characteristic was the size of the sign face. All other factors being equal, a change in the size of the sign face can result in significant changes in overall luminance levels and in lighting uniformity. We believed that it was desirable to have 10 test sites where the signs were close to the same size, where all signs had three lines of legend, where signs were mounted individually (rather than in pairs), and where test site locations were relatively close together for convenience in observer studies. Ambient illumination levels were comparable at all locations. Although it cannot be proven on an objective basis, backgrounds were similar at the 10 test sites.

The method of measuring legibility distances was selected for simplicity. The test method employed by Forbes (sign-reading errors) may be more rigorous. One advantage of the method employed in this project is that the observers were approaching the signs at highway speed—a more realistic condition. The stopwatch method used in this study has also been used in similar signing studies conducted by the Texas Department of Highways and Public Transportation.

We agree that counterbalancing the order of presentation of the 10 test sites would have been a more rigorous approach.

It is our opinion that twilight sky luminance had no impact on the observer studies. All observations at actual test sites were made more than 1 hr after sunset. In the urban area test site environment skyglow caused by urban lighting overpowered any twilight sky luminance at 1 hr after sunset.

Evaluation of the Effectiveness of Crash Cushion Delineation

F. THOMAS CREASEY, CONRAD L. DUDEK, AND R. DALE HUCHINGSON

The objective of this study was to evaluate the effectiveness of a limited number of crash cushion delineation techniques in the field. Three candidate treatments were selected for field testing: *(a)* a yellow diamond-shaped object marker, *(b)* a yellow-and-black chevron-patterned nose panel, and *(c)* yellow-and-black chevron-patterned nose and back panels. Because accidents involving crash cushions are relatively rare events, it is difficult to make statistically valid comparisons. In this study vehicle encroachments into the gore area were considered to be indicators of the potential for accidents with crash cushions. Studies were conducted at three sites in El Paso, Texas. A low-light-level camera and time-lapse video recorder were used to collect continuous encroachment and traffic volume data at the sites. Three candidate delineation treatments and the existing delineation treatment were tested at each of the study sites. A classification system was developed to differentiate among the gore sites on the basis of the geometrics of the gore approach. Data were collected over a 3-day period for each of the candidate treatments and for the existing treatment at the three sites. Crossover rates were used to compare the effectiveness of the delineation treatments. Analysis of the data indicated no difference in crossover rates among the treatments. The results, based on a limited sample, suggest that added delineation did not reduce crossover rates at locations where sight distance was not a critical factor and that accident problems at these sites may not be related to poor conspicuity alone, but instead may have also been influenced by informational deficiencies in signing and markings.

The use of crash cushions (impact attenuators) to protect vehicles from crashes with fixed objects in freeway gore areas has become a widespread practice. Use of crash cushions has been shown to reduce impact severity *(1)*. However, crash cushions increase the frequency of accidents. This increase may result from reducing the area of the recovery zone, reducing decision or reaction time or both, or simply adding another fixed object in the roadway environment for vehicles to strike. Although crash cushions reduce fatalities and injury severity, collisions with crash cushions may lead to serious secondary accidents or disruptions in traffic flow. There is also a risk to maintenance personnel who are exposed to traffic during repair operations. Thus, the safety benefits derived from crash cushion use are offset to some degree by increased maintenance, labor, and operational costs.

A possible reason that some impact attenuators are more frequently struck than others may be a lack of conspicuity in gore areas. Drivers having to simultaneously process complex information inputs from geometric features, signing, and markings and from other vehicles in the traffic stream may fail to distinguish a gore area or crash cushion embedded in the visual

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field and may strike the cushion while entering, exiting, or making evasive maneuvers. Thus, improving crash cushion conspicuity in gore areas by providing effective delineation may be helpful in reducing certain accidents in which drivers fail to perceive the presence of the crash cushion.

OBJECTIVE

The objective of the field studies was to evaluate the effectiveness of a limited number of crash cushion delineation techniques. The purpose of the field evaluation was not to determine the best treatment, but rather to determine those treatments resulting from the laboratory studies *(2)* that are effective in the field. Thus, it was not necessary to test differences between treatments, but rather to test operational differences resulting from a candidate delineation treatment. Three candidate delineation treatments—a yellow diamond-shaped object marker, a yellow-and-black nose panel, and yellow-and-black nose and back panels—were selected for field testing.

Both short- and long-term analyses were to be conducted. The short-term analysis included a study of driver performance. The long-term analysis involved visual field inspections of the delineation treatments after 4 to 6 months. Limited funding prevented traffic stream measurements during the long-term evaluations.

DATA COLLECTION

Selection and Classification of Study Sites

El Paso, Texas, was selected as the location for the study. The El Paso District Office of the Texas State Department of Highways and Public Transportation (SDHPT) identified three sites for the study as the most frequently hit crash cushions. All three sites were located within the Interstate 10–US-54 interchange near downtown El Paso. The study sites and existing delineation treatments before the installation of the test treatments are described in the following paragraphs.

Site 1: I-10 Westbound at US-54

This location, referred to as Interchange Ramp A, is the exit ramp for all US-54 traffic from westbound I-10. The existing delineation treatment consisted of a black-and-white chevron-patterned wraparound nose panel and a Type 1 diamond-shaped object marker as specified by the *Manual on Uniform Traffic Control Devices* (MUTCD) *(3)* (Figure 1). There were three crashes involving repairs at this location between May 1983 and July 1985.

Site 2: I-10 Westbound at US-54 East-West Split

Referred to as Interchange Ramp A-F, this site is located at the split of US-54 immediately downstream from Site 1 (Interchange Ramp A), with the eastbound (right-hand) split heading toward New Mexico and the westbound (left-hand) split heading toward Juarez, Mexico. The existing delineation treatment consisted of a black-and-white chevron-patterned wraparound nose panel, an MUTCD Type 1 object marker in the front, and two MUTCD Type 2 object markers, one vertical and one horizontal, in the rear (Figure 2). The crash cushion installation at this site was struck twice in 1985 (records of repairs that may have been made before then were not available).

FIGURE 1 Existing delineation treatment at Site 1 (Interchange Ramp A).

Site 3: I-10 Eastbound Entrance Ramp (Gateway Boulevard East) at Copia Street

This location, referred to as the Copia Street Ramp site, is a left-hand entrance ramp from the frontage road onto I-10 eastbound. The existing delineation consisted of a black-and-white chevron-patterned wraparound nose panel, an MUTCD Type 1 diamond-shaped object marker, and two rows of small rectangular yellow reflective-tape sections arranged in a checkerboard pattern (Figure 3). The crash barrels at this site were repaired five times between July 1982 and July 1985.

Delineation Treatments

Four crash cushion delineation treatments were studied at each site:

FIGURE 2 Existing delineation treatment at Site 2 (Interchange Ramp A-F).

FIGURE 3 Existing delineation treatment at Site 3 (Copia Street).

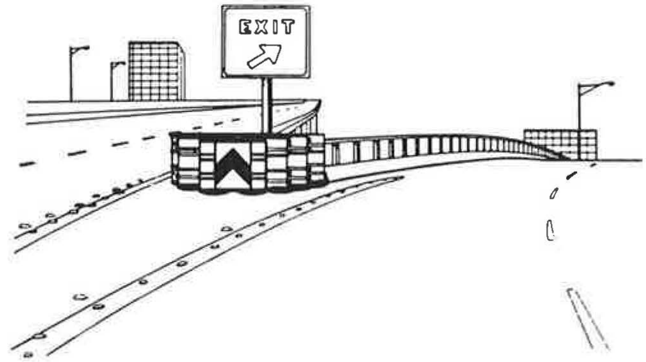

FIGURE 5 Nose panel delineation treatment.

1. Existing,
2. Object marker,
3. Nose panel, and
4. Nose panel and back panel.

The first test treatment was the existing treatment previously discussed. The second test treatment consisted only of an all-yellow, diamond-shaped 18- × 18-in. MUTCD Type 1 object marker. The marker was mounted on a small sign post with its bottom tip located at the top surface of the front crash barrels (Figure 4).

The third test treatment was a 2- × 3-ft yellow-and-black chevron nose panel (Figure 5). High-intensity reflective sheeting was used for the yellow portions of the panel.

The fourth experimental treatment combined the nose panel mentioned earlier with an 8- × 8-ft yellow-and-black chevron-patterned back panel (Figure 6). The back panel also utilized high-intensity reflective sheeting and was mounted behind the back barrels of the crash cushion with its bottom edge flush with the top of the barrels.

Measures of Effectiveness (MOEs)

The effects of the delineation treatments should be evaluated either directly in terms of accident reduction or indirectly through surrogate measures. From a literature review to examine MOEs used in past gore area studies to quantify driver behavior and traffic performance, the following four MOEs were identified:

1. Accidents,
2. Repair history,
3. Erratic maneuvers, and
4. Gore intrusions (encroachments).

The most direct MOE is the number of vehicles colliding with the crash cushion during a specified period. However, there were some practical limitations to using accidents as an MOE in this study. First of all, the number of vehicular collisions with a crash cushion at a given gore area within the 4- to 6-month field test period available in this study was expected to be too small for statistical testing. Second, gore area accident records are not always available. Although the literature did not provide any definitive answers as to the most effective MOE, crash cushion repair history and gore intrusions (encroachments) were initially selected as the MOEs in this study because they appeared to be the most promising alternatives.

Encroachments were classified as either crossover or sideswipe. Four types of crossovers and two types of sideswipe encroachments considered in this study are shown in Figures 7 and 8.

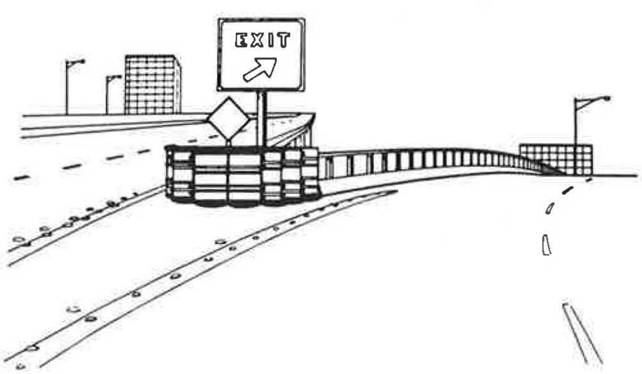

FIGURE 4 Object marker delineation treatment.

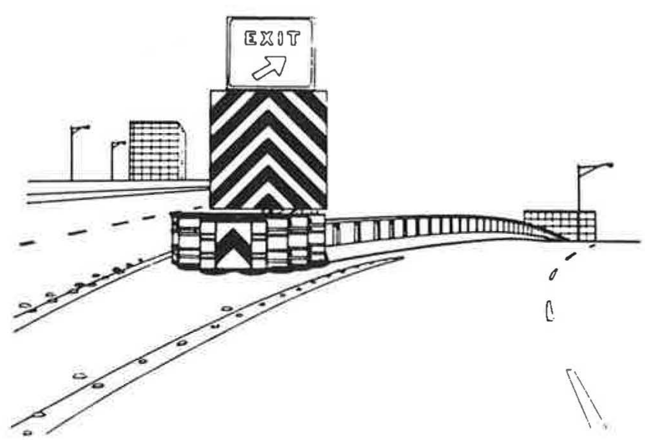

FIGURE 6 Nose and back panel delineation treatment.

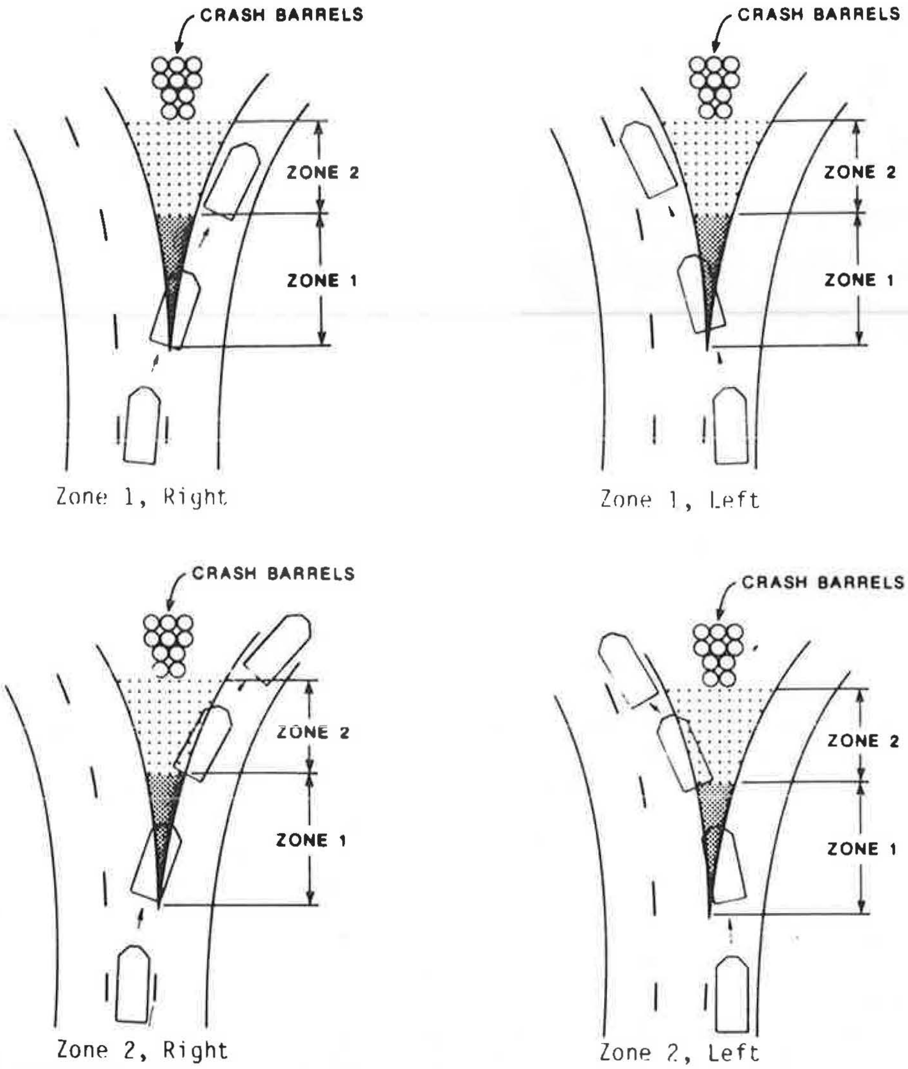

FIGURE 7 Crossover encroachments.

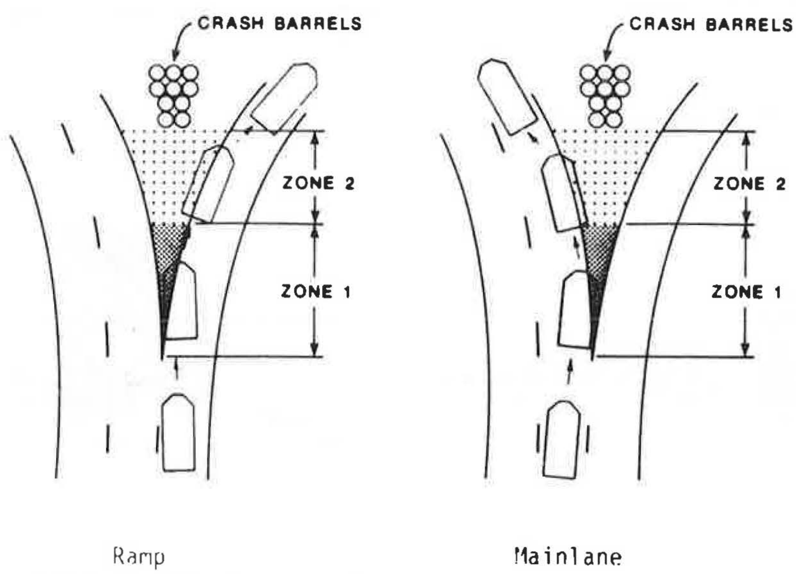

FIGURE 8 Sideswipe encroachments.

Experimental Design

The willingness of the El Paso District to install more than one treatment at each site, with certain restrictions, prompted an experimental design that allowed each delineation treatment to be studied at each of three different sites. A major restriction was that the District was not receptive to leaving the object marker treatment at any of the gore areas for prolonged time periods (more than one week) because of a concern for safety. In addition, the District did not want the object marker installed after either of the two experimental treatments. It was the opinion of District engineers that the object marker treatment was a step down from the existing treatments.

The experimental design is shown in Table 1. The fourth (last) treatment for each site was scheduled to remain at the site for approximately 4 to 6 months in order to conduct long-term visual evaluations. The insistence by the District that the object marker not remain at a site longer than one week or that the object marker not be installed after either of the other two experimental treatments required another revision to the experimental design. Note in Table 1 that only the nose panel alone and nose panel plus back panel were varied in order from site to site.

TABLE 1 EXPERIMENTAL DESIGN

	Treatment Order by Site		
	Site 1 (Ramp A)	Site 2 (Ramp A-F)	Site 3 (Copia St. Ramp)
1	Existing	Existing	Existing
2	Object marker	Object marker	Object marker
3	Nose panel	Nose and back panel	Nose and back panel
4	Nose and back panel	Nose panel	Nose panel

Data Collection

Equipment and Installation

A low-light-level video camera and time-lapse recorder were used to collect the data. The only available camera mounting location for the Ramp A and A-F studies was on a traffic light mast-arm at an intersection southeast of the ramps. Unfortunately, this location was to the side of the gore areas and, as discussed later, this presented some problems with respect to determining sideswipe encroachments.

Scheduling

At each study site, data were collected for four delineation treatments: existing, object marker, nose panel, and nose and back panel. It was desirable to collect data on nights with the highest traffic volumes (to obtain the largest possible sample size). Thus, data were collected on from Wednesday through Friday each week, beginning at approximately 9:00 a.m. on Wednesday morning and continuing until approximately 9:00 a.m. on Saturday morning.

Due to project time constraints, only one full week was devoted to data collection for each candidate treatment at each site. Approximately 72 hr of continuous time-lapse data were collected for each treatment at each site.

CLASSIFICATION OF GORE AREAS

Before the research conducted in El Paso, the Texas Transportation Institute (TTI) completed studies in Houston and Fort Worth *(4, 5)* in which the short-term effects of alternative delineation treatments were evaluated. These studies produced inconsistent results, which prompted TTI to evaluate other factors that might in some way have affected the consistency of the results. It was hypothesized that two major factors could be influential:

1. Total driver information, and
2. Geometrics of approach to the gore area.

Drivers are guided in large part by the formal information (i.e., information provided by signs and markings and by the location and positioning of signs and markings) provided on a highway. Poor information or poorly placed information can have a detrimental effect on driver behavior and could lead to erratic behavior (encroachments) at gore areas. Adequate delineation of gore areas may not be able to offset the erratic behavior caused by insufficient advance information. Study of the total driver information system is outside the scope of the research reported here.

Geometrics also play an important role in driver behavior and, alone or in combination with inadequate driver information, can lead to erratic driving behavior at gore areas. In further analyzing the results of the Houston and Fort Worth gore area studies, it became apparent that delineation requirements may not be the same at all gore areas. Because of geometrics and inadequate sight distances, certain types of gore areas may require extensive delineation, whereas locations with adequate sight distance may require lower levels of delineation. This hypothesis prompted TTI to develop a classification system for gore areas. The classification for right-hand exits is shown in Figure 9. A similar classification could be developed for left-hand exits.

Type I gore area represents a typical gore location with tangent alignment of the main roadway and a well-designed exit ramp. There are no unusual geometric features (e.g., lane drops) and sight distance to the gore area is 1,500 ft or greater. Sight distances of 1,500 ft have been found to provide adequate response time on high-speed facilities *(6, 7)*. Sight distances less than 1,500 ft could result in operational problems.

Type II gore area represents similar conditions to Type I with the exception that sight distance is restricted (e.g., by an overpass). Type IIa represents gore areas in which the sight distance is between 800 and 1,500 ft. Type IIb gore areas have sight distances less than 800 ft. Type II gore areas are more critical than Type I because of the more restricted sight distances. It is likely that Type II gore areas will require more extensive

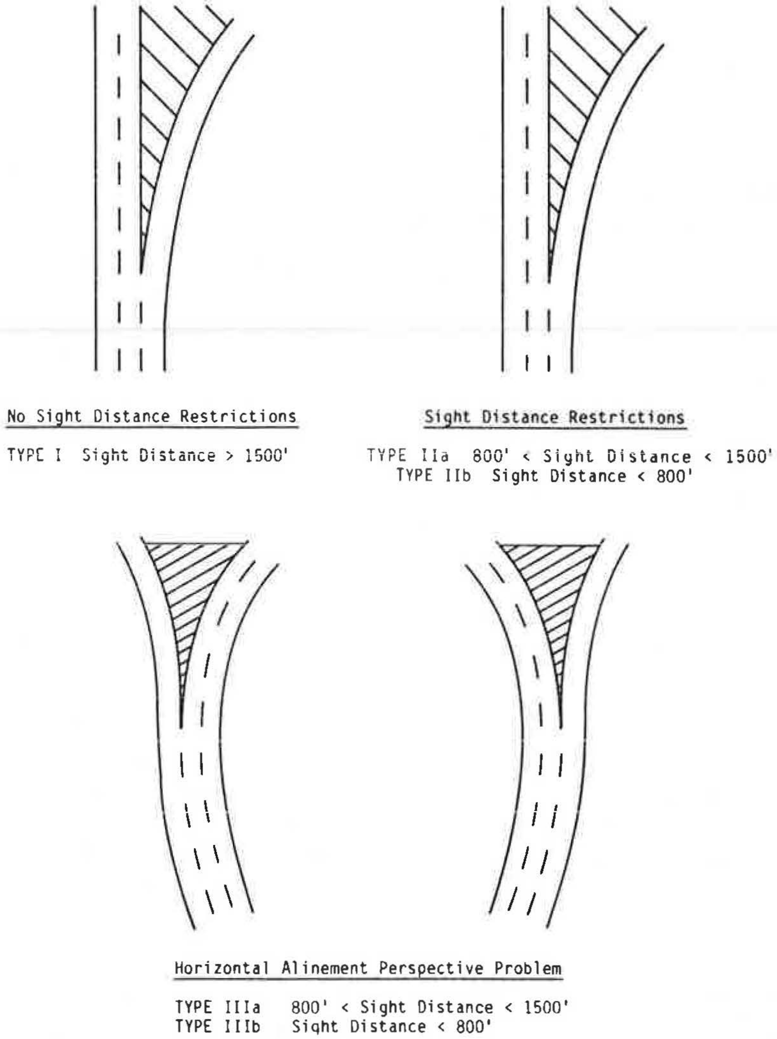

FIGURE 9 Gore area classification system.

delineation treatments than Type I. For example, a delineated back panel may be required to increase the effective sight distance to the gore area for Type II, whereas sight distance is not a problem for Type I and therefore a back panel may not be necessary.

Type III gore areas introduce another geometric feature—curvature—which, in combination with lane drops, lane additions, and so on, results in a visual perspective that may be confusing to the driver. Although Type I and Type II direct the driver past the gore area (either to the left or the right), Type III directs the driver, for a period of time, into the gore area (either into the nose or the side of the crash cushions). The roadway abruptly changes to move the driver away from the gore. However, the perspective problem in combination with inadequate (less than 1,500 ft) sight distance often lead to gore area accidents. It is possible that the perspective and sight distance problems cannot be solved by increased gore area delineation alone. Improvements to the communication system or in some cases improvements in geometrics may be necessary.

Type IIIa gore area contains the characteristics noted earlier with sight distance between 800 and 1,500 ft. The sight distance to Type IIIb gore area is less than 800 ft.

An examination of the conditions in El Paso indicates that the three gore area study sites may be classified as follows.

Site 1, Ramp A—Type IIa;
Site 2, Ramp A-F—Type IIIa; and
Site 3, Copia Street Ramp—Type IIa (left-hand "exit").

A driver's perspective while approaching Site 1 is shown in Figure 10. Similar perspectives of approaches to Sites 2 and 3 are shown in Figures 11 and 12, respectively.

ANALYSIS OF DATA

Sample Periods

From the data collected for each day, a 7-hr nighttime sample period (9:00 p.m. to 4:00 a.m.) and a 7-hr daytime sample period (9:00 a.m. to 4:00 p.m.) were selected for the purpose of analysis. These periods were selected for two reasons. First, peak traffic periods were not included, eliminating the effects of heavy traffic volumes (e.g., close following, abrupt slowing

FIGURE 10 Driver perspective while approaching Site 1.

or stopping, and swerving). Second, the selected periods excluded the transition in lighting conditions that occurs during dawn and dusk hours.

Encroachments

The number of crossovers and sideswipes was totaled to determine the number of encroachments during the nighttime and daytime data collection periods. An analysis of the data, however, revealed serious inconsistencies in the sideswipe data, which prompted close scrutiny of the data reduction process.

It became apparent that the side viewing angle of Site 1 (Ramp A) and Site 2 (Ramp A-F) coupled with video pictures of less than top quality made it difficult to consistently identify sideswipes, particularly when the right tires encroached into the gore area. The video camera was mounted at the best possible locations for the field studies. Unfortunately, the only practical camera location for Sites 1 and 2 was to the side of the sites. Field inspections before the field studies indicated that sideswipes could be identified in spite of the viewing angle. However, losing the three-dimensional perspective while viewing the scenes on a monitor that had a picture of less than high quality made it extremely difficult to identify sideswipes. Consequently, a decision was made to remove the sideswipe data from further analysis and to focus entirely on crossover encroachments. The loss of sideswipe data was considered to be less important than the loss of crossover data because with

FIGURE 11 Driver perspective while approaching Site 2.

FIGURE 12 Driver perspective while approaching Site 3.

sideswipes the driver was likely to be in the correct lane, whereas with crossovers the driver was more likely to be confused, leading to a late lane change.

Crossover rates were calculated by dividing the sum of all crossovers during the time period (nighttime or daytime) by the sum of the traffic volumes in the two lanes bordering each side of the gore area. The assumption was made that vehicles traveling in the lanes bordering the gore area would be more likely to cross the gore area.

Statistical Tests

A gore area crossover is a relatively rare event. In general, rates of relatively rare events can be assumed to follow a Poisson distribution. Under the assumption that a vehicle crossover is a Poisson random variable, the crossover rate at a particular site can be considered to be a measure of the average rate of occurrence. The fact that a Poisson distribution has equal mean and variance allows for use of the chi-square test statistic in testing for significant differences among crossover rates for different delineation treatments.

At each of the three study sites, the first step was to test the hypothesis that the average crossover rates for Wednesday, Thursday, and Friday (nighttime and daytime periods) were not significantly different for the delineation treatment in question. If the crossover rates for all three nights or days were not significantly different from each other, then the overall crossover rate for the delineation treatment could be compared with the overall rates for the other treatments (meeting the same criteria) to determine whether any particular delineation treatment was better than the others from a statistical standpoint.

However, if the overall crossover rate chi-square value for a specific delineation treatment exceeded the critical value for the appropriate level of confidence (95 percent) and degrees of freedom, it indicated that one of the nightly or daily rates was drawn from a different population than the other samples. Thus, the overall rate for the treatment could not be considered a good estimate of the crossover rate for that treatment and any comparisons using that overall rate would not be statistically valid. For example, if the Friday night crossover rate for the object marker treatment at one of the study sites was drastically different from the Wednesday and Thursday night rates, the average overall rate for all three nights would not be a good estimate of the crossover rate for that treatment, and would not be valid for statistical comparison with other treatments.

RESULTS

Total Crossovers

Site 1: Ramp A

A chi-square test on the crossover rates for individual nights and days was performed to test the consistency of the individual rates. There was no significant difference among the nighttime or daytime rates within any of the treatments. Therefore the data for individual nights and days were combined to obtain overall rates.

A summary of Site 1 data is shown in Table 2. A malfunction in the video system (assumed to have been caused by a power outage) caused the daytime data sample for the existing treatment on Thursday to be reduced by about 50 percent and the Thursday nighttime data to be totally lost. Overall nighttime crossover encroachment rates were calculated to be 1.1, 0.7, 0.6, and 0.6 crossovers per 1,000 vehicles for existing, object marker, nose panel, and nose and back panel treatments, respectively. Overall daytime crossover rates were calculated to be 1.2, 0.4, 0.6, and 0.5 crossovers per 1,000 vehicles for existing, object marker, nose panel, and nose and back panel treatments, respectively.

TABLE 2 SUMMARY OF SITE 1 (Ramp A) CROSSOVER ENCROACHMENTS

Treatment	Total No. of Crossovers	Sample Period Volumes Combined	Rate (cross/ 1,000 vehicles)
Nighttime (9:00 p.m. to 4:00 a.m.)[a]			
Existing	5[b]	4,403[b]	1.1
Object marker	5	7,058	0.7
Nose panel	4	6,544	0.6
Nose and back panel	5	7,953	0.6
Daytime (9:00 a.m. to 4:00 p.m.)[c]			
Existing	20[d]	17,363[d]	1.2
Object marker	9	21,476	0.4
Nose panel	10	18,141	0.6
Nose and back panel	10	20,122	0.5

[a]No test could be performed.
[b]Thursday night data not available because of video system malfunction.
[c]$\chi^2 = 9.69$;
[d]Thursday data sample size reduced because of video system malfunction.

The nighttime crossover rates could not be compared among treatments because of the low crossover frequencies. There was a significant difference in the daytime rates among treatments [$\chi^2 = 9.68$ ($p = .02$)], with the existing treatment having a higher crossover rate than the other treatments. However, there was no significant difference among the other three treatment rates (object marker, nose panel, and the nose and back panel).

Site 2: Ramp A-F

A summary of Site 2 crossover data is shown in Table 3. Wednesday nighttime existing treatment data were excluded because of rain and fog. Overall nighttime crossover rates were calculated to be 1.0, 0.7, 2.0, and 2.6 crossovers per 1,000 vehicles for existing, object marker, nose panel, and nose and back panel treatments, respectively. Overall daytime crossover rates were calculated to be 2.1, 2.3, 2.8, and 3.2 crossovers per 1,000 vehicles for existing, object marker, nose panel, and nose and back panel treatments, respectively. A chi-square test on the crossover rates for individual nights and days during each treatment showed the data to be consistent in each situation. A comparison was made among the four treatments and no statistically significant difference was found among them for nighttime or daytime conditions [$\chi^2 = 7.00$ ($p = .07$) and 4.12 ($p = .25$)].

TABLE 3 SUMMARY OF SITE 2 (Ramp A-F) CROSSOVER ENCROACHMENTS

Treatment	Total No. of Crossovers	Sample Period Volumes Combined	Rate (cross/ 1,000 vehicles)
Nighttime (9:00 p.m. to 4:00 a.m.)[a]			
Existing	4[b]	4,119[b]	1.0
Object marker	4	5,354	0.7
Nose panel	10	4,927	2.0
Nose and back panel	13	5,072	2.6
Daytime (9:00 a.m. to 4:00 p.m.)[c]			
Existing	30	14,475	2.1
Object marker	33	14,299	2.3
Nose panel	41	14,630	2.8
Nose and back panel	44	13,798	3.2

[a]$\chi^2 = 7.00$; $p = .07$.
[b]Wednesday night data excluded because of rain and fog.
[c]$\chi^2 = 4.12$; $p = .25$.

Site 3: Copia Street Ramp

A summary of Site 3 crossover data are shown in Table 4. The existing-treatment data for Wednesday nighttime and daytime periods were not available because of technical difficulties, and the nose panel treatment data for the Wednesday daytime period could not be used because of rain. Overall nighttime crossover rates were calculated to be 4.2, 3.7, 2.9, and 3.9 crossovers per 1,000 vehicles for existing, object marker, nose panel, and nose and back panel treatments, respectively. Overall daytime crossover rates were calculated to be 4.3, 3.1, 3.0, and 4.2 crossovers per 1,000 vehicles for existing, object marker, nose panel, and nose and back panel treatments, respectively. A chi-square test on the crossover rates for individual nights and days during each treatment showed the data to be consistent in each situation, meaning that all four overall rates were considered to be good estimates of crossover rates for the four delineation treatments. A comparison was made among the four treatments and no statistically significant difference

TABLE 4 SUMMARY OF SITE 3 (Copia Street) CROSSOVER ENCROACHMENTS

Treatment	Total No. of Crossovers	Sample Period Volumes Combined	Rate (cross/ 1,000 vehicles)
Nighttime (9:00 p.m. to 4:00 a.m.)[a]			
Existing	8[b]	1,924[b]	4.2
Object marker	10	2,719	3.7
Nose panel	8	2,740	2.9
Nose and back panel	11	2,852	3.9
Daytime (9:00 a.m. to 4:00 p.m.)[c]			
Existing	41[b]	9,637[b]	4.3
Object marker	43	13,838	3.1
Nose panel	29[d]	9,632[d]	3.0
Nose and back panel	64	15,282	4.2

[a] $\chi^2 = 0.58$; $p = .90$.
[b] Wednesday nighttime and daytime data not available because of technical difficulties.
[c] $\chi^2 = 4.38$; $p = .22$.
[d] Wednesday daytime data not available because of rain.

was found among them for nighttime or daytime conditions [$\chi^2 = 0.58$ ($p = .90$) and 4.38 ($p = .22$)].

Crossovers by Type of Gore Area

As previously noted, Sites 1 and 3 were classified as Type IIa gore areas and Site 2 as Type IIIa. Consequently, assuming that the motorist information (signing, lane markings, etc.) upstream of the gore is adequate at Sites 1 and 3, one would expect a random distribution of crossovers across type of crossovers and gore area treatments. Higher frequencies of crossovers during specific gore area treatments would be attributed to the differences between the treatments.

In contrast, one would expect a specific pattern (type) of crossovers at Site 2 (Type IIIa) regardless of treatment. Geometrics plays a significant role in the type of crossovers at Type IIIa gore areas.

In order to further evaluate the four gore area treatments, the data were classified and analyzed by crossover type. The results of this analysis are presented in the following sections.

Site 1: Type IIa

Table 5 compares crossover encroachments by summarizing frequency totals across sites and lighting conditions, and also presents the crossover rates for each condition. The results indicate that there were not discernible nighttime crossover patterns for this site (row 1, Table 5). Crossover frequencies appeared to be randomly distributed by type of crossover and across gore area treatments.

Site 2: Type IIIa

For both nighttime and daytime data, it is evident from Table 5 that significantly more crossovers were occurring in a left direction than in a right direction. Referring back to Figure 11, it may be noted that the left fork leads to Juarez, Mexico, a large traffic generator, and that vehicles in the right lane at Site 1 have only about 1,500 ft to move into the center or left lanes. Unless adequate advance signing exists, the drivers may be trapped in the right lane headed for New Mexico. It is surmised that a large number of drivers (146) made a crossover to the left because of *(a)* the Type IIIa geometrics, *(b)* the congestion, *(c)* inadequate advanced lane directions, or *(d)* a combination thereof. Number of lanes available in a left-hand exit may also be a factor in some applications.

Site 3: Type IIa

The Copia Street entrance to I-10 is again a left-hand entrance so it is not too surprising that crossovers were predominantly in a right-to-left direction, both night and day (Table 5, rows 5 and 6). Note that at Site 1, which was a right-hand exit, the daytime data showed twice as many right crossovers.

Day Versus Night

Frequency of crossovers at all sites was greater for day than night. This was expected because of the much greater traffic volumes and the frequent problem of getting into the exit lane in heavy traffic. The rate data, which correct for volume, show less difference between day and night. At Sites 1 and 3, there was very little difference in day and night rates.

Long-Term Evaluation

One of the objectives of the field studies was to conduct an onsite inspection of the gore area treatments to subjectively assess the quality of the treatments after prolonged use (4 to 6 months' duration).

TABLE 5 TOTAL CROSSOVER FREQUENCIES AND RATES (all treatments)

			Left					Right					
			Zone 1		Zone 2		Total	Zone 1		Zone 2		Total	Left Versus
Site	Type	Time	Frequency	Rate	Frequency	Rate	Frequency	Frequency	Rate	Frequency	Rate	Frequency	Right Frequency
1	IIa	Night	6	0.2	2	0.1	8	6	0.2	5	0.2	11	No difference
1	IIa	Day	9	0.1	6	0.1	15	20	0.2	14	0.2	34	Difference
2	IIIa	Night	17	0.9	12	0.6	39	1	0.1	1	0.0	2	Difference
2	IIIa	Day	88	1.5	58	1.0	146	0	0.0	1	0.0	1	Difference
3	IIa	Night	24	2.4	6	0.6	30	3	0.3	4	0.4	7	Difference
3	IIa	Day	115	2.4	22	0.5	137	10	0.2	30	0.5	40	Difference

The last treatment studied at each site was to remain at the site for at least 4 months before the field inspections. As indicated by the field study experimental design (Table 1), the nose and back panel treatment was to be left at Site 1 (Ramp A) and the nose panel treatment at Sites 2 and 3 (Ramp A-F and Copia Street Ramp). However, three accidents resulting in crash cushion repairs occurred after the completion of the short-term data collection and before the 4-month long-term period, which ruled out any long-term field inspections.

The nose panel treatment left in place at Site 2 was hit sometime in January 1986, requiring the treatment to be replaced. During the Easter weekend (March 28–30), the Site 2 crash cushion again was struck. The Site 1 crash cushion (nose and back panel treatment) also was struck. Both of these sites had new crash cushions and nose panels installed. However, the new nose panels were different from the original nose panels used for the short-term data collection. The chevron patterns were accidentally reversed by the El Paso District maintenance personnel. The new nose panels had a yellow chevron in the center with black corners, while the original nose panels had a black chevron in the center with yellow corners. This was not discovered by the research staff of the El Paso District contact person until the final inspection of the study sites was made in April. Therefore, no long-term comparative assessment could be made.

SUMMARY AND DISCUSSION OF RESULTS

Three candidate gore area delineation treatments were selected for field evaluations: *(a)* object marker, *(b)* yellow-and-black nose panel, and *(c)* yellow-and-black nose and back panel. The I-10–US-54 interchange in El Paso was selected as the study area. Three specific gore area sites at the interchange were identified by the El Paso District of the SDHPT as being problem gore areas. All three sites had an existing treatment that became part of the field evaluation studies. Although it would have been more desirable to study the candidate treatments at sites without an existing treatment in order to have a more suitable base condition, most gore areas exhibiting accident problems will have some type of delineation treatment in place.

The El Paso District of the SDHPT agreed to install all three candidate treatments at each of the three sites. This allowed the opportunity for a much stronger experimental design in terms of evaluating differences between candidate treatments than that specified in the research contract. However, the District would not agree to leaving the object marker in place for longer than one week.

One major problem, discovered after the data had been collected, was that the video camera location for two of the gore area sites (1 and 2) made it difficult to accurately identify all gore area encroachments. Encroachments were identified as either sideswipes or crossovers. The side viewing angle, contrary to expectations based on actual field assessments, made it difficult to identify sideswipes at Sites 1 and 2. Therefore, only crossover encroachments were used in the analysis. Because the number of crossovers was relatively small, the data base was consequently smaller than expected.

However, in rationalizing between crossovers and sidewipes, crossover data would appear to be more relevant. Crossovers can be interpreted to mean that the driver was in the wrong lane and made a late decision to change lanes (or was restricted by traffic from lane changing until it was almost too late). With sideswipes, the driver is in the correct lane and for some reason swerves into the gore area—forced by traffic or wind gusts, not paying attention, and so on. It appears that it is less likely that he was confused by the delineation treatment (or lack thereof) or by advanced signing or geometrics.

A basic gore area classification system was developed and proposed as part of the research study. It was hypothesized that safety problems are more prominent with certain classes of gore areas and that delineation treatments can enhance safety for these classes. Also, there are classes of gore areas for which it may be difficult, if not impossible, to solve the safety problems by increased gore area delineation alone because of less-than-desirable geometrics, sight distance, or advanced driver information or all three. Improvements to the information system, or in some cases improvements in geometrics, may be necessary. The classification system was developed during the course of the research contract and was not used in this research to select gore area study sites. However, it does help to explain the results of the field studies. Perhaps further development and use may lead to a better systematic evaluation of solutions to gore area problems.

The three El Paso study sites were classified by using the scheme proposed by TTI. An evaluation of the crossover data indicated that the results were consistent with expectations based on the classification of the gore area study sites. For example, as expected, Site 2, classified as a Type IIIa gore area, exhibited a very high rate of crossovers from right to left in comparison with Sites 1 and 3, which were classified as Type IIa.

An analysis of the crossover data at each site indicated no difference in crossover rates among the four treatments: existing, object marker, nose panel, and nose and back panel. These results were consistent with the gore area classification concepts. Sites 1 and 3 were classified as Type IIa. Sight distance to the gore areas was not a problem. The results indicated that added delineation, based on a limited sample, did not reduce crossover rates. In particular, the back panel, designed to increase the effective sight distance to a gore area, apparently was not warranted for Sites 1 and 3. Site 2 (Ramp A-F) was classified as a Type IIIa gore area. Sight distance did not appear to be a problem. However, adverse geometrics and inadequate or confusing signing, or both, resulted in a relatively high rate of crossovers. It is hypothesized that additional gore area delineation would not alleviate the crossover problem and that improvements in geometrics or signing or both may be more effective.

The results of this and previous TTI studies indicate that increased delineation can reduce encroachments and accidents at some gore areas where sight distance is restricted *(4, 5)*. However, when sight distance to the gore is not a critical factor, encroachments and accidents may be less affected by increased delineation of crash cushions.

It was assumed that by evaluating all of the delineation treatments at each of the three study sites, a stronger conclusion could be drawn based on the redundancy of the experiment.

However, this procedure reduced the amount of data collected because of time restrictions on the study. Because encroachments are a relatively rare event, the encroachment rates used in the analysis were typically small. Although the chi-square test is sensitive to small sample sizes, the fact that no significant differences were found between treatments indicates that encroachments may be somewhat insensitive when used as MOEs. Because of their rarity of occurrence, simply collecting more encroachment data for the same type of analysis may not provide any different results. It is recommended that further research be performed in this area that will utilize more sensitive MOEs and will also expand that scope of the study to include geometrics of the gore area and the overall information system (signing, markings, delineation, etc.) associated with the gore.

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