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16. Abstract This report summarizes the research activities concerning urban freeway gore area vehicle impact attenuator (crash cushion) delineation. Included in this report are the results of a survey of SDHPT District delineation practices for gore area crash cushions, an analysis of the long-term effectiveness of crash cushion delineation treatments at sites in Houston and Ft. Worth where previous delineation research had been conducted, and an analysis of the motorist information system upstream of three gore area crash cushion locations. The survey found that most Districts used some type of delineation on crash cushions, but varied considerably as to the type and amount of delineation used, from small Type 1 object markers to nose/back panels and flashing lights. The long-term evaluations indicated that the delineation treatments installed several years ago in Houston and Ft. Worth had maintained their effectiveness in reducing gore area encroachment rates and crash cushion repairs over time. As a result of the evaluation of the motorist information systems at three sites, recommendations were made in an attempt to further reduce the crash cushion accidents occurring at these sites.			
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DELINEATION OF URBAN FREEWAY GORE AREA CRASH CUSHIONS

by

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April 1988



METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km

Symbol	When You Know	Multiply by	To Find	Symbol
AREA				
in ²	square inches	6.5	square centimeters	cm ²
ft ²	square feet	0.09	square meters	m ²
yd ²	square yards	0.8	square meters	m ²
mi ²	square miles	2.6	square kilometers	km ²
	acres	0.4	hectares	ha

Symbol	When You Know	Multiply by	To Find	Symbol
MASS (weight)				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t

Symbol	When You Know	Multiply by	To Find	Symbol
VOLUME				
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft ³	cubic feet	0.03	cubic meters	m ³
yd ³	cubic yards	0.76	cubic meters	m ³

TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature
			°C

Approximate Conversions from Metric Measures

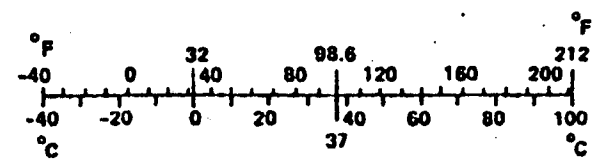
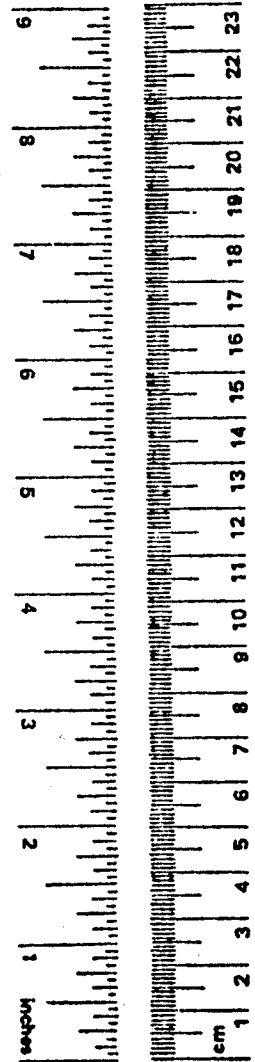
Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi

Symbol	When You Know	Multiply by	To Find	Symbol
AREA				
cm ²	square centimeters	0.16	square inches	in ²
m ²	square meters	1.2	square yards	yd ²
km ²	square kilometers	0.4	square miles	mi ²
ha	hectares (10,000 m ²)	2.5	acres	

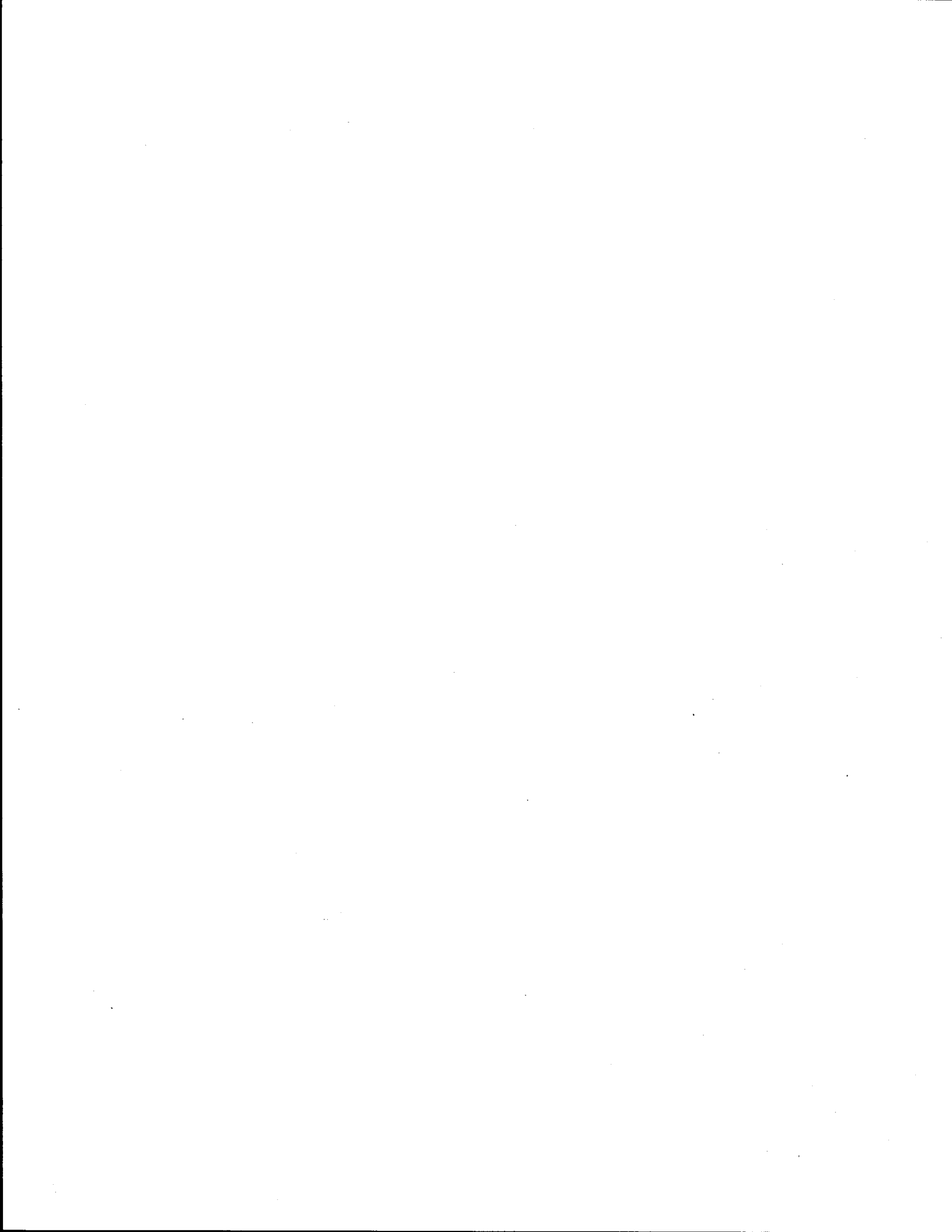
Symbol	When You Know	Multiply by	To Find	Symbol
MASS (weight)				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	

Symbol	When You Know	Multiply by	To Find	Symbol
VOLUME				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m ³	cubic meters	35	cubic feet	ft ³
m ³	cubic meters	1.3	cubic yards	yd ³

TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature
			°F



* 1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price \$2.26, SD Catalog No. C13.10:286.



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The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

SUMMARY OF FINDINGS

This report discusses the research activities conducted as part of Study 408 regarding gore area crash cushion delineation. The primary goals of this research were to 1) identify and document current delineation practices in the state of Texas, 2) evaluate the long-term effectiveness of gore area crash cushion delineation at sites of previous delineation research, and 3) determine if vehicle accidents with the crash cushions could be reduced by improving the motorist information system upstream of selected gore area sites.

A survey of the SDHPT Districts showed that most Districts do use delineation on gore area crash cushions. However, there is considerable variety in terms of the types of delineation used (object markers, nose and back panels, etc.).

Previous research in Houston and Ft. Worth found that crash cushion delineation treatments, immediately after installation, were able to reduce 1) crash cushion repair rates and 2) encroachments into the painted gore tip in advance of the crash cushion. Consequently, District 12 installed nose and nose/back panels at most of the urban freeway gore area crash cushions in its jurisdiction. For Study 408, long-term evaluations of crash cushion delineation treatments installed and evaluated in these previous studies were conducted. Based on the long-term evaluations, it appears that the nose and back panel delineation treatments did continue to be effective at these sites over time. No increase in crash cushion repair records or in nighttime encroachment rates was detected at the sites. It is estimated that the installation of delineation at eight sites studied in Houston has resulted in accident and repair cost savings of over \$174,000 over the past four years.

More recent research on crash cushion delineation has suggested that crash cushion delineation requirements are not the same for all types of gore areas. A classification scheme was developed for gore areas as part of that study, based on the effective sight distance and geometric curvature in advance of the gore area. With this classification scheme, it became apparent that sites with limited sight distance to the crash cushions might benefit from increased delineation (such as a back panel) to increase the effective sight distance. The sites in Houston and Ft. Worth were of this type, explaining the positive results obtained at those sites with the introduction of delineation. However, delineation alone may not be particularly effective at sites where there is a problem with the visual perception of the gore area (due to horizontal alignment or other factors). In this situation, it was hypothesized that improvements to the motorist information system, or in some cases improvements in geometrics, may be necessary.

An analysis of the motorist information system upstream of three gore area crash cushion locations in Ft. Worth and Houston was performed to determine the types of informational deficiencies, if any, that were present and to determine if improvements to the system could be made in an attempt to reduce vehicle accidents with the crash cushions at these sites. Based on the analysis, recommendations were made that would possibly reduce crash cushion accidents at these sites. Unfortunately, these recommendations could not be implemented and evaluated within the time frame and budget limitations of this study.

IMPLEMENTATION STATEMENT

Based on the results of this research, it appears that reflectorized chevron nose and back panels on freeway gore area crash cushions do not lose their effectiveness over time, at least for a period of about four years. Consequently, the benefits of using this crash cushion delineation treatment can be substantial over its service life. Just since 1982, for example, crash cushion repair cost savings at eight urban freeway gore area locations in Houston has amounted to over \$174,000. Given the relatively low costs associated with installing and maintaining this treatment, its implementation at most urban freeway gore area crash cushions does seem justified. District 12 (Houston) has already installed delineation at most of the urban freeway gore area crash cushion locations in Houston.

The effectiveness of crash cushion delineation does appear to depend on the specific characteristics of each site. In particular, factors such as limited sight distance to the gore and visual perception problems caused by geometric inconsistencies may influence accident rates with crash cushions at a particular location. In some cases, crash cushion delineation alone may not be sufficient, and it may be necessary to re-evaluate and modify some aspects of the motorist information system (e.g., signs, pavement markings, etc.) in advance of the gore area in an attempt to counteract these problems.

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1. INTRODUCTION

Background

In the past, crash cushions in gore areas have proven their safety value. However, studies have shown that the introduction of crash cushions at specific gore sites does not, in general, reduce the number of accidents at those sites; rather, they reduce the severity of impact and occupant injuries (1,2). Damaged crash cushions must be repaired, resulting in significant maintenance costs and exposure of maintenance personnel to potentially hazardous situations during these repairs. Thus, the safety benefits derived from crash cushions are offset to some degree by increased maintenance and operational costs.

Recent studies have addressed the idea of increasing crash cushion conspicuity in an attempt to reduce accidents with urban freeway gore area crash cushions. When sight distance to the gore area on an urban freeway is limited, delineation has been shown to reduce crash cushion repairs and encroachment rates (through the painted portion of the gore) (3,4). The short-term reductions in crash cushion repairs were so impressive in Houston that District 12 installed nose and back panels at most urban freeway gore area crash cushions in its jurisdiction.

Recent research on crash cushion delineation (5) has suggested that crash cushion delineation requirements are not the same for all types of gore areas in urban areas. A classification scheme was developed for gore areas as part of that study, based on the effective sight distance and geometric curvature in advance of the gore area (for a full discussion of the classification scheme, see Chapter 4). With this classification scheme, it became apparent that sites with limited sight distance to the crash cushions might benefit from increased delineation (such as a back panel) to increase the effective sight distance. However, it was suggested that delineation alone may not be particularly effective at sites where problems existed with the visual perception of the gore area (due to horizontal alignment or other factors). In this situation, it was hypothesized that improvements to the motorist information system, or in some cases improvements in geometrics, may be necessary.

Statement of the Problem

Very little guidance is available about when and how to best delineate freeway gore area crash cushions in Texas. Information about past experiences and current practices of crash cushion delineation across the state would be extremely useful to engineers and practitioners considering the installation of delineation at a crash cushion location.

Also, previous studies of crash cushion delineation treatments have been limited to short-term evaluations of their effectiveness. Since crash cushion accidents are a relatively rare event, additional research on the performance of delineation over time would be useful in determining whether delineation loses its effectiveness over time (due to weathering or to drivers becoming accustomed to the presence of delineation). In addition, a longer evaluation provides a larger database upon which to evaluate the effectiveness of the delineation treatments.

Finally, there was a need to examine the impact of the motorist information system in advance of freeway gore areas upon crash cushion collisions. Previous research (5) suggests that improvements of the information system (e.g., advance signing, pavement markings) may be necessary to reduce accidents at some locations, particularly those where there are problems with the driver's visual perception of the gore area.

Research Objectives

The specific objectives of this part of the study were to:

1. Determine similarities, differences, and problem areas of gore area crash cushion delineation in Texas
2. Perform a long-term evaluation of crash cushion delineation treatments installed in previous studies to determine the effectiveness of delineation treatments over time in reducing crash cushion accidents and gore encroachment rates
3. Perform an analysis of the motorist information system (including signs, markings, delineation, etc.) upstream of selected gore sites and make recommendations for improvements that would be expected to reduce accidents and crash cushion repairs at these sites.

2. CURRENT GORE AREA CRASH CUSHION DELINEATION PRACTICES IN TEXAS

As the initial step in this study, a telephone survey of 23 of the 24 SDHPT Districts was conducted to determine current practices regarding the delineation of urban freeway gore area crash cushions. The survey provided useful information as to the different types of delineation being used across the state as well as the similarities, differences, and problem areas with current delineation procedures. Site visits were made to five of the Districts to examine and further document the different types of delineation currently in use in Texas.

Extent of Delineation Use

Fourteen of the Districts surveyed were found to use crash cushions at one or more urban freeway gore areas. Three of these reportedly do not use any type of delineation to make the crash cushions more visible. Of the other eleven Districts using delineation, considerable variation was evident as to the amount and type of delineation used. Some Districts used different types of delineation at different gore areas, depending on site-specific characteristics.

Types of Delineation Used

A summary of the different types of delineation used for gore area crash cushions on urban freeways, and the number of Districts using each type, is presented in Table 2-1. The most common delineation treatments used include object markers (Type 1 and Type 2 as described in the Texas Manual of Uniform Traffic Control Devices (6)) and striped reflective nose panels mounted on the front of the cushions. Examples of these treatments are shown in Figures 2-1 and 2-2. The colors that have been used for the nose panels vary District by District, with black/yellow, black/white and orange/white panels currently in place.

In some cases, the nose panel is supplemented with a 4-ft by 8-ft back panel to add conspicuity and increase the effective sight distance to the gore area. Flashing lights have also been installed at some gore areas in Districts 2 (Ft. Worth), 12 (Houston), and 18 (Dallas). Examples of these supplemental delineation treatments are shown in Figures 2-3 and 2-4. At some relatively high-accident locations, several types of delineation have been combined in attempts to further increase the conspicuity of the crash cushions, as Figure 2-4 illustrates.

**TABLE 2-1. COMMON DELINEATION PRACTICES FOR URBAN FREEWAY
GORE AREA CRASH CUSHIONS**

Type of Delineation on or Behind Crash Cushion	Number of Districts Using ^a
Nose Panels	
black/yellow stripes	3
black/white stripes	<u>2</u>
	5
Object Markers on or at Nose	6
Reflective Paint on Crash Cushions	1
Guardrail Delineators	1
Supplemental Delineation:	
flashing lights	3
full gore area lighting	1
back panels	3

^a Some Districts use more than one type of delineation on their crash cushions



Figure 2-1. Type 2 Object Marker at Front of Crash Cushion.



Figure 2-2. Chevron Nose Panel and Type 1 Object Marker At Front of Crash Cushion.

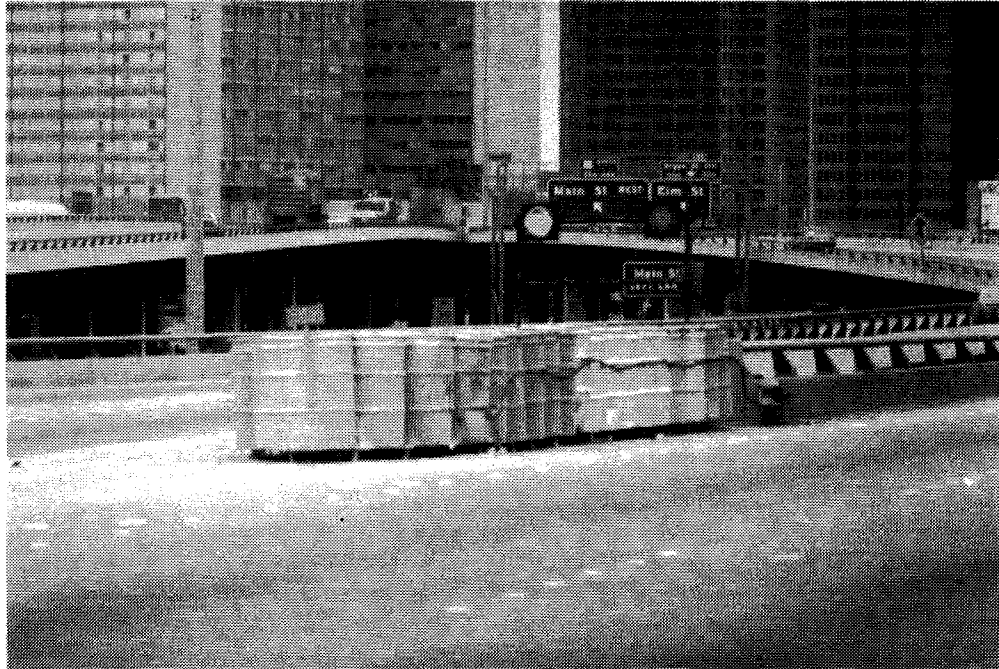


Figure 2-3. Type 1 Object Marker supplemented with Flashing Lights.



Figure 2-4. Nose Panel supplemented with Back Panel, Flashing Lights, and Chevron Alignment Signs.

Delineation Problems Encountered

The most common problem reported by the Districts was with road film quickly covering the delineation and reducing its reflectivity. The Districts do not have an efficient method of cleaning delineation, nor do they have the manpower to clean it often enough. Also, any cleaning that is done requires the worker to be out next to the traffic, increasing the possibility of an injury.

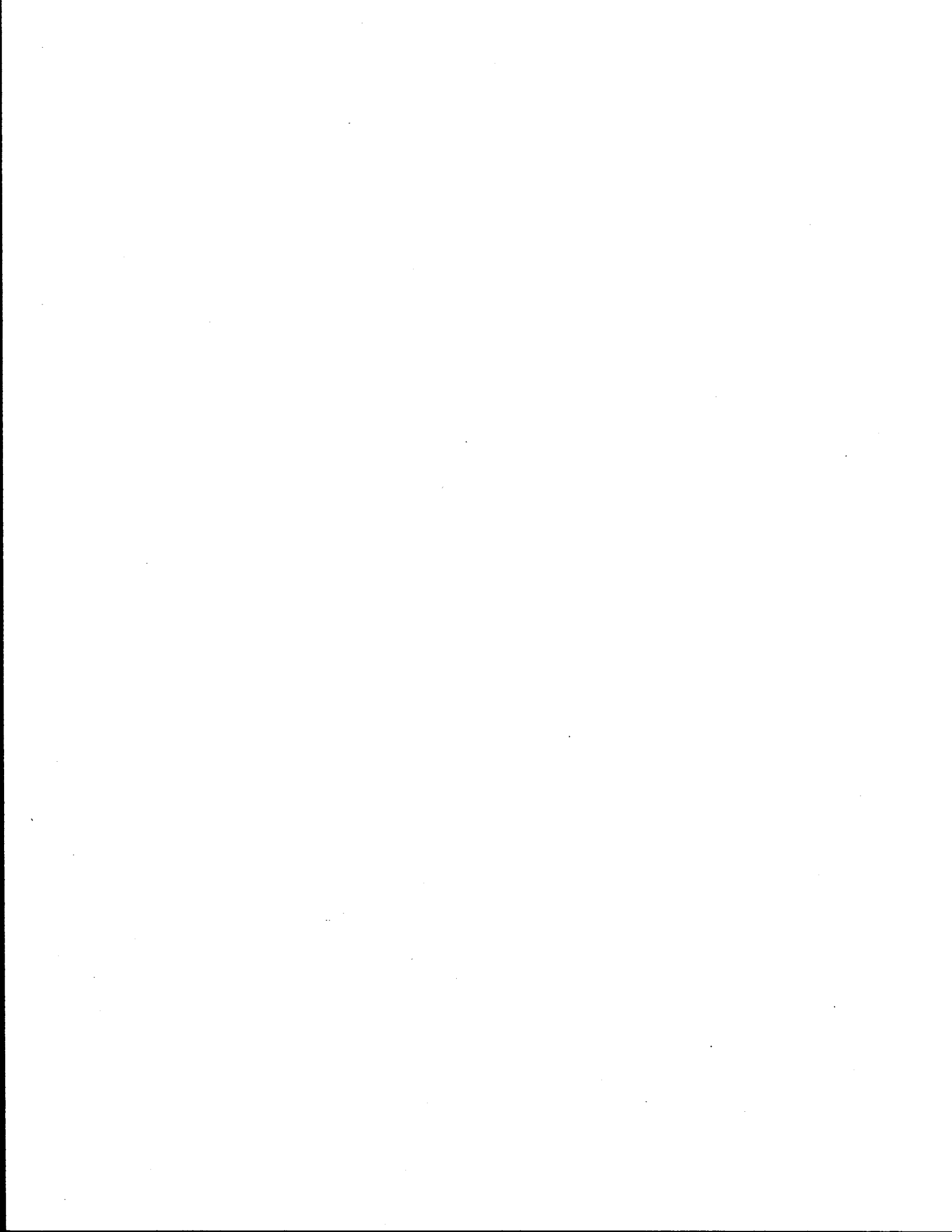
Another problem identified was that no specific guidelines exist as to when delineation should be used, and how much or what type should be used. The wide variety of treatments and combination of treatments shown in Figures 2-1 through 2-4 are evidence of this fact. Finally, there has been little District-to-District communication about delineation techniques/devices that had been tried and the subsequent results. Some Districts were aware of the delineation efforts of another District, but widespread knowledge of the general activities throughout the state was absent.

Summary

Based on the results of this survey, there is considerable variety in delineation procedures statewide. However, a few similarities do exist in terms of the type of delineation used on urban freeway gore area crash cushions. Nose panels and object markers are the most common types of delineation, with supplemental back panels and flashing lights used at some relatively high-accident locations.

Although a few similarities do exist, there are by far more differences among delineation practices across the state. For example, those using nose or nose/back panel combinations on crash cushions differ with respect to the colors used for the panels themselves (i.e., black/yellow, black/white, or orange/white).

Several problem areas in crash cushion delineation were identified. There exists a lack of guidelines or widely accepted practices as to the amount and type of delineation that should be used, as well as guidelines as to when it is feasible or appropriate to delineate gore area crash cushions.



3. LONG-TERM EFFECTIVENESS OF CRASH CUSHION DELINEATION

This chapter summarizes two long-term evaluations of crash cushion delineation at locations in Houston and Fort Worth where short-term evaluations of crash cushion delineation treatments were previously conducted by TTI (3,4). The long-term evaluations used the same measures-of-effectiveness that were used in the previous studies in order to provide a consistent basis for the evaluation over time. The first section summarizes the results of an examination of crash cushion repair rates at eight sites in Houston. The original short-term evaluation of delineation at these sites was conducted in 1982. The second section documents the results of the analysis of gore area encroachment rates at a site in Fort Worth. A short-term evaluation of crash cushion delineation at this site was performed in 1984.

Crash Cushion Repair Rates, Houston

Background

In a 1982 TTI study of urban freeway gore area delineation (3), crash cushion repair rates were used to evaluate four delineation treatments at eight gore area sites in Houston. The treatments are described in Table 3-1. These treatments consisted of varying levels of static delineation (pavement markers, chevrons, nose and back panels) and one dynamic (flashing lights) treatment. Each treatment was installed at two sites. Two additional sites did not receive any delineation and were used as control sites. Crash cushion repair records from each site were obtained for three years prior to treatment installation. The repair records were then collected for a period of time after treatment installation (17 to 22 months), and compared to the records from before installation.

The records showed that static delineation (nose and back panels, chevrons, pavement markings) in combination with flashing lights significantly reduced crash cushion repairs at sites with initially high (6 or more repairs per year) repair rates. However, it appeared (from the data collected) that the static delineation treatments alone did not, as a group, reduce repair rates at sites with moderate (4 to 6 per year) repair rates. When evaluated on a site-by-site basis, though, some reductions in crash cushion repair rates were evident (3).

Method of Study

For this evaluation, crash cushion repair records for the eight Houston sites were again examined, this time for four years before and four years after the initial installation of the treatments. These records were obtained to determine how the delineation treatments continued to perform over time. In particular, did crash cushion repairs remain lower, or did they increase over time?

Results

Table 3-2 is a summary of crash cushion repairs from 1979 to 1986 at the eight gore area sites examined in the earlier study. Also shown in the table is the treatment level that was installed at each site. Visual examination of the number of repairs shown in the table suggests that the delineation treatments did in fact remain effective over time.

Average yearly repair rates (combining sites with identical treatments) for each treatment are shown graphically in Figures 3-1 through 3-4. Again, it is apparent that the treatments continued to be effective through the four-year period following installation of the delineation treatments. Some year-to-year variation is evident, but overall, crash cushion repair rates do not appear to have increased over time.

TABLE 3-2. SUMMARY OF CRASH CUSHION REPAIRS (HOUSTON SITES)

Location	Treatment Level	Year							
		Before Delineation				After Delineation			
		79	80	81	82	83	84	85	86
IH-10 EB @ US 59 NB	1	4	4	2	6	3	2	1	2
IH-610 (E.L.) NB @ SH 225 EB	1	0	4	3	3	2	3	3	1
IH-610 (W.L.) SB @ US 59	2	6	6	4	6	3	3	3	2
IH-610 (W.L.) SB @ IH-10	2	5	8	4	4	0	3	4	1
US 59 SB @ IH-45	3	10	6	3	6	4	2	2	3
IH-45 NB @ US 59 SB	3	10	5	6	5	6	2	3	1
IH-610 (W.L.) NB @ US 59	4	12	10	13	12	5	7	7	5
US 59 NB @ RICHMOND AVE.	4	3	7	14	5	4	2	2	4

W.L. = West Loop

E.L. = East Loop

NB = Northbound, SB = Southbound, etc.

ANNUAL CRASH CUSHION REPAIRS

Treatment 1

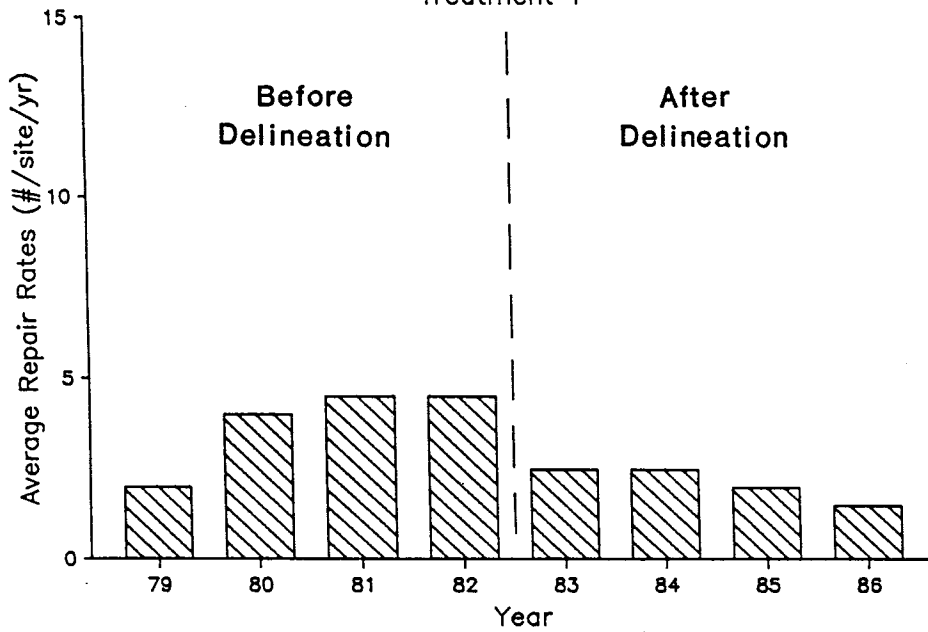


Figure 3-1. Average Crash Cushion Repair Rates at Treatment 1 Sites in Houston.

ANNUAL CRASH CUSHION REPAIRS

Treatment 2

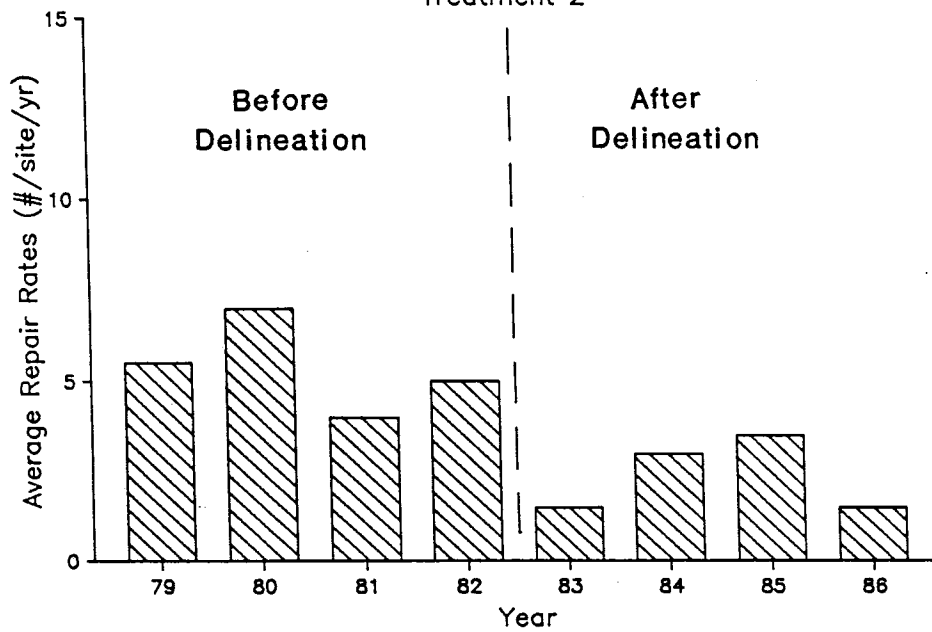


Figure 3-2. Average Crash Cushion Repair Rates at Treatment 2 Sites in Houston.

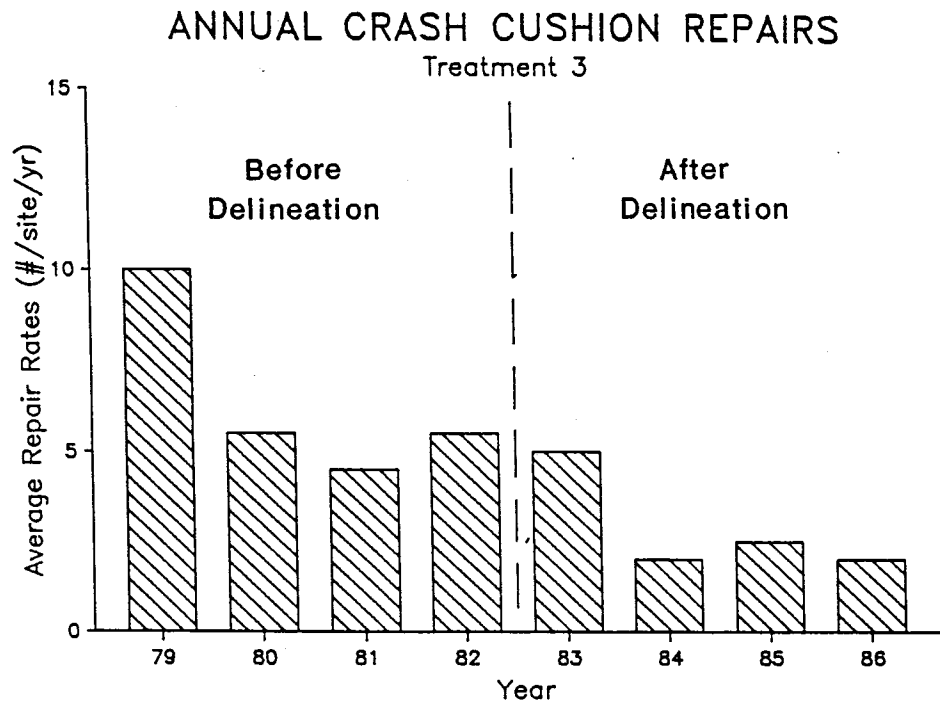


Figure 3-3. Average Crash Cushion Repair Rates at Treatment 3 Sites in Houston.

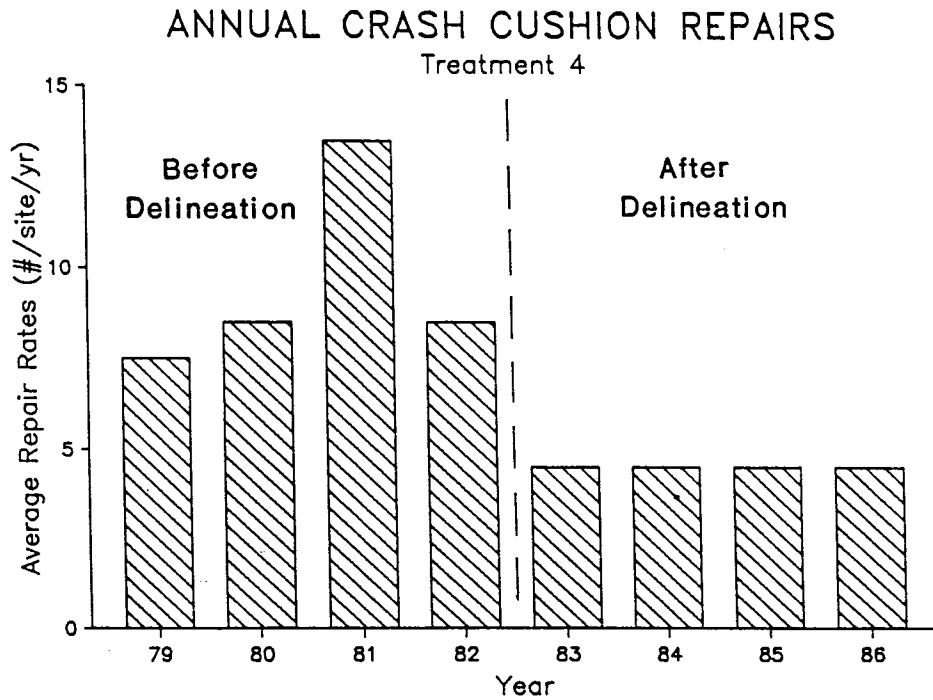


Figure 3-4. Average Crash Cushion Repair Rates at Treatment 4 Sites in Houston.

The earlier study suggested that repair rates were not affected by Treatments 1, 2, and 3 at the sites with moderate repair rates. This data was based on less than two years experience after the treatments were installed. Looking at the repair rates over a four-year period, though, it appears that these treatments were indeed effective in reducing crash cushion repairs to some degree.

Figure 3-5 summarizes the average effect each delineation treatment has had on crash cushion repairs, presenting the average repair rates (by sites with identical treatments) per year before and after installation of crash cushion delineation. Over the four-year period, yearly repair rates were reduced (on the average) 33% at Treatment 1 sites, and 53-55% at sites where Treatments 2, 3, and 4 were installed.

Using a recent cost estimate (7) of \$1,760 per repair of the steel drum crash cushions, the average annual savings in repair costs for the various treatments ranged from \$1,940 to \$8,800 per year (Figure 3-6). This cost estimate per repair includes both the labor and material costs for the actual repair of the cushion as well as an estimate of an average accident cost to motorists who collide with a steel drum cushion.

The values in Figure 3-6 are presented to show that all treatments did result in some yearly cost savings. These values should not be used to compare the relative effectiveness between treatments. The crash cushion repair rates before delineation was installed varied dramatically from site to site. The treatments were not evaluated across sites with similar repair rates (the sites where Treatment 4 was used had much higher repair rates initially) and so a relative comparison between treatments is not appropriate.

Overall, the delineation of the crash cushions at the eight study sites has been very cost-effective. Total savings at the original eight study sites, accumulated from the installation of the delineation treatments through 1986, has amounted to over \$174,000, based on the above cost estimates. The installation and maintenance costs for the delineation treatments themselves are, for the most part, minimal. Treatment 4, which uses flashing lights, is the most expensive of the treatments examined since it requires a source of power to operate the lights. The cost of items such as pavement markers, chevrons, and nose and back panels are relatively minor by comparison.

COMPARISON OF BEFORE VS. AFTER REPAIR RATE 1979 to 1986

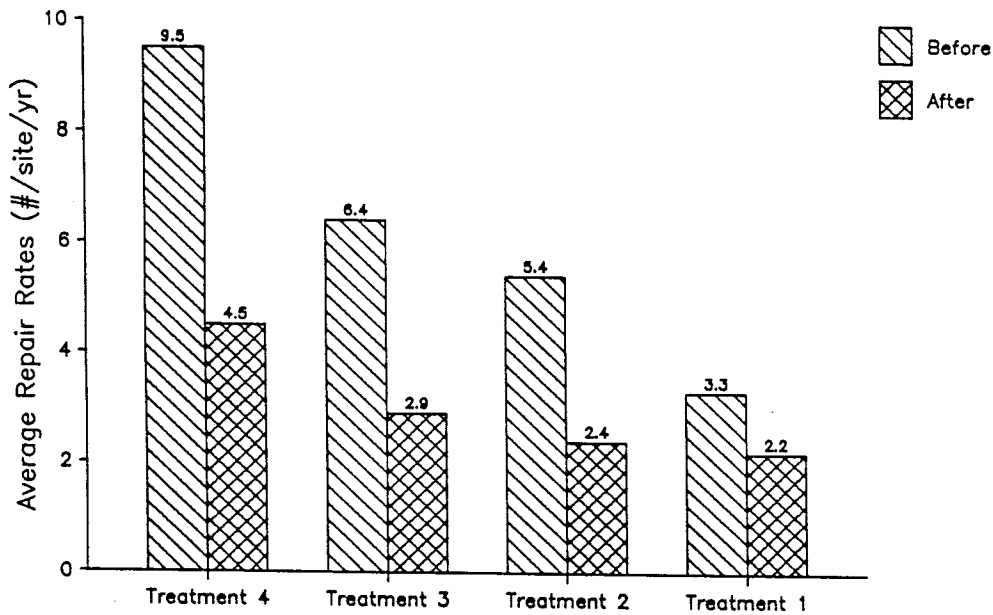


Figure 3-5. Average Annual Crash Cushion Repair Rates for Four Years Before and Four Years After Treatments were Installed at Houston Sites.

SAVINGS IN CRASH CUSHION REPAIR COSTS 1983 to 1986

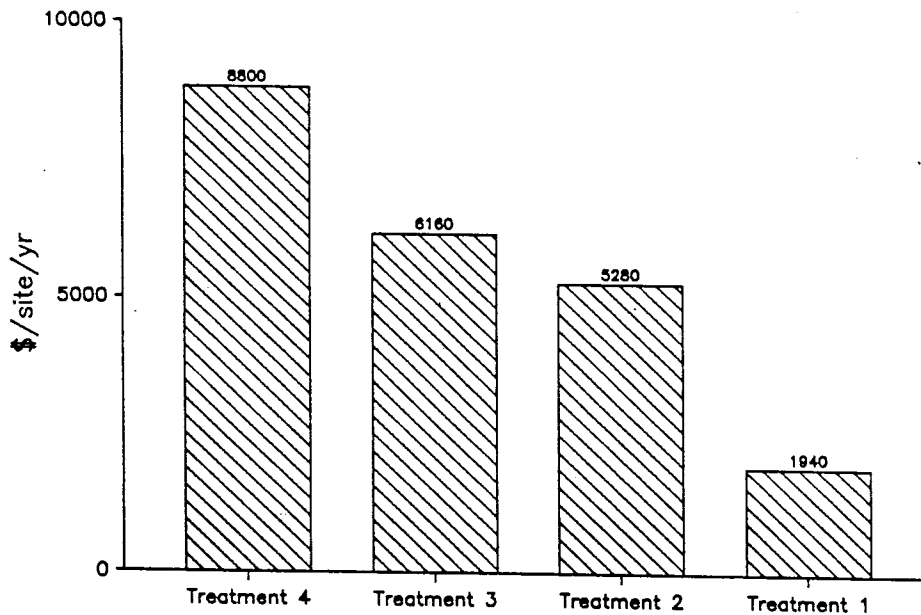


Figure 3-6. Average Yearly Savings in Crash Cushion Repair Costs at Houston Study Sites.

Gore Area Encroachment Rates, Ft. Worth

Background

An analysis of encroachment rates was performed by TTI in 1984 to evaluate the short-term effectiveness of crash cushion delineation at three urban freeway gore area sites in Ft. Worth (4). Reflectorized chevron nose and back panels were used at each site. At one site, the basic delineation treatment was supplemented with alternately flashing yellow lights (vertically positioned on the back panel). Encroachment rates - encroachments per thousand vehicles - were used as the measure of effectiveness in the study. The assumption was that accidents with crash cushions are related to encroachments through the gore area in that a vehicle striking a crash cushion must first encroach onto the painted gore. Because accidents with crash cushions are rare, it was assumed that using encroachments as the measure of effectiveness would permit larger amounts of data to be collected.

The results of the study showed that encroachments into the painted gore area were reduced after the delineation treatments were installed. The effect was greatest upon encroachments occurring during the nighttime hours. Overall, nighttime encroachment rates were 40% lower after the delineation treatments were installed.

One of the major issues brought up in the study was with how the treatments would perform over time. It was noted that as the material used for the delineation treatments aged, some reduction in the effectiveness might occur. It was also noted that, because the delineation was located close to the travel lanes, it might become dirty quickly and lose reflectivity. As a follow-up to the 1984 study, additional data were collected at one of the original study sites (with the flashing yellow lights) as part of Study 408 to determine if the encroachment rates had changed since the time of the short-term studies. Because of construction work and other problems, it was not possible to collect data at the other two original sites.

Method of Study

The crash cushion delineation treatment at the Ft. Worth site was installed in July, 1984. Before installation of the treatment, data were collected using a low-light-level camera and time lapse video recorder. Immediately after treatment installation (August, 1984), data were collected again in this same manner. For the long-term study, this procedure was once again repeated in April, 1986.

Results

The "Before", Short-term "After", and Long-term "After" encroachment rates for nighttime and daytime conditions are shown in Table 3-3. For nighttime conditions, the encroachment rate originally decreased from 3.0 to 1.9

encroachments per one thousand vehicles after installation of the delineation treatment (4). A rate of 2.2 encroachments per one thousand vehicles was computed from the long-term "After" data, indicating that there has been a slight, but not significant, change in effectiveness over time.

TABLE 3-3. COMPARISON OF ENCROACHMENT RATES
Ft. Worth

<u>NIGHTTIME</u>			
	<u>BEFORE (1984)</u>	<u>Short-Term AFTER (1984)</u>	<u>Long-Term AFTER (1986)</u>
Encroachments	36	23	21
Volume	12,072	12,283	9,374
Rate*	3.0	1.9	2.2
<u>DAYTIME</u>			
	<u>BEFORE (1984)</u>	<u>Short-Term AFTER (1984)</u>	<u>Long-Term AFTER (1986)</u>
Encroachments	71	43	139
Volume	58,205	52,692	42,340
Rate*	1.2	0.8	3.2

*Encroachments per 1000 vehicles

For daytime conditions, the encroachment rate originally decreased from 1.2 to 0.8 encroachments per one thousand vehicles. A rate of 3.3 encroachments per one thousand vehicles was computed from the long-term "After" data. The authors cannot readily explain this increase in the daytime encroachments. However, it is believed that the effectiveness of delineation is more important under nighttime conditions when driver visibility is reduced to some degree. Since the long-term nighttime data does not indicate an increase in the encroachment rate from the short-term data, there appears to be no significant decrease in the effectiveness of crash cushion delineation over time (about two years) at this site.

Summary

The long-term effectiveness of urban freeway gore area crash cushion delineation treatments have been examined by collecting additional data at sites examined in previous studies of crash cushion delineation. Crash cushion repair records were obtained for eight urban freeway gore area sites examined in the 1982 study of crash cushion delineation in Houston. Data were available for four years after the treatments were initially installed at the sites. The data indicate that crash cushion repair rates continued to be lower following the installation of the delineation treatments, suggesting that the treatments were continuing to be effective.

The additional long-term data also suggested that the static delineation treatments at the sites with moderate repair rates did, in fact, result in lower repair rates, based on four year's worth of "After" data. It is estimated that the installation of the delineation treatments have resulted in a total savings of over \$174,000 in accident and cushion repair costs at the eight sites over the four year period.

The results of the long-term data collected at the site in Ft. Worth indicate that delineation at this site had not lost its effectiveness in reducing nighttime gore area encroachments after two years in the field.

4. MOTORIST INFORMATION SYSTEM EVALUATION

Background

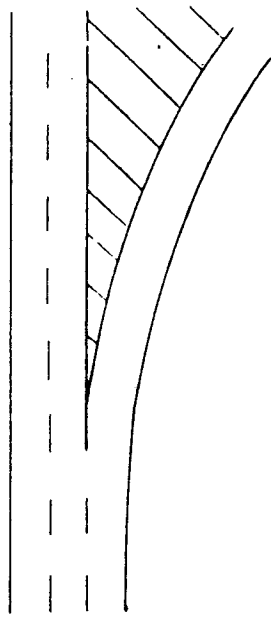
The previous studies of crash cushion delineation (3,4) showed that encroachments through the gore area and crash cushion repair rates could be reduced with chevron nose and back panels (sometimes supplemented with alternating flashing lights) mounted on and behind the crash cushion. A long-term evaluation of these treatments (see Chapter 3) found that the treatments continue to be effective even after four years.

However, a recent study of crash cushion delineation (5) has suggested that delineation requirements may not be the same at all gore areas. Drivers are guided in large part by the formal information (e.g., information provided by signs and markings, and by the location and positioning of signs and markings) provided on the highway. Poor information or poorly placed information can have a detrimental effect on driver behavior and could lead to erratic behavior caused by insufficient advance information.

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. 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 Dudek and Creasey (5) to develop a classification system for gore areas. The classification is illustrated in Figure 4-1.

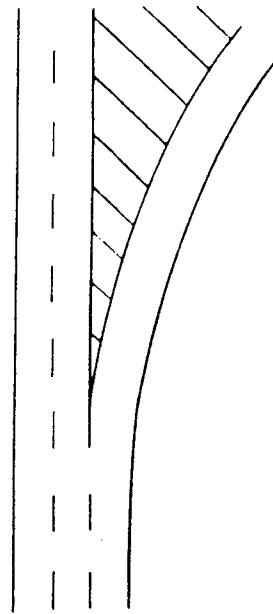
The Type I Gore Area represents a typical gore location with tangent alignment of the main roadway and a well-designed exit ramp. There are no unusual geometric features (e.g., lane drops) and sight distance to the gore area is 1500 feet or greater. Sight distances of 1500 feet have been found to provide adequate response time on high speed facilities (8,9). Sight distances less than 1500 ft could result in operational problems.

The Type II Gore Area represents similar conditions to the Type I with the exception that sight distance is restricted (e.g., by an overpass or crest vertical curve). The Type IIa represents gore areas where the sight distance is between 800 and 1500 feet. The Type IIb Gore Areas have sight distances less than 800 feet. The Type II Gore Areas are more critical than the Type I because of the more restricted sight distances. It is likely that Type II Gore Areas will require more extensive 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 the Type II, whereas sight distance is not a problem for the Type I and therefore a back panel may not be necessary.



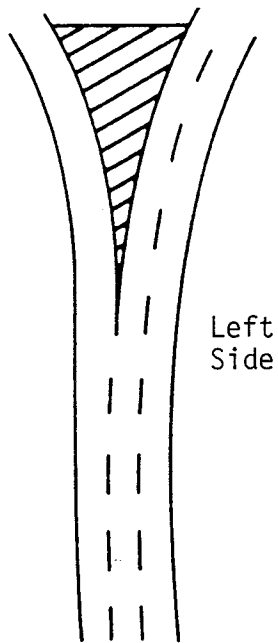
No Sight Distance Restrictions

TYPE I Sight Distance > 1500'

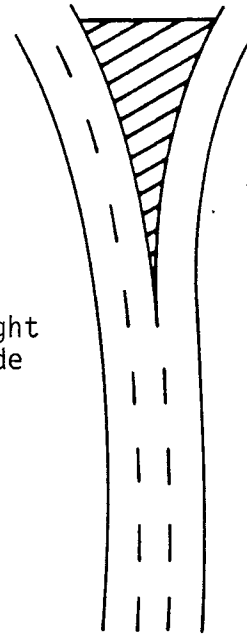


Sight Distance Restrictions

TYPE IIa 800' < Sight Distance < 1500'
 TYPE IIb Sight Distance < 800'



Left
Side



Right
Side

Horizontal Alinement Perspective Problem

TYPE IIIa 800' < Sight Distance < 1500'
 TYPE IIIb Sight Distance < 800'

Figure 4-1. Gore Area Classifications.

The Type III Gore Areas introduce another geometric feature, curvature, which in combination with lane drops, lane additions, etc., results in a visual perspective that may be confusing to the driver. The Type IIIa Gore Area contains the characteristics noted above with sight distance between 800 and 1500 feet. The sight distance to the Type IIIb Gore Area is less than 800 feet.

Whereas, the Type I and the Type II direct the driver past the gore area (either to the left or the right), the 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 perspective problem in combination with inadequate (less than 1500 feet) sight distance oftentimes leads 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 motorist information system, or in some cases improvements in geometrics, may be necessary. This chapter presents the results of a motorist information system evaluation that was performed at three gore area sites in Ft. Worth and in Houston as part of Study 408.

Method of Study

The Ft. Worth site and one of the Houston sites was evaluated in earlier studies by TTI (3,4). An evaluation of the geometrics and formal information system (consisting of signing, marking and delineation) was conducted at each of the three sites. Based on the evaluation, improvements to the formal system were recommended that were expected to yield safety and operational benefits. A research report, "Evaluating Urban Freeway Guide Signing - Executive Summary and Level of Service," prepared by TTI for the SDHPT was used as a guideline for evaluating and recommending improvements to the formal informational system (10).

Results

Site 1 - Ft. Worth

The study site gore, located at the Interstate (IH) 35W North -- IH-30 East-West Interchange in Ft. Worth, is the left-hand exit to IH-30 West. This is the site where long-term encroachment rate data (discussed previously) were collected. A schematic diagram of Site 1 and its sign locations with respect to the gore area is shown in Figure 4-2. Approaching the interchange are two through lanes and a left-hand exit lane. The crash cushions at the gore area are delineated with yellow and black chevron-patterned nose and back panels, supplemented by a pair of alternately flashing yellow beacons, vertically positioned on the back panel (see Figure 4-3). Because of vertical highway curvature and an overpass that limits the effective sight distance to the gore area, this site was classified as a Type IIa (left) Gore Area by the researchers.

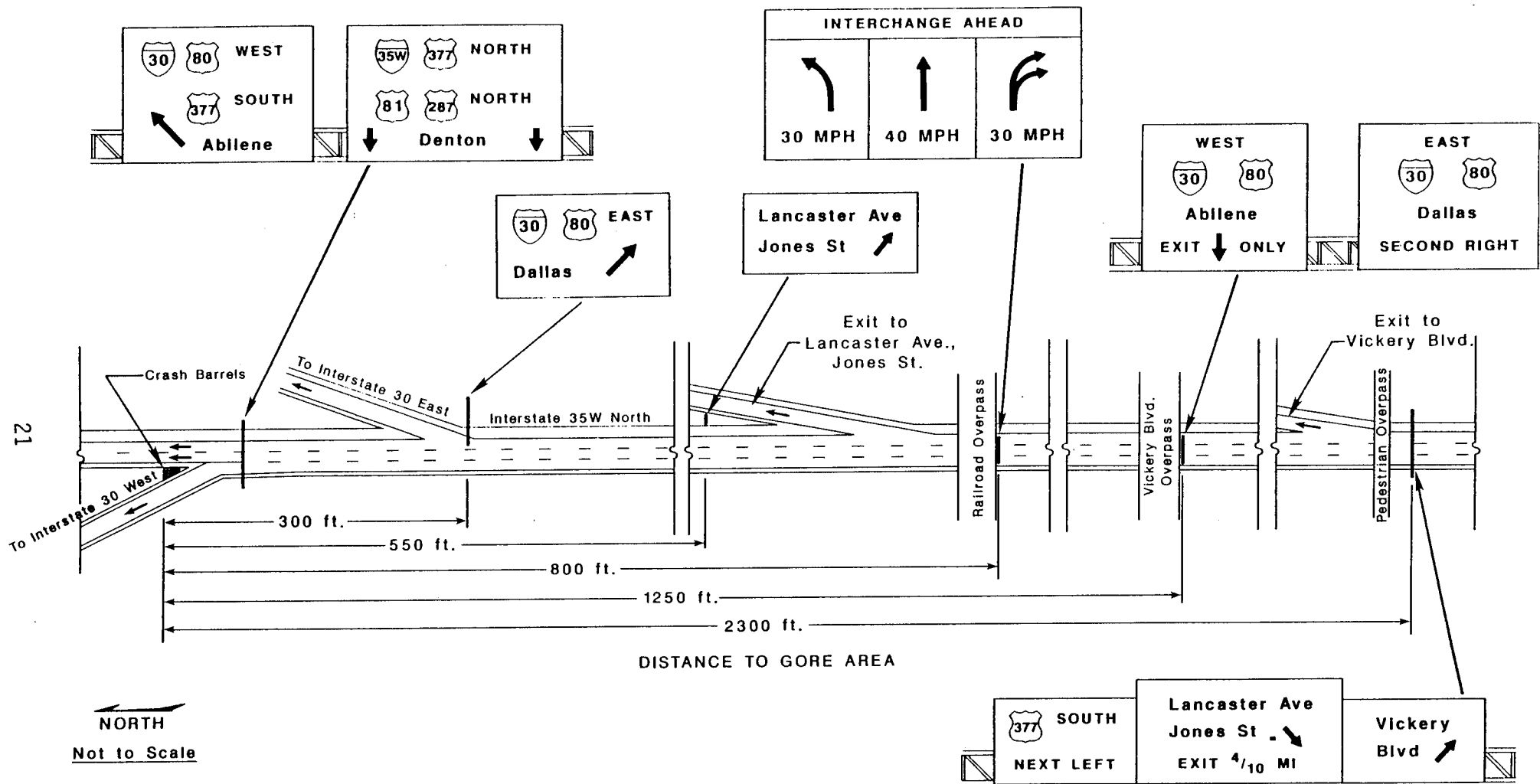


Figure 4-2. Site 1 Schematic Diagram, IH-35W Northbound to IH-30 (Fort Worth)



Figure 4-3. Crash Cushion and Pavement Delineation - Site 1 (Ft. Worth).

Documentation of Existing Conditions

A drive-through of the study site was performed, inspection was made of the pavement markings and geometric perspective, and photographs were taken of the existing signs in advance of the interchange. The photographs are shown in Figures 4-4 through 4-8. The first set of signs that gives the motorist any information about the gore area is approximately 2300 feet from the gore area (Figure 4-4). There are three panels located on the overhead sign bridge: the left panel displays "US 377 SOUTH, NEXT LEFT," the middle panel shows "LANCASTER AVE., JONES ST., EXIT 4/10 MI. ↘", and the right panel displays "VICKERY BLVD. ↗".

The second set of signs, located on the Vickery Blvd. overpass, has two sign panels and is approximately 1250 feet from the gore tip (Figure 4-5). The left panel contains the information, "IH-30 -- US 80 WEST, ABILENE, EXIT ONLY," while the panel on the right displays, "IH-30 -- US 80 EAST, DALLAS, SECOND RIGHT."

The third set of signs, located on the railroad overpass, is approximately 800 feet from the gore area (Figure 4-6). Above all three panels lies a strip which reads "INTERCHANGE AHEAD." The three panels, from left to right, give advisory speeds for the legs of the interchange and contain the following information: "↖ 30 MPH" (left), "40 ↑ MP" (middle - the "H" in MPH is missing), and "↗ 30 MPH" (right). Just beyond this location,



Figure 4-4. First Sign Location - Site 1 (2300 Ft. From Gore Area).



Figure 4-5. Vickery Blvd. Overpass Sign Location - Site 1 (1250 Ft. From Gore Area).



Figure 4-6. Railroad Overpass Sign Location - Site 1
(800 Ft. From Gore Area).



Figure 4-7. Lancaster Ave., Jones St. Exit Sign Location - Site 1
(300 Ft. From Gore Area).

there is a small sign on the right-hand shoulder at the gore area. This sign is located approximately 300 feet from the gore area and displays the message: "IH-30 -- US 80 EAST, DALLAS ↗" (Figure 4-7).

An overhead sign bridge exists directly above the gore area and has two panels (Figure 4-8). On the left, the message "IH-30 -- US 80 WEST, US 377 SOUTH, ↙ ABILENE" points toward the left-hand exit to Abilene. On the right is a "pull-through" sign for motorists remaining on IH-35W NORTH. It contains the message "IH-35W -- US 377 NORTH, US 81 -- US 287 NORTH, ↓ DENTON ↓".



Figure 4-8. Gore Area Signs - Site 1.

Areas for Potential Improvement

The large number of cross streets and corresponding exit/entrance ramps to the freeway upstream of the interchange limits how far in advance drivers can be informed of the interchange ahead. Presently, there is no mention of the interchange until the motorist is only 1/4 mile away (Figure 4-5). It may be especially difficult for an unfamiliar driver in the far right lane to perform two lane changes over 1250 feet in heavy traffic in order to make the left-hand exit. Also, the motorist does not receive any information related to lane assignments for IH-30 until these same signs come into view.

In addition, drivers approaching the interchange are presented with a tremendous amount of information in a short period of time. The combination of signing for the interchange and signing for each of the exits in advance of the interchange requires the driver to scan a large amount of information to obtain the information he/she needs. As the amount of information increases, the driver's ability to receive and process it, and react properly, decreases (10).

Finally, geometric inconsistencies exist because the exit ramp to IH-30 is a left-hand exit. According to the AASHTO Green Book (11), "Left-hand entrances and exits are contrary to the concept of driver expectancy when intermixed with right-hand entrances and exits." The Green Book also states that, "... special attention should be given to signing and the provision for decision sight distance in order to alert the driver that an unusual situation exists."

Recommended Changes

Recommended signing improvements that were estimated to provide the greatest benefit for the least cost involved three changes described below.

1. The first signs that provide any indication about the interchange are approximately 1/2 mile from the gore area (Figure 4-4). The left panel, which presently reads "US 377 SOUTH, NEXT LEFT," could be changed to read "IH-30 WEST, NEXT LEFT." This would involve changing the US Highway shield to the Interstate shield and changing the directional wording from "SOUTH" to "WEST". This change is consistent with maintaining primary interstate routes and eliminating redundant US numbered routes through major interchanges (10).

2. A diagrammatic sign suggested for use at this interchange is shown in Figure 4-9. It is recommended that the sign be installed at the Vickery Blvd. overpass (see Figure 4-2) and that the two existing panels be removed. This would give motorists more time to receive and process the information on the sign than if it were placed on the railroad overpass closer to the interchange. Installing the sign at the suggested location would give drivers up to 1800 feet to receive and process the information and navigate the interchange.

3. It is recommended that the advisory speed panels mounted on the railroad overpass (Figure 4-6) be removed and be replaced with the two panels taken from the Vickery Blvd. overpass (those presently seen in Figure 4-5). The bottom line of the right panel, which currently reads "SECOND RIGHT", should be changed to read "EXIT 1/10 MI. ". This refers to the exit ramp to Interstate 30 East to Dallas (Figure 4-8). While this ramp is still the "second right" as indicated by the existing sign, the closeness of the exit ramp to Lancaster Avenue and Jones Street (Figure 4-7) may cause confusion for some drivers. The arrow pointing upward and to the right is consistent with the thought process that the eastbound exit for Interstate 30 is "up ahead" and to the right.

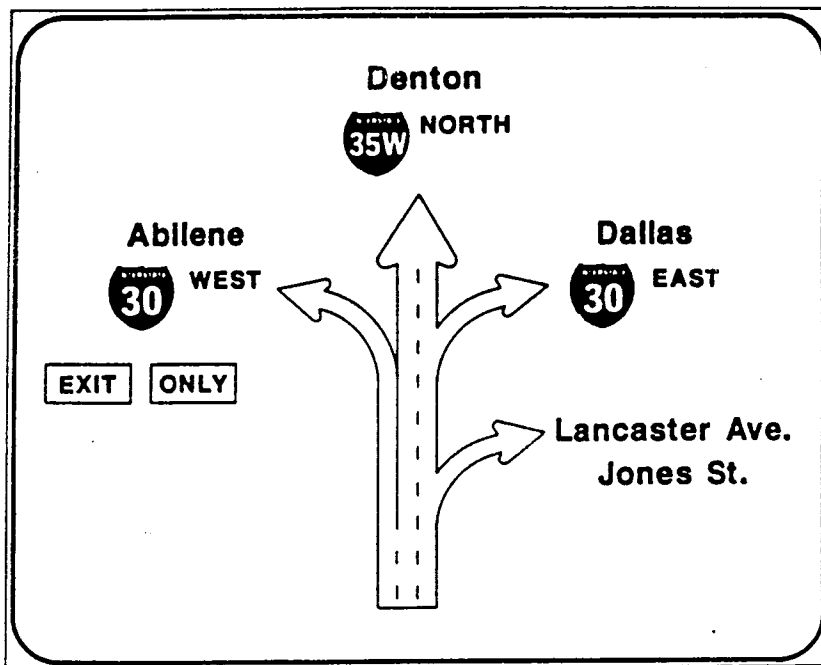


Figure 4-9. Proposed Diagrammatic Sign - Site 1 (Ft. Worth).

Site 2 - Houston

Site 2 is located at the IH-610 (West Loop) North -- US 59 (Southwest Freeway) Interchange. A diagram of the site and existing signing leading to the exit is shown in Figure 4-10. The crash cushion and existing delineation treatment are shown in Figure 4-11. The delineation treatment consists of orange and white chevron-patterned nose and back panels with two side-by-side alternately flashing yellow beacons mounted on the back panel. There are also three yellow and black chevrons on each side of the bridge rail directly behind the crash cushion. Because the visual perception of the gore at this appears to lead drivers into the crash cushions, researchers classified this site as a Type IIIa gore area. The SDHPT reports that, from 1978 through 1986, this site had been hit more frequently than any other crash cushion location in Houston (12).

Documentation of Existing Conditions

As with the first site, TTI researchers made a drive-through, examining the geometric and visual perspective of the gore area, pavement markings in advance and leading to the gore, and took photographs of the existing advance signing. These photographs are shown in Figures 4-11 to 4-15. The first sign giving information about the interchange is located on an overhead sign bridge 2.4 miles from the exit (Figure 4-11). There are four panels, with a pull-through sign on the far left that displays "IH-610 NORTH." The next sign indicates the exit at Site 2: "US 59, EXIT 2 4/10 MI." The third panel indicates an upcoming exit: "Fournace Pl., EXIT 1 6/10 MI." On the far right is a sign indicating the exit ramp that says "Evergreen St., Bellaire Blvd. "

The next set of signs is located on an overhead sign bridge 0.8 miles (4200 feet) from the interchange (Figure 4-12). There are three panels, with a pull-through sign on the far left that shows "IH-610 NORTH". The middle sign reads "US 59, EXIT 8/10 MI". The right sign points to the exit at that location: "Fournace Pl. ↙ ". On the right-hand shoulder of the roadway, 1300 feet from the gore area, is a sign that reads "RIGHT 2 LANES MUST EXIT" (Figure 4-13). Just upstream of the gore, approximately 800 feet away, is a diagrammatic sign located above the far left lane that specifies lane assignment for the interchange ahead (Figure 4-14). On the left are three upward arrows located beneath an IH-610 shield, indicating that the three left lanes continue straight ahead for IH-610. On the right are two curved arrows under a US 59 shield, pointing up and to the right, indicating that the two right lanes exit to US 59.

Above the gore area is a sign bridge with two panels (Figure 4-15). On the left, the panel shows "IH-610 NORTH" with three downward-pointing arrows underneath. The panel on the right displays the US 59 shield, with "SOUTH" to the left of the shield and "NORTH" to the right. There are two diagonal arrows, one under "SOUTH" and one under "NORTH", pointing upward and to the right. Atop the crash cushion back panel is an exit sign indicating an exit to the right (Figure 4-16).

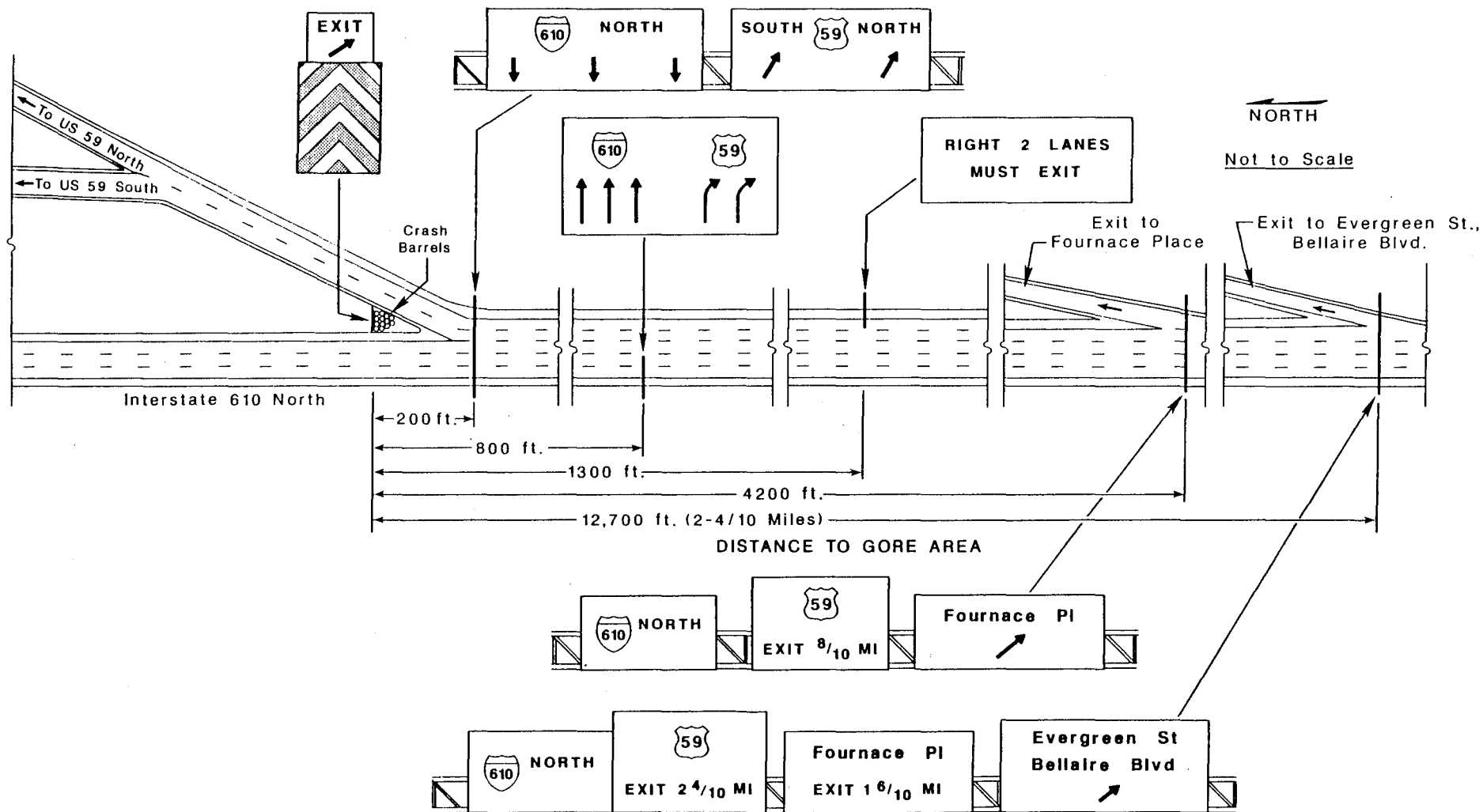


Figure 4-10. Site 2 Schematic Diagram, IH-610 Northbound to US59 (Houston)



Figure 4-11. Crash Cushion And Pavement Delineation - Site 2 (Houston).



Figure 4-12. Evergreen St., Bellaire Blvd. Exit Sign Location - Site 2 (2.4 Miles From Gore Area).



Figure 4-13. Fournace Place Exit Sign Location - Site 2
(0.8 Miles From Gore Area).



Figure 4-14. Exit Lane Sign - Site 2 (1300 Ft. From Gore Area).



Figure 4-15. Diagrammatic Sign Location - Site 2
(800 Ft. From Gore Area).



Figure 4-16. Gore Area Signs - Site 2.

Areas of Potential Improvement

As already stated, roadway geometry at this site results in a somewhat misleading visual perspective for drivers approaching the gore area. There are five lanes approaching the site: three mainlanes and two exit lanes. As can be seen in Figure 4-15, the second lane from the right shoulder (left exit lane) appears to be headed directly toward the crash cushion. In moderate to heavy traffic, the crash cushion may be obscured by other vehicles, and it is entirely possible that the delineation itself may be mistaken for the back of a large truck moving in the traffic stream. As stated previously, this site was classified as a Type IIIa gore area.

Recommendations

It is possible that the high number of crash cushion accidents at this site are due, at least partially, to the actual roadway geometry that provides a strange visual perspective of the gore area. Obviously, in situations such as this one, it is not feasible to make costly geometric improvements. Thus, the next best alternative is to provide effective information to motorists and insure that they are given enough time (i.e., decision sight distance(10)) to properly receive, process, and react to it.

Two improvements are suggested at this site.

1. A diagrammatic sign, like the one in Figure 4-17, could be constructed and placed on an overhead sign bridge far enough upstream to inform drivers of the upcoming interchange (at least 1500 feet). However, it should not be so close to the sign location in Figure 4-14 that it interferes with the sign. It would even be suitable to combine the two signs (diagrammatic and "RIGHT 2 LANES MUST EXIT") on the same sign bridge.
2. An additional diagrammatic sign like the existing one shown in Figure 4-15 could be placed on the right side of the road at that location in order to insure that all drivers in all five lanes are able to see this information at this location.

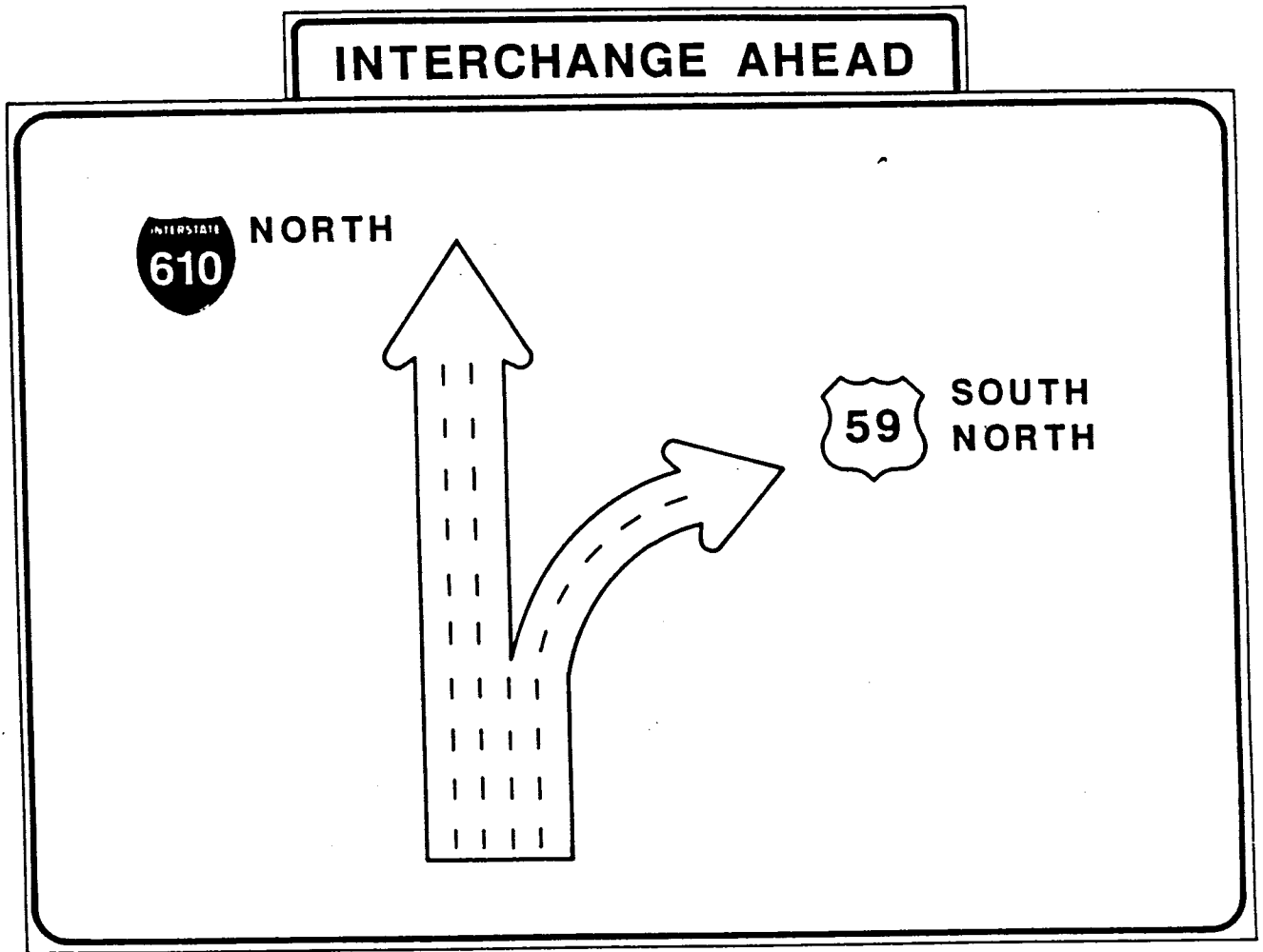


Figure 4-17. Proposed Diagrammatic Sign - Site 2 (Houston).

Site 3 - Houston

Site 3 is located at the S. Post Oak Road Exit from IH-610 (West Loop) South. A diagram of the site conditions (including signing) is shown in Figure 4-18. Existing crash cushion delineation includes orange and white chevron-patterned back panels supplemented by three yellow Type 1 TMUTCD (6) diamond-shaped object markers beneath the back panel (Figure 4-19). As with Site 2, this site was classified as a Type IIIa gore area due to geometric factors which direct a driver's visual perception of his travel path into the gore area.

Documentation of Existing Conditions

A drive-through of the study site was performed and photographs were taken to document the existing signing. These photographs are shown in Figures 4-19 to 4-23. At the first sign location, Figure 4-20, there are three panels on an overhead sign bridge. The left-most one reads "S. Post Oak Rd., EXIT 1 MI." The middle panel reads "N. Braeswood Blvd., S. Braeswood Blvd., EXIT 7/10 MI.," and the one on the right reads "Beechnut St. ↗", referring to the exit seen in the photograph. The next sign location, shown in Figure 4-21, is another overhead sign bridge with three panels. On the left is a pull-through panel that displays "IH-610". In the middle is a panel that reads "S. Post Oak Rd., EXIT 4/10 MI." On the right, "N. Braeswood Blvd., S. Braeswood Blvd. ↗", directs traffic toward the exit seen in the photograph. Approximately 800 feet before the gore area, on the right-hand shoulder, is a sign that displays, "RIGHT LANE MUST EXIT" (Figure 4-22). Finally, a sign bridge with two panels is located above the gore area (Figure 4-23). The one on the left reads "IH-610 East" and has three diagonal arrows underneath pointing upward and to the left. The panel on the right says "S. Post Oak Rd." and has two arrows located underneath pointing straight down.

Areas of Potential Improvement

The geometric design of the freeway and exit ramp at this location may give drivers a misconception of the actual roadway ahead. Figures 4-20 to 4-22 illustrate the situation. A long tangent section of roadway begins to curve to the left at the gore area while the exit ramp continues on a tangent. The mainlanes to the left are somewhat hidden by a flyover left-hand entrance ramp to the opposing northbound lanes of IH-610 (see Figure 4-20), and drivers approaching the gore area may not realize in time that it is necessary to veer to the left to remain on the freeway.

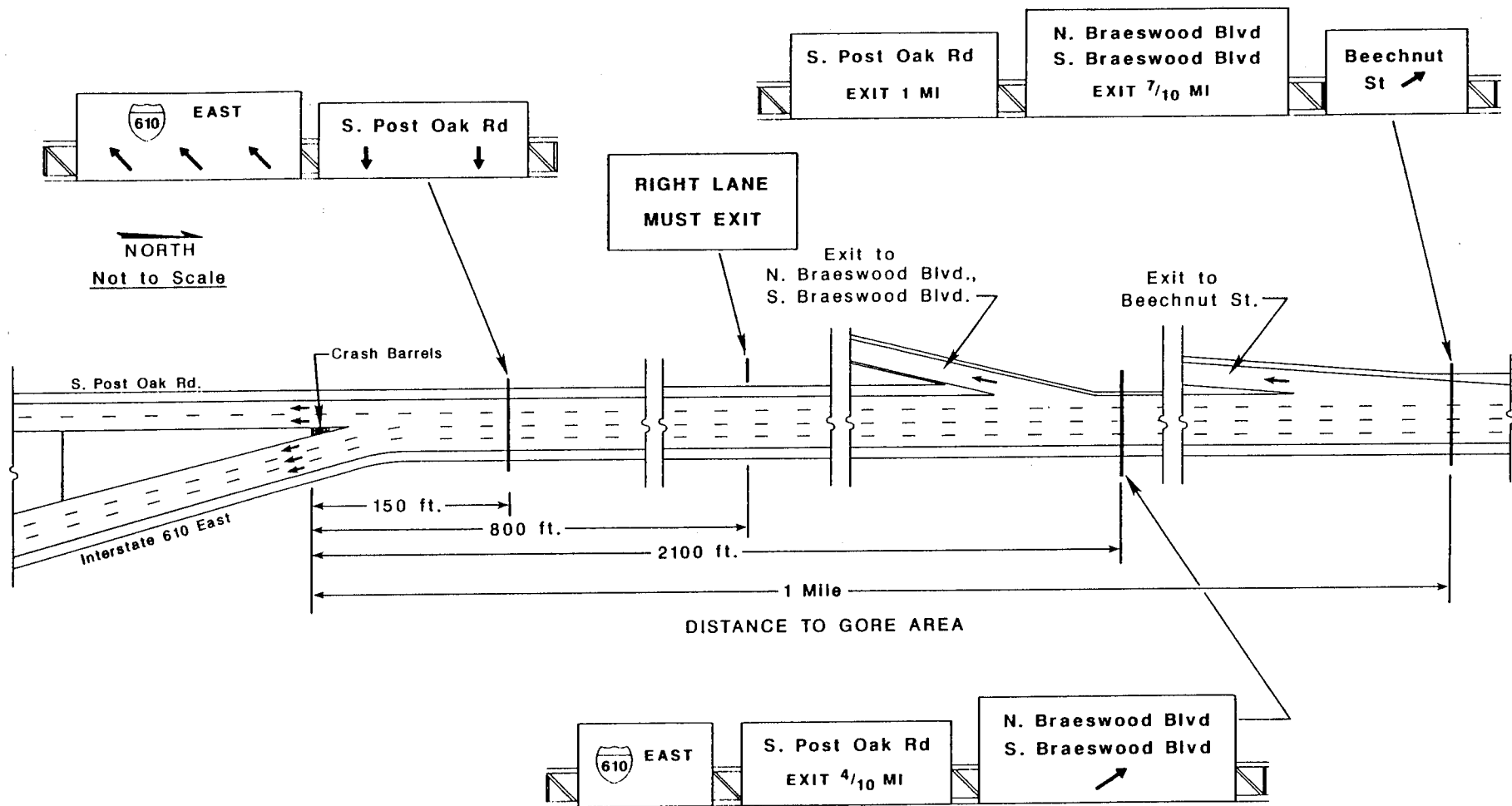


Figure 4-18. Site 3 Schematic Diagram, IH-610 Southbound to S. Post Oak Rd. (Houston)

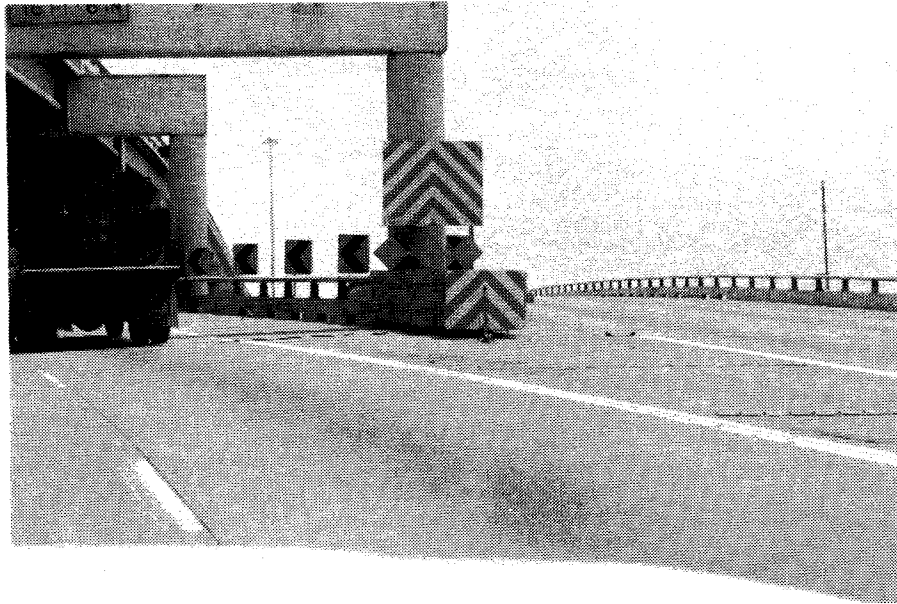


Figure 4-19. Crash Cushion and Pavement Delineation - Site 3 (Houston).



Figure 4-20. Beechnut St. Exit Sign Location - Site 3
(1 Mile From Gore Area).



Figure 4-21. Braeswood Blvd. Exit Sign Location - Site 3 (2100 Ft. From Gore Area).



Figure 4-22. Exit Lane Sign - Site 3 (800 Ft. From Gore Area).



Figure 4-23. Gore Area Signs - Site 3.

Recommendations

The situation here is similar to that at Site 2; costly geometric improvements are not feasible to eliminate the possible misconceptions. The most practical improvement at this site would be to provide additional information about the roadway geometry in an attempt to better warn drivers of the roadway alignment ahead.

1. A diagrammatic sign like that shown in Figure 4-24 is suggested to better illustrate the roadway features. The proximity of the Braeswood Blvd. Exit (Figure 4-21) limits where the diagrammatic sign could be placed. The sign should be located on an overhead sign bridge somewhere between 1500 to 2100 feet from the gore area, but should not be placed so close to the Braeswood Blvd. Exit that it would be in competition with the existing signs. The best solution would be to locate the diagrammatic sign 1500 feet from the gore and move the existing sign shown in Figure 4-22 ("RIGHT LANE MUST EXIT") to this new location. It would be more desirable to have two panels on one sign bridge than to have individual signs spaced only a few hundred feet apart.

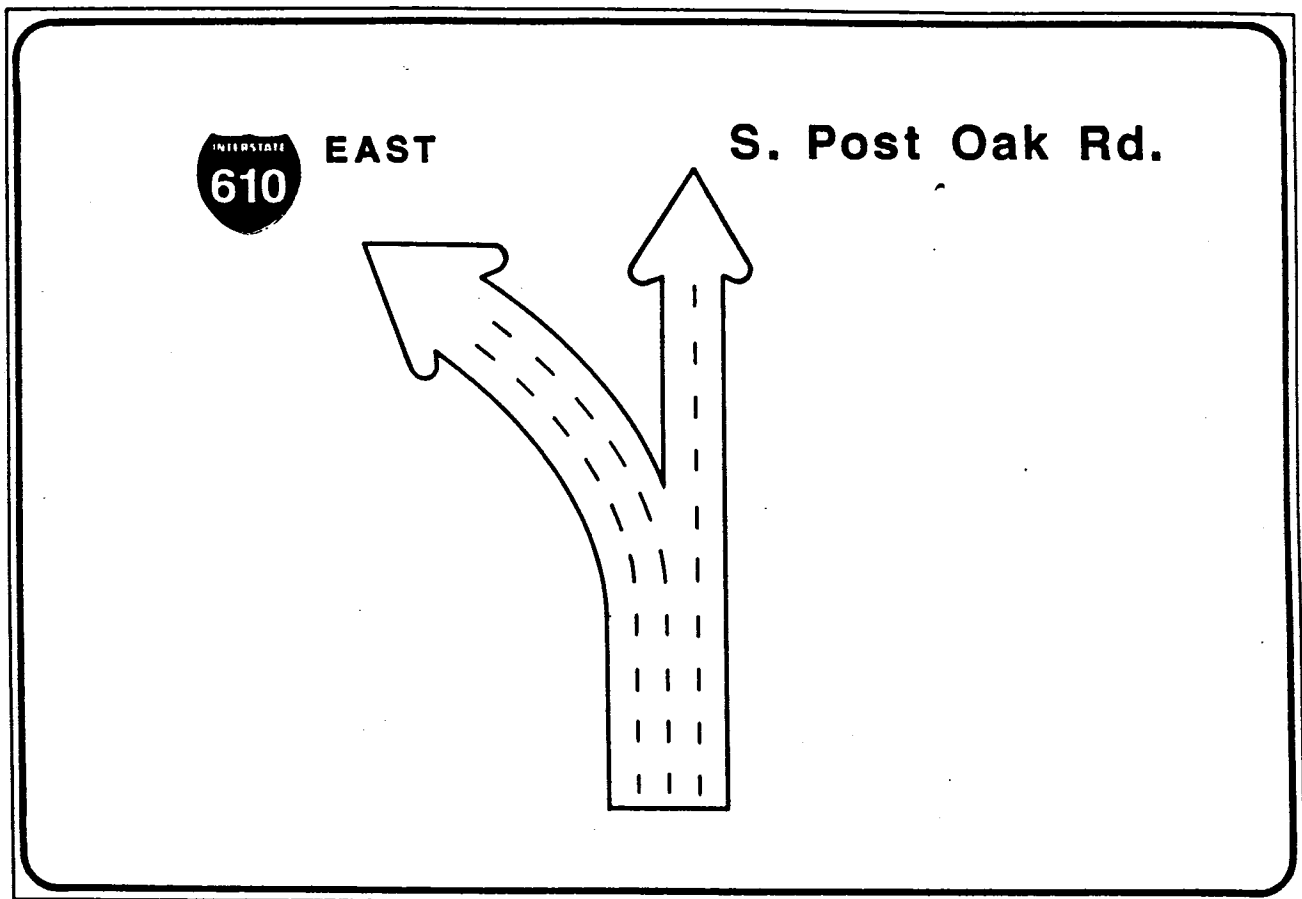
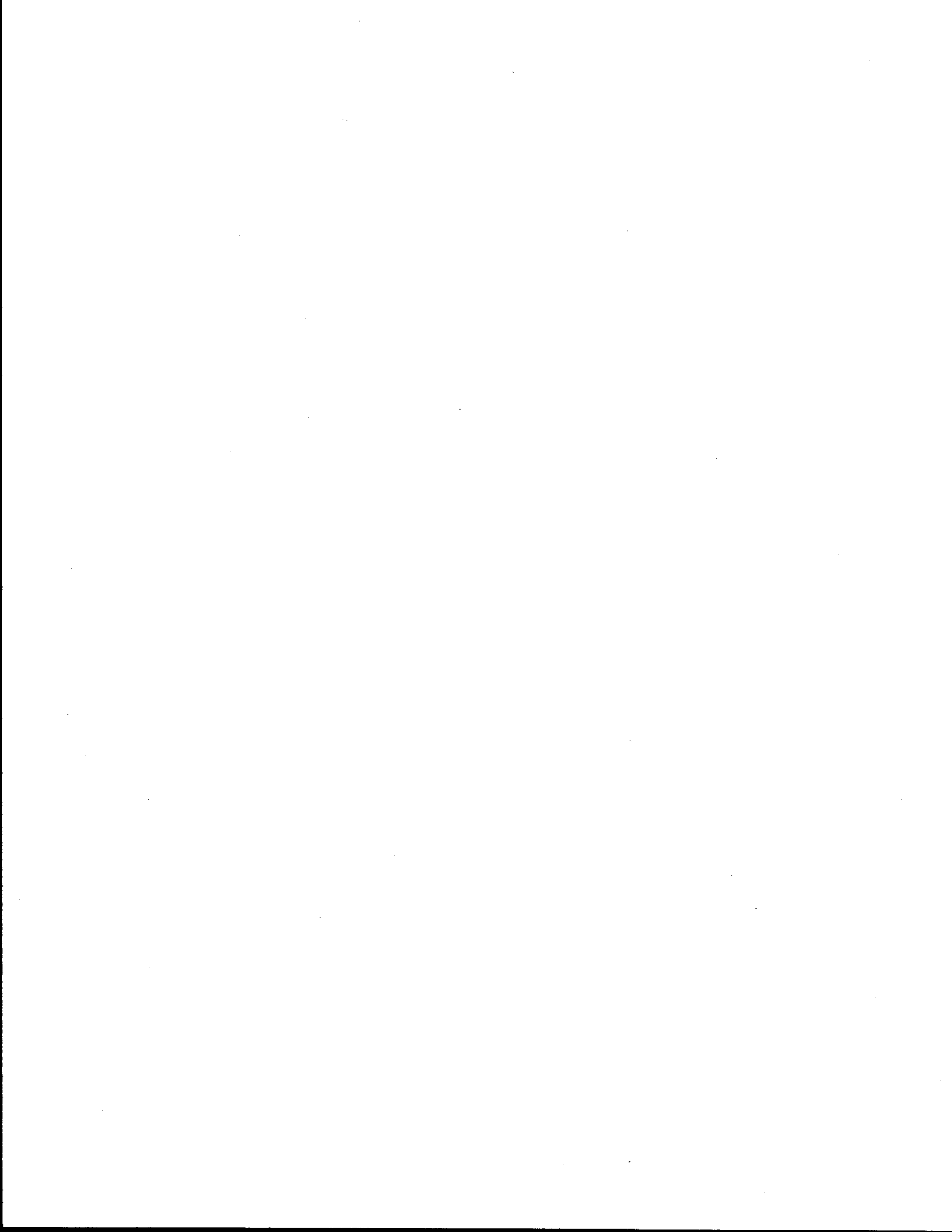


Figure 4-24. Proposed Diagrammatic Sign - Site 3 (Houston).

Summary

These evaluations of the advance signing upstream of Type II and Type III Gore Area crash cushions have found that geometric inconsistencies may often mislead drivers, and may be partially responsible for higher crash cushion accident rates. In these situations, it may be possible to adjust the information system upstream of the gore in an attempt to counteract these inconsistencies and give drivers critical information sooner and in a more easily understood manner.

Unfortunately, study funds did not allow the researchers to implement the above recommendations and evaluate the effectiveness of each using objective driver performance data. Consequently, it is not known whether the improvements would indeed be cost-effective to implement. As stated earlier, it may be difficult to overcome geometric inconsistencies with informational signing, since signing is used primarily for guidance and navigational purposes by drivers. Any future implementation of these recommendations should be evaluated using objective driver performance measures to determine if the changes have had the desired effect upon traffic operations and safety.



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