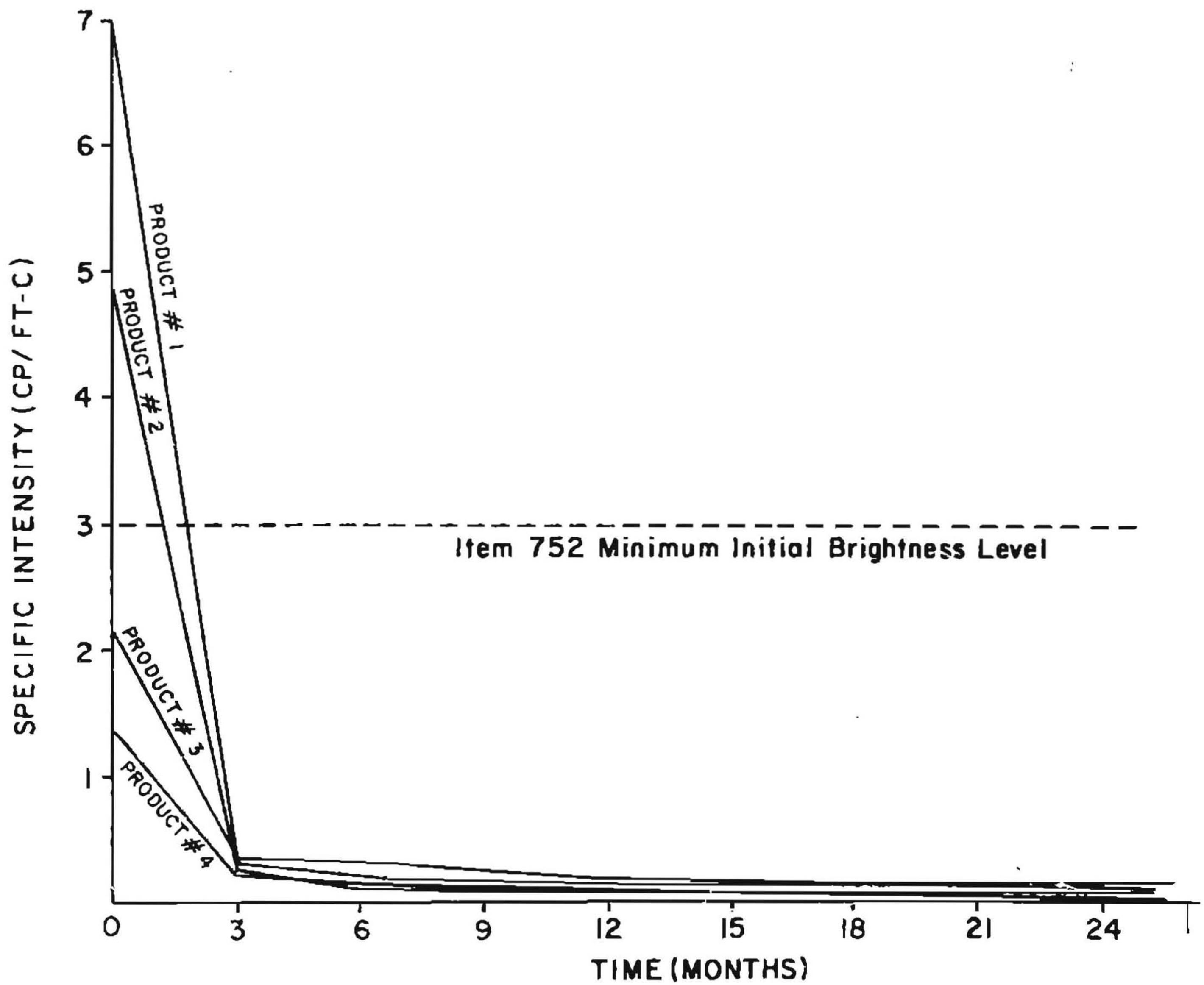


Figure 1. Specific Intensity Levels For Four Major Suppliers Of Pavement Markers By Length Of Time.

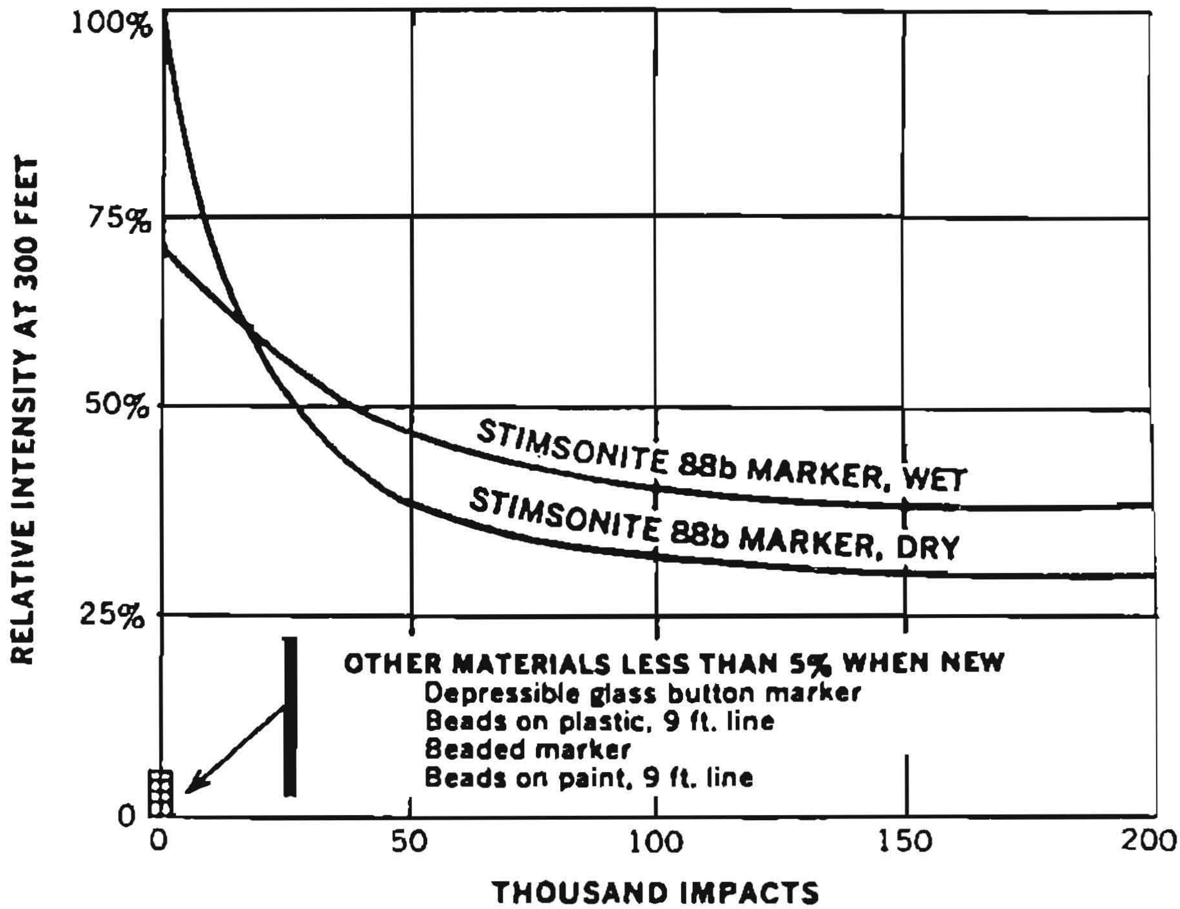


Figure 2. Accelerated Wear Test Results (2).

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.

placed too close (within 50 feet) to the intersection and those not protected by being located behind solid pavement marking lines will be more susceptible to impacts than those which are protected. Some patterns will result in more impacts to the markers than others. Markers used to channelize traffic into a single lane will lose virtually all of the markers in the transition zone between lanes. This type of pattern is common on two lane facilities where a turning lane is placed at an intersection.

Improper Installation

Another cause of marker loss is the improper installation of RPMs. Many markers were dislodged because the epoxy had been improperly mixed or an improper ratio of resin to hardner was used. The former problem can be determined because the epoxy is streaked; the latter problem is detected by the color of the epoxy. When too much resin is used the epoxy will be light in color whereas too much hardener makes the epoxy dark. Proper mixing and mixture ratios will result in a grey colored epoxy.

Missing Markers

The final cause of missing markers on asphalt is the asphalt itself. Many markers are missing because large portions of asphalt on which the markers must rest are dislodged from the roadway. Two factors have been identified which contribute to this problem, moisture and temperature.

Those factors which are directly related to a reduction in the reflectance properties of the markers are (1) abrasions to the markers reflective face, (2) an accumulation of road dirt and tar, and (3) moisture on the reflector. Each of these will be discussed in order.

Abrasion

The reflector face is abraded for several reasons. The most obvious is the number of impacts the marker sustains. The number of impacts is highly dependent on the location of the marker on the roadway and the pattern at the site. The material which the marker is made is susceptible to scratches from these impacts. The plastic will scratch very easily upon impact. After many thousands of impacts the marker has been abraded sufficiently so that the reflectivity has been reduced. Stimsonite has tried to counteract this problem by placing a piece of tempered glass on the face to reduce the scratching. While this has been accomplished, to some extent, the bonding of the glass to the marker leaves a lot to be desired. Many markers with improperly attached or missing glass faces have been observed. After the glass has been removed, the marker will abrade the same as a marker without the glass face.

Road Dirt and Asphalt

Road dirt and asphalt accumulations on the face of the marker will reduce the reflectivity of the marker. A related problem is tire scuffing. The plastic material discolors as a result of the staining effect road asphalt has on it. Dirt will also accumulate near the base of the marker and on the bottom edge due to the scratches and entrapment by the epoxy and marker. Most of this dirt is eliminated by impact of the tire on the marker face. A portion of the reflective face is not struck upon impact. Resulting in a reduction of reflectivity, because the dirt is not removed due to vehicular impact.

Water and Humidity

Roads having insufficient drainage accumulate water near the base of the markers. This leaves a residue on the bottom of the marker which reduces the reflectivity. In areas of West Texas, where there is very little rainfall, the markers will not be washed resulting in a certain amount of lost reflectivity.

In areas where there is a large amount of rainfall or high humidity, moisture seeping between the plastic cover and the reflector is a serious problem. If the marker is properly installed and has structural integrity, this problem will not exist. In most instances, this problem results from improper epoxy installation. All four corners are not covered resulting in a corner or corners having a space between it and the pavement. After many impacts this corner will break off, providing a place for moisture to enter the markers' reflector system. A marker with a cracked plastic shell will also allow moisture to enter resulting in reduced reflectivity.

CERAMIC BUTTONS

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

Road Dirt and Asphalt

One problem the ceramic marker has with respect to reflectivity 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 remain. This debris collects against the reflector rod due to 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 velocity due to passing vehicles removes the debris.

Broken Reflector Rods

Another problem with the ceramic marker is broken reflector rods. The major cause of this problem is improper gluing of the rod to the marker body. If the marker is not glued properly or the glue is applied over glazing, the bond will be inferior resulting in missing reflector rods. In some instances, the reflector rod is partially missing. This is caused by either weak reflector rods or the rod being struck by a tire or a rock striking the rod.

Missing Markers

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

Abrasion

Abrasion to the reflector rod due to tire scuffing was apparent in approximately five 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.

OBJECTIVES OF RESEARCH

Two of the objectives of this research were to:

1. Identify the causes of marker reflectivity loss.
2. Relate route guidance to the percent of markers remaining, functional reflectance levels, percent truck traffic and raised pavement marker pattern and type.

RESEARCH APPROACH USED TO ACHIEVE PROJECT OBJECTIVES

The project objectives were achieved using two research approaches. The first objective, to relate the types of marker failures to their causes, was achieved using physical counts and personal observations at sites across the state. This approach was selected because of the nature of the problem and the objectivebeing addressed. The failures are related to many factors which could not be adequately studied in a controlled field or laboratory study. Physical counts constitute a field study approach. The data required to successfully complete this objective could be attained more economically than with other more costly approaches.

The second objective, relate effectiveness of markers to other pertinent factors, utilized a subjective evaluation of markers by a team of experts. The subjective evaluation was conducted using 35mm slides of sites selected because of the characteristics of the site. The site characteristics were selected by the Technical Advisory Committee (TAC) and are contained in Appendix A. The members of the TAC formed the evaluation team for this project.

A study was conducted to determine the appropriate camera settings to use in the 35mm evaluation. Camera settings ranging from 1/250 (sec) with an f-stop of 1.8 to time exposures of 10 seconds were taken using a Nikkon 35mm SLR with a 50mm lens. Photographs of each site were taken from the drivers eye height and lateral position in the vehicle with no other illumination other than ambient lighting and the vehicles low and high beams. This approach was selected because the markers should be evaluated in the environment in which they operate. One method of doing this was to photograph the site and let the TAC evaluate the photographs.

Film Latitude

A major problem with respect to using photographs to record and analyze ambient lighted scenes is the range of camera settings required for duplication of any lighted composite scene. This physical phenomenon is represented in Figure 3. The amount of light illuminating any object is inversely proportional to the square of the distance to the object. From Figure 3, it can be shown that if X amount of light illuminates Marker 1 then

one-fourth as much light (1/4X) will illuminate Marker 2 and one-ninth as much
Figure 3

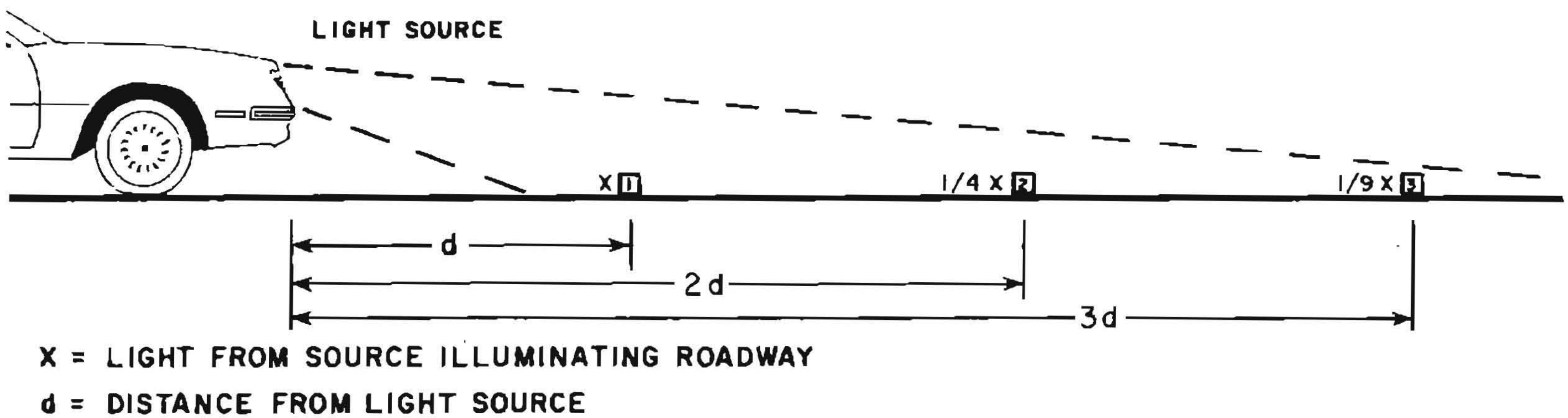


Figure 3. Light Level Differentials In Any Scene.

light (1/9X) will illuminate Marker 3. Each of these illuminance levels require a different camera setting (f-stop, and shutter speed) for each marker if a picture of a specific marker were being taken. In the procedure used in this study, one camera setting was used at each site for evaluation. Several photographs with different camera settings were taken at each site. The photograph used for evaluation was selected based on the photographs ability to duplicate color balance and lighting levels at that particular site.

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

The TAC evaluated the different sites with respect to the effectiveness of the marker system in the environment in which the system exists. 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 would be judged to be effective if, in the mind of the evaluator, the raised pavement marking system provided sufficient information to the driver without any maintenance being performed at the site. The raters must judge the effectiveness of the raised pavement marking system with respect to the number of missing markers, the reflectivity of the markers, the test conditions, the color of the markers, the spacing of the markers and the intended purpose of the pattern.
2. SEMI-EFFECTIVE: A site would be rated semi-effective if in the mind of the rater the site would have to be maintained within the next six months to a year for it to be effective. This is dependent on the availability of funds and placement of the site in the maintenance schedule. At the time the raters are rating the location the raised pavement markers are providing sufficient information to the driver.

3. INEFFECTIVE: A site would be rated ineffective if in the minds of the raters the raised pavement markers are not providing sufficient information to the driver and immediate maintenance is required. No other treatment except total maintenance of the site could be employed to provide the required positive route guidance to the driver.

The judged effectiveness were related to factors such as the number of missing markers, length of time on road, specific intensity, amount of truck traffic, color of markers and vehicle headlamps used.

RATED EFFECTIVENESS OF MARKER SYSTEMS

INTRODUCTION

To successfully attain the objectives of this research a photographic field study technique was used. The research methodology used a panel of experts from both the SDHPT and FHWA to evaluate a set of slides at 33 test locations (Appendix A) dictated by the statistical design. Each site was rated as to its effectiveness in transmitting sufficient information for positive route guidance according to the effectiveness definitions previously defined. Appendix B contains the complete set of instructions presented to the TAC. Appendix C contains the statistical evaluation for the effectiveness of all the test sites used in the study.

FACTORS AFFECTING MARKER SYSTEM EFFECTIVENESS

Marker system effectiveness is related to two factors, (1) number of missing markers and (2) reflectivity levels of remaining markers. The number of missing markers are dependent on: length of time on road, average daily traffic, and truck traffic. Reflectivity levels are dependent on: color of markers, truck traffic, average daily traffic, use of high or low beam headlamps, and length of time on the road. These factors have been developed from marker observation by the researchers, TAC and from discussions with product manufacturers and sales representatives.

The effectiveness of the markers relates to the overall marking system at the site. The ambient lighting and condition of existing pavement markings are taken into consideration. The existence of other markings and ambient lighting affect the positive route guidance effectiveness of the raised pavement marker system. Markers, as they deteriorate, result in reduced reflectivity and associated effectiveness as a positive route guidance system. Markers never hit will eventually have a reduction in reflectivity due to the action of the physical elements (rain, snow, heat and cold) on the plastic shell or rod. The number of hits a marker sustains also determines the useful service life of the RPMs and RTBs. The number of hits is a function of the pattern (centerline or lane line) and the average daily traffic (ADT) at a specific site.

MISSING MARKERS

Length of Time on Road

Figure 4, relates the judged effectiveness of the marker system to the length of time the markers are on the roadway. The figure relating system effectiveness with time uses (1) high beams, (2) low beams and (3) an average of both high and low beams. The average of both beams is a better indicator because it tends to average (or smooth out) individual site specific differences. Both the effective and ineffective sites where high beam were used were on the road for longer periods of time than at those sites where low beams were used. The low beams resulted in less reflectance than high beams, therefore markers which have been on the roadway longer will appear as bright or brighter with high beams than when low beams are used. This was not the case for those sites the experts rated as semi-effective. Those sites rated semi-effective where low beams were used were placed on the roadway at least six months earlier than those sites where high beams were used. However, the average of both beams indicate a steady increase in the number of years on the road as the effectiveness of the markers decrease. It appears that markers become totally ineffective the second and third year the markers are in place.

Figure 5 presents the cumulative distribution of missing markers by time the markers are in place for the three levels of effectiveness. Those sites rated effective by the majority of the panel were used in determining the shape of the effective curve. The effective curve remains relatively constant as the percentage of missing markers increase. In the case where the sites were rated effective with approximately 85 of the markers missing was a rural tangent site with the remaining markers having a relatively high level of reflectivity. This may be an atypical site because of the conditions under which it was rated, however, it points out that geometrics and level of reflectivity are as important factors as the number of missing markers. If the site had been an urban location or if the geometrics had been anything other than tangent, it would have been rated semi-effective or possibly ineffective depending on the level of retroreflecitivity of the markers. The trend for all three levels is uniform and indicates that between the second and third year the percentage of missing markers increased from 40 percent

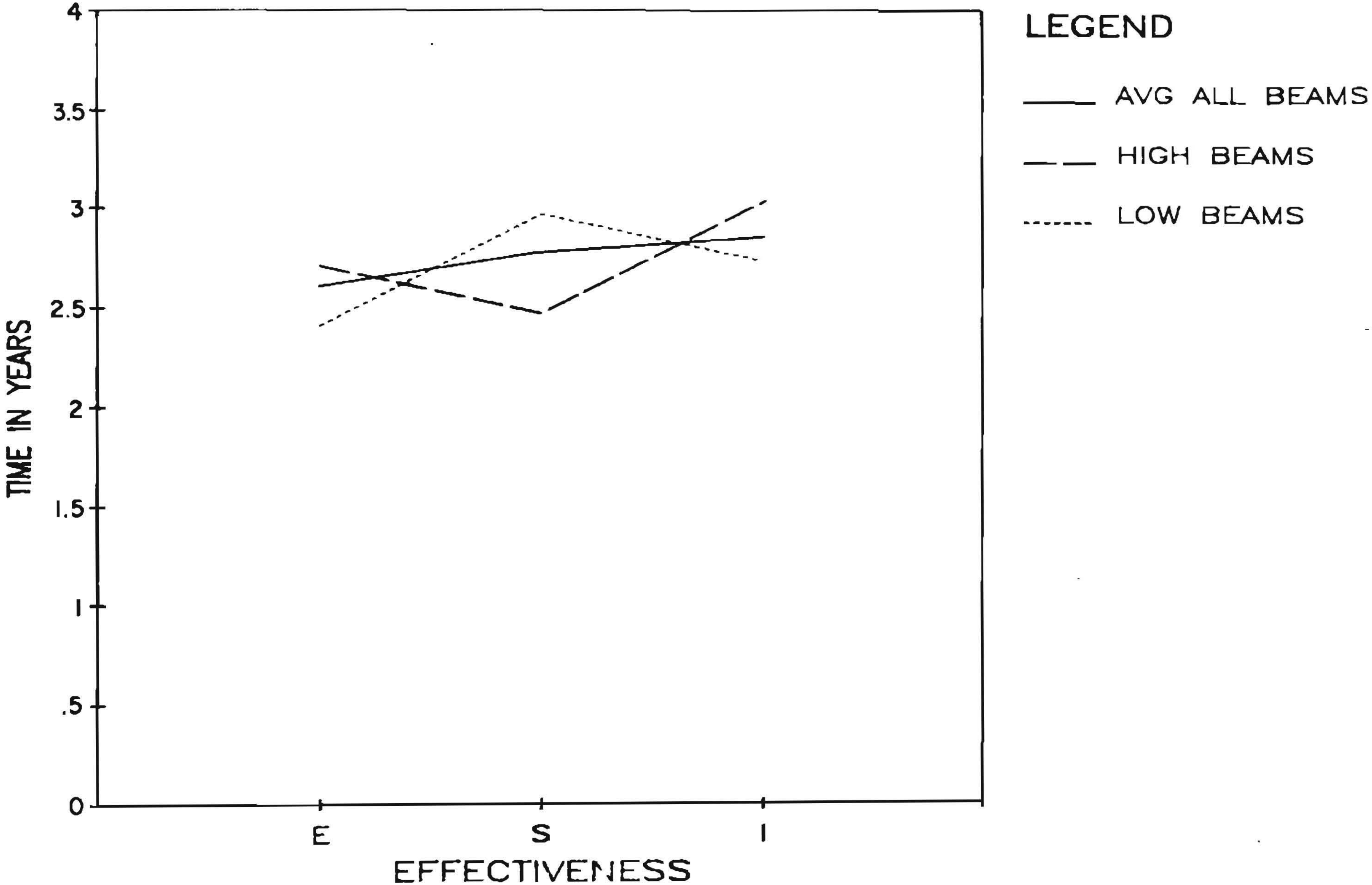


Figure 4. Time On The Road Versus Effectiveness.

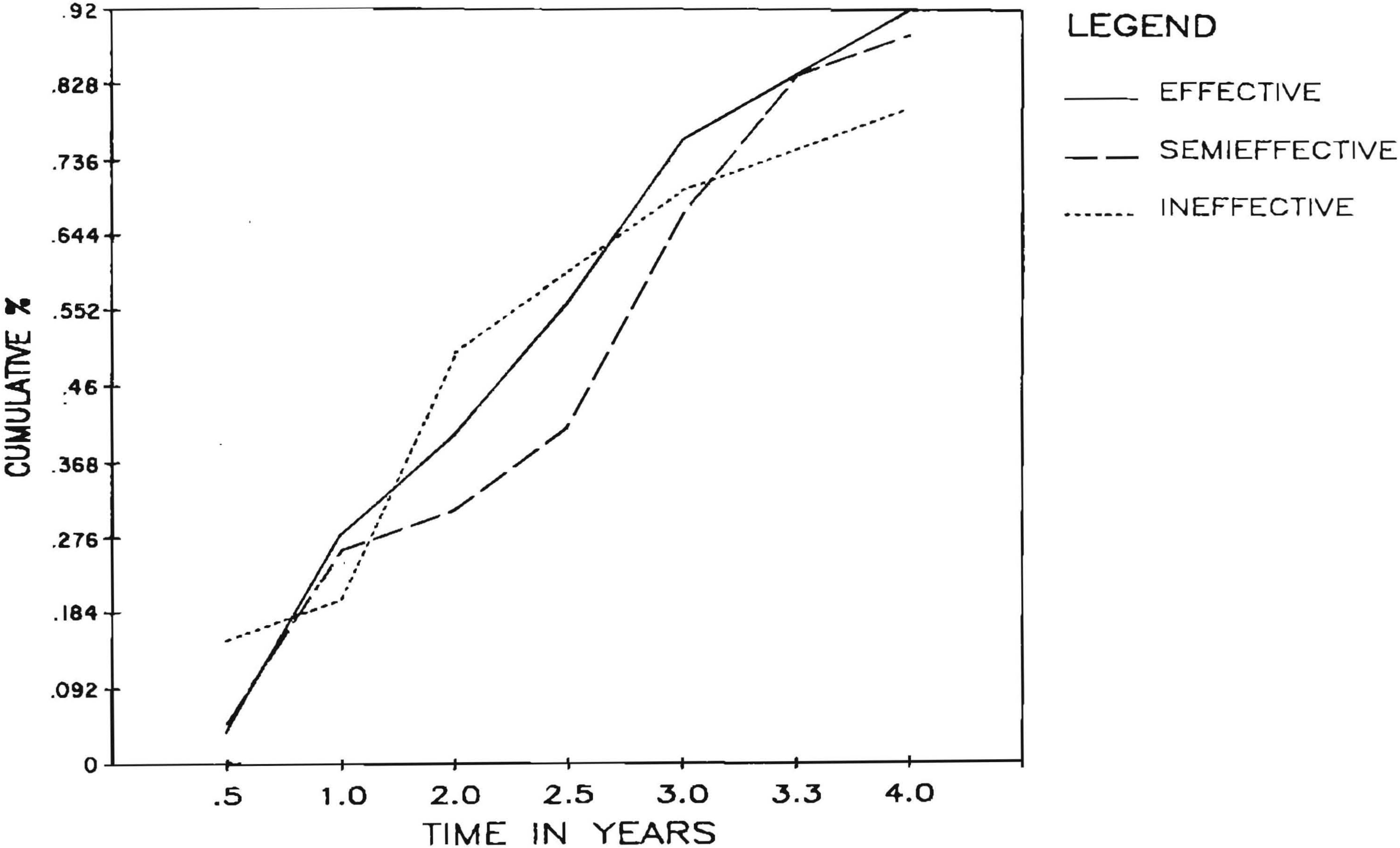


Figure 5. Cumulative Percent Of Total Sites Versus Time On The Road By Effectiveness.

to 72 percent. Those sites judged as effective after two years had lost 40 percent of their markers whereas those sites judged as semi-effective had lost 31 percent of their markers. This would indicate that the level of reflectivity was higher at the sites judged effective than at the sites judged semi-effective. The difference in rated system effectiveness when considering the percentage of missing markers must be associated with the reflectivity of the markers and not the missing markers. Those sites evaluated as ineffective had lost 50 percent of the markers by the second year. By the fourth year 90 percent of all markers at the sites were missing.

An analysis was performed to determine the percent of missing markers which affected the marker system level of effectiveness. The results of this analysis are presented in Figure 6. The average of both low and high beams is a better indicator of the markers functionality. The change in the level of effectiveness is a function of the number of missing markers. A marker system is considered effective when 73 percent or more of the markers are in place, semi-effective when the number of markers in place range between 75 percent and 45 percent and ineffective when less than 45 percent of the markers are remaining.

Average Daily Traffic

The percentage of remaining markers is also related to the average daily traffic (ADT). Figure 7, relates the percentage of remaining markers with ADT using data in Appendix A. This relationship indicates that missing markers increase as ADT increases. Thirty percent of the markers are removed from service at the sites investigated as ADT rises to 2500 VPD. Between thirty percent and sixty percent are removed from service as ADT increases to 17,500 VPD. The ADT's represented in this study do not represent very heavy traffic; however, a large proportion of the markers are lost very rapidly. As ADT increases the loss of markers effectively reduce the guidance ability of any pattern. In urban areas with high traffic volumes the markers will not generally stay on the roadway for a year. Other rural sites, the markers stay on the road for several years. The first half of the curve is characterized by rural sites with asphaltic concrete roadways. The latter half of the curve is characterized by urban sites with Portland cement concrete roadways. This is one explantion for the change in scope.

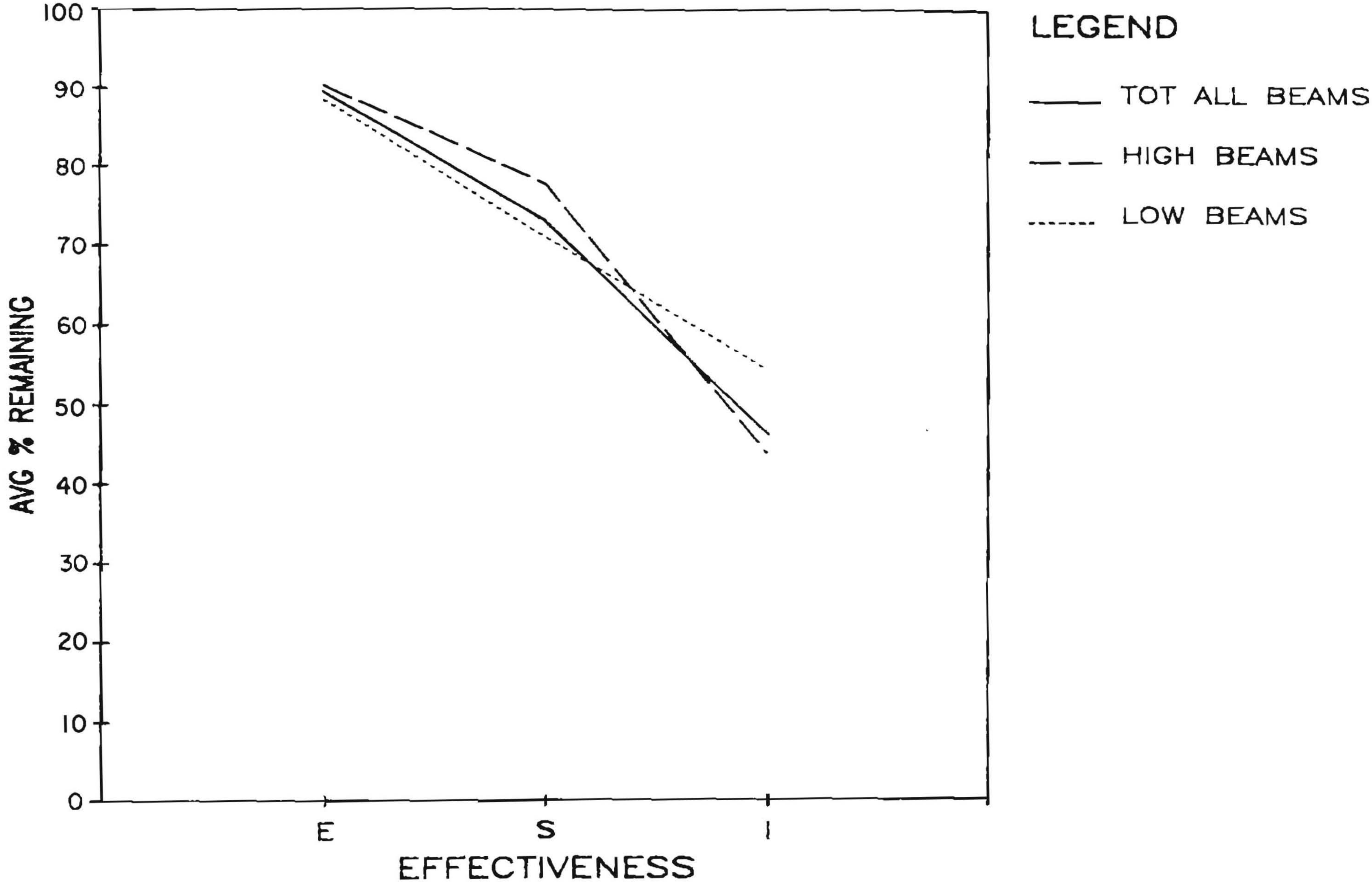


Figure 6. Average Percent Remaining Versus Effectiveness.

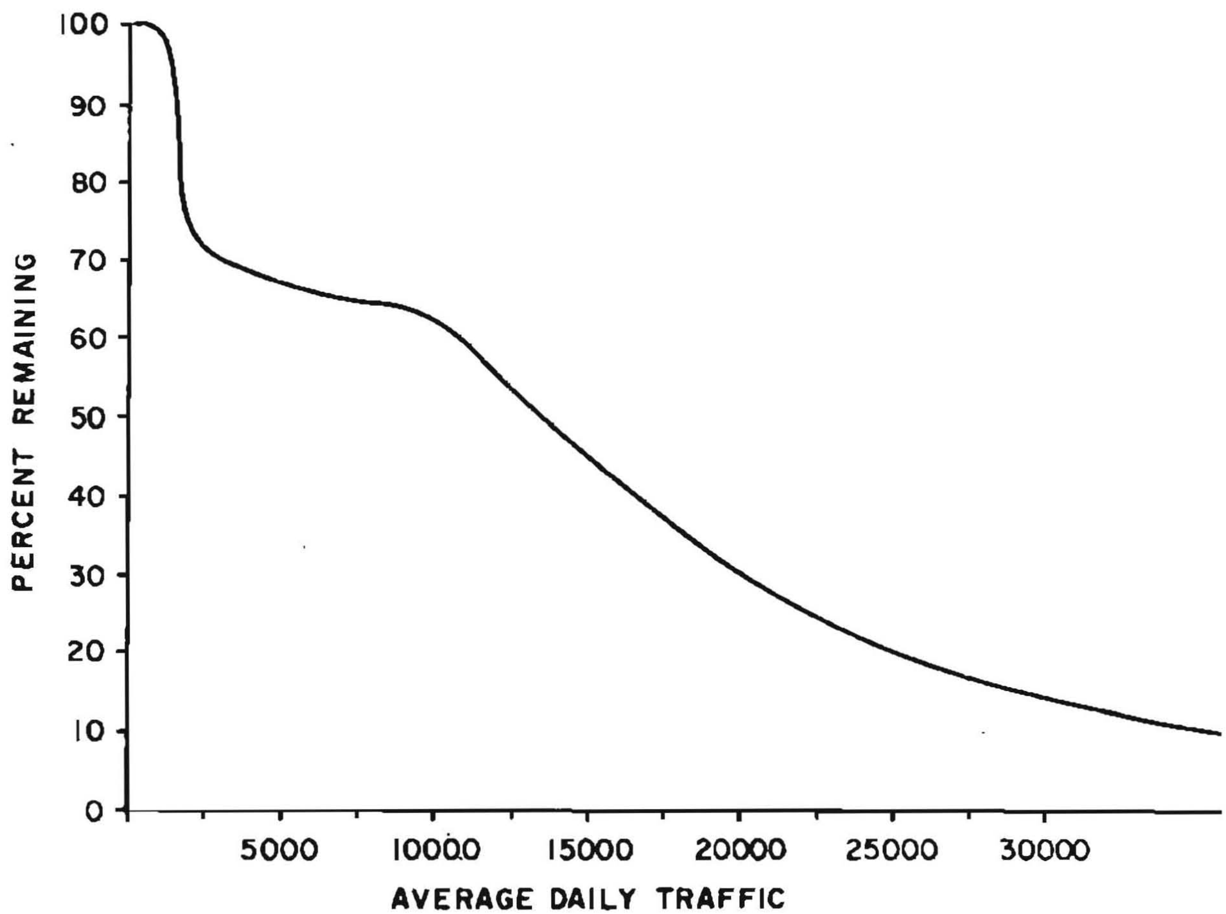


Figure 7. Percent Remaining Markers Related To Average Daily Traffic.

Truck Traffic

The percentage of trucks in the traffic mix would change the effectiveness of the markers. This change could occur either by (1) increasing the number of missing markers or (2) decreasing the reflectivity of the markers.

Figure 8, presents the rated effectiveness of the markers as a function of the percentage of trucks in the traffic flow with high and low headlamp beams. Sites rated effective on low beams had 10 percent truck traffic. Sites rated effective with high beams had 13 percent trucks. Those sites evaluated to be semi-effective with both high beams and low beams were characterized by a traffic mix containing 14 percent trucks. These are not significant differences. Those sites judged as ineffective were characterized with a traffic mix of 20 percent at the low beam sites and 23 percent at the high beam site.

Figure 9, related the centerline, laneline, and the combination of both centerline and laneline patterns to the percent of trucks and the levels of effectiveness. Centerlines usually are not subjected to the impacts lanelines would incur. In most cases, centerlines on multi-laned facilities and line lines are normally impacted; therefore, trucks would have a greater impact on effectiveness in these situations. The effective centerline sites had approximately 9 percent trucks, the semi-effective sites had 14 percent, and the ineffective sites had 15 percent. There is a significant difference between the effective and semi-effective sites; however, the difference between the semi-effective sites and ineffective sites was non-significant. When considering lanelines the percentage of trucks had a greater effect than did the centerlines. This is to be expected because of the weave pattern and weight of the trucks. With respect to truck traffic, those sites judged to be semi-effective were atypical. When comparing the effective sites, trucks had a greater impact on lanelines (12.4 percent) than on centerlines (9 percent). This also holds true for those sites judged to be ineffective (15 percent centerlines, 22 percent lanelines). However, at those sites judged to be semi-effective, trucks had more of an impact on the centerlines (14 percent) than on lanelines (10 percent). The difference between the effective laneline sites (12 percent) and the semi-effective laneline sites (12 percent) were not significant. There is a significant difference between the effective laneline

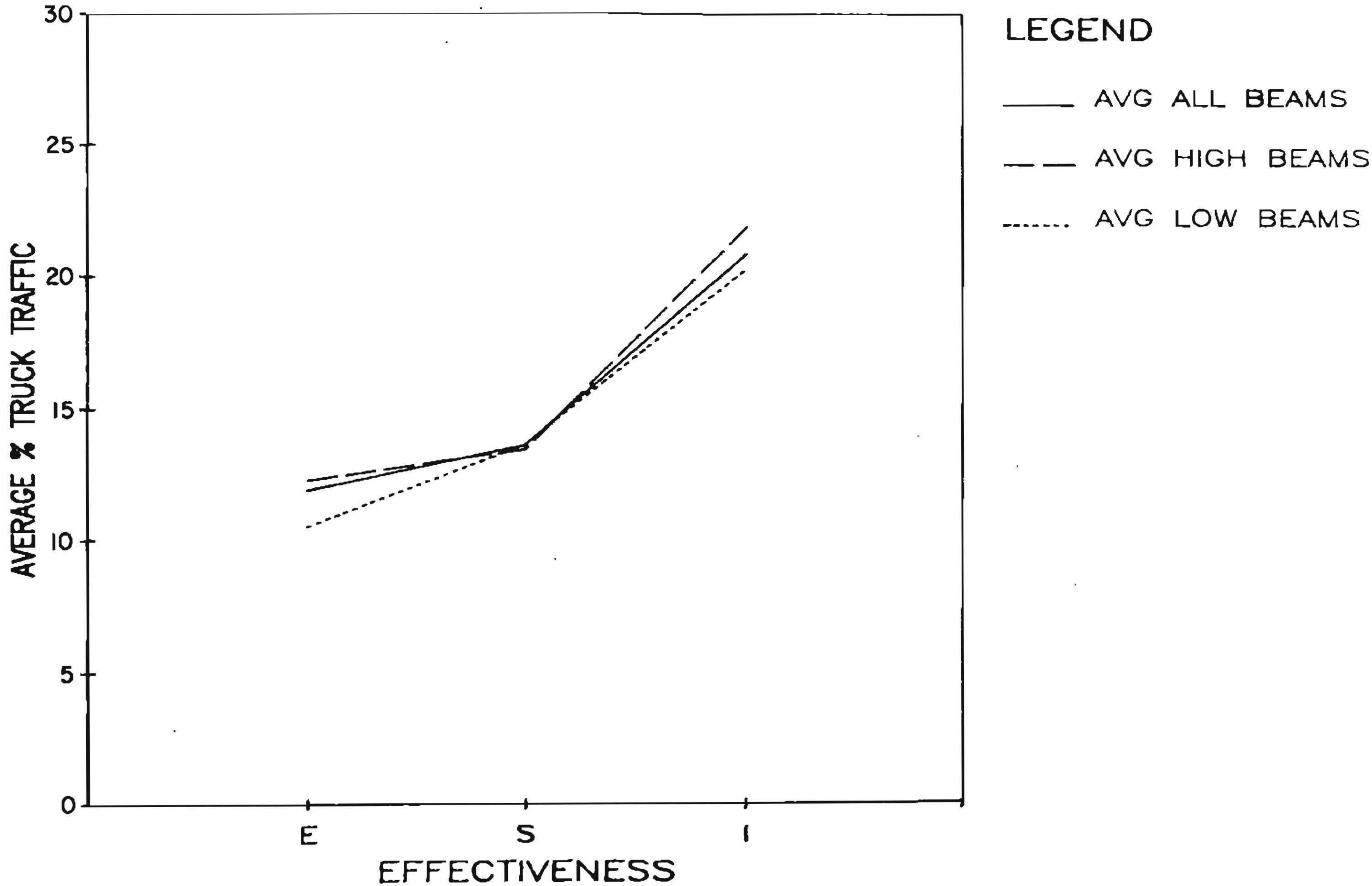


Figure 8. Percent Truck Versus Effectiveness.

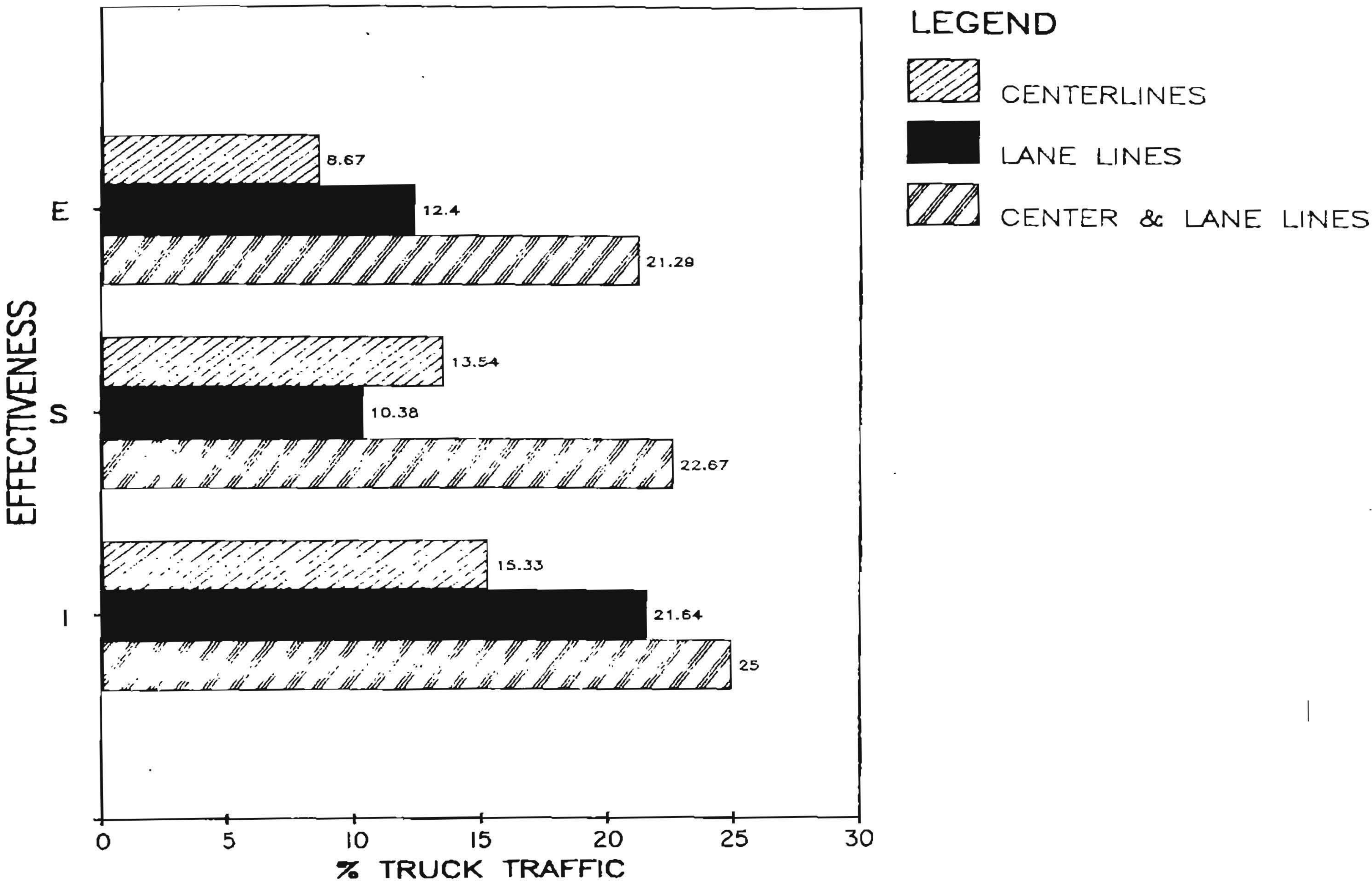


Figure 9. Percent Truck Traffic By Pattern Of Markers and By Effectiveness.

sites (12 percent) and the ineffective sites (22 percent). Those sites in which both centerlines and lanelines were evaluated had a higher percentage of trucks for all three levels of effectiveness. The non-significant differences occured between combination patterns judged ineffective (25 percent) and lanelines judged ineffective (22 percent). In all other situations there was a significant difference. However, the differences between the levels of effectiveness and truck traffic at those sites evaluating the combination markings were non-significant. The effective sites had 21 percent trucks, and the ineffective sites had 25 percent.

Figure 10 illustrates the overall effect trucks have on the markers level of effeciveness. Those sites evaluated as effective were characterized with 11 percent trucks. Those judged semi-effective had 13 percent trucks, and those judged ineffective had 22 percent trucks.

MARKERS REFLECTIVITY

The effectiveness of any marker system is dependent on the number of remaining markers, and the amount of light reflected back to the driver. Missing markers play an integral part in the reflectivity effectiveness of any pattern due to the absence of reflected light. The effectiveness of the reflective properties of any pavement marking pattern should be evaluated at the site in which they operate. While the researchers were photographing the sites, a representative sample of markers was removed after the photographs were taken for reflectivity analysis at the Texas SDHPT File D-9 Laboratory. The evaluation of the reflectivity of the RPMs and RTBs were made using these data.

Length of Time

Figure 11, illustrates the rapid loss of reflectivity over time. Over two-thirds of the markers initial brightness of 3.0 (CP/FT-C) is lost within the first year. The brightness falls from 3.0 (CP/FT-C) to 0.67 (CP/FT-C)

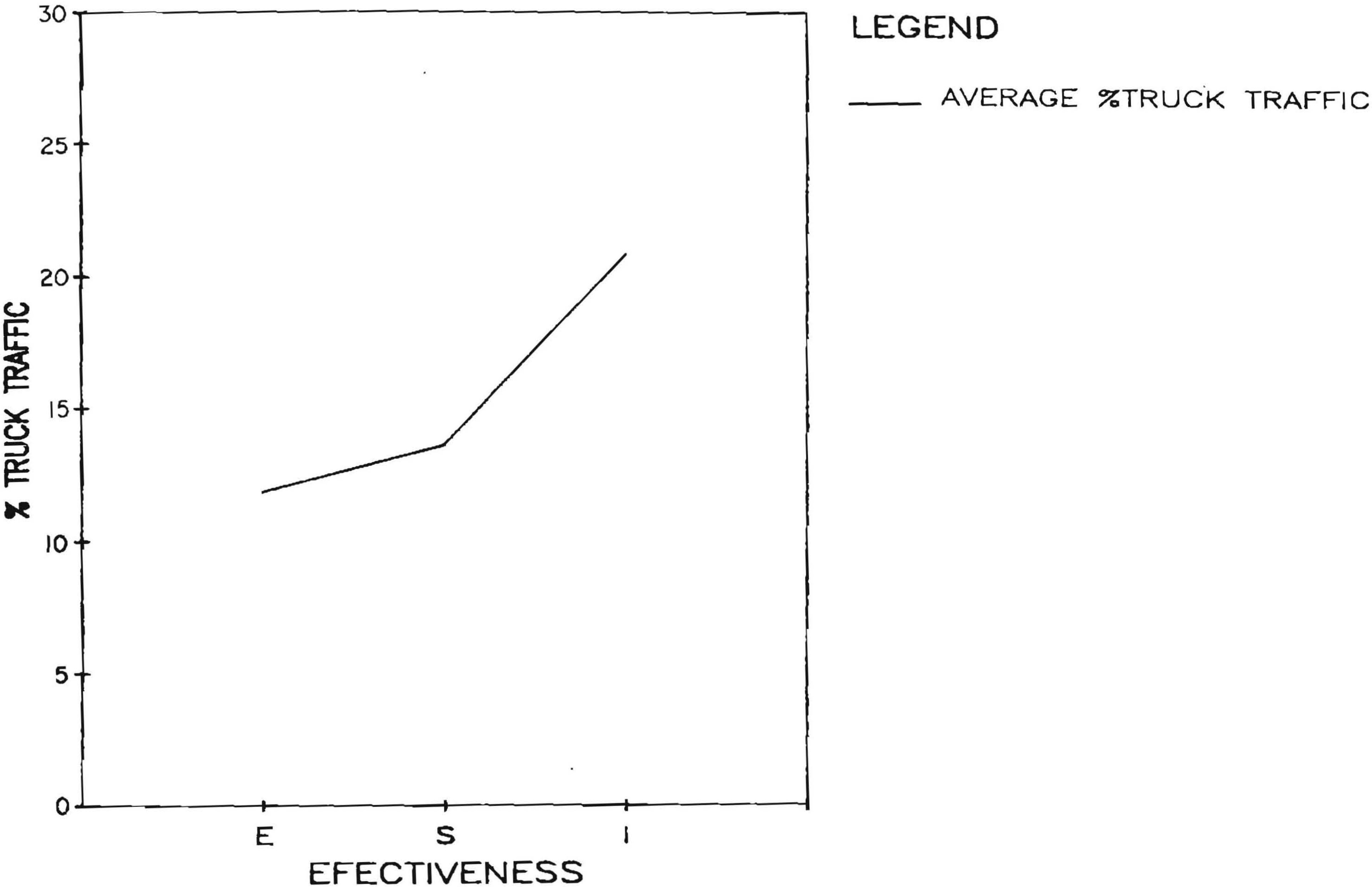


Figure 10. Percent Truck Traffic Versus Marker Effectiveness.

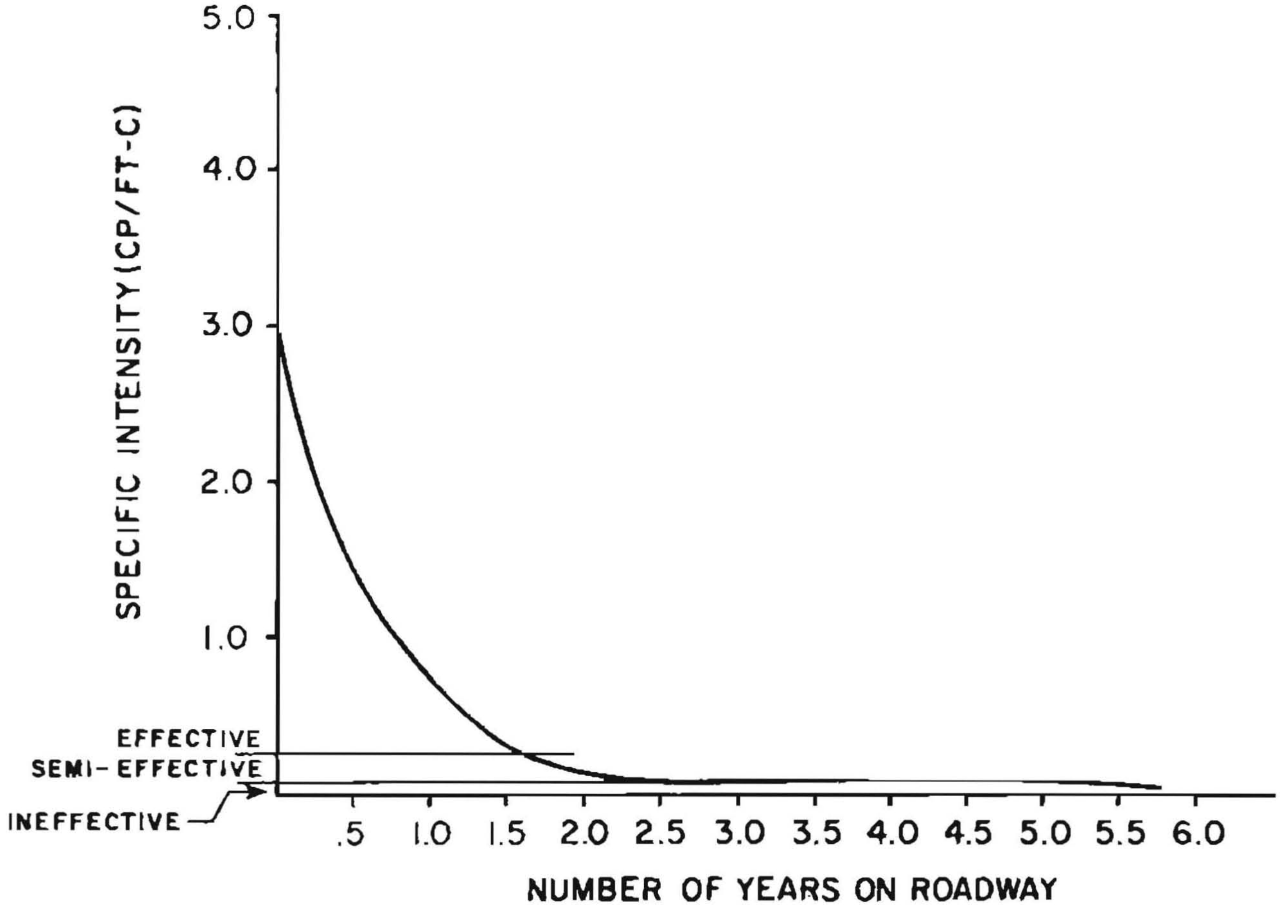


Figure 11. Loss Of Reflectivity Over Time With Levels of Effectiveness.

during this time period. Three years after installation the S.I. is 0.07 (CP/FT-C) and four years after installation they are down to 0.03 (CP/FT-C). Figure 12, illustrates these S.I.'s with respect to other visual parameters.

Length of Time on Road

Markers remain effective at a very low level of reflectivity (.23 (CP/FT-C)) between 1.5 and 2.0 years (Figure 8, p. 22). This analysis does not separate the effect of the markers color or headlight beam usage of the vehicle. Both crystal (white) and yellow markers were combined and both high and low beams were combined. In a later section, these factors will be segregated and the effectiveness evaluated with respect to both color and headlight beams. Figure 13 illustrates the levels of effectiveness as a function of the S.I. value before washing and after washing. The average S.I. values for effective markers before washing was .23 (CP/FT-C) and after washing the S.I. value was .30 (CP/FT-C). An increase in reflectivity due to removal of road grime and dirt was 30 percent. The average ineffective marker S.I. was .05 (CP/FT-C) for unwashed markers and 0.065 (CP/FT-C) for washed markers. This is an increase of 30 percent in reflectivity. This reduction (.23 to .05 (CP/FT-C)) in S.I. occurs approximately 4 years after installation. Between 2 and 4 years the markers would remain semi-effective with an average S.I. of .14 (CP/FT-C). After washing the reflectivity increases to .18 (CP/FT-C), a 29 percent increase. When markers are wet, an increase of 50 percent may be expected in some cases.

Color of Marker

Color of the markers and vehicle headlight beam have an effect on the overall effectiveness of the markers. Figures 14 and 15 relate reflectivity levels to levels of effectiveness, color of marker, number of years in service and vehicle headlamp beam. These figures emphasize that the color of the marker has a significant effect on the effectiveness of the marker. The markers have been segregated into the two primary colors (yellow and crystal) which are directly related to centerline and laneline patterns. Besides being segregated by colors the level of effectiveness has been combined so a direct comparison by color, effectiveness and specific intensity may be performed. Numbers enclosed in parentheses are the average number of years the markers have been in service.

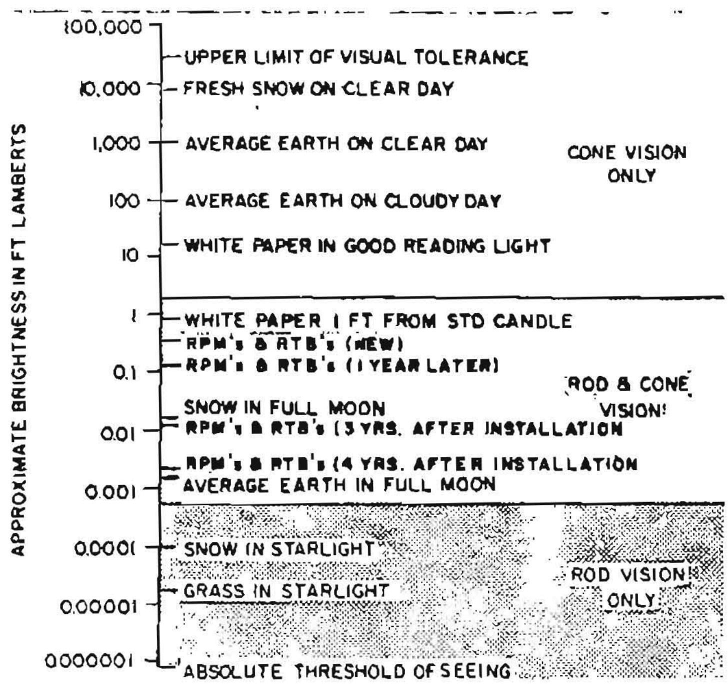


Figure 12. Specific Intensity Levels Of Markers Related To Other Visual Phenomena.*

* "Human Engineering Guide to Equipment Design", edited by Harold VanCott and Robert G. Kinkade, McGraw-Hill Publishing Co., 1972.

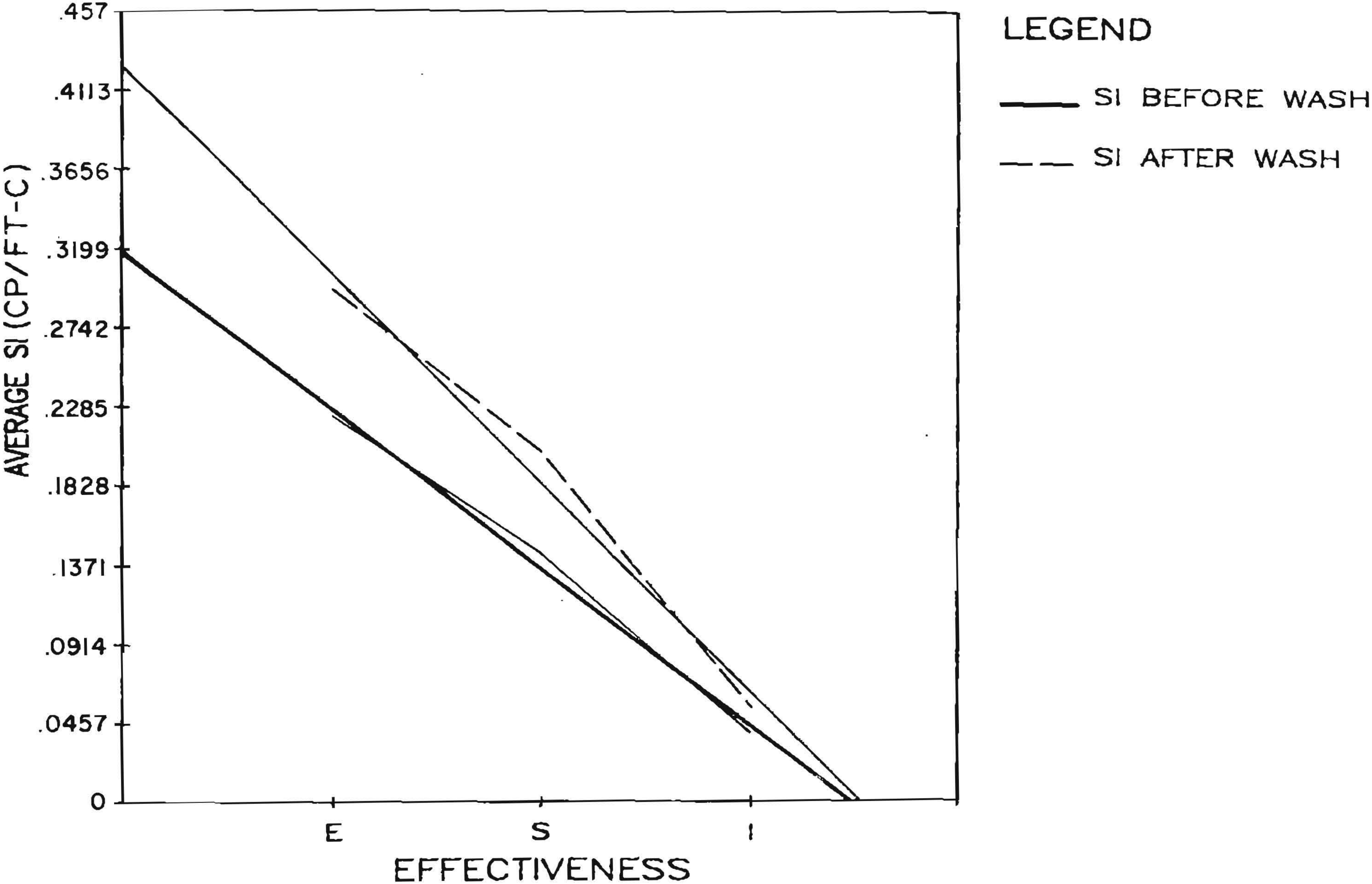


Figure 13. Average S.I. Values Versus Effectiveness Of Markers.

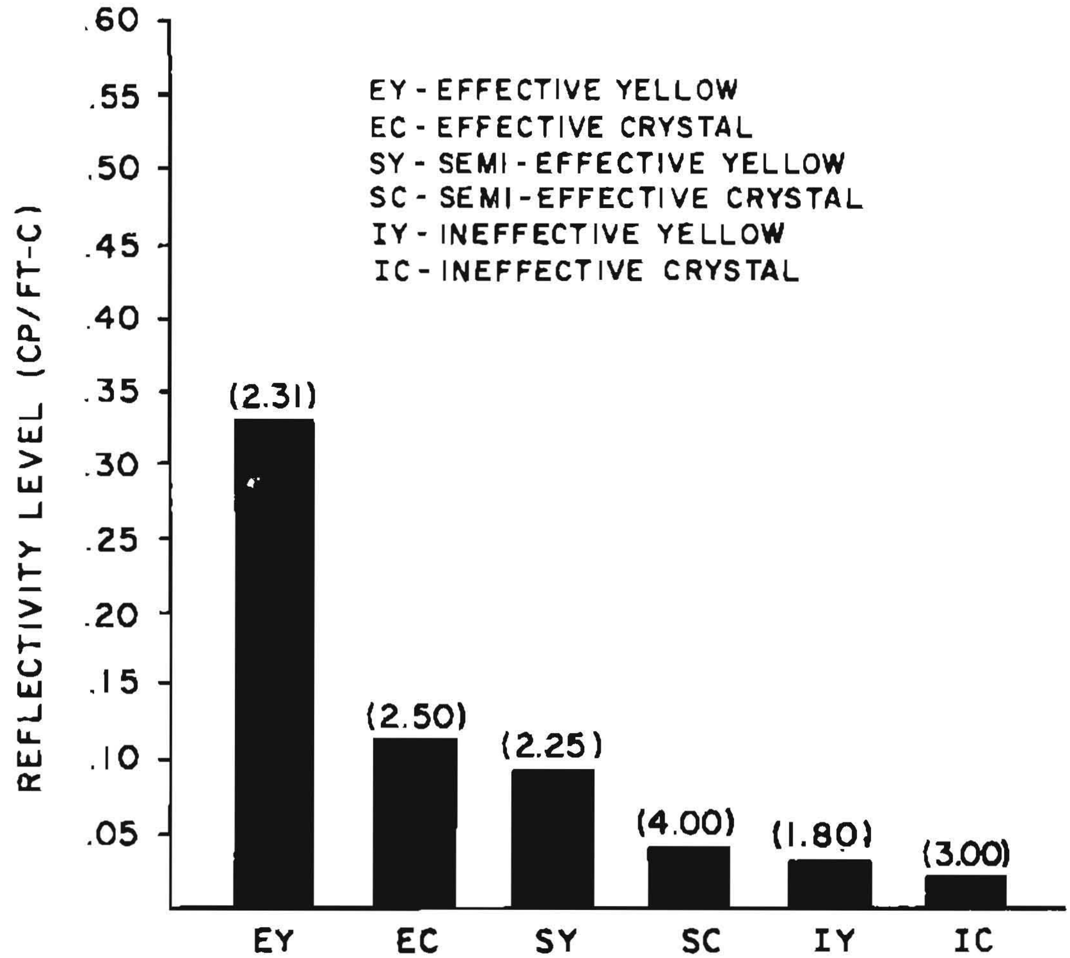


Figure 14. Reflectivity Levels Of Yellow And Crystal Markers For High Beams, At 20° Incidence Angle And Number Of Years In Service.

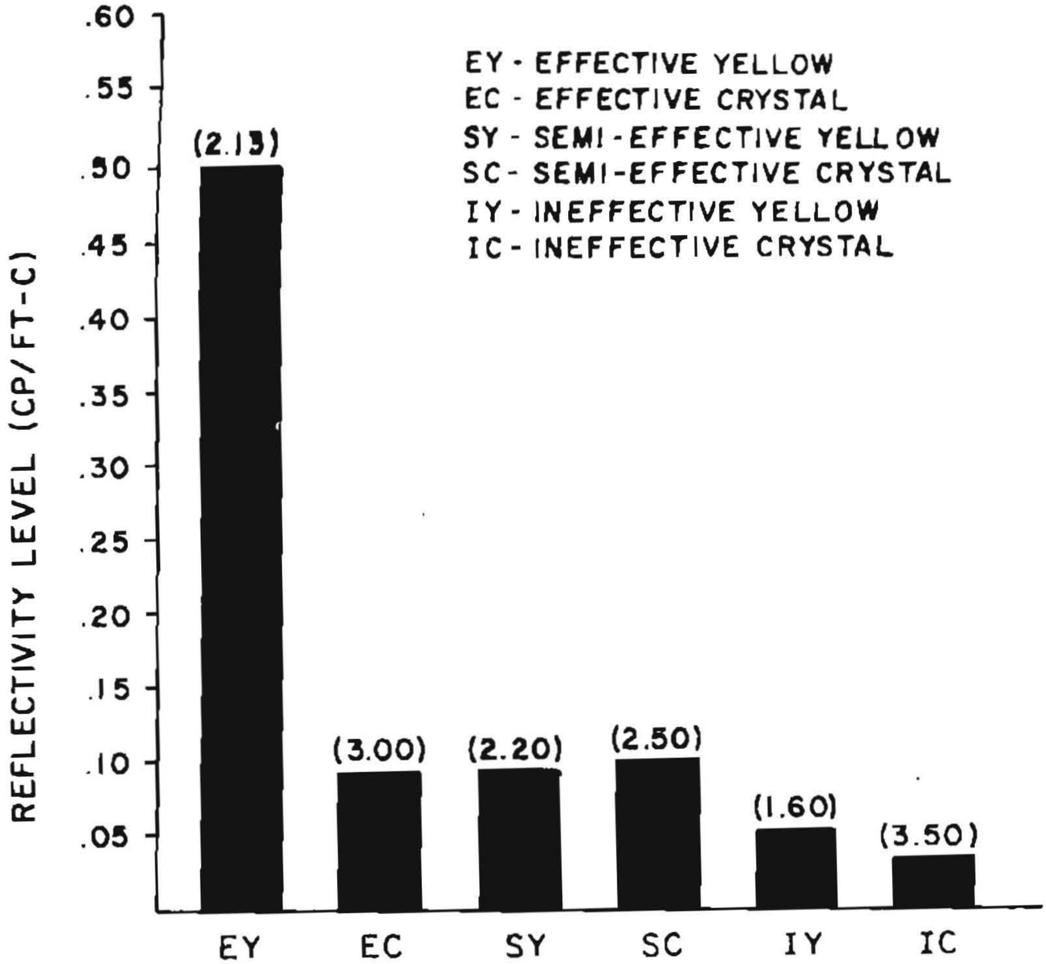


Figure 15. Reflectivity Levels Of Yellow And Crystal Markers With Low Beams At An Incidence Angle Of 20° And Number of Years In Service.

Headlamp Beams

When the vehicles high beams were used (Figure 14), there is a significant difference between the yellow and crystal markers for each level of effectiveness. The effective yellow markers had a specific intensity of .33 (CP/FT-C) and .12 (CP/FT-C) for crystal. Yellow markers should be almost three times as bright as the crystal markers to obtain the same level of effectiveness. Yellow markers in the semi-effective range were significantly lower in intensity (.09 (CP/FT-C)) than those in the effective range (.33 (CP/FT-C)). The effective markers were in service 2.3 years and the semi-effective markers were in service 2.25 years. The differences in intensity and effectiveness cannot be attributed to the age of the marker. The semi-effective crystal marker has a lower specific intensity (.04 (CP/FT-C)) than the associated yellow markers (.09 (CP/FT-C)). The semi-effective crystal markers are approximately one-half the intensity of the effective crystal markers. The ineffective yellow markers had an average specific intensity of .03 (CP/FT-C), whereas the ineffective crystals was 0.02 (CP/FT-C).

Crystal markers had been in service twice as long as the yellow markers at the same level of effectiveness. At present, it is not possible to segregate the two factors to determine the effect color has on effectiveness and the effect service life has on effectiveness. The high beam analysis was performed because this is the normal headlamp configuration in unopposed rural driving situations. The initial brightness level specified by the Texas SDHPT is 3.0 (CP/FT-C), with a 20_ incidence level. Yellow markers are required to have an initial brightness of 2.0 (CP/FT-C). In this environment, a yellow marker can lose approximately 60 percent of its initial brightness and remain effective, 91 percent to be semi-effective, and 96 percent to be ineffective. Crystal markers can lose 90 percent to remain effective, 97 percent to be semi-effective, and 98 percent to be ineffective.

Figure 15, presents the corresponding data with headlamps on low beam. The intensity levels of all markers were higher than the corresponding sites with high beams. Two exceptions were noted first the effective crystal marker with low beams were .12 (CP/FT-C) and its corresponding site with high beams were .09 (CP/FT-C). Semi-effective yellow markers were .09 (CP/FT-C) with both low and high beams. The effective crystal markers and semi-effective yellow and crystal markers did not have significantly different S.I. values. However, at these extremely low S.I. values significant differences may be difficult to detect with the human eye. At this point, the number of missing markers or the condition of the paint stripes will have more of an effect on the effectiveness of the marker system than the brightness level. This analysis points out that the reduction in headlamp intensity requires that the pavement markers must have a corresponding increase in intensity to remain at the same effectiveness level. The yellow markers evaluated as effective on low beams had 1.5 times higher S.I.'s than those evaluated with bright lights. The semi-effective crystal markers were 2.5 times brighter than those evaluated with bright light and those evaluated ineffective with low lights were 1.67 times brighter (yellow) and 2.0 times brighter (crystal) than yellow and crystal markers evaluated with high beams. Color of the markers and headlamp beams have a significant effect on the required levels of reflectivity of the markers. Markers regardless of colors lose between 90 and 98 percent of their initial brightness level in a short period of time (2.5-3.0 years). They can lose approximately 30 percent of their original intensity and still remain effective on low beams with yellow markers and 60 percent with high beams. The crystal markers can lose 90 percent of their original brightness level and remain effective for both high and low beams. These results indicate that all markers reflectivity is diminished after two years and in some cases after six months.

Truck Traffic

Figure 16 points out that truck traffic has no significant effect on the specific intensity level of the markers. As the percentage of trucks increase there is no significant change in the intensity level. It would be expected that, if truck traffic had an effect, the specific intensity levels would decrease as truck traffic increased. This relationship was not detected except for those sites where the trucks constituted 10 percent of the traffic mix. The reflectivity level was .22 (CP/FT-C) and where the percentage of trucks totaled 20 percent (or more) the reflectivity level was .10 (CP/FT-C). Figure 16

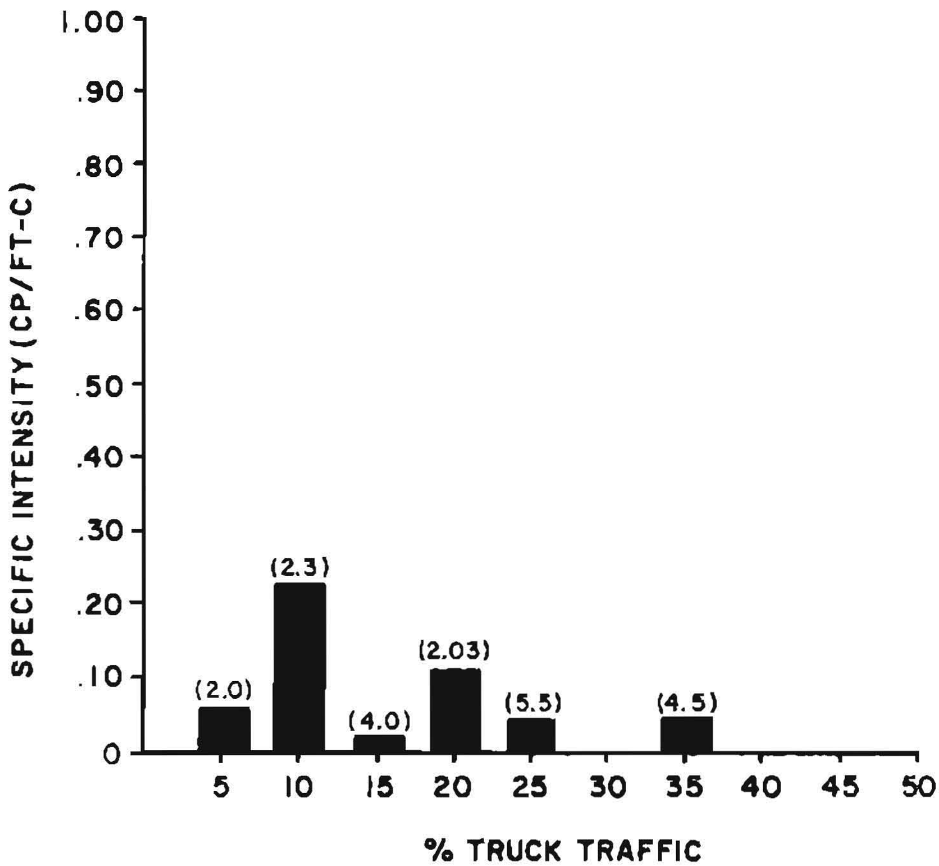


Figure 16. Specific Intensity Related To Level Of Truck Traffic And Number Of Years After Installation.

For all other truck mixes their S.I. was approximately .04 (CP/FT-C). The two points which were different (20% and 10%) appeared to be isolated locations. Truck traffic data was not obtainable in most situations and were estimated at others.

Average Daily Traffic

The amount of traffic passing markers has an effect on the marker's reflectivity. As traffic hits the markers, the lenses become scratched reducing the reflective properties of the marker. Figure 17, presents data showing the decline in specific intensity as a function of ADT. The test sites consisted of locations with high weave rates since the majority of the specific intensity is lost with ADTs less than 5,000 VPD. An additional .10 CP/FT-C is lost between 5,000-30,000 vehicles. Stimsonite believes their 947s will remain reflective twice as long due to the glass face inserted over the regular lens. In effect this does not occur because the glass will also scratch resulting in a reduction in S.I. Eventually the glass face will wear off, leaving the original reflector system, and the marker will again have an S.I. of 1.2 if it is a crystal marker at a horizontal angle of 20_. However, the glass face wears off unevenly, resulting in some reduction in the new S.I. level. The level of reflectivity will increase but this study did not determine the exact amount of increase in reflectivity.

OVERALL EFFECT OF SPECIFIC INTENSITY WITH RESPECT TO RATED EFFECTIVENESS

Figure 18 illustrates unwashed markers remain effective with a specific intensity of .23 CP/FT-C. Markers become ineffective with specific intensity of .09 CP/FT-C or less. It should be pointed out that specific intensity alone does not determine effectiveness. The number of missing markers and the condition of the other pavement markings affect the effectiveness of any marking system. These two factors could not be eliminated. Therefore, the S.I. values stated as break values for the various levels of effectiveness take these two factors into consideration.

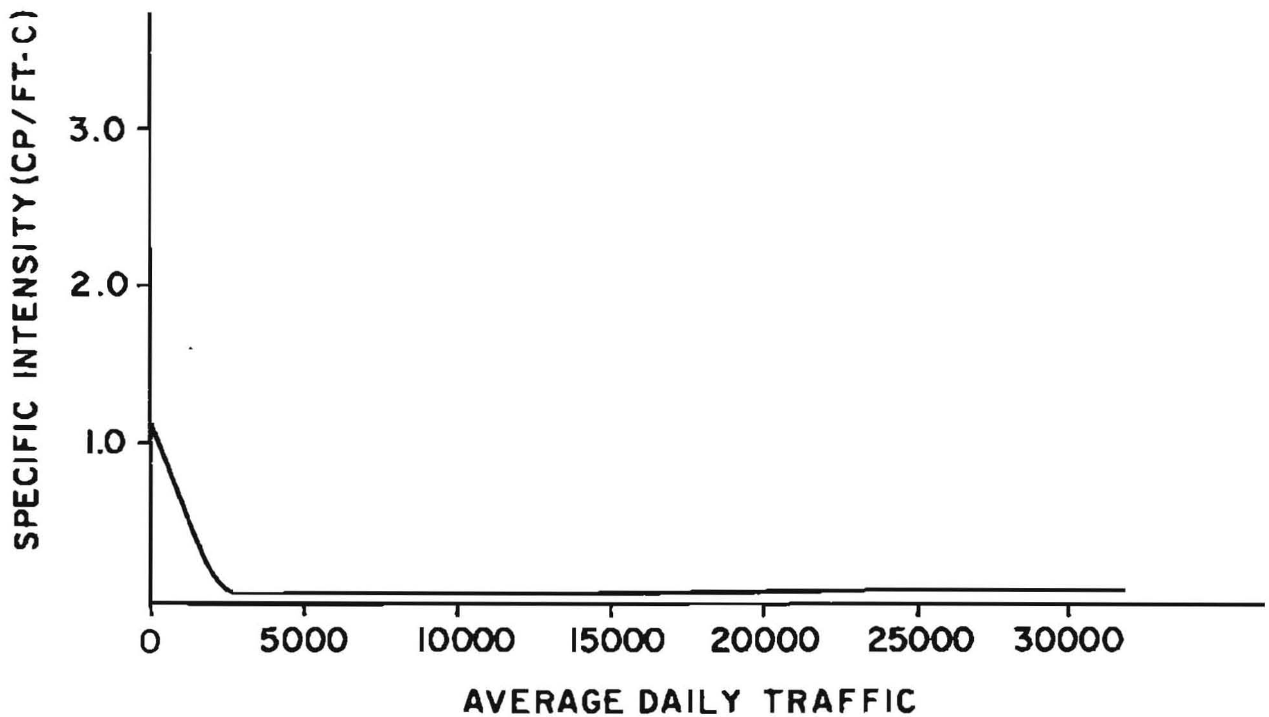


Figure 17. Specific Intensity Related To Average Daily Traffic (ADT).

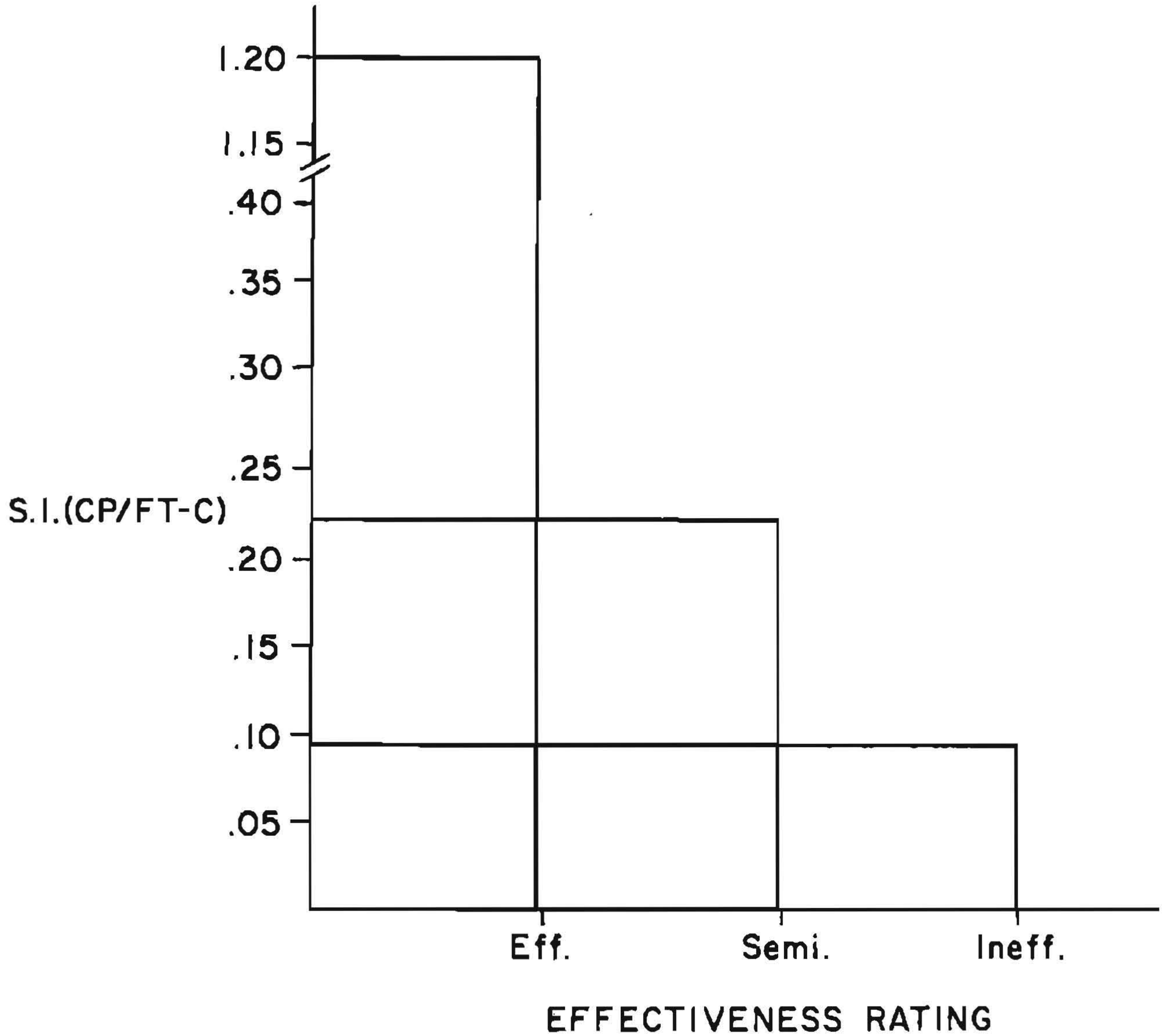


Figure 18. Specific Intensity (S.I.) Values Versus Expert Effectiveness Ratings For ALL MARKERS. Unwashed Markers At 20° Angle.

Vehicle Headlamps

The effectiveness proved that headlamps have an effect on the overall effectiveness of any marker system. Sites which were evaluated as semi-effective or ineffective on low beams were evaluated as effective or semi-effective, respectfully, when high beams were used. Nine (9) sites (27 percent of the sites) incurred a shift in effectiveness when headlamp usage was changed. A larger proportion (6 sites) shifted from semi-effective to effective than those (3 sites) that shifted from ineffective to semi-effective. This shift occurs at sites in which the marker system is borderline between levels of effectiveness. The shift will not occur if the system is not borderline.

RESULTS OF EFFECTIVENESS STUDY

There are several important results obtained from the rated effectiveness:

1. RPMs and RTBs lost a significant (99 percent or more) amount of their initial reflectivity in the two years after installation. Over two-thirds of their initial brightness is lost in the first year.
2. Vehicles headlamps have an effect on the rated effectiveness of the markers. RPMs and RTBs which are marginal with respect to one level of effectiveness using low beams will increase one level of effectiveness on high beams.
3. The loss of initial brightness appears to be unrelated to (1) the type of marker and (2) the initial brightness. Both RPMs and RTBs are at the same reflectivity level within a year after installation.
4. The markers remain effective for the first two years. Between the second and third year the markers become ineffective.
5. The marker system will remain effective with 80 percent or more of the markers on the road. The markers are semi-effective as long as 40-80 percent of the markers are remaining and when 40 percent or less of the markers are remaining the system becomes ineffective regardless of the reflectivity level.
6. Trucks have a significant impact on the number of remaining markers. They have little if any impact on the markers loss of reflectivity.

7. Markers with average S.I. values of .15 (CP/FT-C) are effective providing no more than 20 percent of the markers have S.I. values lower. Markers which have average S.I. values between .15 and .10 are semi-effective. Markers with S.I.'s of .10 or less would be ineffective. Markers that have been washed or wetted increase S.I. values by at least 20 percent.
8. The color of the marker has a significant effect on the level of reflectivity required to attain a certain level of effectiveness. Yellow markers in most cases require a higher reflectivity level than did the crystal markers.

RELIABILITY OF PHOTOGRAPHY

INTRODUCTION

Photographs were made at a broad selection of F-stops and shutter speeds so that the correct settings would be bracketed and the most representative slide for each site selected. The slides for each site were selected for their salient features and overall illumination levels which most closely resembled the environment at the site. The reliability study was conducted to determine the accuracy of the slides with respect to the site.

RESEARCH METHODOLOGY

Test Subjects

Twenty-three 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. Table 2, presents the distribution of the subjects used in the study. Each subject read and signed an instrument to acknowledge informed consent which is contained in Appendix D.

Test Equipment

Two passenger vans in which the subjects were equally divided were used. 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 were 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 3 lists the sites and presents the general information concerning each location.

Table 2. Distribution of Subjects Used in Reliability Study by Age, Sex, and Visual Acuity.

	Sex		Visual Acuity		
Age	Male (f)	Female (f)	Reading	Near (f)	Far (f)
18-24	7	7	20/17	11	1
25-29	2	1	20/18	7	4
30-34	3	0	20/20	3	7
35-39	0	1	20/22	1	4
40-44	0	0	20/25	0	5
45-49	0	2	N/A	1	0
Total	12	11		23	23

Table 3. 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

Test Protocol

The instructions for Part I (Appendix E) contained the objective of the study which was to determine which slide best depicts the roadway environment at each site. The answer sheet for this part of the test is contained in Appendix F.

In this study six 35 mm slides were randomly placed in sequence. In this way the slides were not ordered from dark to light or were the subjects always able to select the same slide due to relative position. The sequencing at each site is given in Table 4. Table 5, lists the slides letter and camera setting by site.

The objective of Part II was to determine which photograph best depicts what each subject saw at the site. In Part I the subjects were evaluating various slides with the environment to determine that camera setting which results in the most accurate representation of the site. Part II compares the photographs to the raised pavement markings to determine whether the panel of experts evaluation corresponded to that of the subjects. An evaluation of the quality of the photographs could be made.

The subjects were told to match the quality of the raised pavement markers to those in the photographs on the answer sheet contained in Appendix H. A complete set of instructions is presented in Appendix G. At each site the photographs were randomized according to the sequence contained in Table 6.

STATISTICAL ANALYSIS

Slide Validation Study

Table 7, presents the subjects responses at each site. A chi-square (X^2) analysis was performed to determine whether any significant difference existed in the subjects responses at each site.

Two sites which showed a significant difference between the slides, camera settings of 1/60 of a second with an f-stop of 1.4 and 1/30 of a second with an f-stop of 1.8 were used. At those sites where there was no significant difference, the camera setting selected was 1/30 of a second with an f-stop of 1.8. Based on these results it appears that camera settings of 1/60 of a second with an f-stop of 1.4 or 1/30 of a second with an f-stop of 1.8 results in slides accurately representing sites with low ambient light levels.

Table 4. 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

Table 5. Camera Settings and Slide Letter.

Site #	Slide Letter	Camera Setting
1	M	1/60 sec. f 1.8
	P	1/15 sec. f 1.4
	N	1/60 sec. f 1.4
	R	1/30 sec. f 1.8
	S	1/30 sec. f 1.4
	Z	1/15 sec. f 1.8
2	Y	1/60 sec. f 1.8
	L	1/15 sec. F 1.4
	M	1/60 sec. f 1.4
	T	1/30 sec. f 1.8
	Z	1/30 sec. f 1.4
	P	1/15 sec. f 1.8
3	Z	1/60 sec. f 1.8
	M	1/15 sec. f 1.4
	T	1/60 sec. f 1.4
	L	1/30 sec. f 1.8
	H	1/30 sec. f 1.4
	U	1/15 sec. f 1.8
4	T	1/60 sec. f 1.8
	W	1/15 sec. f 1.4
	Z	1/60 sec. f 1.4
	N	1/30 sec. f 1.8
	S	1/30 sec. f 1.4
	Y	1/15 sec. f 1.8

Table 6. Randomized Sequence Of Photographs.

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

Table 7. 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

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:

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

Table 8 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 with an f-stop of 1.4 or 1/30 with an f-stop of 1.8.

Photograph Evaluation Study

Table 9 presents the results of the photographic study by sites and the levels of effectiveness.

At Site #1, the subjects selected photograph "T". This photograph is of a rural tangent roadway with lanelines and an edgeline. The lanelines have reflective markers whereas, the edgeline is painted. This is the exact duplication of site #1 on U.S. 290 East. A chi-square analysis was performed and a significant difference was determined between those that rated site #1 as effective and those that rated it semi-effective and ineffective. A chi-square value of 14.25 was obtained for site #1. This meant that the site was effective in the view of the subjects. The experts also rated the site as effective. Figure 19 illustrates the site.

The subjects selected photograph "H" at site #2. This photograph depicts a highly effective marker system on a rural multi-laned curved road. Both centerline and laneline markers were visible and highly effective. Photograph "H" is representative of this type of effective marker system. A chi-square of 36.75 was obtained indicating a high degree of significance at this site with respect to the photographs. Figure 20, is the selected photograph and illustrates the site.

Site #3 had a greater spread of responses than either site #1 or #2. Less than 50 percent of the subjects selected photograph "T" as most representative of the site. The site was classified as urban, because of its traffic characteristics more than its lighting characteristics. The roadway is relatively dark with little ambient lighting. The subjects rated this scene identical to that of the panel of experts.

The subjects selected photograph "W" as the most accurate representation

Table 8. Frequencies With Equivalent Slides Combined.

Site #	Camera Settings 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

Table 9. Photograph Evaluation By Site And Level Of Effectiveness.

Sites	Effective (Letter) (f)	Semieffective (Letter) (f)	Ineffective (Letter) (d)	Chi-Square
1	H 1	N 1	L 1	
	M 2	R 0	P 2	X^2 = 14.25*
	S 0	U 0	W 4	
	T 13	Y 0	Z 0	
	16	1	7	
2	H 16	N 1	L 1	
	M 3	R 0	P 0	X^2 = 36.75*
	S 0	U 0	W 0	
	T 3	Y 0	Z 0	
	22	1	1	
3	H 4	N 2	L 0	
	M 1	R 0	P 2	X^2 = 13.00*
	S 1	U 0	W 3	
	T 10	Y 0	Z 1	
	16	2	6	
4	H 0	N 2	L 0	
	M 2	R 0	P 3	X^2 = 15.75*
	S 2	U 0	W 11	
	T 1	Y 0	Z 3	
	5	2	17	

* Denotes Significant Results

Figure 19. Photograph Judged Representative of Sites #1 and #3.

Figure 20. Photograph Judged Representative Of Site #2.

of Site #4. The chi-square showed a significant difference (X^2 = 15.75) between the responses. Figure 21 illustrates the photograph judged to be representative of the site.

RELIABILITY STUDY RESULTS

The results of the reliability study indicate several significant factors.

A. 35 mm slides accurately represent sites with low ambient light. There are two major concerns with the use of positive film for low ambient light, (1) the color balance may be incorrect resulting in a yellowing effect and (2) bright objects project halos around the object because of the intensity of the light source. The subjects did not comment on either of these two factors. Kodak grey cards R-27 indicated a slight color shift on the white card.

B. The appropriate camera settings are 1/60 of a second with an f-stop of 1.4 or 1/30 of a second with an f-stop of 1.8.

C. Photographs are a useful tool in aiding to determine when marker systems need maintenance. The subjects were able to relate the real world site with those on the standard photographs.

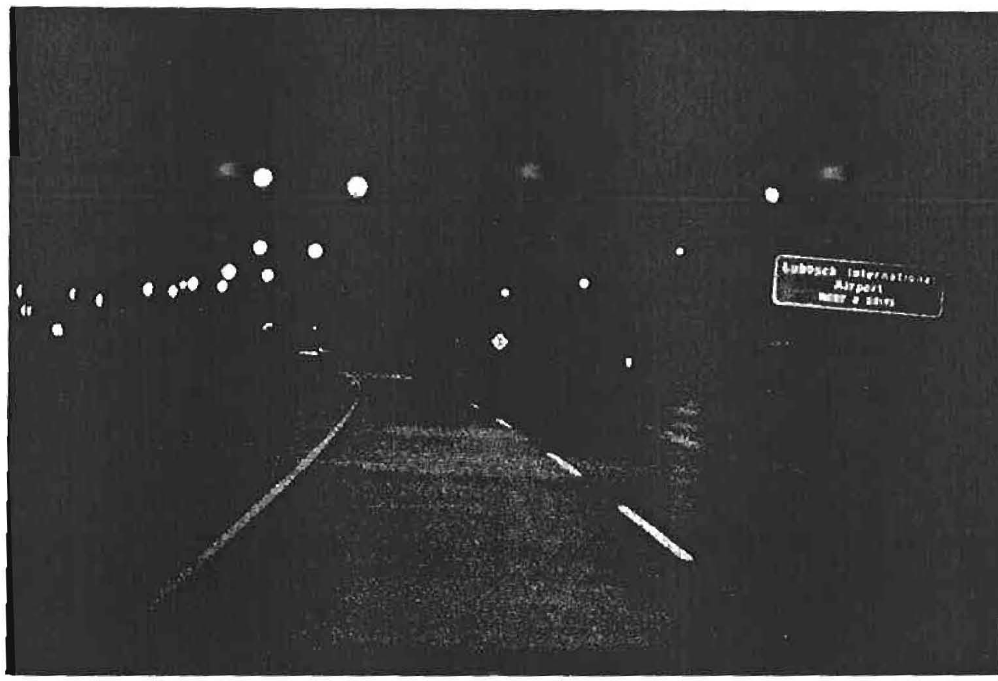


Figure 21. Photograph Judged Representative Of Site #4.

PROPOSED MAINTENANCE PROCEDURE

MAINTENANCE STANDARDS

Appendix I, contains the complete set of photographs to be used as maintenance standards. The set of photographs consist of twelve scenes of rural and urban locations with asphalt and concrete surfaces and with markers on centerlines, lanelines, and left-turn lanes.

The photographs are grouped into three groups of four photographs each as illustrated in Table 9 (page 49). Effective means that the markers are performing satisfactorily as a positive route guidance system and maintenance is not required. The semi-effective markers are not performing satisfactorily, however, immediate maintenance is not needed. As funds become available and the maintenance may begin within three to six months. The ineffective markers are not providing positive route guidance and maintenance is needed.

EFFECTIVE MARKER SYSTEMS

Photograph "H" depicts a typical rural multi-lane curved highway. All of the centerline and laneline markers are present and highly reflective. The markers nearest the leading edge of the headlight beam on the pavement are highly visible. The glare from the oncoming vehicle does not eliminate the visibility of the markers. From this perspective, the driver is presented positive guidance information about the approaching curve. Photograph "M" depicts the markers on a rural two-lane tangent road heading into a built-up or urban area. All of the markers are present and have good reflectivity. The painted centerstripe is also in relatively good condition and the appearance of an edgeline helps define the road to the driver. Photograph "S" depicts an urban multi-lane street with a reversible left turn lane. It is a tangent section which helps offset the loss of information due to missing markers to the driver. It appears that one marker is either non-reflective or missing on the right. Due to the close proximity of the next marker and the street being tangent this does not reduce the amount of information to the driver. Photograph "T" is on a rural divided highway with edgeline. The laneline markers are again all present and highly reflective. The markers are visible for a further distance than the painted edgeline. From this photograph it can be seen that one marker is missing, however the presence of markers further down the road provide sufficient information that the road is tangent and not curved.

SEMI-EFFECTIVE MARKER SYSTEMS

Photograph "N" depicts a rural two-lane road with a slight curve to the left. The brightness of the edgeline presents the information about the curve to the driver and not the raised pavement markers system. Photograph "R" depicts an urban two-lane road. One marker is missing closest to the vehicle. Because of the presence of the streetlight, the brightness of the centerstripe and the contrast between the road and the shoulders, sufficient information is presented to the driver. Presently three (3) markers are visible to the driver. If one of these markers were missing the system would be ineffective. Photograph "U" depicts a rural two-lane road curved extremely hard to the right. The presence of the two markers and the contrast between the road and shoulder presented sufficient information that this site was rated as semi-effective. Photograph "Y" is a semi-effective urban multi-lane street with a reversible left-turn lane. The level of reflectivity of the markers make these markers semi-effective. Because of the reduced reflectivity the glare from oncoming vehicles obliterate the markings on the left-hand side of the vehicle.

INEFFECTIVE MARKER SYSTEMS

The scene depicted in photograph "L" is a rural two-lane road. Even though the road is tangent, the use of low-beam headlamps and the condition of the RPM's do not provide sufficient information with respect to the direction of travel. The reflective highway sign ahead aids the driver in interpreting the visual cues with respect to guidance. The number of missing markers and the condition of the painted centerstripes contributes to the ineffectiveness of the markers. Photograph "P" depicts a rural curved two lane road. Only one RPM, which is reflective, is visible in the headlamp beam. There is no contrast between the road and shoulder reducing the information about the curve to the driver. The only information to the driver is presented by the centerline which is highly reflective. Photograph "W" depicts an urban multi-lane concrete roadway. The curve information is presented to the driver because of the condition of the painted roadway markings and the high ambient freeway lighting systems. Two laneline RPMs in this photograph are present and not reflective. Photograph "Z" depicts an urban left-turn lane on a curve. The markers to the right of the vehicle are reflective and present information of the curve to the driver. However, the markers to the left are missing resulting in a total lack of information with respect to the curve and location to turn left.

MAINTENANCE PROCEDURES

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

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 (1) 1/60 of a second with an f-stop of 1.8 or (2) 1/30 of a second with an f-stop of 1.4. A high speed 35 mm film such as ASA 400 pushed 2 stops or a night 8 mm movie film such as Type G should be used.

2. Evaluation of the Site

   A panel of individuals, selected by the 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 this number is large enough to adequately evaluate a site but not too big that the members cannot adjust their schedule to evaluate the sites. The odd number is to prevent a tie from occurring.

3. The Evaluation With Respect to Effectiveness.

   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 semi-effective when 20-30 percent of the markers are missing. Markers become ineffective when their specific intensity is .05 (CP/FT-C) or less for 75 percent of the remaining markers. A system is semi-effective when 75 percent of the remaining markers have a specific intensity between 0.2 and .05 (CP/FT-C). At present the only way in which to determine the S.I. of the markers is to (1) remove several randomly selected markers for analysis in a laboratory or (2) use a photometric van. Figure 22, illustrates the reflective and retention properties of markers with different levels of effectiveness.

4. Maintenance Photograph Set

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

5. Take Appropriate Action.

If the site is judged to be semi-effective or ineffective, the appropriate action would be taken. The maintenance activity decided by the evaluation panel would begin.

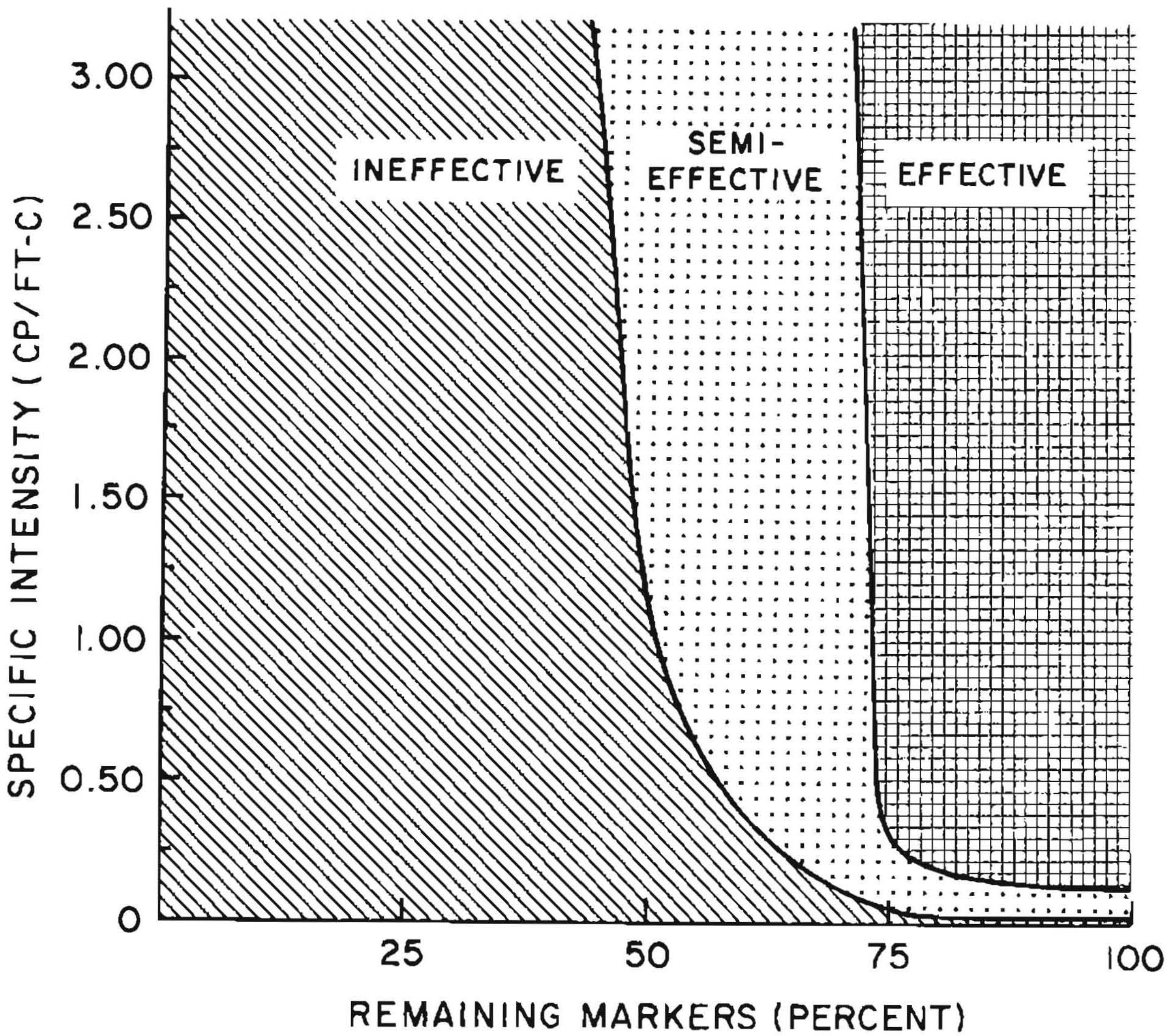


Figure 22. Relationship Between Specific Intensity And Remaining Markers With Respect To Level Of Effectiveness.

REFERENCES

1. Texas SDHPT "Durability of Reflective Markers Under Traffic" (3-03-76-079), 1979.
2. Amerace Corporation "Results of Accelerated Wear Testing". Stimsonite Pavement Markers Model 88, Specification Sheet #PM-2-3/76.

APPENDIX A

TRAFFIC CONDITIONS AND PHYSICAL CHARACTERISTICS OF TEST SITES

Traffic Conditions and Physical Characteristics of Test Sites

Site #	City	Location	Roadway	Geometric	Illumination	Headlamps	ADT	% Trucks	% Missing	Years
1.	Portland	Texas 328	Multi-Lane	Tangent	Rural	L	5000	9	5	2.8
2.	Atlanta	Texas 155	2-Lane	Tangent	Rural	L	1950	18	21	3.0
3.	Brownwood	US 183	2-Lane	Tangent	Rural	H	1350	--	4	2.9
4.	Atlanta	Texas 155	2-Lane	Tangent	Rural	H	1950	18	21	3.0
5.	Lufkin	Texas 7	Multi-Lane	Tangent	Rural	H	5300	9	0	0.9
6.	Brownfield	US 62	Multi-Lane	Curve	Urban	L	5200	3	54	2.5
7.	Abilene	US 89	Multi-Lane	Tangent	Urban	H	1500	23	43	1.5
8.	Lufkin	Texas 7	Multi-Lane	Tangent	Rural	L	5300	9	0	0.9
9.	Abilene	US 89	Multi-Lane	Tangent	Urban	L	1500	23	43	1.5
10.	Abilene	US 89	2-Lane	Tangent	Rural	L	1500	8	43	1.5
11.	San Antonio	Five Palm Rd.	2-Lane	Tangent	Rural	L	9500	--	11	1.0
12.	Atlanta	Texas 155	Multi-Lane	Tangent	Rural	H	1950	18	18	3.0
13.	Atlanta	Texas 155	2-Lane	Tangent	Rural	H	1950	18	38	3.0
14.	San Antonio	FM 2252	Multi-Lane	Tangent	Urban	H	30,000	10	21	4.0
15.	Atlanta	US 59	Multi-Lane	Tangent	Rural	H	16,500	16.8	43	0.3
16.	Atlanta	Texas 155	Multi-Lane	Tangent	Rural	L	1950	18	18	3.0
17.	Atlanta	US 59	Multi-Lane	Tangent	Rural	L	16,500	20	43	0.3
18.	Lufkin	Texas 7	2-Lane	Curve	Rural	L	11,500	9	12	0.9
19.	San Antonio	FM 2252	Multi-Lane	Tangent	Urban	L	30,000	10	21	4.0
20.	Port Lavaca	Texas 2238	Multi-Lane	Tangent	Rural	H	5000	9	5	2.8
21.	Lufkin	Texas 7	Multi-Lane	Tangent	Rural	H	7600	20	43	1.2
22.	Atlanta	US 59	Multi-Lane	Tangent	Rural	H	7600	20	43	4.0
23.	Lufkin	Texas 7	2-Lane	Curve	Rural	H	11,500	9	12	0.9
24.	Victoria	Texas 175	2-Lane	Curve	Rural	L	2200	33	56	3.0
25.	Lufkin	Texas 7	2-Lane	Tangent	Rural	H	1250	9	4	1.2
26.	Brownfield	US 62	Multi-Lane	Tangent	Urban	H	5220	6	44	2.5
27.	San Antonio	Five Palm Rd.	2-Lane	Tangent	Urban	H	9500	--	11	1.0
28.	Brownwood	US 183	2-Lane	Tangent	Rural	L	1350	--	4	2.9
29.	Victoria	Texas 175	2-Lane	Curve	Rural	H	2200	33	56	3.0
30.	Brownfield	US 62	Multi-Lane	Curve	Urban	L	5220	3	54	2.5

Site #	City	Location	Roadway	Geometric	Illumi- nation	Head- lamps	ADT	% Trucks	% Missing	Years
31.	Brownfield	US 62	Multi-Lane	Tangent	Urban	L	5220	6	44	2.5
32.	Abilene	US 89	2-Lane	Tangent	Rural	H	1500	8	43	1.5
33.	Atlanta	US 59	Multi-Lane	Tangent	Rural	H	16,500	20	43	0.3
34.	Atlanta	Texas 155	2-Lane	Tangent	Rural	L	1950	18	38	3.0
35.	Atlanta	US 59	Multi-Lane	Tangent	Rural	L	16,500	16.8	43	0.3
36.	Atlanta	US 59	Multi-Lane	Tangent	Rural	L	7600	20	43	4.0
37.	Austin	I-35	Multi-Lane	Tangent	Urban	L	27,500	5.4	52	9.5
38.	San Antonio	I-10	Multi-Lane	Tangent	Rural	H	14,100	10	13	2.5
39.	Austin	US 290	Multi-Lane	Tangent	Rural	H	5350	9	25	3.0
40.	San Antonio	I-35	Multi-Lane	Tangent	Rural	L	6000	--	20	--
41.	Lubbock	I-27	Multi-Lane	Curve	Urban	L	13,980	12.2	80	2.2
42.	San Antonio	I-10	Multi-Lane	Tangent	Rural	L	14,100	10	13	2.5
43.	San Antonio	I-10	Multi-Lane	Tangent	Rural	H	16,000	--	71	2.75
44.	Lubbock	I-27	Multi-Lane	Curve	Urban	H	13,980	12.2	80	2.2
45.	Austin	US 290	Multi-Lane	Tangent	Rural	L	5350	9	25	3.0
46.	San Antonio	I-10	Multi-Lane	Tangent	Rural	L	5350	--	71	2.75
47.	San Antonio	I-35	Multi-Lane	Tangent	Rural	L	6600	--	20	--
48.	San Antonio	I-10	Multi-Lane	Tangent	Rural	L	16,000	--	100	2.75
49.	San Antonio	I-10	Multi-Lane	Tangent	Rural	L	16,000	--	100	2.75
50.	Austin	I-35	Multi-Lane	Tangent	Urban	H	27,500	54	52	9.5
51.	Austin	US 71	Multi-Lane	Curve	Urban	L	8350	7.1	67	4.0
52.	Austin	US 71	Multi-Lane	Curve	Urban	L	8350	7.1	67	4.0
53.	Brownwood	US 183	Multi-Lane	Tangent	Rural	H	4300	33	21	6.0
54.	Port Lavaca	Texas 238	Multi-Lane	Curve	Rural	H	4400	7	2	6.0
55.	Brownwood	US 67	Multi-Lane	Tangent	Urban	L	9200	25	43	6.0
56.	Abilene	US 83				H			22	4.5
57.	Abilene	US 83	Multi-Lane	Tangent	Rural	L	4900	--	15	4.5
58.	Brownwood	US 67	Multi-Lane	Curve	Rural	L	6400	25	41	6.0
59.	Abilene	US 83	Multi-Lane	Tangent	Rural	H	4900	--	15	4.5
60.	Austin	US 183	Multi-Lane	Tangent	Rural	L	600	15	23	4.0

Site #	City	Location	Roadway	Geometric	Illumi- nation	Head- lamps	ADT	% Trucks	% Missing	Years
61.	Brownwood	US 67	Multi-Lane	Tangent	Urban	H	9200	25	43	6.0
62.	Port Lavaca	Texas 238	Multi-Lane	Curve	Rural	L	4400	7	2	2.8
63.	Abilene	US 83				L			22	4.5
64.	Austin	US 183	Multi-Lane	Tangent	Rural	L	6600	15	23	4.0
65.	Brownwood	US 67	Multi-Lane	Curve	Rural	H	6400	25	41	6.0
66.	Brownwood	US 183	Multi-Lane	Tangent	Rural	L	4300	33	21	6.0

APPENDIX B
2322 EXPERT SLIDE RATING INSTRUCTIONS

322 EXPERT SLIDE RATING INSTRUCTIONS

When you rate the slides keep in mind that you are concerned with the effectiveness of the RPM systems. You are not judging paint stripe effectiveness or level of ambient light from cars or street lighting. You are concerned with effectiveness as it relates to the maintenance of the RPMs. Please focus your judgement on the RPMs reflectivity level, retention of markers, and ability to convey a pattern .

You are the experts, and we would like your ratings of these RPM systems. We have selected three categories: effective, semi-effective, and ineffective as responses for you to make on each slide. Generally, effective means the marker system gives positive route guidance and no maintenance is required. Semi-effective means route guidance is poor to fair and the markers need maintenance soon or need to be scheduled for future maintenance. Ineffective means route guidance is poor to non-existent and maintenance is needed immediately if the marker system is to be useful to the driver and not used as the basis for a tort liability case against the Department.

(Sample slide = 3)

Any questions?

Once we start the evaluation, we will go through without interruption. If you have a question, which will affect more than one of your evaluations; ask: otherwise give your best estimate and continue.

APPENDIX C

T-VALUES AND SIGNIFICANCE LEVELS FOR ALL 66 TEST SITES

T-Values and Significance Levels for all 66 Test Sites

Site	T-Value for			Site	T-Value for			Site	T-Value for		
	I	S	E		I	S	E		I	S	E
1	-2.07	-0.69	3.45*	23	-2.07	-2.07	4.83*	45	-2.07	4.14*	-1.38
2	-1.38	2.76*	-0.69	24	4.14*	-1.38	-2.07	46	4.83*	-2.07	-2.07
3	-2.07	-0.69	3.45*	25	-2.07	-2.07	4.83*	47	-2.07	1.38	1.38
4	-2.07	-2.07	4.83*	26	0.69	1.38	-1.38	48	4.83*	-2.07	-2.07
5	-2.07	-2.07	4.83*	27	-2.07	0.69	2.07	49	4.58*	-1.96	-1.96
6	2.27	0.0	-2.07	28	-2.07	0.0	2.76*	50	2.07	-0.69	3.45*
7	2.07	0.69	-2.07	29	3.45*	-0.69	-2.07	51	0.0	2.76*	-2.07
8	-2.07	0.69	2.07	30	2.76*	0.0	-2.07	52	3.13*	-0.51	-1.96
9	1.38	1.38	-2.07	31	-0.69	3.45*	-2.07	53	-2.07	-2.07	4.83
10	4.14*	-1.38	-2.07	32	0.69	2.07	-2.07	54	-2.07	-2.07	4.83*
11	0.69	1.38	-1.38	33	-1.38	2.76*	-0.69	55	1.38	1.38	-2.07
12	-2.07	-0.69	3.45*	34	0.69	1.38	-1.38	56	-2.07	0.69	2.07
13	0.69	2.07	-2.07	35	4.14*	-1.38	-2.07	57	-2.07	-2.07	4.83*
14	-2.07	-0.69	3.45*	36	2.76*	0.0	-2.07	58	3.45*	-0.69	-2.07
15	4.14*	-1.38	-2.07	37	-2.07	4.14*	-1.38	59	-2.07	-2.07	4.83*
16	-1.38	3.45*	-1.38	38	-2.07	-2.07	4.83*	60	0.69	1.38	-1.38
17	1.38	1.38	-2.07	39	-2.07	-2.07	4.83*	61	0.69	0.69	-0.69
18	-2.07	2.76*	0.0	40	-2.07	-1.38	4.14*	62	-2.07	-2.07	4.83
19	-2.07	-1.38	4.14*	41	4.83*	-2.07	-2.07	63	-2.07	3.45*	-0.69
20	-2.07	-2.07	4.83*	42	-2.07	-2.07	4.83*	64	0.0	2.07	-1.38
21	-2.07	0.0	2.76*	43	2.76*	0.0	-2.07	65	3.45*	-0.69	-2.07
22	-0.69	3.45*	-2.07	44	4.83*	-2.07	-2.07	66	-2.07	1.38	1.38

APPENDIX D

INSTRUMENT TO OBTAIN INFORMED CONSENT

INSTRUMENT TO OBTAIN INFORMED CONSENT

I, ______________________________, have been informed by the experimenter that I have been selected to participate in a study of photographic techniques.

1. I have been given an explanation of the procedures to be followed, including an identification of those which are experimental.

2. I have been given a description of the attendant discomforts and risks, which include the length of the experiment is to be approximately 4 hours, riding in a van from site to site, and being within traffic control at each site.

3. I have been given a description of the benefits to be expected.

4. I have been offered an answer to any inquiries concerning the procedures.

5. I have been instructed that I am free to withdraw my consent and to discontinue participation in the project or activity at any time.

6. I understand that in the event of physical injury resulting from the research procedures described to me that there will be no financial compensation or free medical treatment offered to me.

7. I have not been requested to waive or release the institution, its agents or sponsors from liability for the negligence of its agents or employees.

I, the undersigned, have understood the above explanations and give my consent to my voluntary participation in Dr. Roger W. McNees' research project.

____
Signature of Subject

Date: February 15, 1984
Location: Austin, Texas

APPENDIX E

SUBJECTS INSTRUCTIONS FOR PART I (SLIDES)

SUBJECTS INSTRUCTIONS FOR PART I (SLIDES)

The objective of this study is to determine which slide best depicts what you see on the road at the various sites.

The van will stop at four different road sites. At each site you will view both slides and photographs. When viewing the slides it is important to:

1. Compare reflective markers on the road to the slides.
2. Compare the brightness of the light from the headlights to the slides.
3. Compare the brightness of the stripes and signs to the slides.
4. Compare the brightness of any street light or billboard to the slides.
5. Compare the colors in the slide to those in the outside scene.

If you will now look at your answer sheet you will notice it is divided in half with answers for the slides on the left and answers for the photographs on the right. The slides will be presented to you in sets at each site. After you have determined which slide best depicts the outside scene write the letter of the slide in the space provided for that particular site.

It is very important that you do not discuss the study or your answers with anyone else until all sites are judged. Please do not point to particular slides when you are viewing them. Also, keep your answers covered on your answer sheet.

The objective of this study is to determine which slide most closely matches the details you see outside.

If you have any questions please ask the experimenter now.

APPENDIX F

Evaluation of Reflective Pavement Markers

Evaluation of Reflective Pavement Markers

Rate these CENTERLINE RPM systems:

	Ineffective	Semieffective	Effective
1.	I	S	E
2.	I	S	E
3.	I	S	E
4.	I	S	E
5.	I	S	E
6.	I	S	E
7.	I	S	E
8.	I	S	E
9.	I	S	E
10.	I	S	E
11.	I	S	E
12.	I	S	E
13.	I	S	E
14.	I	S	E
15.	I	S	E
16.	I	S	E
17.	I	S	E
18.	I	S	E
19.	I	S	E
20.	I	S	E
21.	I	S	E
22.	I	S	E
23.	I	S	E
24.	I	S	E
25.	I	S	E
26.	I	S	E
27.	I	S	E
28.	I	S	E
29.	I	S	E
30.	I	S	E
31.	I	S	E
32.	I	S	E
33.	I	S	E
34.	I	S	E
35.	I	S	E
36.	I	S	E
37.	I	S	E
38.	I	S	E
39.	I	S	E
40.	I	S	E
41.	I	S	E

Rate these LANELINE RPM systems:

	Ineffective	Semieffective	Effective
42.	I	S	E
43.	I	S	E
44.	I	S	E
45.	I	S	E
46.	I	S	E
47.	I	S	E
48.	I	S	E
49.	I	S	E
50.	I	S	E
51.	I	S	E
52.	I	S	E
53.	I	S	E
54.	I	S	E
55.	I	S	E
56.	I	S	E
57.	I	S	E
58.	I	S	E
59.	I	S	E
60.	I	S	E
61.	I	S	E
62.	I	S	E
63.	I	S	E
64.	I	S	E
65.	I	S	E
66.	I	S	E
67.	I	S	E

Rate these CENTER AND LANELINE systems:

	Ineffective	Semieffective	Effective
68.	I	S	E
69.	I	S	E
70.	I	S	E
71.	I	S	E
72.	I	S	E
73.	I	S	E
74.	I	S	E
75.	I	S	E
76.	I	S	E
77.	I	S	E
78.	I	S	E
79.	I	S	E
80.	I	S	E
81.	I	S	E
82.	I	S	E
83.	I	S	E
84.	I	S	E
85.	I	S	E
86.	I	S	E
87.	I	S	E
88.	I	S	E
89.	I	S	E
90.	I	S	E
91.	I	S	E
92.	I	S	E
93.	I	S	E
94.	I	S	E
95.	I	S	E
96.	I	S	E
97.	I	S	E
98.	I	S	E

Select the slide which has the grey and white qualities closest to the cards presented before you.

Set	1.	a	b	c	d
	2.	a	b	c	d
	3.	a	b	c	d
	4.	a	b	c	d

APPENDIX G

SUBJECTS INSTRUCTIONS FOR PART II (PHOTOGRAPHS)

SUBJECTS INSTRUCTIONS FOR PART II (PHOTOGRAPHS)

The objective of this study is to determine which photograph best depicts what you see on the road at the various sites.

The van will stop at four different road sites. At each site you will view both slides and photographs. When viewing these photographs you will notice that the photograph is not the exact scene you see outside. The emphasis with the photographs is to march the quality of the raised pavement markers on the road to those shown in the photographs.

Quality of the markers includes; the brightness of the markers, color, the number of reflective markers on the road, and the ability of the pavement markers to present guidance information to you.

You are not concerned with the paint stripes, signs, or other features of the roadway. Find the photo which most closely resembles the quality of the markers on the road.

You will notice your answer sheet is divided in half with answers for the slide on the left and answers for the photographs on the right. Each photograph has a letter on the back. Once you have determined which photograph best depicts the markers you are viewing, write the letter of the photograph on the right side of your answer sheet corresponding to the appropriate site number.

Please do not tell anyone your choice at any of the sites, do not point to the slides or photos as you view them. After studying all the photographs write your answer on your answer sheet beside the site number. It is important that you do not discuss the study or your answers with anyone else until the end of the study. Keep your answers covered. If you have any questions ask the experimenter now.

ANSWER SHEET

SLIDES

SITES

1. ______ 3. ______

2. ______ 4. ______

Things to look for:

1. Notice the reflective markers in the road.
2. Notice the light from the headlights.
3. Notice the brightness of the stripes and signs.
4. Notice the colors in the slide and the outside scene.
5. Compare the Whole scene to each slide.
6. Choose the best slide depicting the present road scene.

PHOTOGRAPHS

SITES

1. ______ 3. ______

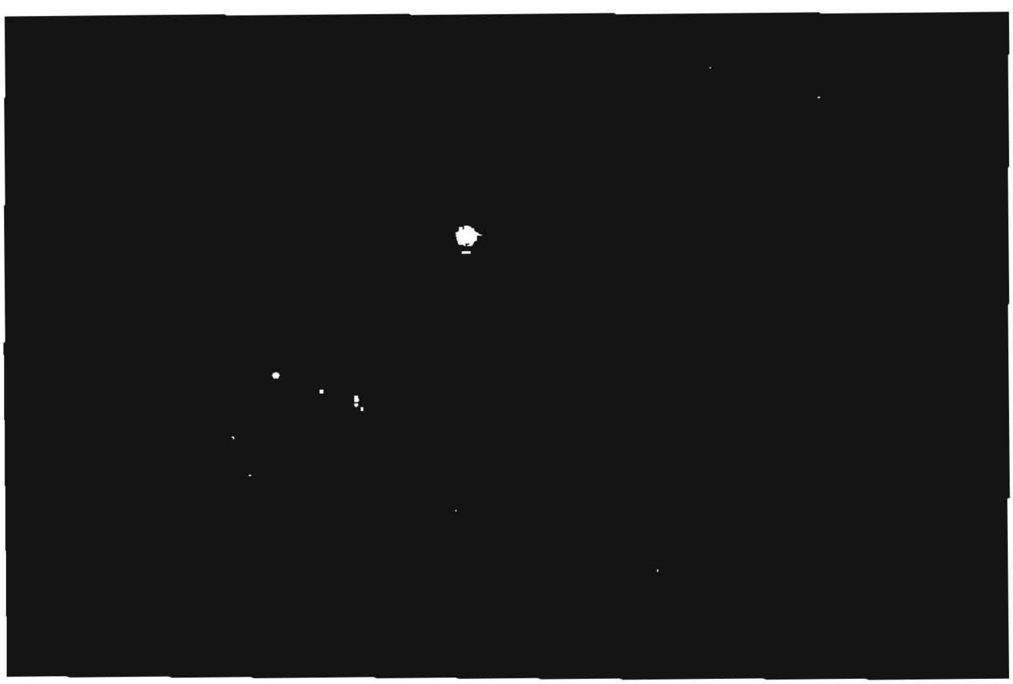
2. ______ 4. ______

Things to look for:

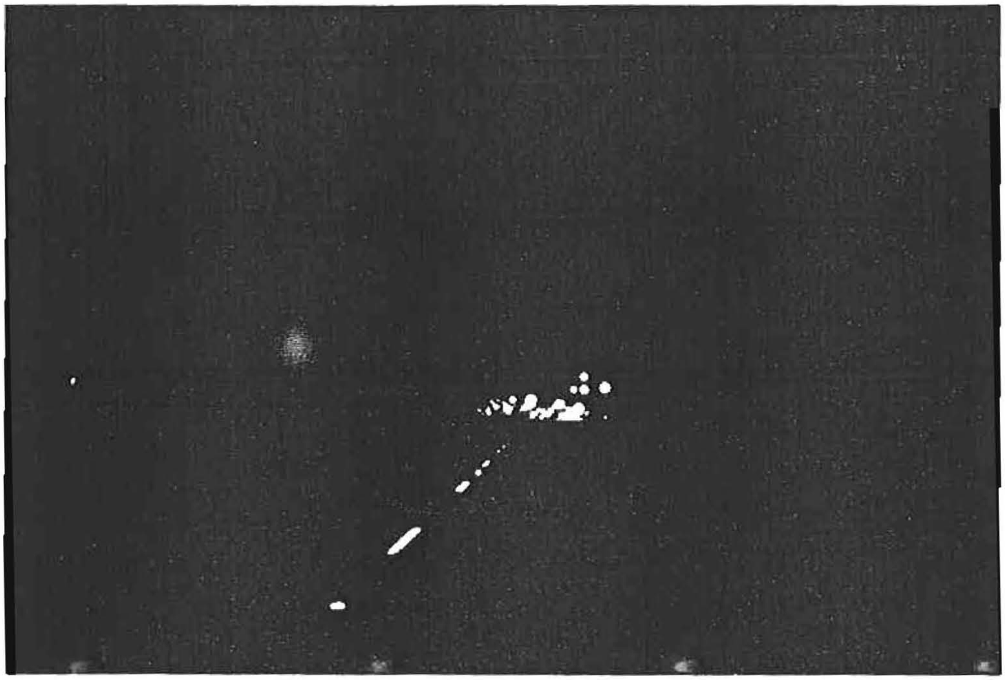
1. Compare the brightness or quality of the reflective markers in the photo to the one on the road.
2. Choose the photo best depicting the present reflective markers.
3. Choose the photo which best matches the reflective marker system in regards to brightness, number missing and ability to provide land guidance.

APPENDIX H

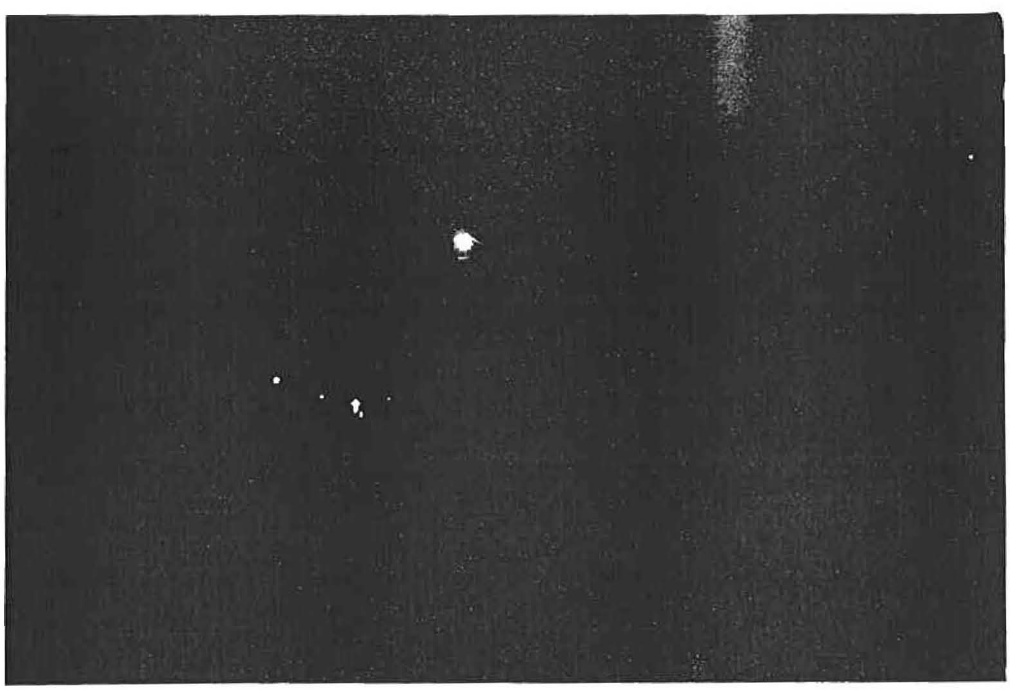
STANDARD PHOTOGRAPH SET



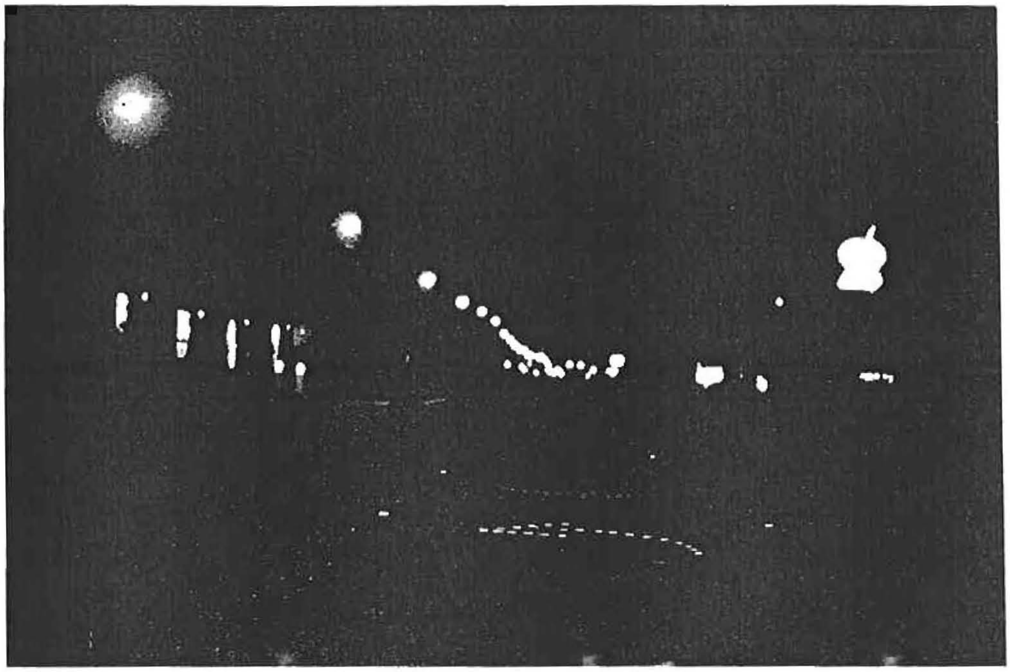
Effective Sites

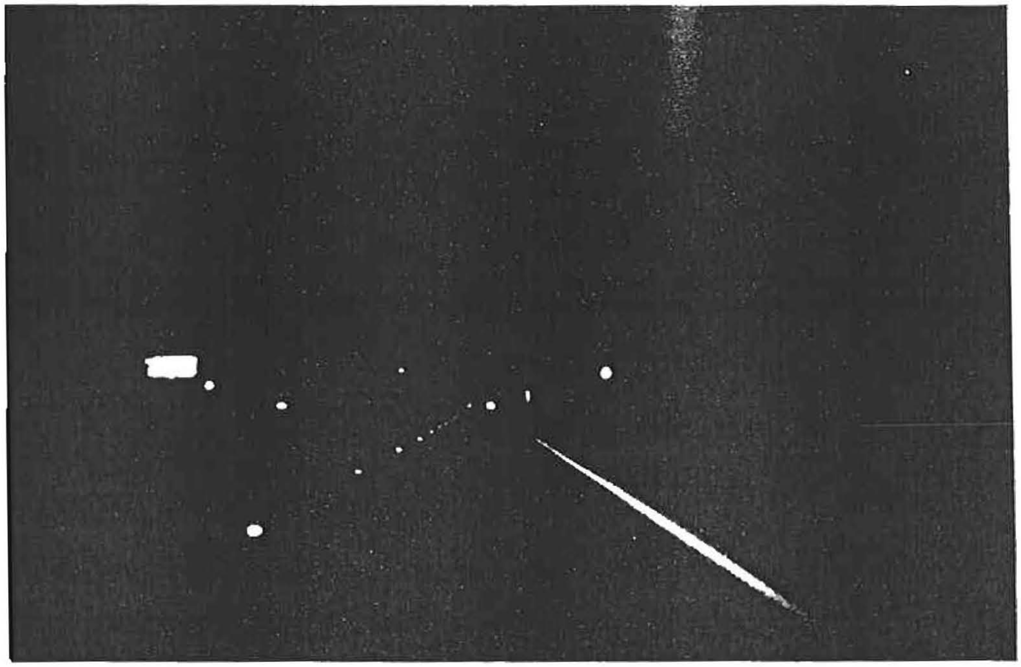


Effective Sites

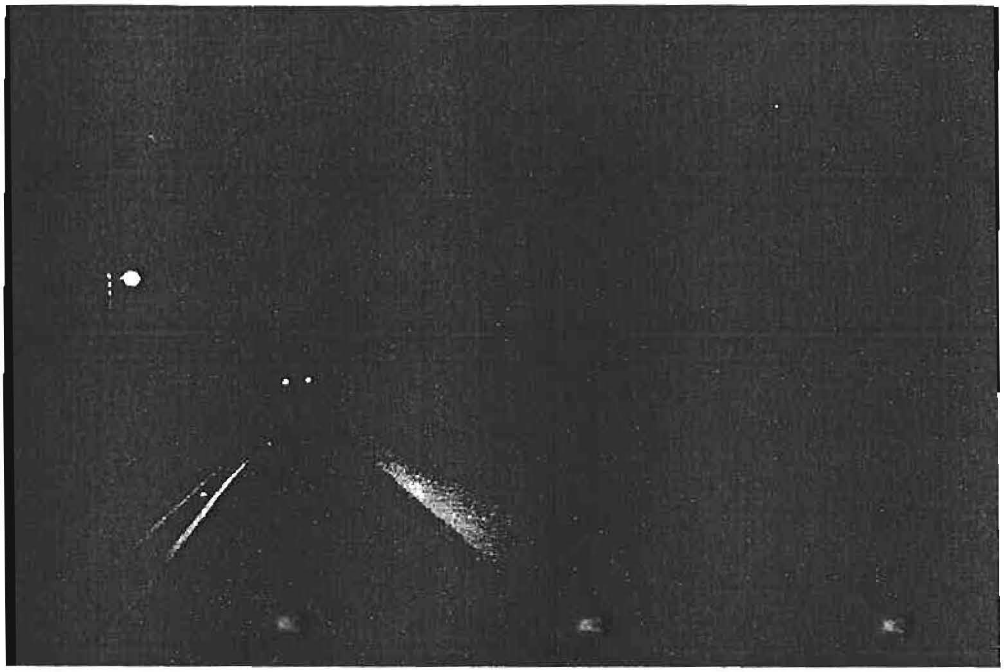


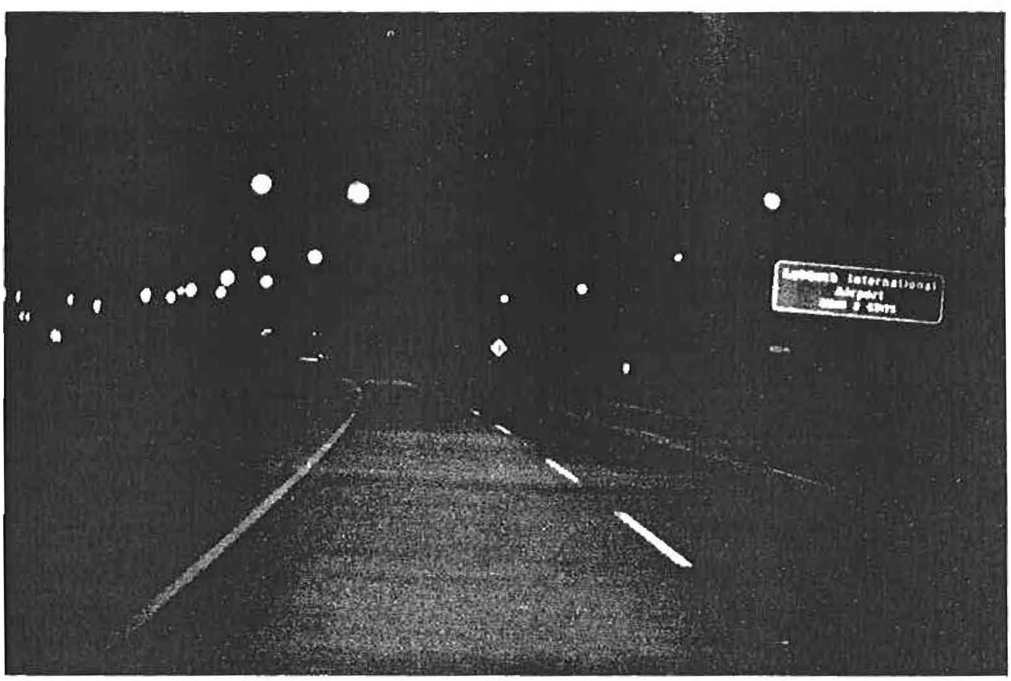
Semi-Effective Sites





Semi-Effective Sites





Ineffective Sites