Final Report

Evaluation Of Delineation Systems For Temporary Traffic Barriers In Work Zones

WA-RD 115.1

Washington State Department of Transportation
in cooperation with the
United States Department of Transportation
Federal Highway Administration

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16. ABSTRACT

This study investigated the effectiveness of various barrier-mounted reflectors. Barrier delineators come in different shapes and sizes, and their materials and installation labor costs also differ. They can be mounted on the barrier top, the barrier face or even on the pavement. A delineator's level of effectiveness depends on the type of delineator as well as its placement.

This study evaluated the effectiveness of seven concrete barriers delineators: Astro-optics on the barrier top, Reflexite on the barrier top, reflective cylinders on the barrier top, hazard panels, raised pavement markers on the barrier face, Astro-optics on the barrier face, and Davidson markers on the edge line.

The study included a literature review, observations of the delineators at a test site, and having motorists drive by the delineators and rate them.

The study concluded that drivers need the guidance of delineators most when they are confronted with opposing traffic headlight glare. Devices placed on top of teh barrier are washed out by headlight glare and therefore are not effective. The best placement of concrete barriers is on the barrier face. A delineator loses more than half of its reflectiveness in a short period due to dirt accumulation.

The study recommended that the Manual on Uniform Traffic Control Devices make note of the effect of opposing traffic headlight glare on delineators' effectiveness, that delineators be placed on the top of concrete barriers, that prism-lensed devices are the most effective, and that delineators should be cleaned regularly.

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EVALUATION OF DELINEATION SYSTEMS FOR TEMPORARY TRAFFIC BARRIERS IN WORK ZONES

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DISCLAIMER

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EXECUTIVE SUMMARY

INTRODUCTION

Concrete median barriers are often used in construction zones to keep traffic from entering a work area or from hitting an exposed object or excavation, to protect workers, to separate two-way traffic and to protect construction such as false work for bridges. In some construction zones, especially on interim roadways, concrete barriers are installed where the roadways are not only substandard but also lack adequate illumination. In these cases, barrier-mounted reflectors are commonly used as aids to nighttime visibility.

This study was sponsored by the Federal Highway Administration to investigate the effectiveness of various barrier-mounted reflectors. Barrier delineators come in different shapes and sizes, and their materials and installation labor costs also differ. They can be mounted on the barrier top, the barrier face or even on the pavement. A delineator's level of effectiveness depends on the type of delineator installed as well as its placement.

STUDY OBJECTIVES

This study evaluated the effectiveness of seven of the concrete barrier delineators currently on the market (see plates 2-1 through 2-7, pages 5 through 11):

- Astro-optics placed on the barrier top,
- Reflexite placed on the barrier top,
- reflective cylinders placed on the barrier top,
- hazard panels,
- raised pavement markers placed on the barrier face,

- Astro-optics placed on the barrier face, and
- Davidson markers placed on the edge line.

The delineators were compared among each other and with the Washington State Department of Transportation's (WSDOT) current delineation system, raised pavement markers placed on the the barrier side of the edge line.

STUDY PLAN

A literature review proved to be inconclusive about the effectiveness of various delineators. Therefore, the study team installed the delineators on a test site on Interstate 90 near Seattle (see Figure ES-1) to make observations, measurements, and to allow drivers to compare and rate the various delineators. The study team observed and measured luminance, the effects of dirt and moisture on the devices, the effects of snow, and the relationship between placement of the devices and the amount of dirt that accumulated on them. The team also observed the effects of wind and gravity and noted whether the devices could be used again, how easy they were to vandalize, and how long it took to install them.

Motorists drove over the test course and answered a questionnaire designed to test their perception of the delineators' brightness, their comfort with the roadways' alignment, the effects of opposing traffic headlight glare on the delineators' effectiveness, at what distance from the barrier the drivers felt most comfortable, how fast they felt comfortable driving, and how they liked the delineators in general. In the first stage of the tests, drivers compared the seven delineators described above, and then in the second stage drivers compared the best of the seven with WSDOT's current delineation system.

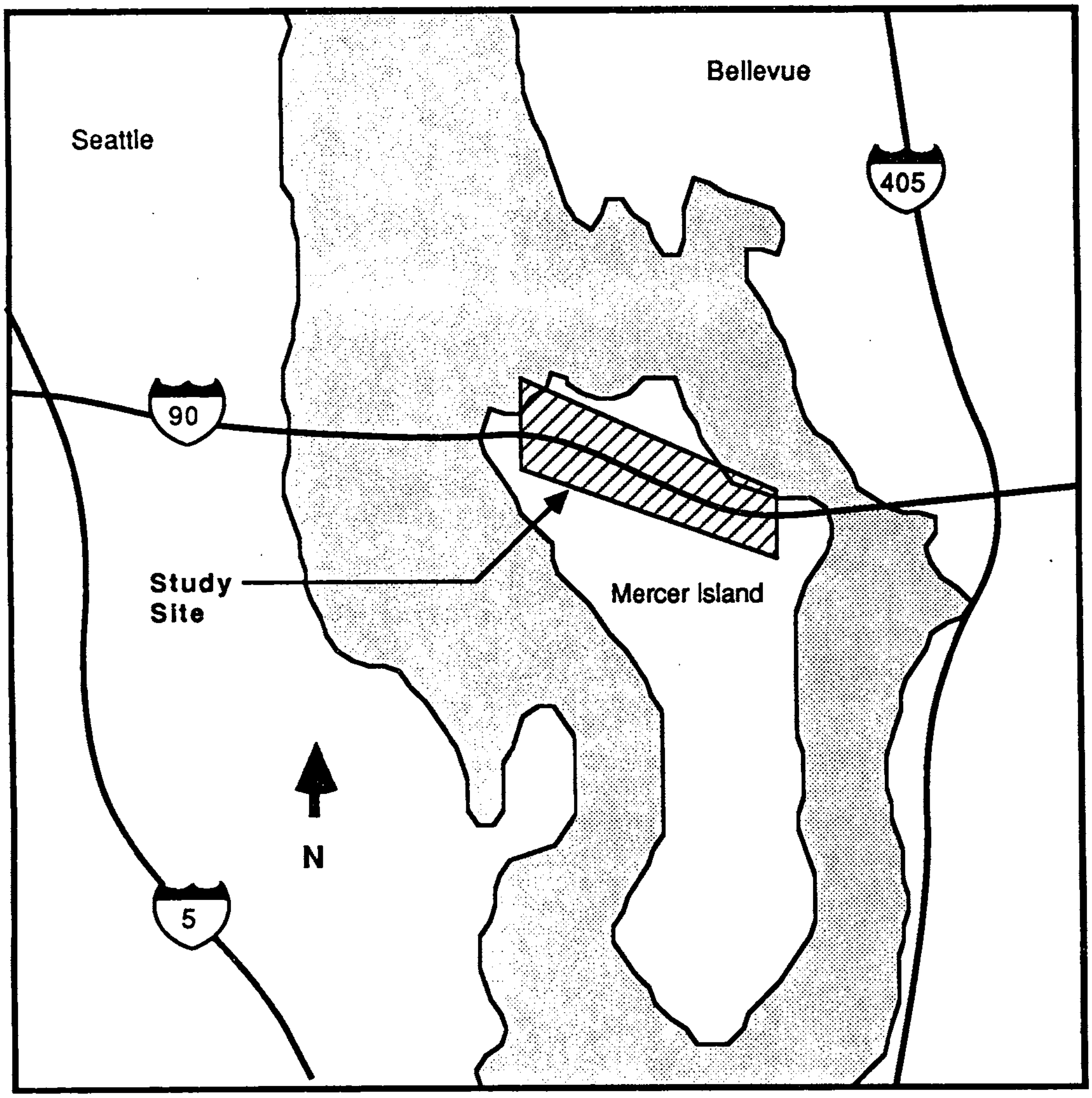


Figure ES-1. Vicinity Map

RESULTS

Luminance measurements showed that, even when dirty, Astro-optics were the brightest devices (see Table ES-1). However, some of the markers, including the raised pavement markers and the Davidson markers, were not measurable by a retro-Tech instrument because their reflective sheetings were too narrow to measure.

The study team made the following observations:

- moisture rusted the outer edges of the hazard panels and reflective cylinders but did not affect the other delineators;
- snow would have covered the barrier-top mounted devices, the raised pavement markers and the Davidson markers; Astro-optics would have been least prone to snow coverage;
- generally, those devices placed higher up on the barrier collected relatively less dirt;
- wind had no observable effect;
- gravity affected the installation of the barrier-face mounted devices;
- all the devices were reusable except the Davidson markers; and
- Davidson markers took the least amount of time to install; hazard panels the most time. Astro-optics on the barrier face were at the mid-point (see Table ES-2).

As Table ES-3 indicates, analysis of material and labor installation costs showed that Davidson markers were the least expensive to buy and install, using unit prices for comparison. 3M high intensity sheeting for cylinders was the most expensive. Astro-optics fell at the mid-point.

Analysis of the questionnaire results showed that opposing traffic headlight glare was the most important factor to the drivers in rating their comfort with the roadway's alignment. In other words, those delineators that were still visible

Table ES-1. Average Luminance Readings for Astro-Optic, Reflexite and Cylinders/Hazard Panels

	Astro-Optic	Reflexite	Cylinders/Hazard Panels
Before Cleaning	256.56	75.40	14.81
After Cleaning	1482.12	377.76	49.54

* Note that the more useful readings are those of the dirty delineators. Because no standard method of cleaning was used, the readings taken after cleaning are secondary and are only good for comparison to dirty reflectors. Most importantly, they emphasize the need to clean the delineators on a regular basis (monthly).

Table ES-2. Installation Time Summary

Number of Devices per 1000'	Device Type	Total Installation Time* per 1000'
64	Davidson Markers (on edge line)	128 seconds
26	Astro-optics (on barrier top)	383 "
26	Reflexite (on barrier top)	383 "
26	Raised Pavement Markers (on pavement)	383 "
26	Astro-optics (on barrier face)	539 "
26	Raised Pavement Markers (on barrier face)	539 "
11	Cylinders (on barrier top)	772 "
11	Hazard Panels (on barrier top)	1003 "

* Total installation time does not include the following:

- Travel time from the shop to the field,
- Set up time,
- Travel time between delineators, and
- Time for mixing epoxy.

For hazard panels and cylinders, installation time includes time for preparing these devices for installation (i.e. , punching holes, mounting reflective sheeting, etc.)

Table ES-3. Material and Installation Time Unit Costs of Reflectors

Reflector	Unit Price
Davidson markers	$ 0.52
Bare Cylinder	0.76
Raised pavement markers	1.20
Reflexite	1.66
Astro-optics	2.45
Hazard panels	8.28
3M High Intensity Sheeting for Panels: 3" wide (per 50 yds.)	132.44
" " " " " Cylinders: 4" wide (per 50 yds.)	176.58

* Prices were obtained from purchase invoices and suppliers.

despite opposing traffic headlight glare were the most effective. Similarly, brightness of the delineators was also important. Drivers also liked a delineator better if it made them feel comfortable going faster. However, where motorists felt comfortable placing their vehicles in relation to the barrier had little effect on their opinions.

Table ES-4 shows that the drivers rated Astro-optics on the barrier face significantly higher than the other six delineators. Cylinders and hazard panels tied at a distant second, due primarily to the fact that their larger sizes made them partially visible in the presence of opposing traffic glare.

In comparing Astro-optics on the barrier face with WSDOT's current system, raised pavement markers on the inside of the edge line, 88 percent, or 15 out of 17, of the drivers preferred Astro-optics placed on the barrier face.

CONCLUSIONS

The conclusions that can be drawn from the results of this study are as follows:

1. Drivers need the guidance of delineators most when confronted with opposing traffic headlight glare. They, therefore, prefer devices that guide them most effectively under such conditions.
2. Devices placed on top of the barrier are washed out by opposing traffic glare and, therefore, are not effective delineators (especially when they are small).
3. The best placement of concrete barrier delineators is on the barrier face.
4. A delineator loses more than half of its reflective properties in a short period due to dirt accumulation. For the brightest delineator in this study this period was one month.

Table ES-4. Transformed Total Ranking Frequencies

		Device						
		Astro-Optics (Face)	Cylinder (Top)	Hazard Panel (top)	Astro-Optics (top)	Davidson Markers	Raised Pavement Markers	Reflexite (Top)
Frequency	First	138	21	30	27	30	6	9
	Second	26	42	40	18	20	24	4
	Third	15	23	16	16	1	7	8
Sum		179	86	86	61	52	37	21
Rank		1	2/3	2/3	4	5	6	7

RECOMMENDATIONS

Based on the findings of this study, the following recommendations are made:

1. The "Manual on Uniform Traffic Control Devices" calls special attention to the effects of water and snow on delineators. It also needs to call special attention to the effect of opposing traffic headlight glare. This is the condition under which the need for delineators appears to be most critical.

2. For positive guidance, delineators should not be placed on top of concrete barriers.

3. Astro-optics placed on the barrier face was found to be the most effective barrier. Therefore, prism-lensed devices of this type are recommended for use as positive barrier delineators.

4. A delineation system must be maintained (or cleaned) on a regular basis. A dirty delineator reflects no light and is not effective in guiding traffic.

CHAPTER ONE
SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

This study was sponsored by the Federal Highway Administration to investigate the effectiveness of various barrier-mounted reflectors. The study team reviewed previous literature and set up a test site on Interstate 90 near Seattle to make observations, measurements, and to allow drivers to compare seven different delineator types.

The study team observed and measured luminance, the effects of dirt and moisture on the devices, the effects of snow, and the relationship between placement of the devices and the amount of dirt that accumulated on them. The team also observed the effects of wind and gravity and noted whether the devices could be used again, how easy they were to vandalize, and how long it took to install them.

Motorists drove over the test course and answered a questionnaire designed to test their perception of the delineators' brightness, their comfort with the roadways' alignment, the effects of opposing traffic headlight glare on the delineators' effectiveness, at what distance from the barrier the drivers felt most comfortable, how fast they felt comfortable driving, and how they liked the delineators in general.

Results of the analysis of the study team's observations and measurements and the motorists' questionnaires produced the following conclusions and recommendations:

CONCLUSIONS

1. Drivers need the guidance of delineators most when confronted with opposing traffic headlight glare. They, therefore, prefer devices that guide them most effectively under such conditions.

2. Devices placed on top of the barrier are washed out by opposing traffic glare and, therefore, are not effective delineators (especially when they are small).
3. The best placement of concrete barrier delineators is on the barrier face.
4. A delineator loses more than half of its reflective properties in a short period due to dirt accumulation. For the brightest delineator in this study (Astro-optics), this period was one month.

RECOMMENDATIONS

1. The "Manual on Uniform Traffic Control Devices" calls special attention to the effects of water and snow on delineators. It also needs to call special attention to the effect of opposing traffic headlight glare. This is the condition under which the need for delineators appears to be most critical.
2. For positive guidance, delineators should not be placed on top of concrete barriers.
3. Astro-optics placed on the barrier face was found by this study to be the most effective delineator. Prism-lensed devices of this type are therefore recommended for use as a positive barrier delineator.
4. A delineation system must be maintained (or cleaned) on a regular basis. A dirty delineator reflects no light and is not effective in guiding traffic.

CHAPTER TWO
INTRODUCTION AND STUDY OBJECTIVES

INTRODUCTION

The "Manual on Uniform Traffic Control Devices" (MUTCD) requires that motorists ". . . be guided in a clear and positive manner while approaching and traversing construction and maintenance work areas" (1). Because timber barricades are not as effective as concrete barriers in restraining errant vehicles, concrete barriers are used increasingly for traffic control on large projects.

Concrete barriers serve various functions, including

- keeping traffic from entering a work area or from hitting an exposed object or excavation,
- providing positive protection for workers,
- separating two-way traffic, and
- protecting construction such as false work for bridges (2).

In some construction zones, especially on interim roadways, concrete barriers are installed where the roadways are not only substandard but also lack adequate illumination. In these cases, barrier-mounted reflectors are commonly used as aids to nighttime visibility.

This study was sponsored by the Federal Highway Administration to investigate the effectiveness of various barrier-mounted reflectors. Barrier delineators come in different shapes and sizes, and their material and installation labor costs also differ. They can be mounted on the barrier top, the barrier face or even on the pavement. Obviously, each of these placements has its own level of effectiveness. The level of effectiveness also depends on the type of delineator installed. The cheapest delineator may not be the most effective. On the other hand, the most costly delineator also may not be the most effective.

This study evaluated seven of the concrete barrier delineators currently on the market. They are the following:

- Astro-optics placed on the barrier top (at 40-foot intervals) (see Plate 2-1 on page 5),
- Reflexite placed on the barrier top (at 40-foot intervals) (see Plate 2-2 on page 6),
- reflective cylinders placed on the barrier top (at 40-foot intervals) (see Plate 2-3 on page 7),
- 8-inch by 24-inch hazard panels (at 100-foot intervals) (see Plate 2-4 on page 8),
- raised pavement markers placed on the barrier face at one foot above the pavement (at 40-foot intervals) (see Plate 2-5 on page 9),
- Astro-optics placed on the barrier face at 26 inches above the pavement (at 40-foot intervals) (see Plate 2-6 on page 10), and
- Davidson markers placed on the edge line (at 16-foot intervals) (see Plate 2-7 on page 11).

<u>**Study Objectives**</u>

This study sought to determine which of the above seven devices is most effective in guiding traffic based on

- brightness,
- visibility,
- material and installation labor costs,
- driver preference, and
- comparison with WSDOT's current delineation system.

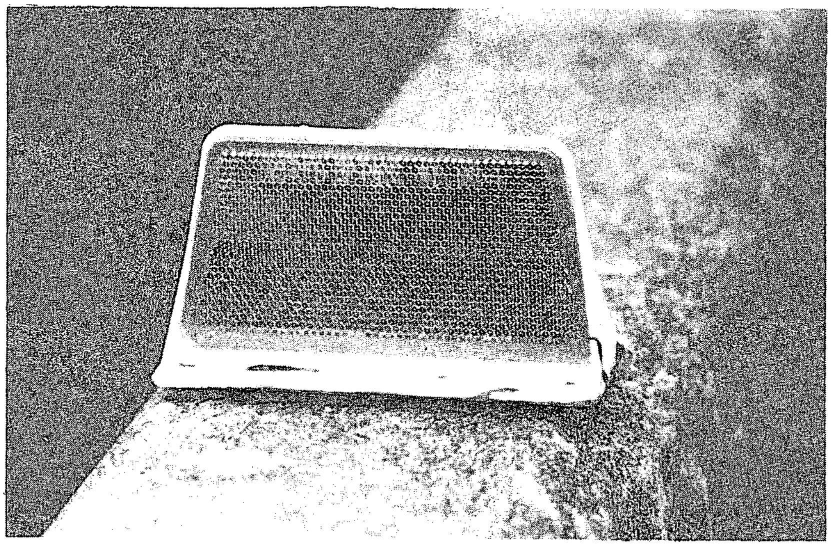


Plate 2-1

Astro-optics on Barrier Top

Dimensions (inches)

Overall: Width = 4.60, Height = 2.80, Thickness = 0.45
Reflective Surface: Width = 4.5, Height = 2.60
Spacing = 40 ft., Length of Section = 1,000 ft.

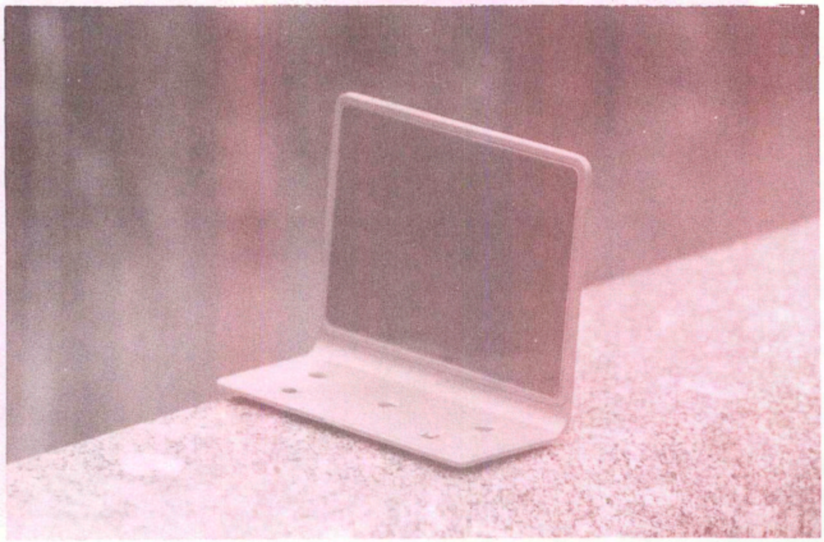


Plate 2-2

Reflexite on Barrier Top

Dimensions (inches)

Overall: Width = 4.50, Height = 3.50, Thickness = 0.10
Reflective Surface: Width = 4.25, Height = 3.00
Spacing = 40 ft., Length of Section = 1,000 ft.

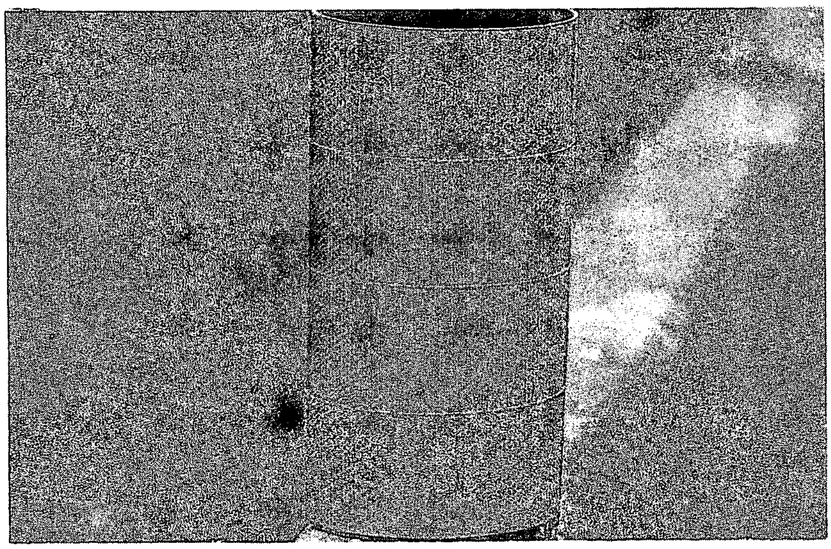


Plate 2-3

Reflective Cylinders on Barrier Top

Dimensions (inches)

Overall: Height = 12, Diameter = 6
Reflective Surface: Height = 12, Diameter = 6 (Three 4-inch wide stripes of high intensity sheeting)
Spacing = 100 ft., Length of Section = 1,000 ft.

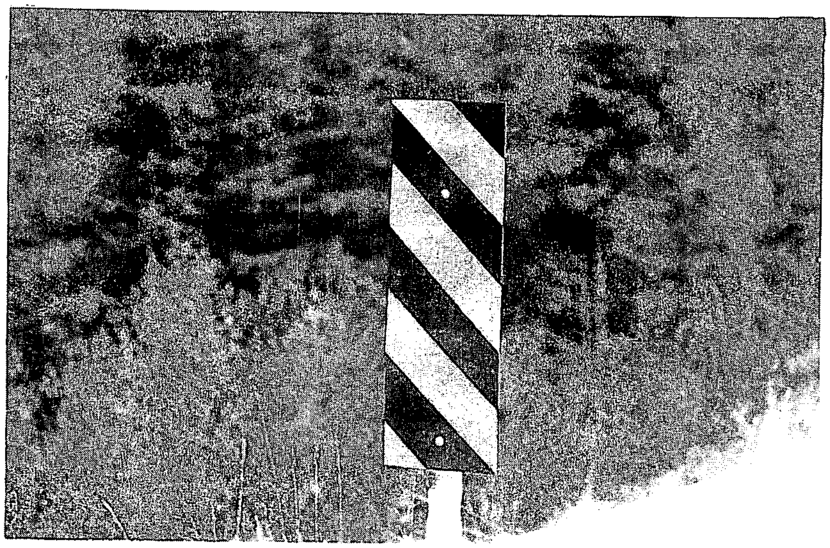


Plate 2-4

Hazard Panel on Barrier Top

Dimensions (inches)

Overall: Height = 24, Width = 8
Reflective Surface: Three 3-inch-wide stripes of high intensity sheeting
Spacing = 100 ft., Length of Section = 1,000 ft.

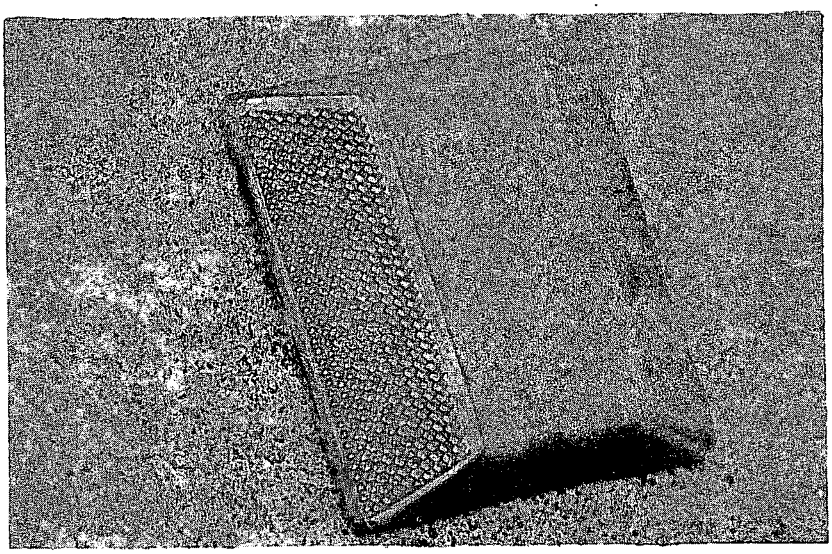


Plate 2-5

Raised Pavement Marker on Barrier Face

Dimensions (inches)

Overall: Length = 4, Width = 4, Height = 0.60
Reflective Surface: Length = 4, Slant Height = 1.20
Spacing = 40 ft., Length of Section = 1,000 ft.

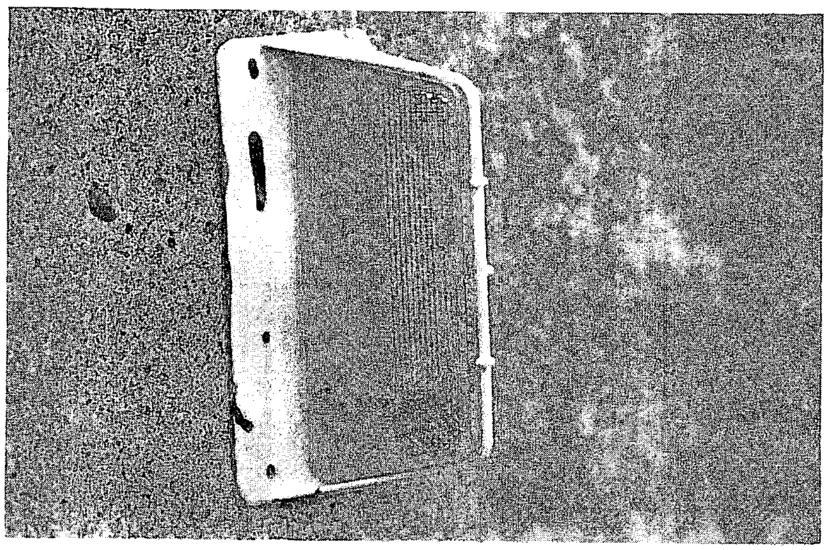


Plate 2-6

Astro-optics on Barrier Face

Dimensions (inches)

Overall: Length = 4.60, Width = 2.80, Thickness = 0.45
Reflective Surface: Length = 4.5, Width = 2.60
Spacing = 40 ft., Length of Section = 1,000 ft.

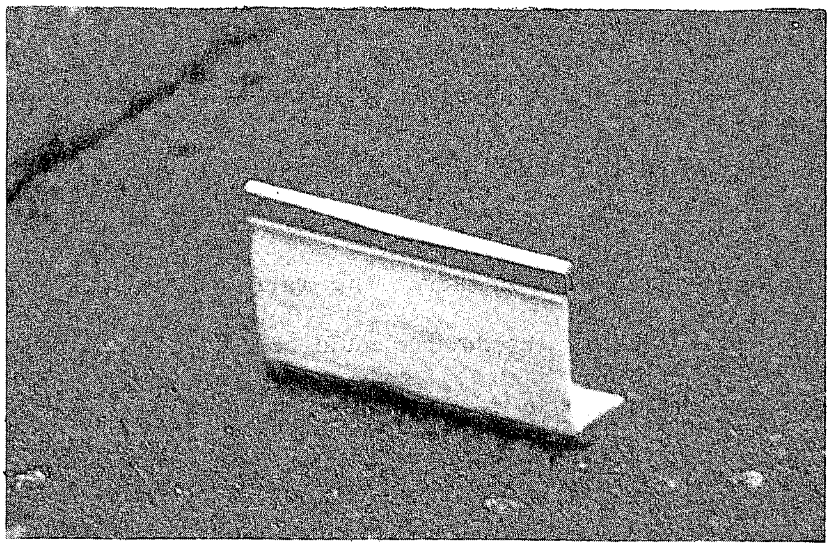


Plate 2-7

Davidson Markers on Edge Line

Dimensions (inches)

Overall: Length = 3.50, Height = 2.00, Thickness = 0.05
Reflective Surface: Length = 3.50, Width = 0.25
Spacing = 16 ft., Length of Section = 1,000 ft.

Study Plan

In order to investigate the effectiveness of the seven barrier delineators, previous studies were consulted. Then a study was devised, based on information gathered from the literature. The research team began by selecting a study site that was dark, was an actual construction site, had average daily traffic above 10,000 vehicles, was long enough to install the devices 1,000 feet apart, and included a combination of curves and tangents on which to test the devices.

The devices were installed on a site on Interstate 90 and a number of variables were observed. The study team observed the effects of dirt and moisture on the devices, the effects of snow, and the relationship between placement of the devices and the amount of dirt that accumulated on them. The team also observed the effects of wind and gravity and noted whether the devices could be used again, how easy they were to vandalize, and how long it took to install them.

The study plan included measuring drivers' responses to the delineators. Therefore, a questionnaire was devised for the motorists. The questionnaire was designed to test the drivers' perception of the delineators' brightness, their comfort with the roadways' alignment, the effects of opposing traffic headlight glare on the delineators' effectiveness, at what distance from the barrier the drivers felt most comfortable, how fast they felt comfortable driving, and how they liked the delineators in general.

The field tests took place in two phases. In the first phase drivers tested all of the seven delineators. After appropriate sample sizes were determined for the test, subjects were randomly selected by telephone. They drove the designated route on Interstate 90 and then filled out the prepared questionnaires. Their answers were then analyzed to find the preferred delineator. The second phase entailed drivers comparing Astro-optics on the barrier face, the "best" delineator system selected from phase one, and WSDOT's current delineation system, raised pavement markers, in order to compare them.

CHAPTER THREE
REVIEW OF PREVIOUS WORK

Blaauw and Padmos evaluated seven reflective delineation materials over a two-year period (3). The following delineation materials were evaluated:

1.	Raised pavement marker, type A (metallic mounting with three large biconvex lenses)	45 x 9
2.	Stripe of white traffic paint with sprayed-on glass beads	150 x --
3.	Raised pavement marker, type B (plastic mounting with 21 small biconvex lenses)	55 x 6.5
4.	Stripe of thermoplastic material, with drainage grooves spaced at 0.50 m intervals, without sprayed-on glass beads	150 x --
5.	Stripe of thermoplastic material with vertical ribs and sprayed-on glass beads (ribbelreflex): profile 1	150 x --
6.	Raised pavement marker, type C (plastic mounting with "corner-cube" lenses)	88 x 11
7.	Stripe of thermoplastic material with a vertical profile spaced at 0.10 m intervals and sprayed-on glass beads: profile 2	150 x --

Blaauw and Padmos measured the optical characteristics of the delineators in dry and wet pavement conditions. Rain was simulated by a moving water sprinkler, and measurements were taken after ten minutes of sprinkling. For the duration of the experiment, the roadway section was closed to other traffic. Blaauw and Padmos concluded that "the measurements over the period of 22 months (corresponding to approximately two million vehicles passed) show that the nighttime visibility of road markings can be improved considerably by the application of continuous stripes with a vertical profile or by raised pavement markers."

Using theoretical analysis, Godthelp and Riemersma predicted the effectiveness of some delineation systems as references to course and speed perception. They concluded that "delineations which are mounted at eye height function poorly and that improvements can be reached by lowering the delineation" (4).

Davis tested the effectiveness of construction-zone delineation devices under field conditions (5). Among the devices tested were steady burn lights, vertical panels, Type 3 barricades, and raised pavement markers (as a paint supplement and as a paint alternative). His conclusions were as follows:

- although 12.7 by 25.40 centimeter (5 inches by 10 inches) yellow high-intensity reflectors were less expensive, more easily checked, and more reliable than steady burn lights, reflectors did not change vehicle speed averages and variances or the proportions of vehicles using the lane adjacent to the reflectors;
- although tall vertical panels used less space and could be seen over the tops of lead vehicles when compared with Type 3 barricades, panels decreased lane encroachments and did not change vehicle mean speeds or variances;
- raised pavement markers as a paint supplement reduced undesirable lane weaves and encroachments both day and night;
- removable traffic tape was easy to install, easy to remove and caused no problems in use; and
- raised pavement markers as a paint replacement were easy to install and easy to remove, and they reduced lane weaves day and night and reduced lane encroachments.

Brackett, et al., evaluated ten types of concrete barrier delineators (14). They included the following:

- 2-inch by 2-inch yellow cube reflectors at 50-foot spacing (mounted 6 inches below the barrier top),

- 2-inch by 4-inch yellow reflectors at 50-foot spacing (mounted 6 inches below the barrier top),
- 2-inch by 2-inch orange reflectors at 50-foot spacing (mounted on the barrier top),
- 2-inch by 4-inch orange reflectors at 50-foot spacing (mounted on the barrier top),
- 1/2-inch by 4-inch thin yellow reflectors at 50-foot spacing (mounted 6 inches below by the barrier top),
- 1/2-inch by 4-inch thin yellow reflectors at 100-foot spacing (mounted 6 inches below the barrier top),
- 6-inch by 12-inch reflective cylinders at 100-foot spacing (orange on white stripes, mounted on the barrier top),
- 8-inch by 24-inch vertical panels at 100-foot spacing (orange on white stripes, mounted on the barrier top),
- 8-inch by 24-inch vertical panels at 150-foot spacing (orange on white stripes, mounted on the barrier top, and
- continuous 12-inch-wide reflective paint on the face of the barrier.

Brackett, et al., photographed these delineator types in the field. They then took these pictures to a shopping mall where volunteers ranked them using questionnaires that asked them to choose which delineators they thought would be most effective.

Based on the results of this ranking, Brackett, et al., screened out six of the delineator types, leaving the following delineation systems for further evaluation:

- 8-inch by 24-inch vertical panels at 100-foot spacing (orange on white stripes, mounted on the barrier top),
- continuous 12-inch-wide reflective paint on the face of the barrier,

- 2-inch by 2-inch yellow cube reflectors at 50-foot spacing (mounted 6 inches below the barrier top), and
- 1/2-inch by 4-inch thin yellow reflectors at 50-foot spacing (mounted 6 inches below by the barrier top).

These four delineator types were then installed at a simulated site where 25 subjects evaluated them, as well as the lack of any delineation. The simulated site was a 300-foot curve. The 25 subjects drove the course five times in an instrumented vehicle. Brackett, et al., found that the rankings of the 25 subjects paralleled the rankings by the shopping mall volunteers as follows:

1.	Best	Vertical panel spaced 100 feet
2.	Upper middle	Continuous stripe
3.	Lower middle	Yellow, 2-inch by 2-inch reflectors spaced 50 feet apart
4.	Worst	Yellow, 1/2-inch by 4-inch reflectors spaced 50 feet apart
5.	Baseline	No delineation

Brackett, et al., concluded, "It was apparent in the screening studies that, with few exceptions, the subjects were evaluating the photographic depictions in terms of the absolute area (surface area times frequency) of delineation present. The correlation between absolute area and average rank was about -0.86."

Two points need to be noted about Brackett:

- evaluating the delineators by looking at their pictures may not have produced results as accurate as those that might have been produced by actually driving the route where they were mounted; and
- the sample size of 25 subjects may not have been large enough for evaluating the five objects.

In 1985 three other studies on delineation systems for temporary traffic barriers in work zones were conducted for the Federal Highway Administration. Shpard compared the fabrication, installation, durability and cost of 6-inch by 12-inch cylinders spaced 100 feet apart, 8-inch by 24-inch hazard panels spaced 100 and 150 feet apart, 4-inch continuous striping, and steady burn warning lights spaced 96 feet apart (6). He concluded that the cylinders, panels, and steady burn lights were the easiest to install and replace, all systems were durable except that the panels tended to bend and rotate, and the cylinders were the most economical of the systems.

Khan compared installation, placement, cost, durability, visual performance and retro-reflectivity among 6-inch by 12-inch cylinders, Astro-optics JD-1 reflectors spaced at 100-feet intervals, Stimsonite 965 delineators spaced at 100 feet apart, Reflexite spaced at 50-feet intervals, hazard panels 100 feet apart, paint striping, and the Safe-T-Spin roating reflectors at 50-feet intervals (7). Khas concluded that the cylinders were the easiest to install because orientation was not important. The Safe-T-Spin delineators worked well in both the daytime and at night in a steady breeze and kept motorists farther away from the barrier. Khan also concluded that the Astro-optics, Stimsonite and Reflexite delineators did not provide adequate delineation by themselves but were good supplements for other methods.

Dowden looked at Astro-optics spaced 10 feet apart, hazard panels spaced 100 feet apart, 12-inch reflective tape, cylinders spaced at 50-feet intervals, and Safe-T-Spin delineators spaced 100 feet apart (8). He concluded that in the daytime the tape was the most dramatic, but it was also the most expensive and came off the barrier too easily. Devices mounted on the top of the barrier were the next most effective during the day. At night, the Astro-optics were the most noticeable, with the cylinders being the second most effective. The Astro-optics were also the least expensive option he studied.

At the time this report was being written, the Texas Transportation Institute at the Texas A&M University was also conducting a study on the same topic. The researchers were comparing plastic "cube-corner" reflectors with high-intensity sheeting on a flat rubber bracket or on a small cylinder, om top of the barrier and on the side of the barrier, at 50 feet apart and 200 feet apart. This study was expected to end in August 1987.

CHAPTER FOUR
STUDY SITE SELECTION

Since the study was to include field observations and driving tests, the site for this study was selected using the following guidelines:

- the area could not be light,
- it had to be an actual construction site,
- the average daily traffic (ADT) had to be above 10,000 vehicles,
- each device had to be installed over a distance of 1,000 feet, and
- a combination of curves and tangents had to be used where possible.

The Washington State Department of Transportation specified these guidelines because they represent field conditions. The guidelines led to the selection of a segment of Interstate-90 in Seattle (Figure 4-1).

In Washington Interstate-90 serves as a major commute route across Lake Washington between the cities of Bellevue (on the east) and Seattle (on the west). At the time of this study, its capacity was being expanded to increase safety, and high occupancy vehicle (HOV) lanes were also being added. Among the reconstruction taking place was the construction of the world's largest diameter, soft-soil tunnel.

The interim roadway consisted of six eleven-foot lanes: two eastbound lanes, two reversible lanes and two westbound lanes. Jersey concrete barriers separated westbound lanes, reversible lanes and eastbound lanes.

The study was conducted on the westbound lanes with an ADT of over 10,000 vehicles. The combined ADT for both directions ranged from 46,000 to 65,000, with a mean ADT of 57,814 (10). Care was taken to select an unlighted segment of I-90. The alignment of the sections used are shown in figures 4-2 through 4-8. The posted speed limit was 50 miles per hour (mph), but a random sample showed an 85th percentile speed of 58 mph.

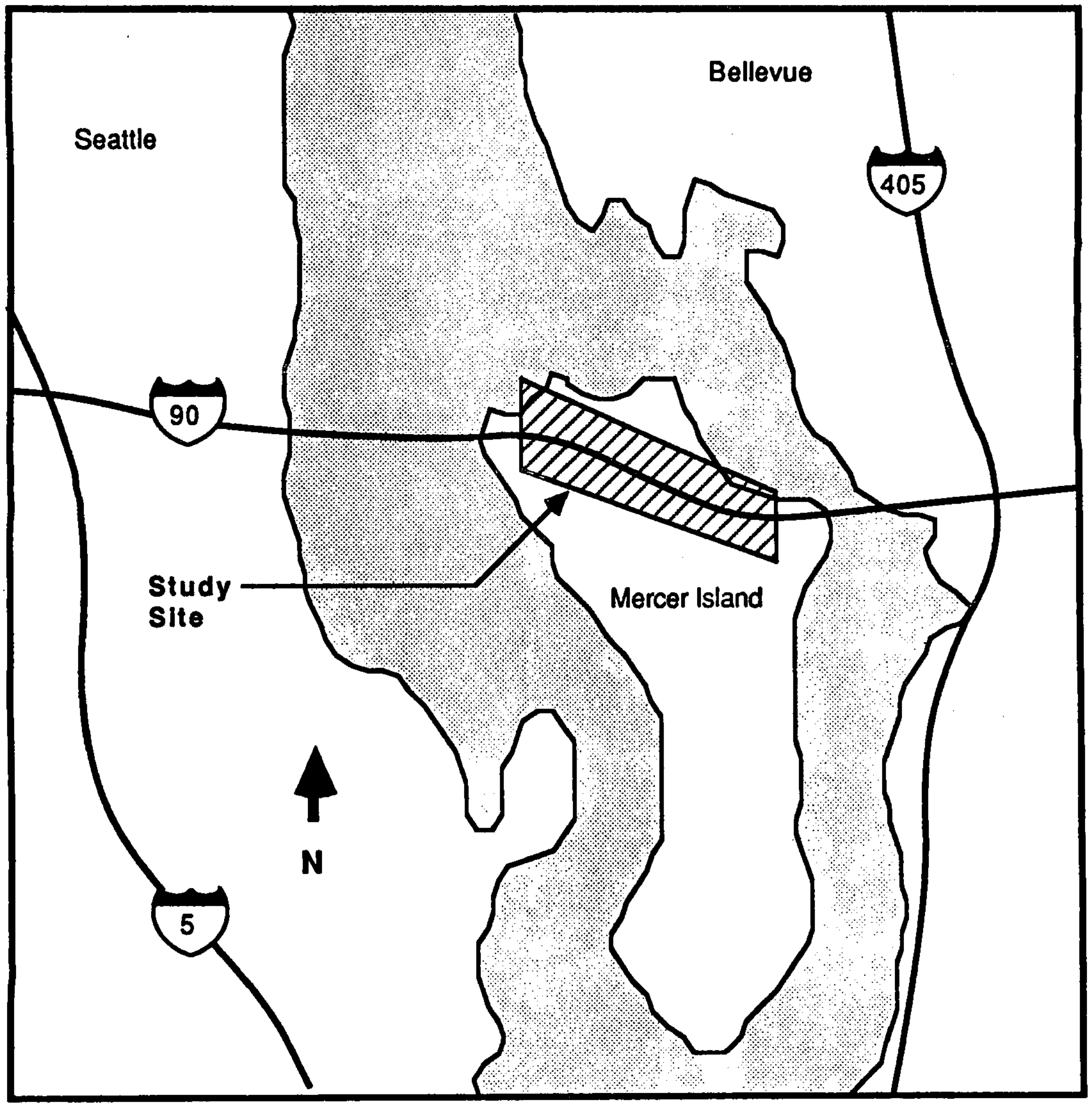


Figure 4-1. Vicinity Map

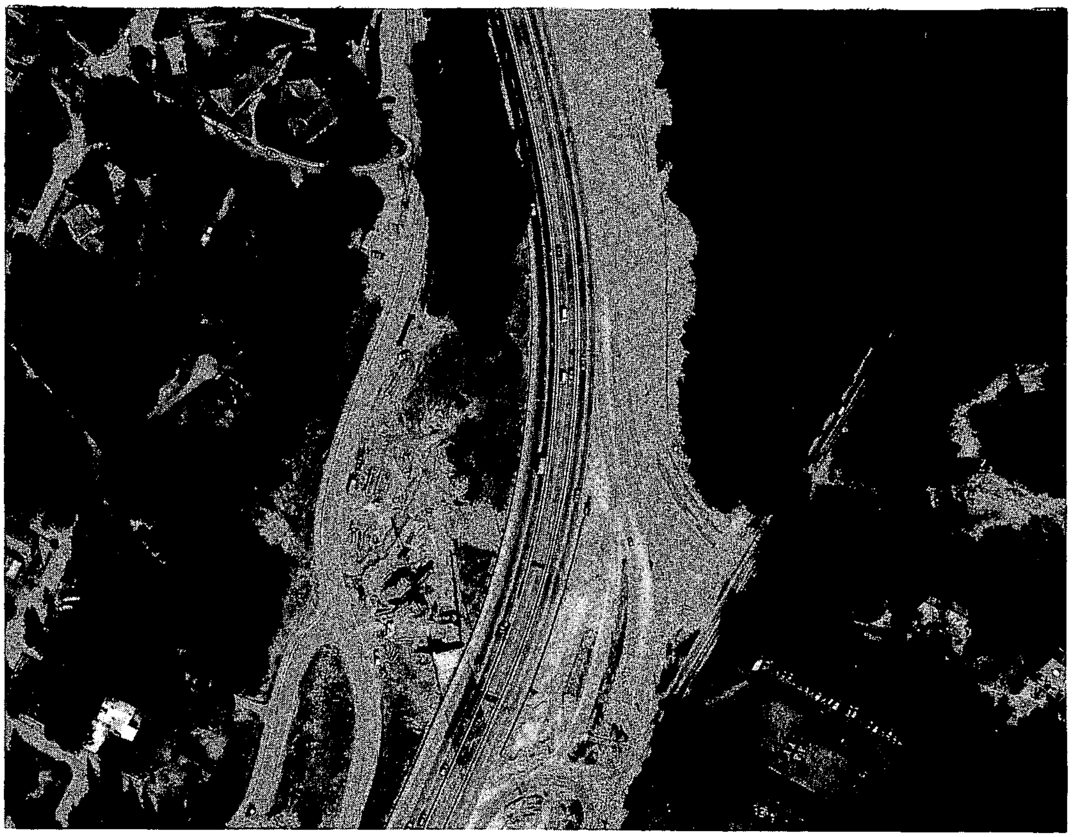


Figure 4-2. Location #1

Curve Data

Central Angle (Δ)	35° 14' 31" Right
Radius (R)	1,200 ft.
Tangent (T)	381.15 ft.
Curve Length (L)	738.11 ft.
Grade	+1.76%
Normal Pavement Crown	±2.00%
Full Super-elevation	4%
Length of Location	1,000 ft.

Figure 4-3. Location #2

Curve Data

Tangent	
Grade	+2.57%
Normal Pavement Crown	±2.00%
Length of Location	1,000 ft.

Figure 4-4. Location #3

Curve Data

Tangent Section	
Grade	-.60%
Normal Pavement Crown	±2.00%
Length of Location	1,000 ft.

Figure 4-5. Location #4

Curve Data

Tangent Section	
Grade	-1.60%
Normal Pavement Crown	±2.00%
Length of Location	1,000 ft.

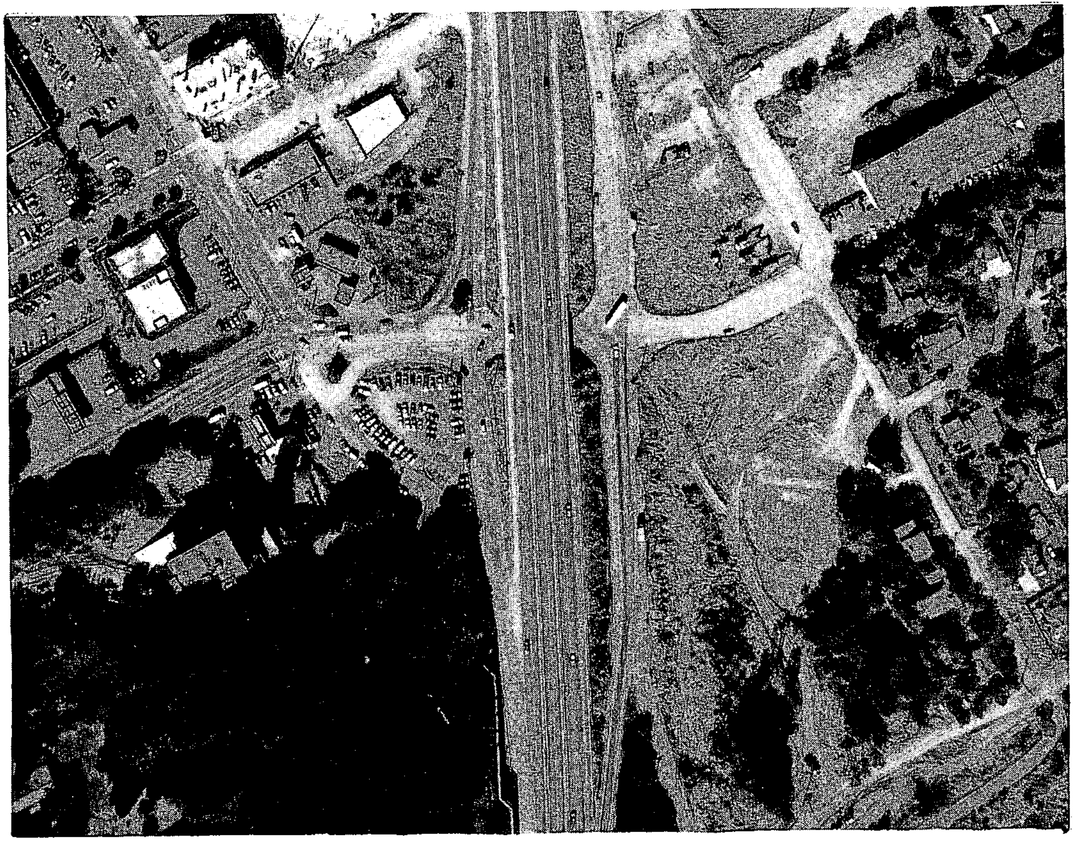


Figure 4-6. Location #5

Curve Data	
Tangent Section	
Grade	-0.80%
Normal Pavement Crown	±2.00%
Length of Location	1,000 ft.

Figure 4-7. Location #6

Curve Data

Central Angle (Δ)	30° 13' 31" Right
Radius (R)	1,910 ft.
Tangent (T)	515.81 ft.
Curve Length (L)	1,007.56 ft.
Grade	+1.40%
Normal Pavement Crown	±2.00%
Full Super-elevation	4%
Length of Location	1,000 ft.

Figure 4-8. Location #7

Curve Data

Central Angle (Δ)	100° 55' 24" Left
Radius (R)	955 ft.
Tangent (T)	1,156.93 ft.
Curve Length (L)	1,682.18 ft.
Grade	+1.40%
Normal Pavement Crown	±2.00%
Full Super-elevation	7%
Length of Location	1,000 ft.

CHAPTER FIVE
FIELD MEASUREMENTS AND OBSERVATIONS

After the devices were installed on Interstate-90, a number of variables were observed and measured, including luminance, the effects of dirt and moisture on the devices, the effects of snow, and the relationship between placement of the devices and the amount of dirt that accumulated on them. The team also observed the effects of wind and gravity and noted whether the devices could be used again, how easy they were to vandalize, and how long it took to install them.

SPECIFIC LUMINANCE MEASUREMENTS

The reflectors were installed on July 22, 1985, and their specific luminance (in Candelas/square foot/foot candle) was taken on August 22, 1985, after one month of exposure. A retro-Tech instrument with a 910 optical head was used to take the readings. The research team zeroed the instrument, checked its battery power level, and then checked its accuracy by measuring the specific luminance of a specimen material (supplied with the instrument). The instrument was adjusted until its reading matched the known luminance of the specimen. At this point the equipment was ready for use. The delineators were cleaned with a few towel strokes, then readings were taken by pressing the instrument (which is like a radar gun) on the reflective surfaces and reading their specific luminance values. The same instrument was used to evaluate all the reflectors. Tables 5-1 through 5-3 show the specific luminance readings.

Note that the more dependable readings were from the dirty devices. Because the devices were not cleaned using any standard procedure (i.e., constant pressure of applied strokes, constant cleanliness of the rag used, etc.), the reflectivity values for the reflectors after cleaning should be considered secondary.

Table 5-1. Specific Luminance Readings for Astro-optics*

Delineator Number	Before Cleaning (cd/sf/fc)	After Cleaning (cd/sf/fc)
1	325	1312
2	497	1738
3	350	1129
4	481	1650
5	281	1150
6	306	1298
7	297	1486
8	315	1513
9	234	1669
10	343	1430
11	235	1136
12	276	1786
13	253	1807
14	224	1580
15	156	1056
16	266	1769
17	226	1509
18	217	1650
19	165	1658
20	160	1735
21	164	1503
22	191	1600
24	94	1164
25	172	1505

Average reflectance = 256.56 cd/sf/fc (Dirty); Standard Deviation = 96.05 cd/sf/fc
1482.12 cd/sf/fc (Cleaned); Standard Deviation = 235.39 cd/sf/fc

* Note that the more useful readings are those of the dirty delineators. Because no standard method of cleaning was used, the readings taken after cleaning are secondary and are only good for comparison to dirty reflectors. Most importantly, they emphasize the need to clean the delineators on a regular basis (monthly).

Table 5-2. Specific Luminance Readings for Reflexite*

Delineator Number	Before Cleaning (cd/sf/fc)	After Cleaning (cd/sf/fc)
1	55	430
2	60	392
3	66	428
4	66	386
5	57	360
6	85	388
7	66	340
8	79	315
9	93	350
10	120	480
11	111	445
12	110	403
13	82	343
14	97	412
15	80	377
16	59	375
17	73	330
18	59	395
19	74	320
20	47	324
21	71	395
22	70	306
23	67	343
24	80	418
25	68	389

Average reflectance = 75.40 cd/sf/fc (Dirty); Standard Deviation = 19.57 cd/sf/fc
377.76 cd/sf/fc (Cleaned); Standard Deviation = 44.39 cd/sf/fc

* Note that the more useful readings are those of the dirty delineators. Because no standard method of cleaning was used, the readings taken after cleaning are secondary and are only good for comparison to dirty reflectors. Most importantly, they emphasize the need to clean the delineators on a regular basis (monthly).

Table 5-3. Specific Luminance Readings for Cylinders and Hazard Panels*

Delineator Number	Before Cleaning (cd/sf/fc)	After Cleaning (cd/sf/fc)
1	17	48
2	15	55
3	13	45
4	14	57
5	11	54
6	14	47
7	13	56
8	19	54
9	10	36
10	17	48
11	20	45

Average reflectance = 14.8182 cd/sf/fc (Dirty); Standard Deviation = 3.1545 cd/sf/fc
49.5455 cd/sf/fc (Cleaned); Standard Deviation = 6.3461 cd/sf/fc

* Note that the more useful readings are those of the dirty delineators. Because no standard method of cleaning was used, the readings taken after cleaning are secondary and are only good for comparison to dirty reflectors. Most importantly, they emphasize the need to clean the delineators on a regular basis (monthly).

A comparison of the average specific luminances of the Astro-optics, Reflexite barrier-top markers, hazard panels and cylinders, showed the former to be the brightest device. The Astro-optics and the Reflexite barrier-top markers were placed on top of the barrier and at approximately the same roadway segment. 3M high intensity grade flexible sheeting was used on both the hazard panels and the cylinders. Readings were taken from the hazard panels' lower stripes. The flat surfaces of the panels were more amenable to the measuring instrument than were the curved surfaces of the cylinders. Thus, the readings given in Table 5-3 apply to both devices.

The other delineators were not measureable. The reflective surfaces of the raised pavement markers were too narrow for the retro-Tech instrument to measure. A possible solution to this problem would have been to remove a sample and send it to the state materials laboratory in Olympia (60 miles from the study site). However, a serious disadvantage of this solution would have been that some of the attracted dirt would have fallen off during packaging and in transit. In addition, some of the adhesive dirt would have been rubbed off, if not in packaging, probably in transit. With some of the naturally attracted dirt gone, a fair comparison between this device and the others would not have been possible.

Additionally, the reflective surfaces of the raised pavement markers placed on the barrier face were too narrow to be measured (see plate 7-5, page 59). Raised pavement markers placed on the pavement on the barrier side of the edge line (second stage of the survey) performed even worse because they were covered by sand and debris.

The reflective sheeting of the Davidson markers was also too narrow for the retro-Tech instrument to measure. Due to this narrowness and their placement on the pavement, they lost reflectivity rapidly. Like the raised pavement markers, they were also covered by debris and sand.

DETERIORATION AGENTS

Consideration of the causes of deterioration associated with the environment in which the reflectors are placed is appropriate. Such agents, though numerous and complex, can be grouped under manageable categories for ease of discussion.

Sources of Dirt

Dirt accumulates on reflectors from two sources:

- traffic, and
- work done in the surrounding area (9).

Dirt may be of three types:

- adhesive,
- attracted, or
- inert.

Dirt in all three categories may come from intermittent or constant sources.

While attracted dirt clings to the reflector surface by means of electrostatic forces, adhesive dirt sticks to the reflector surface by virtue of its adhesive properties. Examples of adhesive dirt include exhaust fumes from automobiles, fumes from construction equipment, construction chemicals, and oil vapor. This kind of dirt is ordinarily harder to wipe off than attracted or inert dirt. The accumulation of such dirt varies with

- the intensity of construction work in a particular area,
- the type of chemicals and machinery used,
- the volume and speed of traffic, since heavier traffic creates more exhaust fumes, and
- pavement condition. Of course, on sections with a relatively higher accumulation of dirt on the pavement, splashes from traffic caused more

dirt accumulation on reflectors. This category of dirt came off more easily by applying a few strokes of the cleaning towel.

In order to remove the adhesive dirt due to exhaust fumes and oil particles, the devices were washed with a mild soap solution.

Attracted dirt includes lint, fibers, and particles which are produced from machine operations. This dirt was easily removed with a towel.

Inert dirt consists of non-sticky, uncharged particles, usually from light dust blown up by passing traffic. Such particles may touch and fall off the surfaces of the reflectors.

The degree to which a particular kind of dirt affected a particular reflector depended on the reflector's shape, size, mounted position on the barrier, and surface luster. Reflexite barrier top markers, for instance, reflected very well when new or washed with soap. However, their drab yellow sheeting accumulated dirt faster, and thus their reflective capabilities were short-lived relative to those of the Astro-optics. The two kinds of reflectors are similar in a couple of ways:

- the areas of their reflective surfaces are fairly equal; and
- they are both mounted on top of the barrier (plates 2-1 and 2-2, pages 5 and 6).

These two sets of devices were mounted back-to-back and were exposed to approximately the same kinds and amounts of dirt. However, their reflectance readings (tables 5-1 and 5-2) were consistently different. The major differences between the Reflexite and the Astro-optics markers include the following:

- Reflexite barrier-top markers have an exposed reflective sheeting. This sheeting was prone to scratching and rapid dirt accumulation. Consequently, the markers' reflectivity degenerated more rapidly. This observation was also made for the other delineators with exposed sheeting: reflective cylinders, hazard panels and Davidson markers.

- Astro-optics barrier-top markers, on the other hand, have reflective prisms encased inside a solid plastic covering. The result of this design is that even after the plastic covering was scratched from cleaning, the reflective properties of the material were not affected. Furthermore, the plastic covering is sturdy. (Another delineator with this type of design is the raised pavement marker). This design provides durability and reusability.

Effect of Moisture

The outer rims of the high intensity sheetings used on the hazard panels and reflective cylinders deteriorated from moisture. This deterioration was observed only along the edges and did not affect the middle region of the sheeting. Reflexite barrier-top markers, Astro-optics and raised pavement markers did not show this kind of deterioration.

Effect of Snow

Barrier-top mounted devices, especially the smaller ones (see plates 2-1 and 2-2 on pages 5 and 6) would have been covered by snow deposits on the barrier top. Just because of their size, the cylinder and hazard panels would still have been visible after a snow storm (see plates 2-3 and 2-4 on pages 7 and 8).

Because of their placement, the raised pavement markers and the Davidson markers would have been buried in snow (see plates 2-5 and 2-7 on pages 9 and 11). Astro-optics on the barrier face, at 26 inches above the pavement, was least prone to snow coverage, and with only its narrow edges vertically exposed, it had no surface on which snow could accumulate (see Plate 2-6 on page 10).

Placement and Dirt Accumulation

The devices accumulated dirt in proportion to their proximity to the pavement. Raised pavement markers and Davidson markers were covered with sand. Some of these devices became totally hidden from view.

Raised pavement markers placed on the barrier face one foot from the base accumulated dirt from several sources.

- Dirt washed down the barrier face. However, prolonged and heavy rainfall cleaned the reflectors.
- Dirt splashed from traffic, making the devices very non-reflective. This, especially, was the source of the dirt accumulated by raised pavement markers on the barrier face.

Generally, devices placed higher up on the barrier collected relatively less dirt from splash.

Problems with Current Delineation Practice

Currently, the state requires raised pavement markers to be placed on the barrier side of the edge line. One reason for this is that, although vehicle tires may polish and clean some raised pavement markers placed on the traveled-lane side of the edge line, they damage many others when they run over them. The research team observed this problem. On the other hand, markers placed on the barrier side of the edge line became covered by sand and debris, especially where the gap between the edge line and the barrier was one foot or less. In most cases, they got so buried in sand that they were completely non-reflective. However, on wide shoulders, raised pavement markers placed behind the edge line were not covered by sand as often.

Because of these problems, the author suggests placing raised pavement markers on the barrier side of the edge line in wide shoulders and delineating concrete barriers by some other effective means (to be suggested later in this report) in narrow shoulders.

OTHER FIELD OBSERVATIONS

Wind Forces

Wind forces had no observable effect on any of the seven delineators. Hazard panels, which were the most likely to be disturbed by wind, showed no deflections. They were as firm as the others.

Gravitational Forces

This was a major problem with the barrier-face mounted devices. They slid down the barrier while the epoxy was wet. However, after the epoxy was set, they were firm.

Reusability

All the devices were reusable except for the Davidson markers, which would not stick a second time. The hazard panels were reusable, but their base caps were absolutely not reusable. New base caps had to be set up in every new location. When they were not properly aligned, the pin tore through the base caps and the shafts, destroying them permanently.

Vandalism

Vandalism was minimal. Four of the numbering panels and three cylinders were lost to vandalism. After replacing these, they stayed intact throughout the study. None of the other delineators was affected by vandalism.

Installation Time

Table 5-4 summarizes installation times for comparison purposes. Davidson markers took the least amount of time to install, hazard panels the most time. Astro-optics on the barrier face were at the mid-point.

Table 5-4. Installation Time Summary

Number of Devices per 1000'	Device Type	Total Installation Time* per 1000'
64	Davidson Markers (on edge line)	128 seconds
26	Astro-optics (on barrier top)	383 "
26	Reflexite (on barrier top)	383 "
26	Raised Pavement Markers (on pavement)	383 "
26	Astro-optics (on barrier face)	539 "
26	Raised Pavement Markers (on barrier face)	539 "
11	Cylinders (on barrier top)	772 "
11	Hazard Panels (on barrier top)	1003 "

* Total installation time does not include the following:

- Travel time from the shop to the field.
- Travel time between delineators.
- Time for mixing epoxy.

For hazard panels and cylinders, installation time includes time for preparing these devices for installation (i.e. , punching holes, mounting reflective sheeting, etc. See Appendix A).
These are relative installation times for comparison purposes.

A time and motion analysis is presented in Appendix A. The time as calculated did not include time for moving from one installation to another. This was accomplished by walking, running, or driving. Only the time needed to prepare and place the delineators on the barrier was considered. In addition, time was based on three people working in concert.

The installation times reflect the ease of installation. For instance, Astro-optics on the barrier face required more time than Astro-optics on the barrier top because the former needed to be held in place (with electrical tape) while the epoxy was wet (see Appendix A).

CHAPTER 6
QUESTIONNAIRE DESIGN

The study plan included measuring drivers' responses to the delineators. Therefore, a questionnaire was devised for the motorists. The questionnaire was designed to test their perception of the delineators' brightness, their comfort with the roadways' alignment, the effects of opposing traffic headlight glare on the delineators' effectiveness, at what distance from the barrier the drivers felt most comfortable, how fast they felt comfortable driving, and how they liked the delineators in general.

STATEMENT OF HYPOTHESES

Four hypotheses were used in the early stages of the study to aid in the development of the questionnaire. These hypotheses included the following:

> Hypothesis #1: Drivers who are not sure of the roadway alignment will apply their brakes more often than drivers who are familiar with the roadway alignment.

A traditional way of checking for brake application is by counting brake light indications. This is a fairly easy task in the daytime. However, at night cars' taillights are on and brake lights are not easy to see. More importantly, the 85th percentile speed at the study location was 58 miles per hour. Thus, drivers were not using their brakes often.

> Hypothesis #2: A driver who is not sure of the roadway alignment will drive at a relatively lower speed.

Traditionally, this would be measured by traffic speeds before and after the installation of the devices. However, Davis found that there was no significant speed change due to the installation of delineation devices (5). In addition, a random sample of speeds taken before and after the installation of reflective cylinders showed no significant difference in vehicle speed.

Hypothesis #3: A driver who is not sure of the roadway alignment will encroach relatively more often on the roadway centerline.

Davis found that the installation of delineation devices at the centeline significantly affected drivers' proximity to the centerline (5). Therefore, the study team speculated that delineators installed on or near the barrier would have an effect, although not measureable because of the number of variables, on how close to or far from the barrer motorists drove.

Hypothesis #4: All of the above conditions will be easily observed if the driver is not familiar with the roadway section.

This hypothesis was based on the fact that drivers unfamiliar with the road would depend more on the reflectors for guidance and would show observable reaction to the positive or negative guidance provided by them.

MEASURES OF EFFECTIVENESS

Based on these hypotheses, the questionnaire was designed to test the psychological responses of a random sample of motorists to the different reflector sets. A sample of the questionnaire is shown in Appendix C. Among the factors investigated were those below, the order of which changed from one questionnaire to another.

Brightness

Although the brightness of the reflectors was measured by a reflectometer, drivers' perception of their brightness was also considered helpful. Brightness may be influenced by device shape and placement (either on top or on the face of the barrier or even on the pavement). This is because the amount of light reflected by a device depends on the height of a vehicle's headlights, the surface area of the reflective surface and the angle of observation.

Subjects were, therefore, asked to rate each device on a scale of "bright/not bright" (see Appendix C).

Driver Comfort with Roadway Alignment

This question was derived from hypotheses #1, #2, and #3. Reflectors are meant to show the driver how the roadway is aligned. They may or may not influence the decisions to drive faster, apply the brakes, or encroach on the adjacent lane. However, comfort with roadway alignment is a basic function of barrier delineators.

Subjects were asked to rate each reflector set on a scale of "comfortable/not comfortable" (Appendix C).

Effect of Opposing Traffic Headlight Glare

A common problem in nighttime driving is the effect of opposing headlight glare on visibility. The reflectors, therefore, needed to be evaluated for their effectiveness under such conditions. Subjects were asked to rate each reflector set on a scale of "could see reflectors/could not see reflectors" (Appendix C).

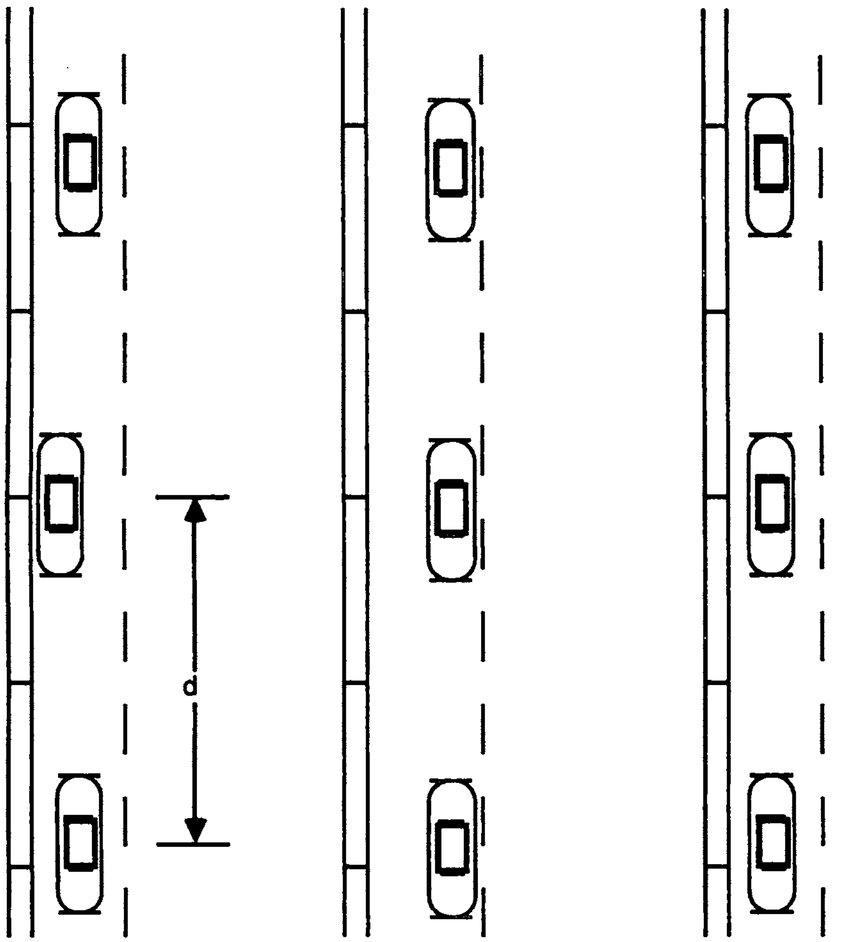
Vehicle Placement

Hypothesis #3 postulated that drivers who are not sure of roadway alignment will encroach more on the adjacent lane. In other words, drivers will "keep their distance" from the barrier. A statistical test by Davis found a significant difference in "weaving" before and after the installation of delineation devices (5).

Vehicle placement can be broken down into three scenarios:

Scenario 1: The driver drives too close to the barrier. He almost hits the barrier. He then corrects his course. After the same mistake again and again, he experiences Scenario 2. Scenario 1 is equivalent to "weaving" (see Figure 6-1).

Scenario 2: In this scenario, the driver decides to keep a "safe distance" from the barrier. This safe distance may encroach on the adjacent lane or center line. Scenarios 1 and 2 are most likely to occur where the driver is not sure of roadway alignment (Figure 6-1.)



Scenario 1

Scenario 2

Scenario 3

Note: For Scenario 1, Distance "d" may vary from hundreds of feet to miles.

Figure 6-1. Vehicle Placement Scenarios

Scenario 3: In Scenario 3, the driver is sure of the roadway alignment (i.e., the location of the concrete barrier). Such a driver stays close enough to the barrier to place his or her vehicle in the middle of the lane, without encroaching on the center line (Figure 6-1).

Scenario 3 is most likely to occur where an effective barrier delineator is installed. An ineffective delineator will cause scenarios 1 and 2.

Subjects were asked to rate each reflector set on a scale of "closer to barrier/further away from barrier" (Appendix C).

Speed

This question was derived from hypotheses #1 and #2. The question measured a psychological rather than physical reaction. Because Davis (5) showed that there was no significant change in speed (5), the speed question was framed thus:

"Please rate each set of reflectors on how much it tempted you to go faster or slower than you usually drive."

The rationale for this question was that drivers who are sure of roadway alignment ahead of them will be more confident to go faster. This questions was reworded to aid subjects in judging their responses:

"Please rate each set of reflectors on how much it tempted you to remove your leg from the gas pedal."

Common sense dictates that a person who removes his or her leg from the gas pedal is trying to "figure out something." His or her leg will either go to the brake pedal or go back to the gas pedal depending on what he or she figures out. This question was intended to measure temptation and not the actual action per se. Obviously, the precise measurement of a factor as subliminal as this would need a much finer instrument than the questionnaire used here. But no doubt, the factor has a bearing on the effectiveness of a delineator.

Subjects were asked to rate the reflectors on a scale of "faster/slower" (Appendix C).

Personal Opinion

This was a catch-all question. The driving public may like a reflector for several reasons, including its shape, size, placement on the barrier, and brightness. Therefore, this question was intended to help the subject to put these attributes together and formulate an opinion. It was meant to shorten the length of the questionnaire. An excessively lengthy questionnaire might have alienated the subject and negatively impact his or her responses to the questions generally. Subjects were asked to rate each reflector set on a scale of "like/dislike" (Appendix C).

Comments by subjects were solicited between questions (Appendix C). Finally, subjects were asked to rank the three best reflectors in order to check the consistency of their responses. The research team anticipated that subjects who really paid attention and participated sincerely in the study would answer consistently, and they would rank the three reflectors that received the most favorable marks in their other ratings. On the other hand, people who did not really do the evaluation might give unfavorable ratings to some reflectors and yet rank them as the best three. The reseràchers would drop inconsistent returns from the analysis.

This question was framed thus:

"Please rank your choice of three best sets of reflectors by entering their appropriate numbers.

1st Reflector # ______

2nd Reflector # ______

3rd Reflector # ______"

(See Appendix C.)

Other questions included the following:

- "How often do you drive this route at night?"

This question was intended to ascertain driver familiarity with the study section and was derived from Hypothesis #4.

- "For how many years have you held a driver's license?"

Besides helping to estimate driving experience and skills, this question also helped determine the ages of the drivers. Since most Americans get their driving license at the age of 18, an estimate of age could also be made by adding 18 years to the length of experience (probably plus or minus a two-year error range). This was another effort to avoid alienating the subjects by asking them directly how old they were. Some might have seen no relationship between a question of age and the subject matter.

- "How often do you drive on a highway at night?"

This question was intended to identify subjects who drive on a highway very often at night. Thus, they would be able to indicate the needs of the nighttime driver. Commuters would register higher highway nighttime driving.

A question on driver occupation was considered potentially alienating because it had no bearing on the study. Moreover, it would have contributed little information as long as the sampling process was random. Note that biographical information was collected to help choose the best delineator in case of ties.

CHAPTER SEVEN
SURVEY STAGE ONE

The study's field tests took place in two phases. In the first phase drivers tested all of the various delineators. After appropriate sample sizes were determined for the test, subjects were randomly selected by telephone. They drove the designated route on Interstate-90 and then filled out the prepared questionnaires. Their answers were then analyzed to find the preferred delineator.

SAMPLE SIZE DETERMINATION

The number of judges necessary to ensure that the seven reflectors were significantly different at the 95 percent confidence level was determined as follows (11):

$$N = \frac{Q^2 \alpha(K)(K+1)}{12}$$

where

α = 0.05

Q = studentized range for K objects at infinite degrees of freedom at 0.05 level of significance = 4.17

K = 7

N = $(4.17)^2(7)(8) = 81.1482 = 82$

This non-parametric model is useful in multiple comparisons. It gives the required number of judges necessary for detecting the differences between objects. The model declares that objects whose rank sums are significantly large would have significantly different means. The test for significance is performed on page 69.

SAMPLING PROCEDURE

A random sample of telephone numbers of Eastside residents was obtained using the Eastside telephone and the Rand Corporation's Random Digit Book (12), a book developed by the Rand Corporation to serve as a pool of random numbers for research. The Eastside telephone directory covers the cities of Bellevue, Issaquah, Kirkland, Redmond, Bothell, Duvall, Juanita, Kenmore, Mercer Island, and Woodinville. All the phone numbers in the 873-page directory had an equal chance of being selected.

The steps involved in selecting phone numbers are shown in Figure 7-1.

A total of 1,225 phone numbers were called, with a response rate of 8.6 percent (see Table 7-1). A subject was required to have a valid driver's license in order to qualify.

The phone numbers called had the following prefixes:

232	451	641	746
233	453	643	747
236	454	644	
		455	

A constant digit of 1 was added to the last digit of every phone number. For instance, 451-5838 became 451-5849. Changing the phone numbers this way expanded the database and made the inclusion of unpublished numbers possible.

INSTALLATION CONFIGURATIONS

The reflectors were installed on an unlighted segment of Interstate-90 on Mercer Island (see plates 7-1 through 7-8). Each reflector set was installed over a 1,000-foot segment of the study section. Each set was numbered by placing the number in the middle of each location, i.e., 500 feet from the beginning of each set of reflectors. The installation procedure and times for each reflector set are summarized in Appendix A.

The plan was to switch the reflector sets so that each set would have a chance to be on a right curve, a left curve, on a tangent, and to precede and be preceded by the other reflectors. Based on this idea, the plan shown in Table 7-2 was drawn up. The numbers refer to the locations. However, a reflector set at a particular location was

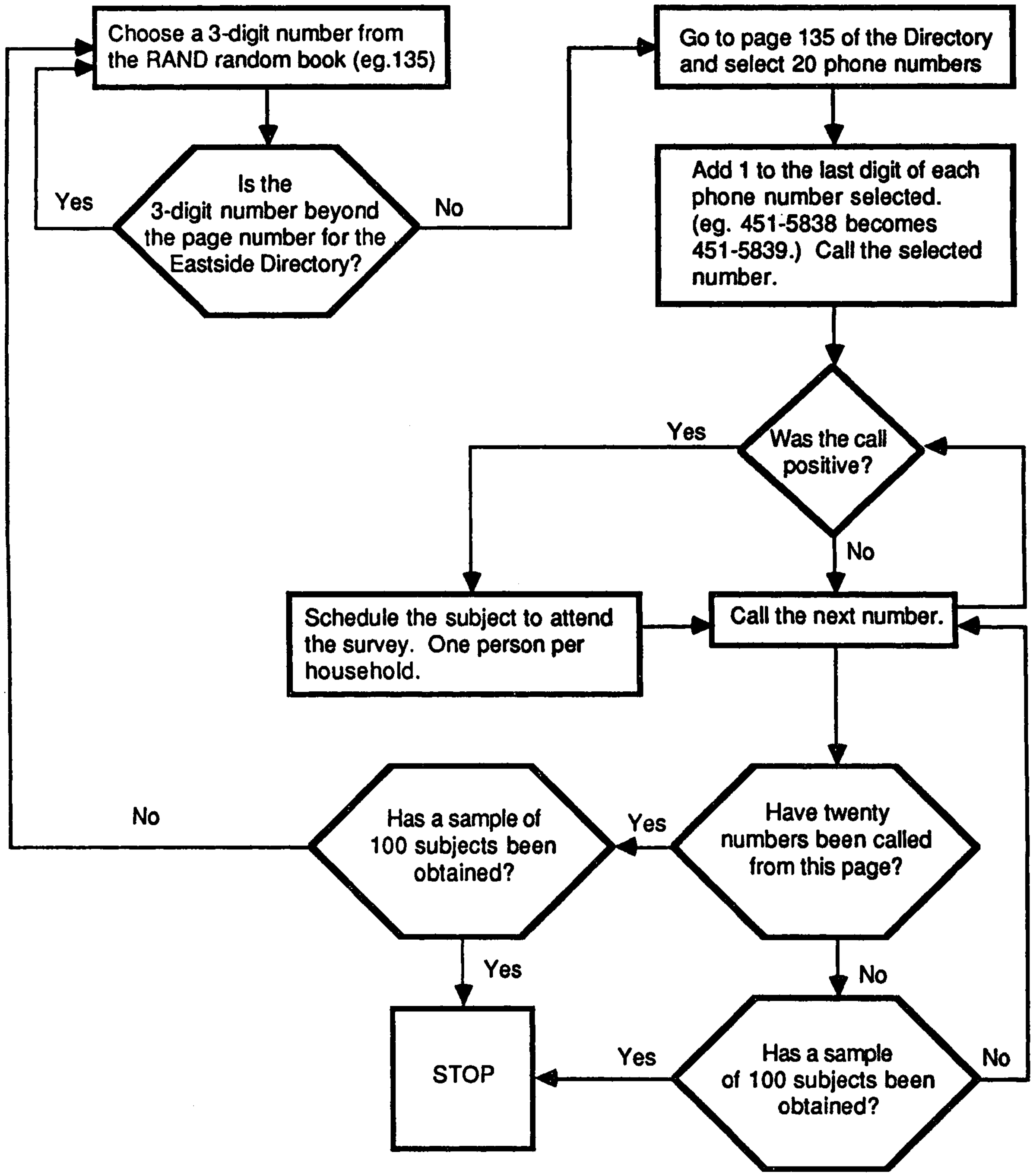


Figure 7-1. Subject Recruitment Routine.

Table 7-1. Results of Phone Calls

Number of Calls	Outcome of Calls
197	Refused to participate.
237	Agreed to participate but did not show up.
43	Had no valid driver's license.
14	Disabled.
107	Agreed to participate and showed up. Two did not complete study.
26	Business phones.
601	Unable to reach.

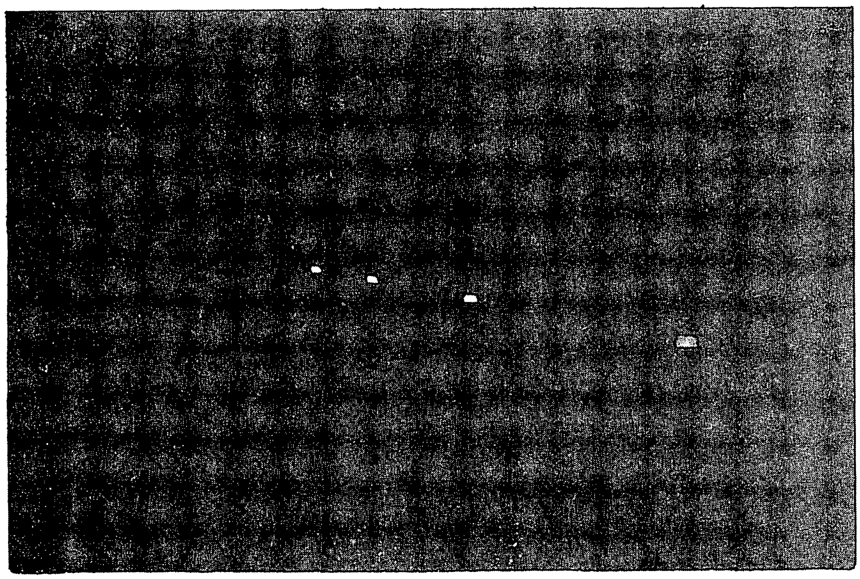


Plate 7-1

Nighttime View of Astro-optics on Barrier Top

Plate 7-2

Nighttime View of Reflexite on Barrier Top

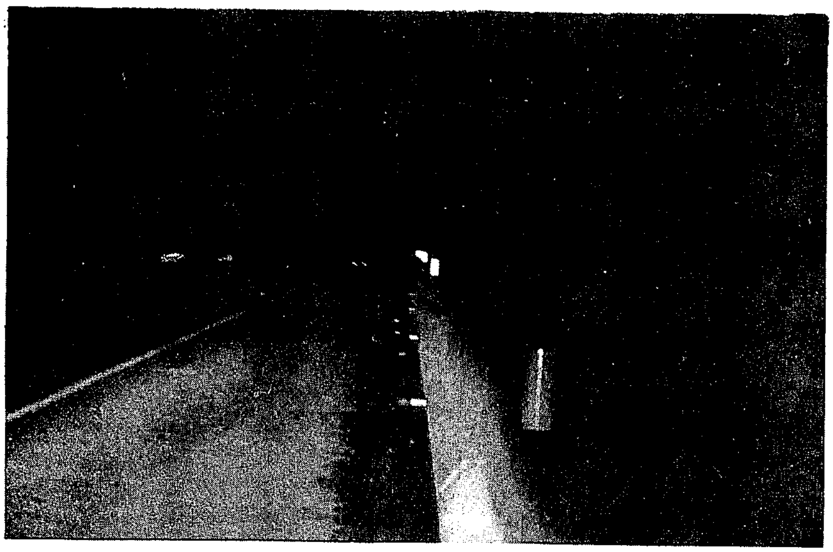


Plate 7-3

Nighttime View of Cylinders on Barrier Top

Plate 7-4

Nighttime View of Hazard Panels on Barrier Top

Plate 7-5

Nighttime View of Raised Pavement Markers on Barrier Face

Plate 7-6

Nighttime View of Astro-optics on Barrier Face

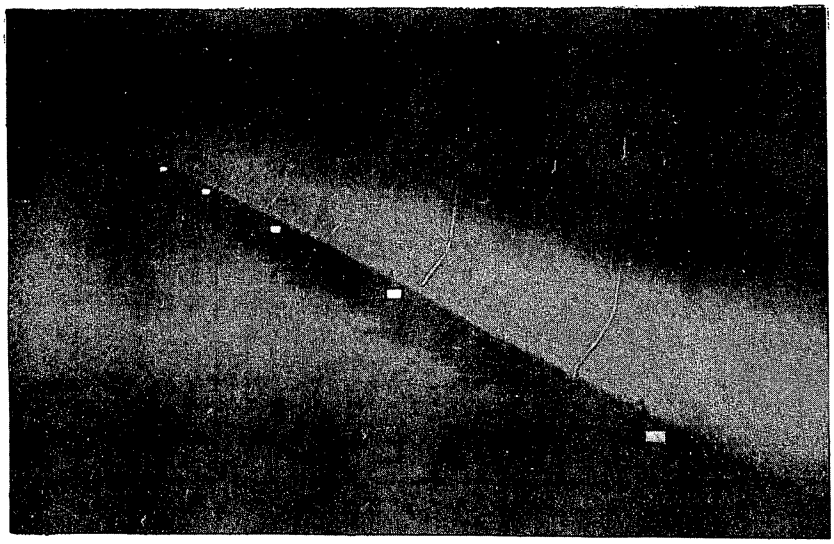


Plate 7-7

Nighttime View of Davidson Markers on Edge Line

Table 7-2. Planned Device Configurations

A	B				C	D
1	2	3	4	5	6	7
7	6	5	4	3	2	1
4	1	7	1	6	3	5
5	3	6	1	7	1	4
2	4	1	7	3	5	6
3	5	6	1	4	7	1
6	7	2	5	1	4	3

where region A is a right curve
region B is a tangent or straight section
region C is a right curve and
region D is a left curve

1 = Astro-optics on top of barrier
2 = Reflexite Cylinders
3 = Reflective Cylinders
4 = Hazard Panels
5 = Raised Pavement Markers on barrier face
6 = Astro-optics on barrier face
7 = Davidson Markers on edge line

automatically identified by that number in the course of administering the questionnaires.

As the study proceeded, the study team realized that moving the hazard panels (in section 4) was not cost effective. These panels were the most costly of all the devices in terms of both labor and material (Table 7-7, page 73). Moving one hazard panel involved the following steps:

- drilling holes through the new caps,
- setting up new caps at the new location,
- spraying the pins with rust-proof chemical,
- leaving the epoxied new caps overnight for the epoxy to set (see Plate 7-9),
- coming back the next day to very skillfully punch out the pins from the old caps, and
- transferring the usable panels to the new location and going through the regular process of installing them. This involved punching out the pins from the caps, aligning the holes in the shaft and caps, and then punching the pins back in. This had to be carefully done otherwise the pins would tear through the base of the shaft and cap, rendering them useless.

The study team tried moving one panel, base and shaft at the same time, but the bulky panel would not be supported by wet epoxy. Very fortunately, they were already on a straight section. So they were left there throughout the study. The actual configuration was, therefore, as shown in Table 7-3. Note that the hazard panels were meant to serve as glarescreens, also.

Different groups of subjects evaluated each of the four configurations. Appendix E shows that installation configuration, per se, had no effect on ratings.

Table 7-3. Actual Device Configurations

A	B				C	D
1	2	3	4	5	6	7
7	6	5	4	3	2	1
7	6	1	4	2	3	5
5	7	1	4	2	3	6

where region A is a right curve
region B is a tangent or straight section
region C is a right curve and
region D is a left curve

1 = Astro-optics on top of barrier
2 = Reflexite Cylinders
3 = Reflective Cylinders
4 = Hazard Panels
5 = Raised Pavement Markers on barrier face
6 = Astro-optics on barrier face
7 = Davidson Markers on edge line

SURVEY ADMINISTRATION

The subjects arrived at the study center (Washington State Department of Transportation office on Mercer Island) at about 7:30 p.m. The questionnaire administration routine was as follows.

- The purpose of the study was explained.
- Copies of the questionnaire were given to the subjects to read and ask questions.
- Samples of the reflectors were shown.
- The location and placement of each type of reflector were explained.
- Directions on how to get to the study site were explained.
- Subjects were advised to drive the course as many times as they would need to be able to answer the questions. However, they needed to drive the course a minimum of three times.
- Subjects drove their own vehicles.

Before the survey began, the survey administrator drove the course and found that one lap took about seven minutes to complete. Therefore, these trips around the course would take no less than 21 minutes.

- Subjects were asked to leave the questionnaires behind while they went out to drive the course.
- When they came back, they needed to be able to identify the reflector samples in terms of their numbers and placement on the barrier.
- When the subjects did this successfully, they were given back their questionnaires to complete.
- Subjects were asked not to discuss their opinions with others.

The order of the questions was varied by shuffling the pages of the questionnaire. This was thought necessary to de-emphasize the importance (or lack thereof) of the factors. In other words, some subjects might have been led to believe that the brightness factor was more important the others because it appeared first on the questionnaire. Assuming this to be the case, the study team tried to be fair by giving each factor an opportunity to be regarded as prime.

Of the 89 people who showed up for this stage of the survey, only two did not complete it. One subject left and did not come back. The other came back and could not identify the samples. He did not want to drive the course anymore. Because his response would not have been useful, he was not allowed to complete the questionnaire, and therefore, was not paid.

CHECK FOR CONSISTENCY OF RATINGS AND RANKINGS

Consistency was checked for each subject by summing up his or her ratings for each reflector type. Based on these sums, the three best reflectors were ranked. This ranking was then compared with the ranking done by the subject. Questionnaires that were not consistent were dropped from further analysis.

All 87 of the questionnaires in the first stage of the study were consistent. This high level of consistency might be attributed to the fact that this survey was a little different from an ordinary survey. The following peculiar features are rarely found in an ordinary survey.

- Subjects were asked to leave the questionnaires behind while going out to drive. This especially removed the temptation of filling out the questionnaires before finishing the driving.
- Subjects were asked to identify the delineators (by number and placement) before they were given back the questionnaires to fill out. This not only helped prove that the subjects drove the course, it also helped them refresh their memories. On balance, the high level of consistency was a good return on the effort invested in planning and administration.

Having established the rankings to be consistent with the ratings, the number of times each reflector set was ranked first, second and third was tabulated (see tables E-1 through E-8 in Appendix E). Table 7-4 shows the total ranking frequencies for all the the devices evaluated. Fifty-three percent of the subjects ranked Astro-optics on the barrier face (six inches below the barrier top) as the best. Since the Astro-optics placed on the barrier top did not do as well, the author infers that their different positions on the barrier (placement) was a major deciding factor.

TEST FOR SIGNIFICANCE OF DIFFERENCES BETWEEN DELINEATORS

Barrier-top mounted delineators were observed to be washed out by opposing traffic headlight glare. Raised pavement markers and Davidson markers were observed to be most prone to being covered by snow. Therefore, they were dropped from further analysis. However, they were considered in the following test for significance.

Dunn-Ranking and Wilcoxon investigated the distribution of the range of the differences between rank sums (11). The critical values can be calculated using the following relationship:

$$E(S) = \frac{N(K)(k-1)}{12}$$

where E(S) = Expected standard deviation

N = Number of subjects = 87

K = Number of delineators = 7

= 0.05

Q0.05 = 4.17

Thus

$$\text{Critical Range} = \frac{87(7)(6)\,4.17 = 72.76}{12}$$

Table 7-4. Total Ranking Frequencies: Stage 1

		Device						
		Raised Pavement Markers	Davidson Markers	Astro-optics	Hazard Panel	Reflexite	Cylinder	Astro-optics
	Location	1 ft. above pavement	on edge line	barrier top	barrier top	barrier top	barrier top	barrier face
	Spacing	40'	16'	40'	100'	40'	100'	40'
Device Rank	Best	2	10	9	10	3	7	46
	Second Best	12	10	9	20	2	21	13
	Third Best	7	2	16	16	8	23	15

Survey Period: September 26 to October 7, 1985

Total number of subjects: 87

Number of years held driver's license: Range, 5 - 60 years; Mean, 25.9 years.

Approximate Age: Range, 23-78 years; Mean, 43.8 years.

Therefore, any rank difference above 72.76 would be considered significant (i.e., not occurring by chance).

Table 7-4 is transformed into Table 7-5 by assigning the values of 3 for "Best," 2 for "Second Best," and 1 for "Third Best." The rank values in Table 7-5 were obtained by multiplying the corresponding frequencies in Table 7-4 by 3 (for "Best"), 2 (for "Second Best"), and 1 (for "Third Best").

The rank differences shown in Table 7-6 were obtained by finding the difference in the sum of rank values for each pair of delineator types.

Table 7-6 shows that Astro-optics on the barrier face was significantly different from the other delineators. Cylinders and hazard panels tied at a distant second. This might be attributed to their partial visibility in the presence of opposing traffic glare, simply due to their larger sizes (see Appendix F).

CORRELATION ANALYSIS

One of the questions on the questionnaire asked respondents to give their personal opinions by ranking each delineator on a scale of "like/dislike." Obviously, subjects based their decisions largely on other factors mentioned on the questionnaire like brightness, driver comfort, and vehicle placement. Measuring other factors such as device shape and placement would not only have made the questionnaire excessively long but also confusing. These factors, therefore, were also measured on the "like/dislike" rating.

The MINITAB computer program (13) was used to compute the correlation matrix (Table 7-5) using the Pearson product moment model as follows:

r = sum ((X-Xbar) (Y-Ybar))/((N-1) (S1) (S2))

where r = Coefficient of correlation

Xbar, Ybar = mean scores for a pair of performance factors

S1 and S2 = standard deviations for a pair of performance factors

Table 7-5. Transformed Total Ranking Frequencies

		Device						
		Raised Pavement Markers	Davidson Markers	Astro-Optics (top)	Hazard Panel (top)	Reflexite (top)	Cylinder (top)	Astro-Optics (face)
Frequency	First	6	30	27	30	9	21	138
	Second	24	20	18	40	4	42	26
	Third	7	1	16	16	8	23	15
Sum		37	52	61	86	21	86	179

Table 7-6. Matrix of Rank Differences (for Table 7.3)

	Device						
	Raised Pavement Markers	Davidson Markers	Astro-Optics (top)	Hazard Panel (top)	Reflexite (Top)	Cylinder (Top)	Astro-Optics (Face)
Rank	37	52	61	86	21	86	179
37	---						
52	15	---					
61	24	9	---				
86	49	34	25	---			
21	16	31	40	65	---		
86	49	34	25	0	65	---	
179	142 *	127 *	118 *	93 *	158 *	93 *	---

* Significant at 0.05 level (Critical Range = 72.76)

N = number of data points

= 7 x 87 = 609 (see Appendix H)

This model assumes a linear relationship between each pair of factors.

The objective of the correlation analysis, therefore, was to find what factors correlated highly with the "like/dislike" factor and with each other. As the correlation matrix (Table 7-7) shows, opposing traffic headlight glare (OPGL) correlated highly with driver comfort (DRCM). This implies that drivers felt comfortable about roadway alignment when they could see the delineator in spite of opposing traffic headlight glare (correlation coefficient 0.724). Note that driver comfort has the highest correlation coefficient (0.793). This should be expected because driver comfort is the basic function of a delineator.

Barrier-top mounted devices (especially the smaller ones) were washed out in opposing traffic headlight glare (see also comments in Appendix F). Astro-optics on the barrier face (6 inches from barrier top) performed best in this regard. Hazard panels and cylinders performed fairly well by virtue of their sizes, despite the fact that hazard panels had the handicap of giving mixed signals. Hazard panels are normally used for bridge-end indication. (See driver comments in Appendix F.)

The "Manual on Uniform Traffic Control Devices" (MUTCD) needs to call attention to this problem of opposing traffic glare just as it has called attention to water and snow (on page 3D-1). It should also require that devices be visible in spite of opposing traffic headlight glare.

A DISCUSSION OF PERFORMANCE FACTORS

Vehicle Placement (VEPL)

This factor, with correlation coefficients of 0.039, 0.065, 0.048, 0.261 and 0.0666 with the other factors, appears to be relatively inconsequential. This becomes more obvious when one considers its correlation coefficient of 0.066 with the "like/dislike"

Table 7-7. Factor Correlation Matrix*

	Brightness	Vehicle Placement	Driver Comfort about Roadway Alignment	Opposing Traffic Headlight Glare	Temptation to Go Faster/ Slower
Vehicle Placement	0.039	1.000			
Driver Comfort about Roadway Alignment	0.672	0.065	1.000		
Opposing Traffic Headlight Glare	0.642	0.048	0.724	1.000	
Temptation to go Faster/Slower	0.334	0.261	0.414	0.397	1.000
Personal Opinion (Like/Dislike)	0.737	0.066	0.793	0.752	0.401

* See Appendix H for a discussion of statistical analysis.

(personal opinion) factor. In other words, subjects did not think the delineator influenced them one way or another.

Driver Comfort (DRCM)

With correlation coefficients of 0.672, 0.065, 0.724, 0.414 and 0.793 with the other factors, driver comfort was relatively important. The highest correlation coefficients of 0.724 and 0.793 occurred with opposing traffic headlight glare (OPGL) and personal opinion factors, respectively. Again, this emphasizes the need to make a delineator visible to the driver in spite of opposing traffic headlight glare.

Opposing Traffic Headlight Glare

The correlation coefficients shown by this factor with the other factors are 0.0642, 0.048, 0.724, 0.397 and 0.752. The importance of this factor has been discussed earlier. Additionally, the factor showed low correlations with vehicle placement and speed (0.48 and 0.397, respectively), the coefficient with speed being relatively higher (0.397) than the coefficient with vehicle placement. With a posted speed limit of 50 miles per hour and an 85th percentile speed of 58 miles per hour, the effect of glare on speed was assumed to be slight.

Speed

Speed shows correlation coefficients of 0.334, 0.261, 0.414, 0.397 and 0.401 with the other factors. The highest of these occurred with the personal opinion (PEOP) factor (i.e., subjects liked the device better if they felt confident enough to go faster). That all these coefficients were generally low implies that speed is relatively less important. This agrees with the findings made by Davis (5).

Brightness (BRT)

The brightness factor showed correlation coefficients of 0.039, 0.672, 0.642, 0.334 and 0.737. The lowest of these (0.039) was with vehicle placement (VEPL) and the highest (0.737) was with the personal opinion (PEOP) factor. This outcome was consistent with expectations.

Personal Opinion (PEOP)

Subjects liked those delineators that were bright, made them feel comfortable about roadway alignment, remained visible with opposing traffic headlight glare, and somehow made them feel comfortable going faster. Vehicle placement had relatively little influence over their personal opinions about the delineators. Correlation coefficients of 0.737, 0.793, 0.752, 0.401 and 0.066 on the bottom of Table 7-7 on page 75 shows these relationships.

Astro-optics (on the barrier face), hazard panels, and cylinders were chosen for further evaluation due to the following reasons:

- the rank difference analysis (tables 7-5 and 7-6, pages 72 and 73),
- the effect of opposing traffic headlight glare, and
- subjects' comments (Appendix F).

Other barrier-top mounted devices were dropped from further analysis due to the following reasons:

- their poor performance in opposing light glare, and
- subjects' comments (Appendix F).

Reflectors placed on or close to the pavement were dropped due to the following reasons:

- the rank difference analysis (tables 7-5 and 7-6, pages 70 and 71),
- their high potential for being covered by snow, debris, and mud,
- subjects' comments (Appendix F), and
- all other observations discussed in this report.

Table 7-8 shows the means and standard deviations of the total ratings for Astro-optics (on the barrier face), hazard panels and cylinders. Astro-optics (on the

Table 7.8. Mean and Standard Deviations of Ratings*

		Cylinder	Panels	Astro-optics (Barrier Face)
Vehicle Placement	Mean Standard	4.2386 2.4913	4.2045 2.4782	2.9659 2.4375
Opposing Traffic Headlight Glare	Mean Standard	4.5955 2.6099	4.0455 2.7372	2.2727 2.0270
Personal Opinion	Mean Standard	4.5568 2.6689	4.8068 2.7910	2.4091 2.1636
Driver Comfort	Mean Standard	4.5227 2.5550	4.4886 2.7626	2.5227 2.1707

* See Appendix H for a discussion of calculation procedure.

barrier face) consistently performed best on all the prime factors. With means of 2, 3, and 3 on opposing traffic headlight glare, driver comfort about roadway alignment, and brightness, respectively, it was the best delineator with the best placement (see questionnaire sample in Appendix C and comments in Appendix F).

The concrete barrier appears to have provided an opaque background against which Astro-optics (on the barrier face) could be seen in the presence of opposing traffic headlight glare. None of the other delineators had this; therefore, the light they returned to the drivers' eyes was insignificant when compared with the stronger beam of the opposing traffic's headlights. Hence, the expression, "They were washed out" (Appendix F).

By virtue of its placement on the barrier face, Astro-optics not only indicated to the motorists how high the barrier was, it also indicated its proximity to the driver's vehicle. Barrier-top mounted devices, on the other hand, showed only how high the barrier was and not its proximity (see Appendix F).

<u>Labor and Material Costs</u>

An analysis of labor and material costs showed that Davidson markers were the least expensive to buy and install, using unit prices for comparison. 3M high intensity sheeting for cylinders was the most expensive. Astro-optics fell at the mid-point. Details are presented in Appendix B. However, a summary of the calculations is shown in tables 7-9, 7-10 and 7-11. A $10 per hour rate for installation labor has been used in the analysis. Therefore, the costs should be regarded as relative costs for comparison purposes.

Table 7-9. Labor and Material Cost Summary

Number of Devices	Device Type	Labor and Material Cost*
26	Raised Pavement Markers (on pavement	$ 32.26
26	Raised Pavement Markers (on barrier face)	32.70
64	Davidson Markers (on edge line)	33.64
11	Cylinders (on barrier top)	42.87
26	Reflexite (on barrier top)	44.22
26	Astro-optics (on barrier top)	64.76
26	Astro-optics (on barrier face)	65.20
11	Hazard Panels (on barrier top)	119.37

* Labor and material costs do not include the following:

- travel time from the shop to the field,
- travel time between delineators,
- cost of epoxy (Davidson markers did not need exoxy and are still the cheapest on a cost per unit basis), and
- overhead cost of equipment.

Assumed labor cost is $10/hr. Therefore, the costs are relative and should be used for comparison purposes only. (See Appendix B)

Table 7-10. Material and Installation Time Unit Costs of Reflectors

Reflector	Unit Price
Davidson Markers	$ 0.52
Bare Cylinder	0.76
Raised Pavement Markers	1.20
Reflexite	1.66
Astro-optics	2.45
Hazard Panels	8.28
3M High Intensity Sheeting for Panels: 3" wide (per 50 yds.)	132.44
3M High Intensity Sheeting for Cylinders: 4" wide (per 50 yds.)	176.58

* Prices were obtained from purchase invoices and suppliers.

Table 7-11. Installation Time Summary

Number of Devices per 1000'	Device Type	Total Installation Time* per 1000'
64	Davidson Markers (on edge line)	128 seconds
26	Astro-optics (on barrier top)	383 "
26	Reflexite (on barrier top)	383 "
26	Raised Pavement Markers (on pavement)	383 "
26	Astro-optics (on barrier face)	539 "
26	Raised Pavement Markers (on barrier face)	539 "
11	Cylinders (on barrier top)	772 "
11	Hazard Panels (on barrier top)	1003 "

* Total installation time does not include the following:

- travel time from the shop to the field,
- set up time,
- travel time between delineators, and
- time for mixing epoxy (see Appendix A).

These are relative installation times for comparison purposes.

CHAPTER EIGHT
STAGE TWO OF THE SURVEY

The first stage of the study compared seven reflector types while the second stage compared current delineation practice with the best of the seven (using the questionnaire in Appendix D).

SELECTION OF DEVICE TO BE TESTED

By virtue of its reflective qualities, sturdiness, durability, and consistently superior performance, Astro-optics on the barrier face was selected to be compared to the current delineation system. The Davidson markers were also selected to be placed on the barrier face instead of on the edge line by virtue of their low material and installation labor costs. However, they would not stick to the smooth barrier face, even after wiping the dust film off the barrier face. Note that the dimensions of the reflective sheeting on a Davidson marker is substandard (10). Therefore, only two reflector sets were evaluated at stage 2:

- Astro-optics placed on the barrier face, six inches from the top with 40-feet spacing, and
- the current delineation practice of placing raised pavement markers on the barrier side of the edge line at 40-feet spacing.

SURVEY ADMINISTRATION

Appendix D shows a sample of the questionnaire used. It was derived from the questionnaire used in Stage 1 with the same questions. However, the order of the questions was varied from one questionnaire to the other.

SURVEY RESULTS

Eighteen new drivers responded. This sampling size was judged to be adequate. One questionnaire was not used because it failed the test of consistency (see Appendix G). Of the useful 17 samples, two were in favor of raised pavement markers whereas 15 were in favor of Astro-optics on the barrier face (see Table 8-1).

Thus Astro-optics on the barrier face (six inches from the top) was the preferred delineator. It was also the preferred placement because Astro-optics placed on top of the barrier (Plate 7-1, page 55) did not do as well.

Table 8-1. Total Ranking Frequencies; Stage 2

		Device	
		Astro-Optics	Raised Pavement Markers
Location		6" from barrier top	barrier side of edge line
Spacing		40'	40'
Device Rank	First	15	2
	Second	2	15

Survey Period: October 8, 1985

Total number of subjects: 17

Number of years held driver's license: Range, 8 - 45 years; Mean, 26.8 years.

Approximate Age: Range, 26-63 years; Mean, 44.8 years.

Weather: Dark, no clouds, no rain, visibility = 15 miles, temperature = 50° F, Dew point = 27° F.

This stage of the survey compared Astro-optics on barrier face to raised pavement markers on pavement. The latter is the delineation system currently used by the State of Washington at the study site.

CHAPTER NINE
CONCLUSIONS AND RECOMMENDATIONS

SUMMARY OF RESULTS

Luminance measurements showed that, even when dirty, Astro-optics were the brightest devices. However, some of the markers, including the raised pavement markers and the Davidson markers, were not measurable by a retro-Tech instrument because their reflective sheetings were too narrow to measure.

The study team made the following observations:

- moisture rusted the outer edges of the hazard panels and reflective cylinders but did not affect the other delineators;
- snow would have covered the barrier-top mounted devices, the raised pavement markers and the Davidson markers; Astro-optics would have been least prone to snow coverage;
- generally, those devices placed higher up on the barrier collected relatively less dirt;
- wind had no observable effect;
- gravity affected the installation of the barrier-face mounted devices;
- all the devices were reusable except the Davidson markers; and
- Davidson markers took the least amount of time to install; hazard panels the most time. Astro-optics on the barrier face were at the mid-point.

Analysis of material and labor installation costs showed that Davidson markers were the least expensive to buy and install, using unit prices for comparison. 3M high intensity sheeting for cylinders was the most expensive. Astro-optics fell at the mid-point.

Analysis of the questionnaire results showed that opposing traffic headlight glare was the most important factor to the drivers in rating their comfort with the roadway's alignment. In other words, those delineators that were still visible despite opposing traffic headlight glare were the most effective. Similarly, brightness of the delineators was also important. Drivers also liked a delineator better if it made them feel comfortable going faster. However, where motorists felt comfortable placing their vehicles in relation to the barrier had little effect on their opinions.

The drivers rated Astro-optics on the barrier face significantly higher than the other six delineators. Cylinders and hazard panels tied at a distant second, due primarily to the fact that their larger sizes made them partially visible in the presence of opposing traffic glare.

In comparing Astro-optics on the barrier face with WSDOT's current system, raised pavement markers on the inside of the edge line, 88 percent, or 15 out of 17, of the drivers preferred Astro-optics placed on the barrier face.

CONCLUSIONS

The conclusions that can be drawn from the results of this study are as follows:

1. Drivers need the guidance of delineators most when confronted with opposing traffic headlight glare. They, therefore, prefer devices that guide them most effectively under such conditions.
2. Devices placed on top of the barrier are washed out by opposing traffic glare and, therefore, are not effective delineators (especially when they are small).
3. The best placement of concrete barrier delineators is on the barrier face.
4. A delineator loses more than half of its reflective properties in a short period due to dirt accumulation. For the brightest delineator in this study (Astro-optics), this period was one month.

RECOMMENDATIONS

Based on the findings of this study, the following recommendations are made:

1. The "Manual on Uniform Traffic Control Devices" calls special attention to the effect of water and snow on delineators. It also needs to call special attention to the effect of opposing traffic headlight glare. This is the condition under which the need for delineators appears to be most critical.
2. For positive guidance, delineators should not be placed on top of concrete barriers.
3. Astro-optics placed on the barrier face was found by this study to be the most effective delineator. Prism-lensed devices of this type are therefore recommended for use as a positive barrier delineator.
4. A delineation system must be maintained (or cleaned) on a regular basis. A dirty delineator reflects no light and is not effective in guiding traffic.

REFERENCES

1. "Manual on Uniform Traffic Control Devices (MUTCD) for Streets and Highways." U.S. Department of Transportation, Federal Highway Administration, 1978, pages 6A-4.

2. "Traffic Control Devices Handbook." U.S. Department of Transportation, Federal Highway Administration, pages 6-35.

3. Blaauw, G. and Padmos, P., "Nighttime Visibility of Various Types of Roading Markings: A Study on Durability, Including Conditions of Rain, Fog, and Dew." SAE Technical Paper Series 820412 (February 22-26, 1982).

4. Godthelp, H. and Riemersma, J., "Perception of the Delineation Devices in Road Work Zones During Nighttime," SAE Technical Paper Series 820413 (February 22-26, 1982).

5. Davis, T., "Construction-Zone Delineation," Transportation Research Record 811: National Academy of Sciences, Washington, D.C., 1981, pages 15- 19.

6. Shepard, Frank D., "Delineation Systems for Temporary Traffic Barriers in Work Zones," Virginia Highway and Transportation Research Council, VHTRC 86-R43, 1986.

7. Khan, Mohammad M., "Evaluation of Delineation Systems for Temporary Traffic Barriers," Ohio Department of Transportation, 1986.

8. Dowden, Harold E., "Evaluation of Delineation Systems for Temporary Traffic Barriers," Iowa Department of Transportation, FHWA-TS-86-XX, 1986.

9. Raufman, J. and Haynes, H., IES Lighting Handbook 1981, Reference volume. Illumination Engineering Society of North America, page 3-3.

10. "Annual Traffic Report," Washington State Department of Transportation. Planning, Research, and Public Transportation Division: 1984, pages 28-29.

11. Dunn-Ranking, P., "Scaling Methods," Lawrence Erlbaum Associates, New Jersey, 1983, page 58.

12. "A Million Random Digits with 100,000 Normal Deviates by the Rand Corporation," The Free Press, New York, 1955.

13. Ryan, T., et al., "Minitab 82 Reference Manual," The Pennsylvania State University, 1982, page 96.

14. Brackett, R., et al., "Delineation of Temporary Barriers in Work Zones," Texas Transportation Institute, Texas A&M University, College Station, Texas, 1984.

APPENDIX A

TIME AND MOTION STUDIES

All reflective material already at the study site was covered up by spraying with black paint. Then the reflector sets were installed. A crew of three did the installing. Two people did the actual installation while the third person recorded time with a stop watch, observed, and recorded the procedure. The procedure for installing each set of reflectors is now presented:

ASTRO-OPTICS BARRIER TOP MARKERS

ACTION	TIME
- Mark out 40 ft. intervals with cloth tape and chalk.	7 sec./interval
- Putting epoxy on the base of reflector and placing it on top of the barrier.	8 sec./reflector

Number of 40 ft. intervals in 1,000 ft. = $\frac{1000}{40} = 25$

Total time for marking out intervals = 25 X 7 = 175 seconds

Number of reflectors needed for 1,000 ft. section = $\frac{1000}{40} + 1 = 26$

Total time for putting epoxy on device bases and placing them on top of the barrier = 26 X 8 = 208 seconds

Total installation time (excluding time for mixing epoxy) = 175 + 208 = 383 seconds

REFLEXITE BARRIER TOP MARKERS

ACTION	TIME
- Mark out 40 ft. intervals with cloth tape and chalk.	7 sec./interval
- Put epoxy on the base of device and place it on top of the barrier.	8 sec./reflector

Number of 40 ft. intervals in 1,000 ft. = $\frac{1000}{40} = 25$

Total time for marking out intervals = 25 X 7 = <u>175 seconds</u>

Number of reflectors needed for 1,000 ft. section = $\frac{1000}{40} + 1 = 26$

Total time for putting epoxy on reflector bases and placing them on top of the barrier = 26 X 8 = <u>208 seconds</u>

Total installation time = 175 + 208 = <u>383 seconds</u>

CYLINDERS

Reflective cylinders were prepared in the office by placing 3M High Intensity Sheeting around the plastic cylinders. Holes were punched through the bottom of the cylinders. Wet epoxy would protrude through the holes and help hold the cylinders more firm. A hole was punched at the base on opposite ends of the diameter of the cylinder. This was for rain water drainage.

	ACTION	TIME
-	Punch holes through cylinder with an electric drill	12 sec./cylinder
-	Measure out and cut sheeting	9 sec./cylinder
-	Remove lining and mount sheeting	21 sec./cylinder

Time needed to prepare one cylinder in the office = 12+9+21 = 42 seconds

Number cylinders needed for 1,000 ft. section = $\frac{1000}{100} + 1 = 11$

Total time needed to prepare 11 cylinders = 11 X 42 = 462 seconds

-	Mark out 100' intervals in the field	20 sec./interval
-	Put epoxy base of cylinder and mount	10 sec./cylinder

Number of 100 ft. intervals in 1,000 ft. = 10

Total time for marking out intervals = 20 X 10 = 200 seconds

Total time for putting epoxy on the bases of cylinders and placing them on top of the barrier = 11 X 10 = 110 seconds

Total time required to prepare and mount cylinders = 462+200+110 = 772 seconds

HAZARD PANELS

Hazard panels were supplied in 8 in. by 34 in. sizes. Since the size prescribed for study is 8 in. by 24 in., 10 inches had to be cut off.

Since the position of the pin on the panel was too high (as supplied), the base end of the panel had to be cut out in order to bring the pin to a height of about half an inch from the base. Alternatively, the panel shaft could be shortened by cutting above the old pin hole and then drilling a new hole. In the first alternative, the panel stood too high up on the barrier. So the second treatment was employed.

In the office, the panels were made reflective by placing 3M High Intensity Reflective sheeting on them (see plate XI). The steps and time involved in this preparation is as follows:

ACTION	TIME
- Measure off 10 inches of panel	2 sec./panel
- Cut off the excess 10 inches	10 sec./panel
- Shorten panel by cutting above old pin hole	6 sec./panel
- Punch new holes through panel shaft	5 sec./panel
- Remove pin from shaft stub	2 sec./panel
- Put pin back into new holes	2 sec./panel
- Measure out and punch holes through base cap	5 sec./panel
- Cut out high intensity sheeting	8 sec./panel
- Paste sheetings onto panels	8 sec./panel
Time needed to prepare one panel in the office =	48 sec./panel

Number of panels needed for 1,000 ft. section at 100 ft. spacing = $\frac{1000}{100} + 1 = 11$ panels.

Total time needed to prepare 11 panels in the office = 11 X 48 528 seconds

Now the panels are ready to be installed on the barrier:

- Remove pin from shaft — 2 sec./panel
- Spray pin with rust-proof chemical (silicon) — 1 sec./panel
- Measure out 100 ft. intervals with cloth tape — 20 sec./interval (or 200 sec./10 intervals)
- Drive pin through base cap — 2 sec./panel
- Fill base cap with epoxy and place on barrier — 3 sec./panel

Time needed to install 11 base caps = 200 + 88 = 288 seconds

At this point, the caps were allowed to set overnight for the epoxy to dry. Actually, epoxy set in about 24 minutes; but for it to support the 8" X 24" panel, it was thought to be conservative enough to let the caps set overnight. The next day, the panels were installed.

- Remove the pin from the base caps — 10 sec./panel
- Align shaft holes with base cap holes — 2 sec./panel
- Drive pin through shaft and base cap holes — 5 sec./panel

Time needed for 11 panels = 11 X 17 = 187 seconds

Total time needed to prepare and install all 11 panels: 528 + 288 + 187 = 1003 seconds

Having to wait for the base caps to set before installing the panels made this relatively less exciting. Driving the pin through panel shaft and base caps was the most demanding task of all. Sometimes, the holes were not perfectly lined up and the pin would go through the shaft damaging it. At other times, the pin would tear through the base cap. This is a more serious mishap because then a new base cap will need to be installed and allowed to set (overnight). If a panel is installed on an imperfect base cap, the panel is too shaky to stand wind forces.

RAISED PAVEMENT MARKERS ON BARRIER FACE (at about 6 inches from the base of the barrier)

Electrical tapes were used to hold up the raised pavement markers while the epoxy was setting. Gravitational forces made the markers slide down the face of the barrier on wet epoxy. Installation involved the following steps:

ACTION	TIME
- Mark out 40 ft. intervals	7 sec./interval
- Put epoxy on the base of device and place device on barrier face	8 sec./reflector
- Hold device up with electrical tape	4 sec./reflector
- Remove tapes from devices after epoxy dries	2 sec./reflector

Time needed to mark out 40 ft. intervals = 7 X 25 = 175 seconds

Time needed to completely install 26 reflectors = 14 X 26 = 364 seconds

Total time needed to install 26 reflectors = 175 + 364 = 539 sec.

ASTRO-OPTICS ON BARRIER FACE (6 inches below barrier top)

These also needed to be held up with electrical tape.

	ACTION	TIME
-	Mark out 40 ft. intervals	7 sec./interval
-	Put epoxy on the base of reflector and place on barrier face	8 sec./reflector
-	Hold reflector up with electrical tape	4 sec./reflector
-	Remove tapes from reflectors after epoxy dries	2 sec./reflector

Time needed to mark out 40 ft. intervals = 7 X 25 = 175 seconds

Time needed to completely install 26 reflectors = 14 X 26 = 364 seconds

Total time needed to install 26 reflectors = 364+175 = 539 seconds

DAVIDSON MARKERS (ON EDGE LINE)

Davidson markers already have sticky bases protected by paper linings. They were the easiest and quickest to install. All that it took was removing the paper lining and sticking the device onto the pavement. They were placed at six feet intervals which corresponded to barrier ends (each barrier segment is 16 ft. long).

	ACTION	TIME
-	Remove paper lining and stick device pavement.	2 sec./device

Number of reflectors needed for 1,000 feet at 16 feet spacing = $\frac{1000}{16} + 1$ = 64 reflectors

Total time needed to install 64 devices = 64 X 2 = 128 seconds

A cost analysis follows in Appendix B.

APPENDIX B

LABOR AND MATERIAL COST ANALYSIS

Reflector prices quoted here are for bulk purchases as of this date. They were obtained from purchase invoices and suppliers. Labor cost excludes value of time spent walking from one device to the other and overhead.

Table B.1

Unit Costs of Reflectors

Reflector	Unit Price
Astro-optics	$ 2.45
Reflexite	1.66
Bare Cylinder	0.76
Hazard panels	8.28
Raised pavement markers	1.20
Davidson markers	0.52
3M High Intensity Sheeting for Panels: 3" wide	132.44/50 yards
" " " " for Cylinders: 4" wide	176.58/50 yards

At an assumed labor cost of $10. per hour, total material and labor costs for each reflector set could be compared.

ASTRO-OPTICS (ON TOP OF BARRIER)

Labor Cost = $10 \times \frac{383}{3600}$ = $ 1.06

Material Cost = 2.45 X 26 = $63.70

Total cost for material and labor = $64.76

REFLEXITE (ON TOP OF BARRIER)

Labor Cost = $10 \times \frac{383}{3600}$ = $ 1.06

Material Cost = 1.66 X 26 = $43.16

Total cost for material and labor = $44.22

CYLINDERS

Labor Cost = $10 \times \frac{772}{3600}$ = \$ 2.14

Cost of 11 bare cylinders
11 X 0.76 = \$ 8.36

Cost of 2.5 ft. of sheeting/
cylinder = \$ 2.94

Cost of sheeting for 11 cylinders = \$32.37

Total cost for material and labor = \$42.87

HAZARD PANELS

Labor Cost = $10 \times \frac{1003}{3600}$ = \$ 2.79

Cost of bare panels = 11 X 8.28 = \$91.08

Cost of 2.625 ft. of sheeting per panel = \$ 2.32

Cost of sheeting for 11 panels
11 X 2.32 = \$25.50

Total cost for material and labor = \$119.37

RAISED PAVEMENT MARKERS (ON BARRIER FACE)

Labor Cost = $10 \times \frac{539}{3600}$ = \$ 1.50

Material Cost = 1.20 X 26 = \$31.20

Total cost for material and labor = \$32.70

ASTRO-OPTICS (ON BARRIER FACE)

Labor Cost = $10 \times \frac{539}{3600}$ = \$ 1.50

Material Cost = 2.45 X 26 = \$63.70

Total Cost for material and labor = \$65.20

DAVIDSON MARKERS

Labor Cost =	10 X 128	= $ 0.36
Material Cost =	64 X 0.52	= $33.28
Total cost for material and labor		= $33.64

Note: These costs do not include overhead costs of travel and equipment.

APPENDIX C

FIRST STAGE QUESTIONNAIRE SAMPLE

CONCRETE BARRIER DELINEATOR RESEARCH

Washington State Department of Transportation would like to provide positive guidance for all motorists driving through a construction area. This research evaluates seven of the delineators currently on the market. Your responses to the following statements/questions will help the DOT serve you better. Please circle the rating/number that best represents your experience.

Brightness:

Please rate each set of reflectors on a scale of "Bright-Not Bright

Reflector #1

Bright 1 2 3 4 5 6 7 8 9 Not Bright

Comments:

Reflector # 2

Bright 1 2 3 4 5 6 7 8 9 Not Bright

Comments:

Reflector #3

Bright 1 2 3 4 5 6 7 8 9 Not Bright

Comments:

Reflector #4

Bright 1 2 3 4 5 6 7 8 9 Not Bright

Comments:

Reflector #5

Bright 1 2 3 4 5 6 7 8 9 Not Bright

Comments:

Reflector #6

Bright 1 2 3 4 5 6 7 8 9 Not Bright

Comments:

Reflector #7

Bright 1 2 3 4 5 6 7 8 9 Not Bright

Comments:

Vehicle Placement

Please rate each set of reflectors on how much it tempted you to stay close to the concrete barrier or further away from it.

Reflector #1

Closer to barrier 1 2 3 4 5 6 7 8 9 Further away from barrier

Comments:

Reflector #2

Closer to barrier 1 2 3 4 5 6 7 8 9 Further away from barrier

Comments:

Reflector #3

Closer to barrier 1 2 3 4 5 6 7 8 9 Further away from barrier

Comments:

Reflector #4

Closer to barrier 1 2 3 4 5 6 7 8 9 Further away from barrier

Comments:

Reflector #5

Closer to barrier 1 2 3 4 5 6 7 8 9 Further away from barrier

Comments:

Reflector #6

Closer to barrier 1 2 3 4 5 6 7 8 9 Further away from barrier

Comments:

Reflector #7

Closer to barrier 1 2 3 4 5 6 7 8 9 Further away from barrier

Comments:

Driver Comfort

Please rate each set of reflectors based on how comfortable you felt about roadway alignment. Your comments would be most useful.

Reflector #1

Comfortable 1 2 3 4 5 6 7 8 9 Not Comfortable

Comments:

Reflector #2

Comfortable 1 2 3 4 5 6 7 8 9 Not Comfortable

Comments:

Reflector #3

Comfortable 1 2 3 4 5 6 7 8 9 Not Comfortable

Comments:

Reflector #4

Comfortable 1 2 3 4 5 6 7 8 9 Not Comfortable

Comments:

Reflector #5

Comfortable 1 2 3 4 5 6 7 8 9 Not Comfortable

Comments:

Reflector #6

Comfortable 1 2 3 4 5 6 7 8 9 Not Comfortable

Comments:

Reflector #7

Comfortable 1 2 3 4 5 6 7 8 9 Not Comfortable

Comments:

Effect of Opposing Traffic Headlight Glare

Please rate each set of reflectors on how easily you could see them when there was opposing traffic (i.e., traffic going towards Spokane with their headlights on).

Reflector #1

Could see reflectors 1 2 3 4 5 6 7 8 9 Could not see reflectors

Comments:

Reflector #2

Could see reflectors 1 2 3 4 5 6 7 8 9 Could not see reflectors

Comments:

Reflector #3

Could see reflectors 1 2 3 4 5 6 7 8 9 Could not see reflectors

Comments:

Reflector #4

Could see reflectors 1 2 3 4 5 6 7 8 9 Could not see reflectors

Comments:

Reflector #5

Could see reflectors 1 2 3 4 5 6 7 8 9 Could not see reflectors

Comments:

Reflector #6

Could see reflectors 1 2 3 4 5 6 7 8 9 Could not see reflectors

Comments:

Reflector #7

Could see reflectors 1 2 3 4 5 6 7 8 9 Could not see reflectors

Comments:

Speed

Please rate each set of reflectors on how much it tempted you to go faster or slower than you usually drive.

Reflector #1

Faster 1 2 3 4 5 6 7 8 9 Slower

Comments:

Reflector #2

Faster 1 2 3 4 5 6 7 8 9 Slower

Comments:

Reflector #3

Faster 1 2 3 4 5 6 7 8 9 Slower

Comments

Reflector #4

Faster 1 2 3 4 5 6 7 8 9 Slower

Comments:

Reflector #5

Faster 1 2 3 4 5 6 7 8 9 Slower

Comments:

Reflector #6

Faster 1 2 3 4 5 6 7 8 9 Slower

Comments:

Reflector #7

Faster 1 2 3 4 5 6 7 8 9 Slower

Comments:

Personal Opinion

Please rate each set of reflectors on a scale of "like/Dislike". Your comments would be most helpful.

Reflector #1

Like 1 2 3 4 5 6 7 8 9 Dislike

Comments:

Reflector #2

Like 1 2 3 4 5 6 7 8 9 Dislike

Comments:

Reflector #3

Like 1 2 3 4 5 6 7 8 9 Dislike

Comments:

Reflector #4

Like 1 2 3 4 5 6 7 8 9 Dislike

Comments:

Reflector #5

Like 1 2 3 4 5 6 7 8 9 Dislike

Comments:

Reflector #6

Like 1 2 3 4 5 6 7 8 9 Dislike

Comments:

Reflector #7

Like 1 2 3 4 5 6 7 8 9 Dislike

Comments:

OVERALL RANKING:

Please rank your choice of three best sets of reflectors by entering their appropriate numbers.

1st Reflector #____
2nd Reflector #____
3rd Reflector #____

How often do you drive this route at night?

____ Everynight

____ Once a week

____ Once a month

____ Once a year

____ Never but tonight

____ Other

For how many years have you held a drivers license?

____ Years

How often do you drive on a highway at night?

____ Everynight

____ Once a week

____ Once a month

____ Never

____ Other

Comments:

Thank you for your time.

Comments:

APPENDIX D

SECOND STAGE QUESTIONNAIRE SAMPLE

CONCRETE BARRIER DELINEATOR RESEARCH

Washington State Department of Transportation would like to provide positive guidance for all motorists driving through a construction area. This research evaluates two of the delineators currently on the market. Your responses to the following statements/questions will help the DOT serve you better. Please circle the rating/number that best represents your experience.

Driver Comfort

Please rate each set of reflectors based on how comfortable you felt about roadway alignment. Your comments would be most useful.

Reflector #1

Comfortable 1 2 3 4 5 6 7 8 9 Not Comfortable

Comments:

Reflector #2

Comfortable 1 2 3 4 5 6 7 8 9 Not Comfortable

Comments:

Effect of Opposing Traffic Headlight Glare:

Please rate each set of reflectors on how easily you could see them when there was opposing traffic (i.e., traffic going towards Spokane with their headlights on).

Reflector #1

Could see reflectors 1 2 3 4 5 6 7 8 9 Could not see reflectors

Comments:

Reflector #2

Could see reflectors 1 2 3 4 5 6 7 8 9 Could not see reflectors

Comments:

Brightness:

Please rate each set of reflectors on a scale of "Bright/Not Bright

Reflector #1

Bright 1 2 3 4 5 6 7 8 9 Not Bright

Comments:

Reflector #2

Bright 1 2 3 4 5 6 7 8 9 Not Bright

Comments:

Personal Opinion

Please rate each set of reflectors on a scale of "Like/Dislike". Your comments would be most helpful.

Reflector #1

Like 1 2 3 4 5 6 7 8 9 Dislike

Comments:

Reflector #2

Like 1 2 3 4 5 6 7 8 9 Dislike

Comments:

Speed

Please rate each set of reflectors on how much it tempted you to go faster or slower than you usually drive.

Reflector #1

Faster 1 2 3 4 5 6 7 8 9 Slower

Comments:

Reflector #2

Faster 1 2 3 4 5 6 7 8 9 Slower

Comments:

Vehicle Placement

Please rate each set of reflectors on how much it tempted you to stay close to the concrete barrier or further away from it.

Reflector #1

Closer to barrier 1 2 3 4 5 6 7 8 9 Further away from barrier

Comments:

Reflector #2

Closer to barrier 1 2 3 4 5 6 7 8 9 Further away from barrier

Comments:

OVERALL RANKING:

Please rank the two reflectors by entering their appropriate numbers.

1st Reflector # ________

2nd Reflector # ________

Please explain your reasons for so ranking them:

How often do you drive this route at night?

____ Everynight

____ Once a week

____ Once a month

____ Once a year

____ Never but tonight

____ Other

For how many years have you held a drivers license?

____ Years

How often do you drive on a highway at night?

____ Everynight

____ Once a week

____ Once a month

____ Never

____ Other

Comments:

Thank you for your time.

Comments:

APPENDIX E

FREQUENCY OF DEVICE RANKINGS PER CONFIGURATION

Table E.1

Frequency of Device Rankings

Location	1	2	3	4	5	6	7
Device/ Rank	A-O(T)	REF	CY	PAN	RPM	A-O(F)	DAV
Best	4			3			
Second Best	1		1	2		3	
Third	2	2	2			1	

A-O(T) = Astro-optics (on top of barrier)

REF = Reflexite (on top of barrier)

CT = Cylinder (on top of barrier)

PAN = Hazard Panel (on top of barrier)

RPM = Raised Pavement Markers on barrier face (1 foot above the pavement)

A-O(F) = Astro-optics on barrier face (6 inches below the top)

DAV = Davidson Markers on edge line

Configuration: #1

Date: September 26, 1985

Number of Subjects: 7; 5 men, 2 women

Number of Years Held Driver's License: Range = 7-31; Mean = 19.6 years

Approximate Age: Range = 25-49; Mean = 37 years

Weather: Dark, no clouds, no rain, visibility = 15 miles
Temperature = 59° F. Dew point = 49° F.

Table E.2

Frequency of Device Rankings

Location	1	2	3	4	5	6	7
Device/ Rank	A-O(T)	REF	CY	PAN	RPM	A-O(F)	DAV
Best	4		1	3		7	
Second Best	3		2	6		3	1
Third Best	4	4	2	1		4	

A-O(T) = Astro-optics (on top of barrier)

REF = Reflexite (on top of barrier)

CY = Cylinder (on top of barrier)

PAN = Hazard Panels (on top of barrier)

RPM = Raised Pavement Markers (on barrier face 1 foot from the pavement)

A-O(F) = Astro-optics on barrier face (6 inches from barrier top)

DAV = Davidson Markers (on edge line)

Configuration: #1

Date: September 27, 1985

Number of Subjects: 15; 7 men, 8 women

Number of Years Held Driver's License: Range 6-48; Mean = 25.9 years

Approximate Age: Range = 24-66; Mean = 43.9 years

Weather: Dark, no clouds, no rain, visibility = 15 miles
Temperature = 63° F. Dew point = 32° F.

Table E.3

Frequency of Device Rankings

Location	1	2	3	4	5	6	7
Device/ Rank	DAV	A-O(F)	RPM	PAN	CY	REF	A-O(T)
Best		5		1		1	1
Second Best			2	2		2	2
Third Best		1	1		1		5

DAV = Davidson Markers (on edge line)

A-O(F) = Astro-optics (on barrier face 6 inches below barrier top)

RPM = Raised pavement markers (on barrier face 1 foot above pavement)

PAN = Hazard panels (on barrier top)

CY = Cylinder (on barrier top)

REF = Reflexite (on barrier top)

A-O(T) = Astro-optics (on barrier top)

Configuration: #2

Date: September 30, 1985

Number of Subjects: 8; 6 men, 3 women

Number of Years Held Driver's License: Range 5-20 years; Mean = 28.9 years

Approximate Age: Range = 23-65 years; Mean = 46.9 years

Weather: Dark, thin clouds, no rain, visibility = 15 miles
Temperature = 62° F. Dew point = 35° F.

Table E.4

Frequency of Device Rankings

Location	1	2	3	4	5	6	7
Device Rank	DAV	A-O(F)	A-O(T)	PAN	REF	CY	RPM
Best	1	11				1	
Second Best	3		2	3		3	2
Third Best	1	2		2	1	4	3

DAV = Davidson Markers (on edge line)

A-O(F) = Astro-optics (on barrier face 6 inches below barrier top)

A-O(T) = Astro-optics (on barrier top)

PAN = Hazard Panels (on barrier top)

REF = Reflexite (on barrier top)

CY = Cylinder (on barrier top)

RPM = Raised pavement markers (on barrier face 1 foot above the ground)

Configuration: #3

Date : October 1, 1985

Number of Subjects: 13; 7 men, 6 women

Number of Years Held Driver's License: RAnge 10-5- years; Mean = 25.6 years

Approximate Age: Range 26-68 years; Maan = 43.6 years

Weather: Dark, overcase, no rain, visibility = 7 miles
Temperature = 58° F. Dew point = 47° F.

Table E.5

Frequency of Device Rankings

Location	1	2	3	4	5	6	7
Device Rank	DAV	A-O(F)	A-O(T)	PAN	REF	CY	RPM
Best		8		2	1		
Second Best						8	3
Third		2	2	3	1	3	

DAV = Davidson (on edge line)

A-O(F) = Astro-optics (on barrier face 6 inches below barrier top)

A-O(T) = Astro-optics (on barrier top)

PAN = Hazard Panels (on barrier top)

REF = Reflexite (on barrier top)

CY = Cylinder (on barrier top)

RPM = Raised pavement markers (on barrier face 1 ft. above pavement)

Configuration: #3

Date: October 2, 1985

Number of Subjects: 11; 5 men, 6 women

Number of Years Held Driver's License: Range 16-60 years; Mean = 29.7 years

Approximate Age: Range 24-78 years; Mean = 47.7 years

Weather: Dark, overcast, no rain, visibility = 15 miles
Temperature = 58° F. Dew point = 54° F.

Table E.6

Frequency of Device Rankings

Location	1	2	3	4	5	6	7
Device Rank	DAV	A-O(f)	A-O(T)	PAN	REF	CY	RPM
Best		7				1	1
Second Best		1		3		4	1
Third Best				4		4	1

DAV = Davidson Markers (on edge line)

A-O(F) = Astro-optics (on barrier face 6 inches below barrier top)

A-O(T) = Astro-optics (on barrier top)

PAN = Hazard Panels (on barrier top)

REF = Reflexite (on barrier top)

CY = Cylinder (on barrier top)

RPM = Raised pavement markers (on barrier face 1 ft. above pavement)

Configuration: #3

Date: October 3, 1985

Number of subjects; 9; 6 men, 3 women

Number of Years Held Driver's License: Range 8-29 years; Mean = 18.9 years

Approximate Age: Range 28-48; Mean + 36.9 years

Weather: Dark, no clouds, no rain, visibility = 30 miles.
Temperature = 55° F. Dew point = 43° F.

Table E.7

Frequency of Device Rankings

Location	1	2	3	4	5	6	7
Device	DAV	A-O(F)	A-O(T)	PAN	REF	CY	RPM
Best	1	4			1	2	
Second Best	2		1	2		1	2
Third Best			2	3		3	

DAV = Davidson Markers (on edge line)

A-O(F) = Astro-optics (on barrier face 6 inches below barrier top)

A-O(T) = Astro-optics (on barrier top)

PAN = Hazard Panels (on barrier top)

REF = Reflexite (on barrier top)

CY = Cylinder (on barrier top)

RPM = Raised pavement markers (on barrier face 1 ft. above pavement)

Configuration: #3

Date: October 4, 1985

Number of Subjects: 8; 4 men, 4 women

Number of Years Held Driver's License: Range 30-47; Mean = 34.4

Approximate Age: Range 43-65 years; Mean = 52.4 years

Weather: Dark, no clouds, no rain, visibility = 15 miles
Temperature = 59° F. Dew point = 44° F.

Table E.8

Frequency of Device Rankings

Location	1	2	3	4	5	6	7
Device Rank	RPM	DAV	A-O(T)	PAN	REF	CY	A-O(F)
Best	1	8		1		2	4
Second Best	2	4		2		2	6
Third Best	2	1	1	3		4	5

RPM = Raised pavement markers (on barrier face 1 ft. above pavement)

DAV = Davidson Markers (on edge line)

A-O(T) = Astro-optics (on barrier top)

PAN = hazard Panels (on barrier top)

REF = Reflexite (on barrier top)

CY = Cylinder (on barrier top)

A-O(F) = Astro-optics (on barrier face 6 inches below top)

Configuration: 4

Date: October 7, 1985

Number of Subjects: 16; 7 men, 9 women

Number of Years Held Driver's License: Range 8-58 years; Mean = 23.8 yrs.

Approximate Age: Range 26-76 years; Mean = 41.8 years

Weather: Dark, partly cloudy, some rain whowers,
Temperature = 50° F. Dew point = 34° F.

Note that a brand new set of Davidson markers was installed for each configuration. Old Davidson markers were not re-usable. They would not stick to the pavement. Thus, its strong showing here could be attributed to this. For consistency, it was necessary to evaluate all seven for each configuration.

APPENDIX F

COMMENTS MADE BY SUBJECTS

The following are some of the comments made by the subjects. These comments have been copied verbatim. It is left to the reader to form his own opinion. Care has been taken not to group the comments into "positive" or "negative". Again, it is left to the reader to so decide.

CONFIGURATION # 1 *

BRIGHTNESS

Astro-optics (Top of barrier)

"Very reflective."

"I like this one very much."

"Good for making barrier visible."

"Easy to see in dark and oncoming headlights."

"Next best to #6." #6 was Astro-optics (face of barrier).

Reflexite (Top of barrier)

"Difficult to see."

"Does not show up well."

Cylinder (Top of barrier)

"Worst of all with oncoming traffic."

"Made a strobe effect."

Hazard Panels

"Not very reflective."

"Not of much use, too high."

"Easiest to see in all cases."

* Note than no comments were made about those delineations not mentioned under this configuration.

Raised Pavement Markers (On barrier face)

"Not easily visible."

Astro-optics (Face of barrier)

"Very reflective, easily seen."

"Also like this one very much."

"Good, but stands out too much."

"Did not fade out in oncoming traffic."

Davidson Markers

"No good."

"Not much use."

"Almost not visible."

VEHICLE PLACEMENT

Astro-optics (Top of barrier)

"Correct distance"

"Comfortable"

"Not effective"

Reflexite (Top of barrier)

"Difficult to see."

"Comfortable"

"Not effective."

Cylinder

"No use."

"Gave sense of balance."

Hazard Panels

"Very large."

"Felt safer to be closer to barrier."

"No use."

"Gave sense of balance."

Raised Pavement Markers (Face of barrier)

"Not easily seen."

"Not effective."

Astro-optics (Face of barrier)

"Correct distance, easy to see."

"Do not use."

"Really comfortable."

Davidson Markers

"Can't see these at all."

"Do not use."

"Useless."

"Pretty good after located."

DRIVER COMFORT

Astro-optics (Top of barrier)

"Excellent."

"Very good."

"Nice road guide."

Reflexite

"Fair."

"Okey."

<u>CYLINDER</u>

"Questionable."

"Okey."

<u>Hazard Panels</u>

"Not very good."

"Good visibility against oncoming cars, but too large."

"Not much use."

"Too big, too distracting—rather dangerous."

"Causes claustrophobia."

"Stood out. Good alignment."

<u>Raised Pavement Markers</u> (On barrier face)

"Passable."

"Okey, but in lower level of vision."

<u>Astro-optics</u> (Face of barrier)

"Excellent."

"Really like this one."

<u>Davidson Markers</u>

"No good."

"Not much use."

<u>EFFECT OF OPPOSING TRAFFIC HEADLIGHT GLARE</u>

<u>Astro-optics</u> (Top of barrier)

"Excellent."

"Really nice."

"Distracting to have this at the same level as oncoming headlights."

<u>Reflexite</u>

"Fair."

"Okey."

"Distracting to have this at the same level as oncoming headlights."

<u>Cylinders</u>

"Poor."

"Not any help."

"Distracting to have this at the same level as oncoming headlights."

<u>Hazard Panels</u>

"Poor."

"Very good."

"Okey, but not great."

"Most visible and obscured the oncoming headlights to some degree."

<u>Raised Pavement Markers</u> (On barrier face)

"Good."

"Okey."

"Couldn't see them well."

<u>Astro-optics</u> (On barrier face)

"Excellent."

"Nice."

"Kept your eye downward and kept visibility high."

"Could see it best because it was below barrier top and lower than opposing traffic headlight."

Davidson Markers

"Terrible."

"Useless."

SPEED

Astro-optics (Top of barrier)

"Easy to see."

"Comfortable."

Reflexite

"Slower."

"Comfortable."

Cylinders

"Even slower."

"No effect."

Panels

"A little difficult to judge."

"No effect."

Raised Pavement Markers (On barrier face)

"Acceptable."

"Okey."

"Not effective."

Astro-optics (Face of barrier)

"Easy to go faster."

"Comfortable."

Davidson Markers

"Can't see these at all."

"No effect."

PERSONAL OPINION

Astro-optics (Top of barrier)

"Easily seen."

"Hard to see."

"Really nice."

"Could see it well."

"Hard to see against glare."

Reflexite (Top of barrier)

"Hard to see."

"Acceptable."

"Okey."

"Not too bright in oncoming traffic."

Cylinders

"Fair."

"Confusing."

"Can't see them well."

"Not good in oncoming traffic."

Panels

"Not very good."

"Should not be used for permanent."

"Easy to see."

"Can't see them well."

"Great, but seemed to obstruct as so big and lousy."

"I like this on at night, but during the day its not appealing to look at."

"Environmentally obstrusive."

Raised Pavement Markers (On barrier face)

"Acceptable."

"Okey."

"Could not see these nearly as well."

Astro-optics (Face of barrier)

"Very easily seen."

"Easiest to see."

"Really useful."

"Excellent - could see them well regardless of oncoming traffic."

"Most effective."

Davidson Markers

"Can't see them."

"Useless."

"Hardly noticeable."

OVER ALL COMMENTS

"Only #6 was properly placed for maximum response to headlights on low beam." #6 is ASTRO-OPTICS (on face of barrier).

"Top mounted units get lost in oncoming headlamps - except for #4 - the slashes allow them to remain visible." #4 is Hazard panels.

"Street level units are not visible beyond 100 - 150 feet."

"All reflectors except #6 were not at a height that were at the height of your headlights." #6 is ASTRO-OPTICS (on barrier face).

* Note that no comments were made about the delineators not mentioned under this configuration. This applies to the rest of the configurations.

CONFIGURATION # 2

BRIGHTNESS

Astro-optics (Face of barrier)

"At headlight height was most easily seen."

"These were attention getting."

DRIVER COMFORT

Astro-optics (Face of barrier)

"Quite visible, emphasized barrier shape."

Hazard Panels

"This tends to lift my eyes from the pavement. This is not bad. I try to be aware of other cars as far as I can see."

EFFECT OF OPPOSING TRAFFIC HEADLIGHT GLARE

Astro-optics (Face of barrier)

"Good visibility, not affected by other car lights."

"Glare had no effect."

Hazard Panels

"Excellent."

"They disappeared only briefly."

Reflexite (Top of barrier)

"Not bright enough to stand out well."

PERSONAL OPINION

Davidson Markers

"You couldn't see this one at all."

"Not much contrast with striped line."

Astro-optics (Face of barrier)

"Reflected well and was very useful to see the barriers were there and how close you were."

"Best comfort that wouldn't hit barrier; excellent delineation."

Raised Pavement Markers (On barrier face)

"This one was good because it showed the slant of the barrier, the others didn't show this."

Hazard Panels

"You could see this one well, but I felt it made me drive closer to the barrier."

"Could see easily, but no help with bottom of barrier."

Cylinders

"Couldn't see and felt it did no good."

Reflexite

"Didn't reflect that well."

"Did not reflect."

Astro-optics (Top of barrier)

"This was one of the good ones. It was bright and you could see up on top and on the sides as in #2." (#2 was Astro-optics on barrier face)

"Good reflection; best of top mounted reflectors."

OVERALL COMMENTS

"This kind of test is a very good thing in my opinion. The night driver needs all the help you can give."

"Thank you for the chance to influence some of the highway details that can certainly effect traffic safety and lives."

CONFIGURATION #3

BRIGHTNESS

Hazard Panels

"Too bright."

"Ugly and expect it to mean something else."

"Very clear. Oncoming traffic light had no effect."

"Oncoming traffic makes it difficult to see most things on top of the barrier but the size of the reflector helps."

"Large enough to see but bottom of barrier hard to see."

Raised Pavement Markers (On barrier face)

"Very dull."

"Forces vision too far down."

VEHICLE PLACEMENT

Astro-optics (Face of barrier)

"Did not tend to push me away from the barrier and towards the next lane."

"Very helpful in determining proximity to barrier which helped me drive more comfortable."

"Placement of the reflector is very good."

Astro-optics (Top of barrier)

"Placement on top of barrier helped in detecting only the height of the barrier, not its proximity."

Hazard Panels

"Hypnotizing."

"Size seemed to make one tend to stay further out."

DRIVER COMFORT

Astro-optics (Face of barrier)

"This one I felt most comfortable because of the location on the barrier."

Hazard Panels

"Too large, confusing."

"You are able to see the barrier in front of you."

Raised Pavement Markers (On barrier face)

"Too far down on barrier."

EFFECT OF OPPOSING TRAFFIC HEADLIGHT GLARE

Astro-optics (Face of barrier)

"Best in this regard (protected by barrier and brightest)."

Hazard Panels

"Guide visible, but stripes hypnotizing."

"This showed up more as a shadow from oncoming lights."

SPEED

Astro-optics (Face of barrier)

"Felt more confident with this one."

Hazard Panels

"Has the affect of a large oncoming object."

Raised Pavement Markers (On barrier face)

"Has a tendency to pull your eyes in."

PERSONAL OPINION

Astro-optics (Face of barrier)

"Had background of barrier - no distractions and height from roadway was good."

"Very good - easy to see and shows curve in road."

"Easiest to see against opposing traffic and best placement."

Astro-optics (Top of barrier)

"Gives no indication of proximity of barrier, only its height."

Hazard Panels

"Too much distraction."

"Hypnotizing."

"Thought it was extremely annoying and distracting."

"Because of size, you know where you are on highway."

Reflexite

"Very poor quality of light."

Cylinder

"Annoying."

Raised Pavement Markers (On barrier face)

"Was barely seen."

"Too low - I believe in time mud would cover this one."

GENERAL COMMENTS

"I think whatever reflector is chosen should not be top-mounted unless it is very large."

"The small reflectors on the top of the barrier were extremely hard to see. I wouldn't recommend them at all."

"The reflectors on top blended in with traffic lights."

CONFIGURATION # 4*

DRIVER COMFORT

Hazard Panels

"Large enough to see, but almost a distraction."

"Good visibility, even with oncoming traffic lights."

Astro-optics (Face of barrier)

"Best choice with or without oncoming traffic."

"Very comfortable driving."

"Felt confident."

EFFECT OF OPPOSING TRAFFIC HEADLIGHT GLARE

Hazard Panels

"Good - could see outline of sign on barrier at least."

Astro-optics (Face of barrier)

"Oncoming glare not a problem."

"Very easy to see with oncoming traffic."

"Below glare from oncoming traffic."

PERSONAL OPINION

Astro-optics (Face of barrier)

"I knew exactly where the barrier was."

"Well placed."

"Glare from traffic was minimal - right in line of vision."

* Note that no comments were made about the delineators not mentioned under this configuration. This applies to the other configurations.

APPENDIX G

CONSISTENCY CHECK

The goal of the Consistency Check is to catch those questionnaires filled out by inattentive subjects. Who is an inattentive subject? An inattentive subject is the one that would pick up the questionnaire, circle any number his pencil fell on, rank any three delineators without consideration and turn in the questionnaire. Why would he do this? He would do it simply to get done with the study. Does it mean that people are not honest? Of course people are honest, but with a little help, they tend to do a better job. This was why they were required to identify the devices correctly before filling out the questionnaires.

In continuing with the consistency test discussion, let's take the code sheet of subject #1 and let's say he made the following scores:

Code Sheet for Subject # 1

	# 1	# 2	# 3	# 4	# 5	# 6	# 7
BRT	1	3	4	2	1	5	8
DRCM	3	5	1	4	1	6	7
OPGL	5	3	6	1	3	5	6
SPD	3	4	5	7	8	9	1
VEPL	2	9	5	6	7	2	9
PEOP	3	4	6	5	7	8	1

RANKS: Best Delineator # 1
Second Best Delineator # 2
Third Best Delineator # 3

The above is the information supplied by subject #1.

Let's check this code sheet for consistency.

	# 1 DAV	# 2 A-O(T)	# 3 CY	# 4 PAN	# 5 A-O(F)	# 6 RPM	# 7 REF
BRT	1	3	4	2	1	5	8
DRCM	3	5	1	4	2	6	7
OPGL	5	3	6	1	3	5	6
SPD	3	4	5	7	8	9	1
VEPL	2	9	5	6	7	2	9
PIOP	3	4	6	5	7	8	1
	17	28	27	25	28	35	32

Our ranking of the best three delineators would be:

Best Delineator	#1 (DAV)
Second Best Delineator	#4 (PAN)
Third Best Delineator	#3 (CY)

In this case, we have agreed with subject #1 in 2/3 of the cases. He had 1, 2, 3; we had 1, 4, 3. This subject is consistent and his questionnaire is useful.

An inattentive subject may rank the best three delineators as follows:

Best Delineator	#6
Second Best Delineator	#5
Third Best Delineator	#7

This ranking does not agree with the sums of scores for each delineator type as calculated above. None of the 87 questionnaires were inconsistent. Of the 18 questionnaires in the second stage of the study, only one was not consistent.

APPENDIX H

FACTOR CORRELATION ANALYSIS

The goal of the correlation analysis done in this research was to find out the patterns of difference or similarity between Driver Preference (like/dislike) Scale and the other scales (Brightness, Vehicle Placement, Opposing Headlight Glare, Speed, and Driver Comfort About Roadway Alignment). See Appendix C.

For instance, if A is highly correlated with B, it implies that when the value of A is high, the value of B is high; when the value of A is low, the value of B is low. Positive correlation coefficients take on values between 0 and 1. (A zero correlation coefficient may imply that the relationship is not linear. A negative correlation coefficient may imply an adverse relationship).

By the same token, as applied to A and B above, if "Driver Preference" correlates highly (>0.5) with "Opposing Traffic Head Light Glare it implies:

a) The driver liked the delineator set when he could see it in the presence of opposing traffic headlight glare.

b) The driver disliked the delineator when he could not see it in the presence of opposing traffic headlight glare. (See Appendix C)

Statements a) and b) can be applied to any other pair of factors or scales.

The chart below is an example of a code sheet for one questionnaire (for subject 1).

Code Sheet for Subject #1*

	DAV	A-) (T)	CY	PAN	A-O (F)	RPM	REF
BRT	1	3	4	2	1	5	8
DRCM	3	5	1	4	2	6	7
OPGL	5	2	6	1	3	5	6
SPD	3	4	5	7	8	9	1
VEPL	2	9	5	6	7	2	9
PEOP	3	4	6	5	7	8	1

* Symbols are explained on pages 65 and 70.

Let us consider the BRT scale (or factor). For this factor, subject #1 has seven data points; 1, 3, 4, 2, 1, 5, 8. Therefore, for the BRT factor alone, 87 subjects had 7 X 87 = 609 data points. By the same method, DRCM, OPGL, SPD, VEPL, and PEOP each had 609 data points.

The correlation analysis was, therefore, done on six rows of data points. The Minitab computer program (10) was used in the analysis. A simple correlation analysis was done using the Pearson product moment model, which assumes a linear relationship. The results of this analysis is shown on Table 7.5, page 70.

From the results of the correlation analysis, the following statement could be made:

1. Drivers like a delineator if they can see it in the presence of opposing traffic headlight glare.
2. Drivers like a delineator if it makes them feel comfortable about roadway alignment.

3. Drivers like a delineator if it is bright.

Table 7.5 shows the correlation coefficients. Note the underlined coefficients of correlation. The questionnaire sample is in Appendix C. The statistical method used in this study is a very basic one. In my opinion, it is the simplest it can ever be. The average score for a delineator type shows on what end of the scale the delineator type is weighted. The table shown below is the data sheet one subject (subject #1).

	DAV	A-)(T)	CY	PAN	A-0(F)	RPM	REF
BRT	1	3	4	2	1	5	8
DRCM	3	5	1	4	2	6	7
OPGL	5	3	6	1	3	5	6
SPD	3	4	5	7	8	9	1
VEPL	2	9	5	6	7	2	9
PEOP	3	4	6	5	7	8	1

Let's consider delineator type DAV. For this delineator type, subject #1 has six data points; 1, 3, 5, 3, 2, and 3. Therefore, for DAV, 87 subjects would have 87 X 6 = 522 data points. By the same method, each delineator type had 522 data points. These data points were added up and each sum divided by 522. The results are shown on Table 7.6 , page 75. It could be said that a delineator type which had a low average had many more data points on the low end of the scale. (See Appendix C)

The following statements could be correctly made:

1. Drivers like a delineator when they can see it in the presence of opposing traffic headlight glare (from correlation analysis).
2. Drivers feel comfortable about roadway alignment if they can

see the delineator in the presence of opposing traffic head-light glare (from correlation analysis).

3. Drivers like the delineator if it makes them feel comfortable about roadway alignment.

Astro-optics with the lowest average score values (Table 7.6) could be said to be the best delineator.