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Guidance for Effective Use of Pylons for Lane Separation on Preferential Lanes and Freeway Ramps

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16. Abstract

Flexible pylons are gaining popularity as traffic channelizing devices in a variety of applications. The flexible pylons are less rigid (as compared to concrete barriers) enabling easier access for emergency vehicles and provide more positive control than pavement markings for channelizing traffic. In general there are also concerns with the effectiveness of flexible pylons when used as channelizing devices. Motorists frequently strike flexible pylons, which can increase maintenance costs for agencies. In addition, broken pylons may create safety concerns to motorists. While some standards exist to test durability of pylons, there is a lack of guidelines for implementation of pylons. This project identifies factors that influence the effectiveness of pylon implementations and develop guidance to effectively implement pylons on high speed facilities. This report documents the tasks of the first year of research including: a state-of-practice review, vendor survey, agency survey, case studies, and a synthesis of information.

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Pylons, Delineators, Curbs, Lane Separation, Candle Sticks, Plastic Channelizers, Tubular Markers

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation. This report is not intended for construction, bidding, or permits purposes. The engineer in charge of the project was Robert J. Benz, P.E. #85382.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION

Over the past decade, flexible pylons have been increasingly used on Texas roadways for the purposes of lane delineation and separation. Numerous terms have been used to describe the devices herein referred to as pylons, including *flexible pylons*, *delineator posts*, *candle sticks*, *tubular markers*, and *channelizing posts*. Figure 1 shows examples of pylon traffic control devices.

Figure 1. Examples of Pylon Devices.

Pylons are used in various applications on roadways, including lane separation, delineation of median curbs, and access management on arterials, among others. However, there has been some concerns that if pylons are hit by a vehicle, an unsafe condition for motorists could result as debris from broken pylons and/or curbs leave exposed nails or broken curbs. There have also been concerns that the use of pylons can result in increased long-term maintenance costs for the Texas Department of Transportation (TxDOT) and other agencies, even though the initial deployment costs are typically much less than traditional concrete median barrier. While most agencies deploying pylons realize and accept that these devices may be impacted often, it appears that most agencies know very little as to when and why pylons are hit.

There is also a perceived lack of guidance available to assist TxDOT engineers in deciding when pylons are suitable to deploy and what factors, including cost and maintenance requirements, should be considered while implementing pylons. This research report provides a set of initial guidelines and information regarding implementation and maintenance of pylons that should help TxDOT engineers to make more informed decisions when considering implementation.

This research report documents a series of tasks conducted as part of the project, including: 1) surveys of TxDOT districts, other state Departments of Transportation (DOTs), and pylon manufacturers and vendors, 2) video-based case studies of in-field deployments, and 3) experimental studies performed to determine practical spacing limits for pylon deployments. The guidelines developed in this report focus primarily on the following freeway- or frontage road-based pylon applications: 1) separation of preferential lanes (high occupancy vehicle [HOV] or managed lanes) from general purpose lanes, and 2) separation of freeway ramps and auxiliary lanes from frontage lanes. Although most of the guidelines within this report are developed with these two applications in mind, some of the guidelines developed herein can be utilized with discretion for implementing pylons for other applications.

In this chapter authors present background information on lane separation practices, benefits of flexible pylons for lane separation, existing guidelines for pylon implementation and the gaps in guidance which precipitated the need for this study. Also included is a brief summary of the methodology of various tasks performed in this study.

BACKGROUND

Concrete barriers, flexible pylons, and pavement markings are the three most commonly used devices for separating or delineating lanes on high speed facilities (for this report, high speed facilities are those with designated speed limits of over 45 mph). However, each of these devices has benefits and disbenefits regarding their application. Concrete barriers are rigid, have fixed width, and provide physical separation of traffic when used in lane separation applications. When used for lane separation, they provide positive separation and reduce the visual load on the driver as motorists on the other side of the barrier are physically restricted from weaving between separated lanes. On the other end of the control spectrum, pavement markings used for lane separation do not impose any physical restriction and do not provide positive physical separation for drivers. However, flexible pylons have recently gained popularity as lane separation devices as they provide functionality between the totally physically restrictive nature of the concrete barrier and the physically unrestrictive application of pavement markings. Flexible pylons provide some sense of physical (and visual) barrier but are flexible enough for vehicles to cross through in case of an emergency.

Many transportation agencies, including state DOTs, cities, toll authorities, and transit agencies, have been using pylons for lane separation and channelization on a wide range of facilities. However, TxDOT, among other agencies, has expressed concern over the high ongoing cost of maintenance of these devices when used on high speed facilities. Depending on the characteristics of the installation, motorists may frequently strike the pylons, breaking them, and leaving gaps in the system that may create operational or safety concerns.

A review of the pylon offerings in the current market indicates that there are newer products that manufacturers claim to provide increased durability when struck over time. Most of the pylon products undergo durability testing and meet specifications regarding the physical characteristics of the device and ability to be struck before being accepted by transportation agencies for use on roadways. The *Manual on Uniform Control Devices* (MUTCD) provides some guidance regarding the color, height, and retroreflectivity aspect of pylons (which they refer to as tubular markers), but very little guidance is available regarding pylon implementation factors such as longitudinal spacing, buffer spacing, curb spacing, curb height, and visibility (*1*). TxDOT's experience with (and increasing use of) pylons for lane separation and channelization on high speed facilities prompted this study to generate guidance for the implementation of pylons to optimally deploy and minimize the maintenance of pylon devices when deployed.

METHODOLOGY

This project was designed to consist of eight tasks: 1) state-of-practice review, 2) vendor interviews, 3) agency surveys, 4) case studies, 5) documentation of safety experience, 6) documentation of maintenance experience, 7) pylon spacing experimental testing, and 8) development of guidance for implementing pylons. The first three tasks were performed in the first year of the study. The last five tasks were completed in the second year. The following presents an overview of the methodology of the tasks performed in this study.

Task 1: State-of-Practice Review

During the state-of-practice review, researchers queried all published information related to flexible pylons in several library catalogs, databases, and across the Internet. Some general information on the components of pylon assembly and different applications of pylons were reviewed. For clarity, researchers documented various terminologies being used for pylons in the literature. A comprehensive review of selected pylon implementations from information available in the literature was performed and guidelines available from manuals, such as the MUTCD (*1*) and American Association of State Highway and Transportation Officials (AASHTO) *Roadside Design Guide* (*2*) were reviewed. Researchers then documented a summary of the findings from the state-of-practice review and identified potential gaps in operational, safety, or deployment information related to pylon implementation.

Task 2: Vendor Interviews

The goal of the vendor interview task was to gather information on locations where pylons had previously been installed, as well as gather a list of agency contacts that have deployed pylons for use in the case study and agency survey tasks. A list of all pylon manufacturers was compiled from reviewing the qualified product list of several state DOTs. The research team sent a questionnaire to each identified pylon manufacturer to solicit information pertaining to their pylon products, including locations where they are installed, agency contacts using their products, and any pylon implementation guidelines typically provided to their clients.

Task 3: Agency Survey

The transportation agency survey task focused on gathering information primarily regarding 1) the choice to use pylons over other options for lane separation, 2) applicable existing pylon implementation guidelines, and 3) pylon maintenance experience. In addition, researchers wanted to compile any anecdotal guidelines that agencies may be using for making decisions to deploy pylons. The researchers emailed surveys to all TxDOT districts, 51 state and territorial DOTs, selected transit and tolling agencies, and several larger cities in Texas. Follow-up calls and interviews were also made to many of the agencies to solicit additional, specific information regarding their experiences. Agencies were asked to list locations where pylons were installed as a potential input as a case study.

Task 4: Case Studies

In the case study task, researchers recorded video at 17 pylon implementations in the Houston, Dallas, and San Antonio, Texas, regions. These 17 locations were categorized into three different groups, all on higher-speed facilities: 1) preferential lane entry/exit access locations, 2) preferential lane tangent sections, and 3) freeway ramp at frontage road locations.

The sites for case studies were selected based on geometric/implementation considerations, site recommendations from surveys (identified in project Task 3), the feasibility of video recording for analysis, and input from the project team. Researchers recorded video on all the preferential lane locations using existing closed-circuit television cameras (CCTV) where possible, and deployed portable trailers equipped with cameras at freeway ramp and frontage road locations. At each location video was recorded for a seven-day period, resulting in a total of 2,850 hours of video footage collected.

The video was viewed and data pertaining to pylon hits, near misses, and nature of pylon hits (such as type of vehicles and type of maneuvers) were collected. Traffic volumes, vehicle speeds, and crash information were also noted. The data were collated and summarized in 15 minute intervals for analysis. Some general inference on nature of pylons hits were derived by observing the video recordings and statistical analysis performed on the resulting databases in an attempt to identify potential factors that appear to influence pylon hits.

Task 5: Safety Experience

In the surveys completed for Task 3, several agencies indicated that, subjectively and in some instances, the use of pylons provides an increased sense of safety as compared to the use of only pavement markings. However, it was surmised that some applications of pylons have shown the propensity for higher crash rates over the use of more restrictive concrete barriers. In order to assess influence of the use of pylons on safety, crash data before and after implementation of pylons at five different freeway ramp-frontage sites were analyzed. Crash data for the selected sites were queried in TxDOT's Crash Records Information System (CRIS) database. Pertinent crash reports were downloaded and reviewed in detail. Collision diagrams shown on the crash reports were also reviewed to identify pylon related crash. The number of crashes were then tabulated for each study site for the before and after periods.

Task 6: Maintenance Experience

Ongoing maintenance is a critical issue for an agency to plan for (and execute). Pylons were identified as an ongoing maintenance items from most agencies surveyed. Case study interviews expanded on the questions about maintenance. These conversations gathered information on activities, issues, and costs related to pylons. Analysis was conducted on the tradeoffs between various lane separation techniques. Descriptions of the parameters are described and a cost per mile comparison was conducted.

Task 7: Experimental Study on Longitudinal Spacing of Pylons

In this task researchers performed controlled experiments at the Texas A&M Riverside Campus in Bryan, Texas, to determine the minimum pylon spacing that a motorist can maneuver without hitting the devices when traveling at varying speeds. For a given pylon spacing setup and vehicle type, subjects completed three test runs for speeds ranging from 5 mph to 30 mph in 5 mph increments. During these tests, a motorist's ability to maneuver between pylons was noted, and a relationship between spacing and speed was determined.

Task 8: Development of Pylon Implementation Guidance

Researchers synthesized the information obtained from the above tasks and generated guidance based on the lessons learned and best practices observed regarding pylon implementation and maintenance. This guidance can potentially assist TxDOT engineers in making decisions under what conditions and how to deploy pylons, as well as what can be expected regarding the maintenance aspects of pylon deployment. While most of the guidance derived in this research is primarily a result of qualitative assessment, they should provide engineers with some insight as to make informed decisions on pylon implementations.

CHAPTER 2: STATE-OF-PRACTICE REVIEW

This chapter presents a working definition of pylons and a comparison of the various terms used to refer to these devices. It also provides a description of the typical components of pylons, their physical and material characteristics, mounting types, and mechanisms used to affix pylons to the pavement. Also prepared is a representative list of some of the applications where pylons have been used.

In order for pylons to be functional and cost effective, they need to be appropriately implemented depending on the application. Described in this chapter are factors that should be considered for implementation under various higher-speed installations. Standard durability tests and procedures are also summarized from the few existing guidelines available. The use of intrusion analysis in the AASHTO Roadside Design Guide (*2*) was reviewed to identify potential guidance on provision of buffer space around pylons. Finally, issues related to the use of flexible pylons are highlighted, followed by a summary of the state-of-practice and identified gaps in the available implementation guidance.

PYLON TERMINOLOGY

The term "flexible pylons" (as it appears in the project title) is used throughout this report and refers to plastic vertical posts mounted on a base, typically including some type of a hinge mechanism. When reviewing the literature, researchers found many terms being used for flexible pylons. These terms include:

- Candle stick.
- Flexible channelizing device.
- Flexible delineator.
- Flexible guide post.
- Flexible post delineator.
- Flexible traffic separator.
- Mountable curb marker.
- Plastic channelizer.
- Soft delineator barrier.
- Tubular marker.
- Vertical delineators.

In addition to the above terms, several reports reviewed used specific brand names to refer to flexible pylons. A possible reason for so many different terminologies is due to the wide use of pylons in a variety of applications and no discernible common names for the devices. Flexible pylons can be applied for several purposes, most commonly separating (and channelizing) traffic and delineating roadway geometry (and/or hazards). The lack of a clear definition in any standard manuals pertaining to traffic control devices such as the MUTCD (*1*) and the *Texas Manual on Uniform Traffic Control Devices* (TMUTCD) (*3*) may have also led to the adoption of numerous terminologies.

Both MUTCD and TMUTCD discuss delineators and channelizers in various applications, and in several locations within the documents:

- Part 3. Markings (sections on delineators and on channelizing devices).
- Part 6. Temporary Traffic Control (sections on channelizing devices).
- Part 8. Railroad (sections on channelizing at grade crossings).

Part 3 of the MUTCD is titled "Markings" but also includes sections on delineators (Chapter 3F) and other channelizing devices (Chapter 3H). Chapter 3F defines a delineator as follows:

> "*Section 3F.01 Delineators*
>
> *Support:*
>
> 01 *Delineators are particularly beneficial at locations where the alignment might be confusing or unexpected, such as at lane-reduction transitions and curves. Delineators are effective guidance devices at night and during adverse weather. An important advantage of delineators in certain locations is that they remain visible when the roadway is wet or snow covered.*
>
> 02 *Delineators are considered guidance devices rather than warning devices.*
>
> *Option:*
>
> 03 *Delineators may be used on long continuous sections of highway or through short stretches where there are changes in horizontal alignment*" (*1*).

Note that per Section 3F.01 of the MUTCD, delineators are defined as guidance devices rather than warning devices (paragraph 02 above). Standards statements found in this section further define that delineators should be retroreflective and match the color of pavement markings they are supplementing. For preferential lanes that are buffer separated, Chapter 3D calls for white markings separating the preferential lane from the general purpose lane, which can be used to infer that delineators used in this buffer should also be white. The MUTCD Part 3, Section 3H-01, titled *Channelizing Devices Used for Emphasis of Pavement Marking Patterns,* refers to a variety of channelizing devices described in Part 6. Examples of such devices listed in Part 3 use the terms "cones," "tubular markers," "vertical panels," "drums," "lane separators," and "raised islands." Part 6, *Temporary Traffic Control*, addresses pylons and channelizing markers as well. The pylons described in this report closely refer to the tubular markers shown in Figure 2 (reproduced from Figure 6F-7 in section 6F.63 in the 2009 edition of MUTCD) (*1*). The 2006 version of the TMUTCD has adopted the same terminology (tubular markers) (*3*).

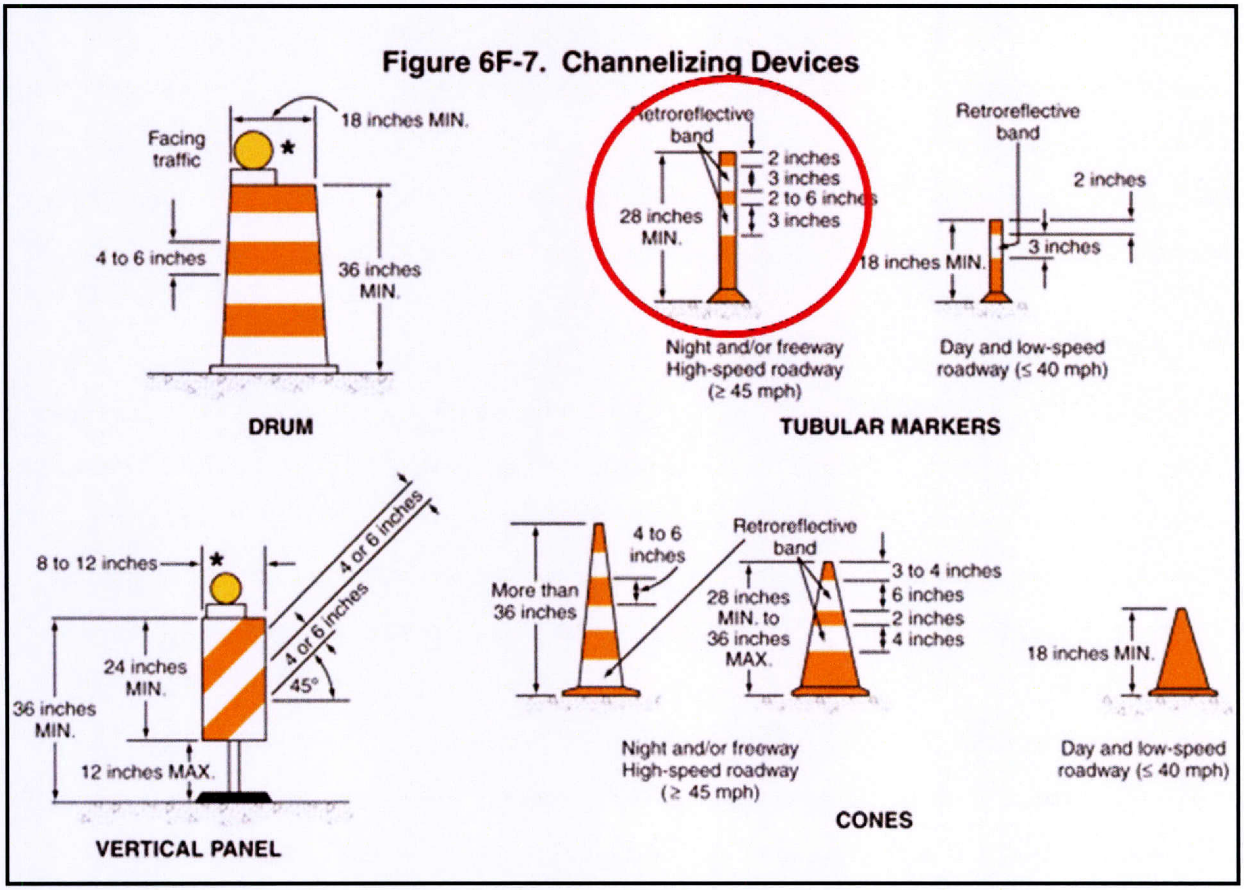


Figure 2. Traffic Control Devices - Channelizing Devices, MUTCD Figure 6F-7 (*1*).

Part 8 of the MUTCD addresses light-rail and railroad grade crossing applications. Section 8C.043 of the MUTCD notes that automatic gates at crossings can be enhanced by "channelizing devices," the same term used in Part 6 (Temporary Traffic Control) (*1*). "Median separator system" or "flexible traffic separator" is the terminology commonly used to refer to pylons in the studies pertaining to the highway-rail grade applications (*4*).

Various terms for pylons have been used in research reports and documentation of field installations. Flexible delineator post or flexible guide post is common terminology in applications where pylons are primarily used for delineation, such as delineation of curves, driving lanes, ramps, acceleration lanes, and deceleration lanes (*5*).

Cooner and Ranft use the term "pylon" in a report highlighting some of the delineation applications in Dallas, Texas, and other locations in the United States (*6*). Another report from Hlavacek et al., which documents best practices for separating toll lanes from non-toll lanes, also refers to these devices as "pylon posts," but the term "post delineator" was also used interchangeably in the UT report (*7*). A pylon application on the Santa Monica freeway in California is referred to as a "Soft Delineator Barrier System" by the National Road Safety Awards organization (*8*). While reviewing the literature, researchers found that pylons were also commonly referred to by specific product (brand) names (*4*) (*8*).

PYLON ASSEMBLY COMPONENTS

Typical components of a flexible pylon assembly, as shown in Figure 3, consist of a pylon post, a curb or base on which the pylon posts are mounted, and fixtures used for securing the post to the base or curb. The pylon posts and curb are usually made of high impact flexible polymers such as polyurethane or polyethylene. These polymers provide high tensile and elongation properties with resistance to tearing and puncture. The polymer typically maintains its flexibility to −50°F and maintains its toughness during exposure to fuels, oils, and grease (*9*). The pylon posts usually have a smooth, weather-durable exterior that does not rust or rot. Pylons are typically tested for durability and may be rated based on how many hits they can withstand before tilting from an upright position. The tilting of the pylons is often termed as "listing" and usually some degree of listing during durability tests is acceptable. Detailed information on testing and standards is presented later in this report.

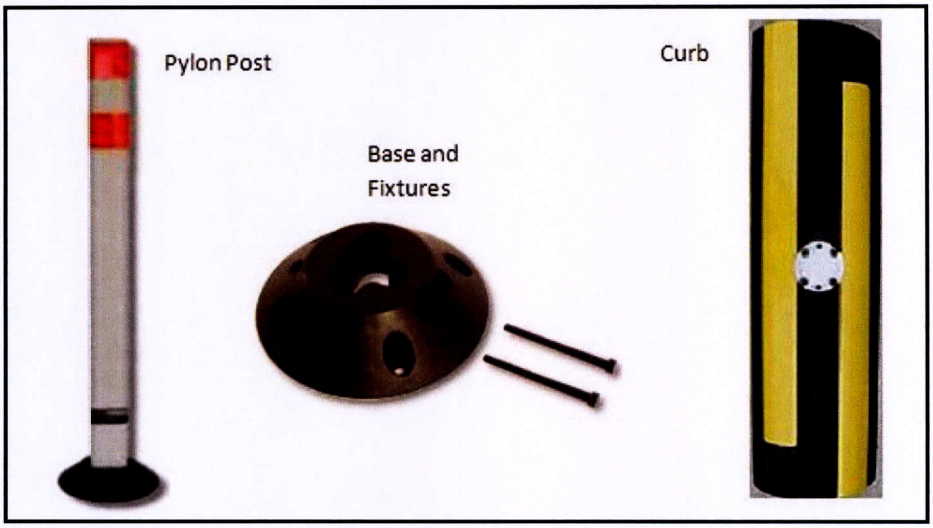


Figure 3. Components of a Typical Pylon Assembly (*9*) (*10*).

Pylon Mounting Techniques

Flexible pylons are classified based on how they are installed, either as *curb-mounted* pylons, *surface-mounted* pylons, or *embedded* pylons. In the curb mounted pylons (shown in Figure 4a), the pylon posts are fixed to a raised plastic curb, whereas in a surface mounted pylon (shown in Figure 4b and Figure 4c), the pylon posts are directly affixed (glued or bolted) to the pavement or to the concrete surface using a pylon base. Embedded pylons (Figure 4d) are usually installed by the side of the roadway (soil-driven) for hazard or curve delineation purposes. Curb mounted pylons and surface mounted pylons are typically used in lane separation on high speed facilities due to their relative ease of installation and replacement.

When curbs are connected or closely spaced, curb mounted pylons provide a picket fence visual effect. The use of pylon mounting curbs may discourage more drivers from crossing across the pylons as compared to directly mounted pylons to the pavement, although this has not been scientifically evaluated. However, curb mounted pylons may, in some conditions, impede drainage capacity when closely spaced. Hence, when curb mounted pylons are used, drainage requirements at the specific site may influence the minimum spacing between the pylon units. Some of the newer curb designs make provision for drainage using a lateral channel to allow water to pass under the curb. Curbs may collect debris against (and between) them, which can present both maintenance and drainage issues. Ice build-up can also be a problem with some curb designs.

(a) Curb Mounted **(b) Pavement Mounted** **(c) Surface Mounted** *(11)* **(d) Embedded** *(11)*

Figure 4. Examples of Pylons and Pylon Mounting Styles.

Methods to Affix Pylon Curb or Pylon Base to the Roadway

The curb or pylon base is usually affixed to the pavement using metal bolts, epoxy adhesives, or temporary adhesives, and the pylon posts are then attached directly to the curb or the base. The curbs used in the curb-mounted pylons are typically bolted directly to the pavement. Some curb manufacturers specify the option of using approved adhesives as an alternative to affix the curb to the pavement. Two-part epoxy adhesive, urethane adhesives, hot melt bitumen, or adhesive pads (hot pads or butyl pads) are typically used to affix the pylon base to the pavement. Epoxy, urethane, and hot melt bitumen adhesives are typically for permanent installations. Bond strength in these permanent adhesives depends on the amount of adhesive to pavement contact, surface dryness, and pressure. Adhesive pads apply quickly, have fast curing times, and are typically used in temporary pylon installations.

Pylon posts are attached to the curb (or base) using twist-lock or pin-lock connections. In a twist-lock connection, the pylon post is inserted into the base and twisted to lock the post to the base. The twist-lock mechanism makes it easy to replace the pylon post as needed. In a pin-lock connection, the pylon post is inserted into the base and pins are driven through the base to lock the post to the base. A pin removal tool can be used to release the pins to quickly unlock the pylon post. The pin-lock connections are slightly more tamper-proof than the twist-lock connections as the pylon posts can only be unlocked with a pin removal tool. However, roadway debris and dirt may jam the pins, making a clean release difficult.

In most pylon products, the bottom portion of the tubular post contains a built-in self-recovery mechanism (usually a hinge, springs, or flexible tubes). One of the pylon products reviewed used an external rubber hinge between the curb and the pylon posts for the pylons to rebound when hit. These self-recovery mechanisms can be either unidirectional or omnidirectional.

Pylon Shape

Flexible pylon posts are available in various shapes and several colors. Flexible pylon posts are broadly classified based on shape as follows:

- Tubular Pylons: These pylons have a circular cross-section. Tubular posts, due to their symmetry, are equally flexible in all directions, have 360 degrees of visibility, and have low wind resistance.
- Flat Front Pylons: These pylon posts have a continuous flat surface with no curvature. Flat posts provide more surface area facing the traffic compared to the tubular posts.
- Other Shaped Pylons: These include pylons that, in cross-section, are neither tubular nor flat-front, but are oval shaped, T-shaped, slightly convex, among other shapes.

In some cases, the top portion of the tubular post is compressed, forming an oval-shaped cross-section in order to provide more target value. Two-part pylon posts with a tubular bottom and flat-front upper are also available, which combines the benefits of tubular and flat front pylons.

Pylon Color

White, yellow, and orange pylon posts are typically used for lane separation and channelization applications on roadways. The 2009 MUTCD, section 3H.01, states that "*The color of channelizing devices used outside of temporary traffic control zones shall be either orange or the same color as the pavement marking that they supplement, or for which they are substituted*" (*1*).

However, pylons are available in the market as other colors, including blue, red, green, brown, and grey. Most durable pylon posts are impregnated with the color during manufacturing so that color does not easily degrade with wear and tear. Section 3H.01 of the MUTCD also states that when channelizing devices are used outside of the temporary traffic control zones, the retroreflective sheeting attached to the device shall be white if the device separates traffic flow in the same direction and shall be yellow if the devices separate traffic flows in the opposite direction (*1*). The use of retroreflective sheeting placed on the pylon (often of contrasting colors) can also increase the visibility of pylons. Although no guidelines are available on the use of contrast colors for channelizing devices, Chapter 3A of the MUTCD provides some guidance with respect to use of black pavement marking with other color marking to enhance the visibility of the markings (*1*). Similar to the use of black and white contrast pavement marking on concrete pavements to enhance visibility, alternating black and white retroreflective sheeting can make pylons more conspicuous.

Pylon Height

Surface mounted pylons with heights of 36 in., 42 in., and 48 in. are more commonly being used on high speed facilities for lane separation. The 2009 MUTCD, Section 6F.65, specifies that tubular markers shall not be less than 18 in. high and 2 in. wide when facing road users (*1*). When tubular markers are used on freeways or other high speed highways, the height of the tubular markers shall not be less than 28 in. However, pylons are available on the market in various heights from 19 in. to 72 in. When pylons are mounted on curbs, the overall installation height can be slightly higher than the height of the pylon post itself due to the added height of the curbs.

COMMON APPLICATIONS OF PYLONS

Flexible pylons have been used in various roadway applications. One of the early uses of flexible pylons was as a replacement for steel delineator posts for delineation of horizontal curves. Figure 5 shows an example of flexible pylons used in the delineation of a freeway exit ramp. Embedded (soil-driven) pylons near the roadside (not mounted directly on the pavement surface) are commonly used in the curve delineation applications. Flexible pylons can take more hits compared to steel posts resulting in less frequent replacement. Flexible pylons also cause less damage to vehicles when hit as compared to steel delineator posts. Given these benefits, flexible pylons are now widely preferred for horizontal curve delineation. However, one study reported that replacement of broken pylons is more tedious than replacing the steel posts due to the accumulated debris at the base of the pylons that makes pylon replacement difficult (*12*).

Figure 5. Example of Pylons Used for Curve Delineation (*11*).

Pylons have also been popular devices to delineate HOV lane and managed lane facilities, both of which the MUTCD refers to as "preferential lanes" (*1*). Pylons used on HOV and managed lanes are used to both delineate and separate these facilities from the general purpose lanes. Concrete barriers and painted buffer spaces were traditionally used for separating HOV lanes from the general purpose lanes, however pylons have increasingly being used in these applications due to the lower initial cost of implementation when compared to concrete barriers. While flexible pylons provide emergency access between preferential and general purpose lanes, they are more likely to discourage illegal lane crossing when compared to painted buffer stripes (*7*). Figure 6 shows examples of pylon use on HOV/managed lane facilities in Texas. To the left in Figure 6 are two-part, tubular, flat-front pylons used on the Katy Managed Lane facility in Houston, Texas. To the right in Figure 6 are curb mounted T-shaped pylons used on the US 75 HOV lane in Dallas, Texas.

The use of flexible pylons at highway-railroad grade crossings is well documented. Figure 7 shows a convex surface (paddle type) pylon, or vertical panel being used along the centerline on approach to a railroad crossing on US 98 in Polk County, Florida. Use of pylons along the centerline approaching a two-quadrant gate system discourages motorists waiting at the highway-rail grade crossing from using the opposing lanes to illegally avoid the gates. Observational studies indicate that when used as a median separator near the highway-grade crossing, pylons do reduce the number of illegal crossing maneuvers. However, the narrow lanes at the US 98 site as shown in Figure 7 resulted in pylons frequently being displaced (*4*).

Figure 6. Pylon Implementation on IH 10 Katy Managed Lane (Houston) and US 75 HOV (Dallas) (*6*).

Figure 7. Example of Curb-Pylons Used at Highway-Rail Grade Crossing (*4*).

Pylons are often used in work zones to channelize traffic, separate traffic, and delineate the travel way. Figure 8 shows the use of pylons in separation of mainlanes (two-lanes on left) and frontage road (far right lane) near a work zone area on State Highway 6, south of College Station, Texas. White pylons were used near a work zone (instead of orange color pylons) because these pylons were deployed for long-term use and MUTCD requires channelizing devices to be orange only when used in a temporary traffic control zone.

Figure 8. Pylons Used in a Work Zone to Separate Mainlanes and Frontage Road.

Pylons are also used in many access management applications on arterials and highways. Figure 9 shows curb pylons being used as median separators on an arterial street in Texas. Figure 10 (left) shows an access management application where pylons are used to discourage merging vehicles from making quick lane changes and turning into the driveways. In one situation, pylons provide left turning lanes at an intersection in Texas, as shown in Figure 10 (right).

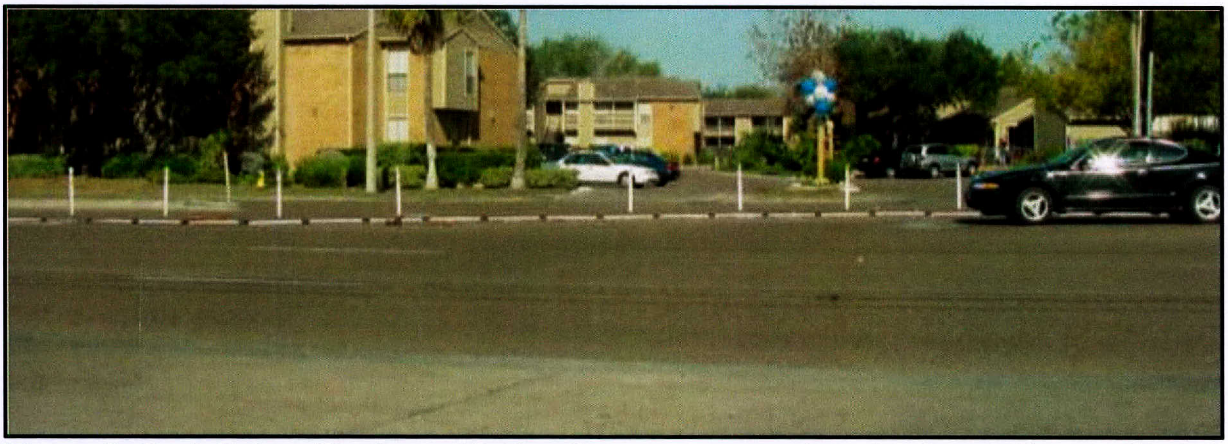


Figure 9. Curb-Pylons Used as a Median Separator on an Arterial Street, Corpus Christi, Texas.

Figure 10. Access Management Applications of Pylons in Laredo, Texas: Left – Blocking Access to Driveways, Right – Delineating Left Turn Lanes.

Figure 11 and Figure 12 show the application of pylons to block crossover movements on a high speed urban highway and rural highway, respectively. Flat-front (paddle type pylon) vertical panels, as shown in Figure 11, provide more surface area for retroreflective sheeting and have higher target value. In the rural application shown in Figure 12, tubular pylon posts are used to delineate a median. Figure 12 also shows a vertical panel (wide-front orange pylons with chevrons) used for lane closure on a rural interstate highway.

Figure 11. Use of Vertical Panels to Prevent Crossover Movements on IH 20, Odessa, Texas.

Figure 12. Pylons Blocking Crossover Movements, Rural Highway, IH 20, Ranger Hill, Texas.

Pylons have also been used for exit ramp gore delineation, raised median delineation, and traffic island creation. Figure 13 (left) shows an example of pylons used to delineate a freeway exit ramp gore on IH 35 in the Dallas/Fort Worth area where a crash cushion was frequently struck. Figure 13 (right) shows a low raised median at an intersection along Business IH 20 frontage in Odessa, Texas, made more visible to motorists by installing pylons. Figure 14 provides an example of pylons used for traffic calming. In this case, the pylons create a center island widening on a two-lane two way county highway in Slater, Iowa. This widening causes a slight path deviation for motorists. A reduced speed limit was also installed to further encourage motorists to slow down (*13*).

Figure 13. Examples of Application of Pylons at Freeway Gore Areas.

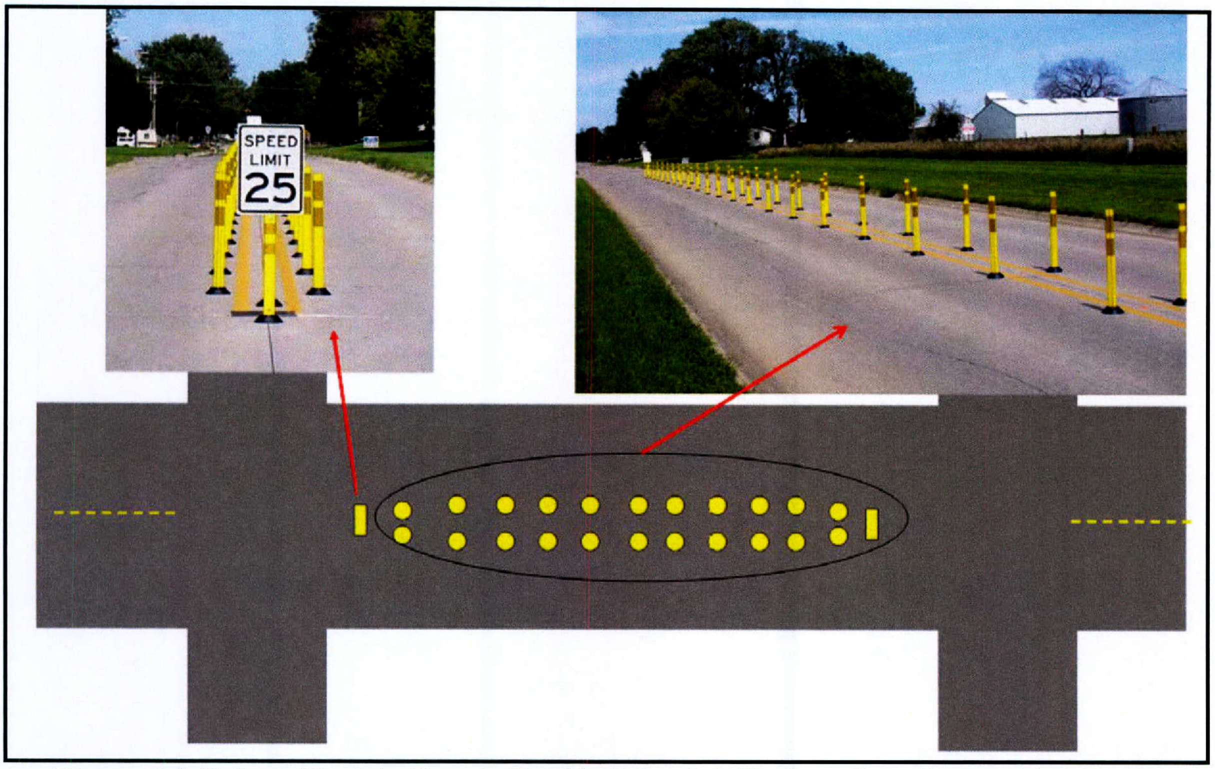


Figure 14. Pylons Used to Create Traffic Island to Reduce Speeds on a Two-Lane Highway (*13*).

PYLON IMPLEMENTATION FACTORS

When implementing pylons, there are several factors that need to be considered for the pylons to be effective. In this section, the authors define some of these factors as these factors will be referenced throughout this report.

Pylon Spacing

Pylon spacing is the distance from the center of one pylon to the center of the adjacent pylon. The spacing of pylons depends on several factors including application, operating or posted speed, pylon type, and cost. For example, if the purpose of the pylon is to improve the visibility of pavement markings or medians, larger spacing may be used to reduce the cost. However, when pylons are used for separation of lanes on high speed facilities with high recurring congestion, a closer spacing is desired to reinforce the lane separation and prevent lane crossing.

Buffer Space

Buffer space is defined as the offset distance separating two adjacent travel lanes in which pylons are installed. In some cases this buffer space functions as a shoulder between the adjacent travel lanes. Buffer space is further classified as left buffer space and right buffer space in relation to the pylons and direction of travel. Buffer space provided depends on several factors, including available cross section width, traffic volume on each lane adjacent to pylons, and horizontal alignment of the road.

Running Length

Running length is defined as the project length or the length of the pylons along the horizontal alignment of the roadway.

Pylon Height

Pylon height in this report refers to the measurement from the pavement surface to the top of the pylon post. In case of curb mounted pylons, the height of the pylon also includes the height of the curb.

Pylon Visibility

Pylon visibility consists of three components: color, target value, and contrast. Target value is typically related to the surface area visible to the driver. Contrast describes how well a device stands out from its surroundings.

Pylon Retroreflectivity

Pylon retroreflectivity is required for night time driving as pylons have limited target value at night. Retroreflectivity is achieved by wrapping the pylon post with retroreflective sheeting.

Curb Spacing

Curb spacing is the longitudinal gap between the adjacent curbs. Curb spacing is usually determined by drainage considerations. In cases where the curb is interlocked longitudinally, there is no space between curb sections.

EXAMPLES OF PYLON USE ON PREFERENTIAL LANE FACILITIES

Pylons are often used on preferential lane facilities to separate the HOV/managed lane from the general purpose lanes. This separation was traditionally achieved by using concrete barriers or buffer-defining pavement markings. However some of the newer HOV/managed lanes use flexible pylons in lieu of barrier or buffer-only separation. Some of the facilities where flexible pylons were implemented are presented in this section. A summary table of the pylon and example locations is presented in the summary section of this chapter.

US 75 HOV Lanes – Dallas/Richardson/Plano/Allen, Texas

The US 75 HOV lanes are concurrent flow lanes in both northbound and southbound directions (the HOV lane is directly adjacent to the general purpose lanes and operating in the same direction). The facility is approximately 14 miles in length and has four access points (two exits and two entrances) (*14*). This facility opened in December 2007 at a cost of $18.1 million. The US 75 HOV facility operates 24 hours a day. The corridor (HOV and General Purpose lanes) carries an average traffic volume of about 233,000 vehicles per day at the south end and about 162,000 vehicles per day at the north end of the facility.

The HOV lanes on US 75 are 12 ft. wide and were retrofitted onto the cross section by reducing the lane widths on freeway mainlanes from 12 to 11 ft. and employing the inside shoulder for the HOV lane. The opposing directions of travel are separated by a concrete median barrier, located to the left of the HOV lane 2 ft. from the left edge line of the HOV lane. Flexible pylons separate the HOV lanes from the adjacent freeway general purpose lane, as shown in Figure 15. The buffer space between the HOV lanes and the freeway mainlanes is 3 ft. wide. Figure 16 shows a typical cross section of the US 75 freeway facility (*6*).

The curb-pylon system installed on the US 75 HOV facility consists of a curb that is 44 in. long and 2.5 in. high. There are two pylons on each curb with 37 in. spacing between them. The curb spacing between curb assemblies is 100 in. to accommodate drainage requirements. This results in 144 in. (12 ft.) between the first pylons on adjacent curbs. The pylon height is 36 in., which includes the curb height. The pylons are fitted with two 3-inch strips of abrasion-resistant retroreflective sheeting at the top end of the pylon to provide retroreflectivity at night. On this particular project, the quoted price for a single curb section with two pylons was $260 (*6*).

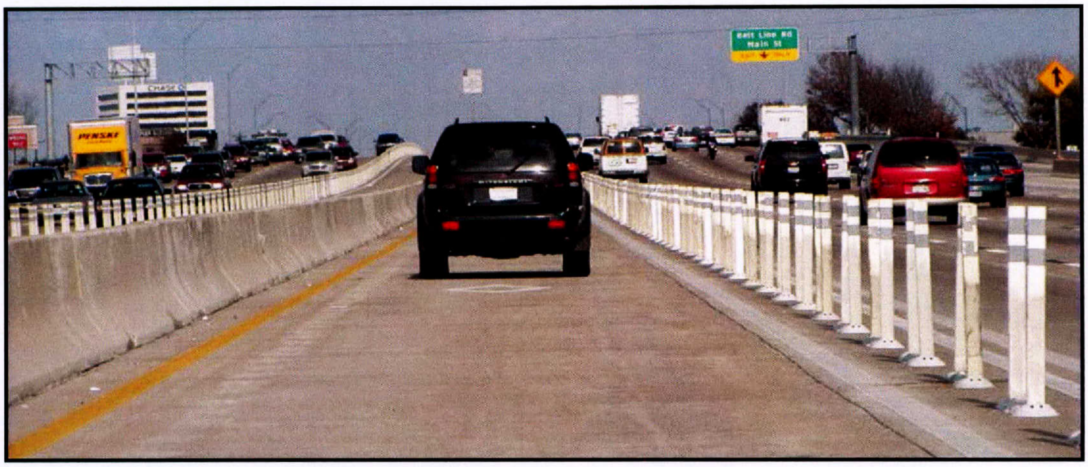


Figure 15. Curb-Pylon Implementation on US 75 HOV in Dallas (*6*).

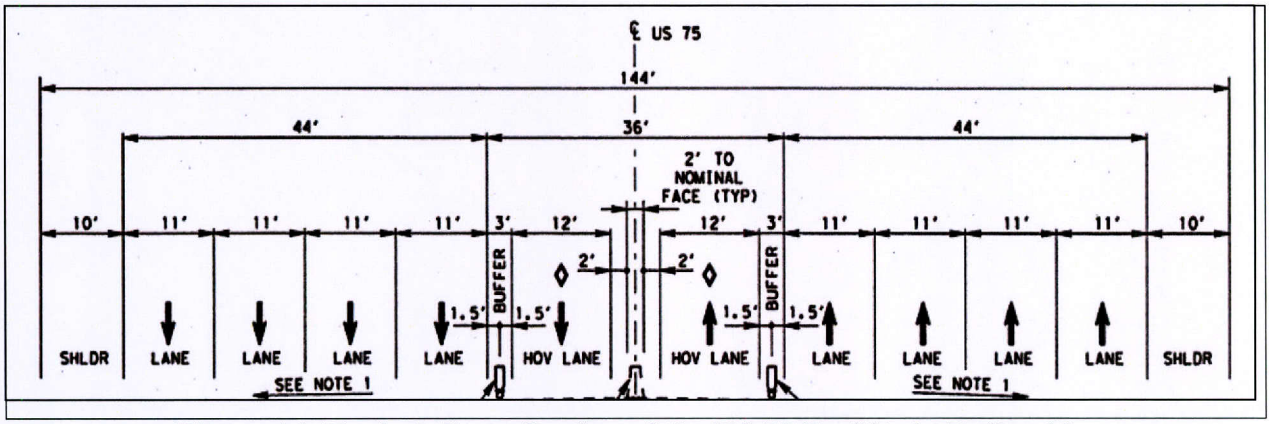


Figure 16. Typical Cross Section of the US 75 Facility in Dallas (*6*).

In the first seven months of the US 75 HOV lane operation, based on Dallas Area Rapid Transit (DART) supervisor logs, a total of 79 crashes were reported (*15*). Also a total of 103 incidents were reported, and 41 percent of those incidents were attributed to flat tires (*15*). There were several issues with the curb-pylons on US 75 HOV facility. Flat tires along US 75 HOV were mostly attributed to the exposed anchor bolts and other debris resulting from broken plastic curbs. Missing pylons frequently caused a gap for motorists to weave around the pylons, reducing the effectiveness of the intended lane separation. However, it is reported that the timeliness of replacement has improved since March 2009 after a dedicated maintenance contract was put in place on the corridor. This contract was valued at $650,000 per year by TxDOT, with funding support from DART (*6*).

IH 635 HOV/Managed Lanes – Dallas/Mesquite, Texas

The IH 635 HOV/Managed Lane facility (shown in Figure 17), located in northeast Dallas, is a 12-mile long concurrent flow facility with two intermediate entry/exit access points that operates 24 hours per day (*14*). The facility was opened for traffic in January 2008 at a cost of $50.6 million. The IH 635 corridor (HOV/managed facility and general purpose lanes) carries about 207,000 vehicles per day on average at the north end of the facility and 188,000 vehicles per day on average at the south end of the facility. The IH 635 HOV lanes were retrofitted by reducing the lane width from 12 ft. to 11 ft. and taking the left shoulder. The HOV lane width at IH 635 is 11 ft. with a buffer space of 5 ft. between the HOV and freeway mainlanes. Compared to the US 75 HOV facility, this facility has narrower lanes but a wider buffer space.

Figure 17. Curb-Pylon Implementation on IH 635 in Dallas (*8*).

The curb-pylon system on IH 635 consists of 58 in. long curbs with a single pylon attached to each curb, as shown in Figure 16. The curb base is 3 in. high, and the pylons are 39 in. high (measured from the pavement surface). The pylon spacing is 14 ft., and a curb spacing of 9 ft. is provided between the curbs for drainage purposes. The bid price for furnish and install of each curb-pylon assembly was $385.15 (*6*).

In the first six months of the operation of the IH 635 HOV lane facility, a total of 76 crashes were reported. Two out of the 76 crashes blocked the HOV facility for over 90 minutes, 48 crashes blocked the facility for 30 to 90 minutes, and 26 crashes blocked the facility for less than 30 minutes. A total of 88 incidents were reported on the facility, with the majority of the incidents being flat tires and running out of fuel (*15*).

State Route 91 Managed Lanes, Orange/Riverside County, California

The SR 91 Express Lanes (shown in Figure 18) consist of a 10-mile segment with two toll lanes in each direction. The SR 91 Express Lane was designed and built by the California Private Transportation Company (CPTC) under the strict supervision of the California Department of Transportation (CALTRANS). The SR 91 toll lanes began operation in 1995, leased and operated by CPTC. However, in April 2002, the SR 91 Express Lane facility was purchased by the Orange County Transportation Authority (OCTA), and in a few months the SR 91 toll road was converted to a High Occupancy Toll (HOT) road facility (*16*).

The HOT lanes are separated from the general purpose lanes by double painted stripes with a buffer space of 4 ft. Pylon posts are installed in the buffer space to provide a soft physical barrier. The pylon spacing is 12 ft. The HOT lane was 12 ft. wide. Cooner and Ranft reported that even with the pylons, many drivers violate the access requirements and, as a result, OCTA replaces approximately 1000 pylons per month (*6*). However, the cost of maintaining the pylons is considered essential for successful operation of the facility (*6*).

Figure 18. Pylon Installation on SR 91 Managed Lane Facility in California.

IH 95 Express Lanes, Miami/Fort Lauderdale, Florida

The IH 95 Express Lanes are a 21-mile HOT lane facility between Miami and Fort Lauderdale in Florida. Registered 3+ person carpools, vanpools, and hybrid cars are allowed to use the express lanes for free and others are tolled based on a congestion pricing scheme (*17*). The Florida Department of Transportation created the IH 95 Express Lanes by converting the existing single HOV lane to two toll lanes and reducing the lane widths of the general purpose lanes from 12 ft. to 11 ft. The shoulder width was also significantly reduced to accommodate the express lanes. The estimated project cost is about $264 million (*18*).

Surface mounted pylons separate the express lanes from the general purpose lanes. As shown in Figure 19, several different types of pylons were deployed as an experiment on this facility (*6*). FHWA specified 20 ft. as the minimum pylon spacing; therefore an initial pylon spacing of 20 ft. was used. However, there was frequent weaving between the pylons with the 20 ft. spacing. In response, the pylon spacing was reduced to 10 ft. (*6*). After initial use of white colored pylons, the initial 500 ft. of an access point were replaced with yellow pylons to increase visibility in contrast to the white concrete pavement, as seen in Figure 20 (*6*). The pylon implementation on the IH 95 Express Lanes has a buffer width of 2 ft.

Figure 19. Pylons Used on IH 95 Express Lanes in Miami, Florida (*6*).

Figure 20. Orange Color Pylons Used to Increase Contrast at Access Points on IH 95 Express Lanes (*6*).

In the initial days after the IH 95 Express Lane facility was opened, several incidents were reported. A news report indicated that on a single day, seven accidents were reported mostly from abrupt lane changes and driving over the pylons (*18*). The IH 95 Express Lanes were designed to accommodate longer distance commuters and deployed with limited exit locations. The Florida Department of Transportation (FDOT) concluded that the high concentration of accidents during the initial days of operation was mostly due to driver confusion and the incidents would subside as motorists gain familiarity with the express lane operation (*6*). Cooner and Ranft reported that FDOT replaces approximately 115 percent of pylons on the facility per year; however, FDOT concluded that this rate of replacement is less than what other managed lane facilities in the country require (*6*).

IH 15 Express Lanes - Las Vegas, Nevada

Flexible pylons were installed on a 3-mile segment on the IH 15 Express Lanes in Las Vegas, Nevada, in mid-2010 to provide additional separation of the express lanes from the general purpose lanes (as shown in Figure 21). The IH 15 Express Lanes allow HOV vehicles to travel free while single occupant vehicles pay a toll through the use of a transponder. Tolls vary based on the number of miles traveled, and the congestion of the lanes at the time of entry.

The pylons were installed initially installed with a spacing of 25 ft., but was later reduced to 12.5 ft. due to motorists frequently weaving between the pylons. The facility has two preferential lanes with 12 ft. wide adjacent lanes. The facility has a very small buffer of 1.5 ft. and uses a 36 in. high white color pavement mounted pylons for lane separation. Every section of the IH 15 Express Lanes is hit frequently, although if the agency had to name one area that was hit the hardest, it would be at the access point. "Motorists appear to hit pylons along the lane indiscriminately" says a Nevada DOT Engineer (*19*). The Nevada Department of Transportation (NDOT) has reported a very high replacement rate for the pylons. Due to the lack of space within the lanes, there is little to no enforcement (*19*).

NDOT has experimented with changes in the pylon deployment scheme to reduce the number of hits with limited success. In addition to reducing the spacing between the pylons from 25 to 12.5 ft., the agency has replaced the original white pylons with orange pylons at access areas and tried using curbed pylons at the access points, but no reduction in hits was realized. While not yet implemented, NDOT has also considered reducing the raised pavement marking spacing and further reducing the pylon spacing from 12.5 ft. to 6 ft. (*19*).

(Image source: David Patree, Nevada DOT)

Figure 21. Pylons Used to Separate Express Lane from General Purpose Lanes in Las Vegas, Nevada.

IH 10 Katy Managed Lanes, Houston/Harris County, Texas

The newly constructed IH 10 Katy Managed Lanes became fully operational in April 2009 (*20*). The managed lanes extend from IH 610 and SH 6 in west Houston and are 11 miles long with two 12-ft wide lanes in each direction. The managed lanes are separated from the general purpose lanes by flexible pylons directly affixed to the pavement between painted buffer stripes, as shown in Figure 22. The painted buffer consists of two, 6 in. wide, white stripes separated by an 8 in. gap. A 10 to 12-ft shoulder on both sides of the flexible pylons provides sufficient lateral clearance between the pylons and each travel lane adjacent to the pylons. The managed lane edge line left of the pylons is white, and the general purpose lane edge line to the right of the pylons is yellow. The MUTCD provides no guidance on pylon color when pylons are installed between white and yellow edge lines. The pylons are 48 in. high and have 10 ft. spacing. Approximately 11,600 pylons are deployed along both directions of the 11-mile section of the managed lanes. The pylons feature a 3 in. by 9 in. white retroreflective sheeting at the top of the pylon post to provide better nighttime target value. The Harris County Toll Road Authority (HCTRA), which operates and maintains the facility, indicated that the cost to furnish and install is $45 per pylon.

Figure 22. Pylon Installation on IH 10 Katy Managed Lanes in Houston, Texas (*6*).

Maintenance information provided by HCTRA indicates that about 200 to 300 pylons are replaced on average per month, which roughly equates to about 25 percent of the pylons being replaced per year. The rate of pylon replacement on the Katy Managed Lane facility is considerably less than replacement rates on other managed lanes/HOV facilities, likely due to the wider shoulders (increased buffer spacing) on both sides of the pylons. The pylons on the Katy Managed Lanes are inspected on a daily basis as part of routine inspection and replacement of broken pylons is scheduled once a week. HCTRA indicated that the majority of their replacements have occurred at entrance locations to the managed lanes. HCTRA has observed no crashes or incidents attributable to pylons on the Katy Managed Lanes.

PRODUCT PERFORMANCE TESTING OF PYLONS

The National Transportation Product Evaluation Program (NTPEP) was established by AASHTO to combine professional and physical resources for testing of materials. This program helps reduce duplication of testing among states and provides the industry with a central source for the evaluation of products for the highway market. NTPEP neither passes nor fails materials that are evaluated under standard protocols; rather, it simply makes test results available to participating members (i.e., states) who can make their own judgments regarding product selection (*21*).

Pylon systems that are in use today have typically been tested in accordance with NTPEP standards. Typical testing of surface-mounted delineators consists of several types of impact, weatherometer, and ultraviolet (UV) resistance testing. The test also documents the pylon's capability to retain any attached sheeting; however NTPEP does not specifically test the retroreflective sheeting on pylons.

NTPEP Impact Test Procedure

The typical impact NTPEP testing procedure is described below (*22*):

> *Eight flexible surface mounted delineator posts, installed by the manufacturer, will be hit ten times (four posts for glancing bumper hits and four posts for wheel hits) by a standard sedan with a bumper height of approximately 1'8" while traveling at a speed of 55 ±2 mph with five of the impacts at an ambient air temperature*

> *of 32 ±5°F and the remaining five impacts at an ambient temperature of 85 ±5°F. The test vehicle shall impact four of the posts at an angle perpendicular to the front of the post and shall impact the remaining posts at an angle of 25 degrees clockwise from the angle perpendicular to the front of the posts. The same test samples will be used for the ten hits. ... A glancing bumper hit is defined as one on the bumper near the vehicle headlight. The delineators shall be installed a minimum of eight hours prior to being hit* (*22*).

After being struck, the delineator posts may not return to their pre-impact (upright) position. Instead, they may retain some list, or tilt, as shown in Figure 23.

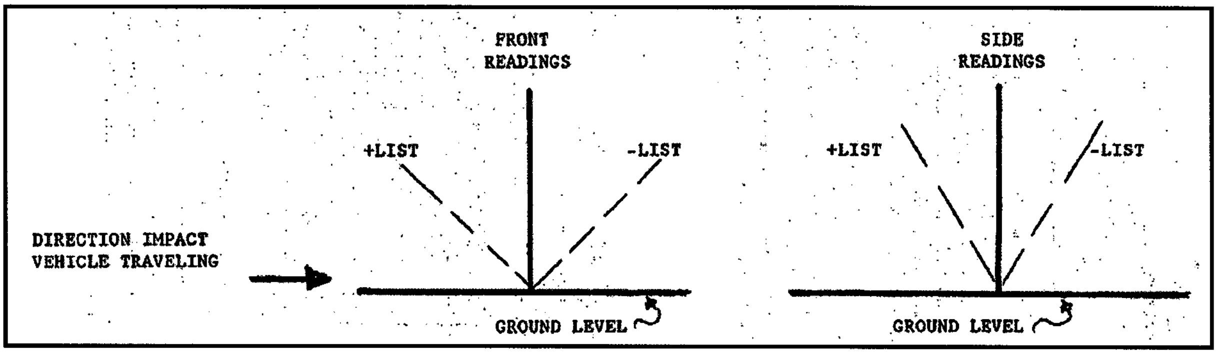


Figure 23. Legend for Impact Readings of NTPEP Flexible Delineator Testing (*21*).

After each impact, the testing agent inspects each post and documents the following:

- Any splits, cracks, breaks or other forms of deformation or distress.
- The percent list to vertical (both front and side readings) measured 120 seconds after each impact.
- The approximate percentage of the reflective area that is damaged after each impact to an extent it no longer performs as intended.
- Bonding agent used to install bases on the roadway surface and any problems or comments regarding the performance of the bases/bonding agent.

- Any problems or comments associated with the installation and removal of the posts and bases. The testing agent will document any special equipment or techniques required to install or remove the posts and bases.
- Any other problems or comments associated with the performance of each flexible surface mounted delineator post, which would be of interest to the member states (*21*).

NTPEP Ultraviolet (UV) Test Procedure

Two posts are evaluated using this procedure. Each post is first evaluated for tensile strength and elongation according to American Standards for Testing Materials (ASTM) D-638 (*23*). These strength and elongation values are recorded. The specimens are then exposed to 1000 hour weathering according to ASTM G-53 or ASTM G154-06 (*24*). This process creates a highly variable mixture of UV light that is intended to reproduce the damage caused by sunlight on plastic materials. After the prescribed exposure, the D-638 test is performed again so that the results can be compared. Once the tests are complete and the results are documented, NTPEP retains the data in an online database called *DataMine 2.0* (*21*).

Although most states follow the NTPEP testing protocols, TxDOT utilizes Departmental Materials Specification (DMS) 4400, *Flexible Delineator and Object Marker Posts (Embedded and Surface-Mount Types)* (*25*). DMS 4400 does not require the winter/summer test cycle, so obtaining results can be much quicker than with NTPEP testing. Impact testing in Texas is done with a protocol that specifies that a minimum of eight posts must be impact tested using a passenger car at a speed between 50 and 55 mph. The posts must survive (i.e., remain in place and not have a list in any direction greater than 20 degrees from vertical). In addition, after five hits, the delineator must be certified to meet minimum reflectivity requirements specified in DMS 8600 (*26*). In addition to the impact testing, Texas has other testing requirements for infrared and x-ray spectra, as well as specific gravity of the materials used to manufacture the posts. The post must show no significant change in color, flexibility, or integrity after a 1000 hour exposure test according to ASTM G 155 protocols. Finally, the posts must show no significant change in color, flexibility, or integrity after a 48-hr exposure to herbicides test. The Texas standards for testing are considered more appropriate for the Texas environment than

NTPEP tests. However, TxDOT will accept NTPEP test results from vendors who are submitting pre-qualification requests for their products.

IMPLEMENTATION GUIDANCE

To date, pylons have been used by numerous agencies to address channelizing, delineation, and lane separation problems on a case-by-case basis. Although many state DOTs have added pylon products to their Qualified Products Lists, they do not necessarily prescribe when and where these devices should be used. For example, while pylons may provide more positive lane separation guidance than regular pavement markings, they do not provide as much positive lane separation as concrete barriers, which can be much more imposing in appearance (*7*).

There are no national guidelines regarding the use of pylons that provides typical applications, or recommended minimum or maximum pylon spacing, buffer space, pylon height, pylon visibility, or curb spacing. Some guidance on buffer space can be adopted from the encroachment chart presented in the *Roadside Design Guide* (*2*), which is elaborated in the following section. Pylon color and retroreflectivity typically follows the MUTCD for tubular markers. However, guidance for determining when and where delineators are most appropriate are needed.

PYLON ENCROACHMENT

Pylons, or flexible delineators, are commonly used on the edge of roadways to delineate roadway alignment around horizontal curves. Pylons are also often used as channelizing devices along lane lines to preclude lane changing between general purpose and managed lanes (*1*). The researchers conducted a thorough literature search and found no research reports for studies of pylon strikes in managed lane applications. However, other documents related to lane departures, such as work zone intrusions and errant vehicle encroachments are available, and can provide some insight into driver behavior that may be applicable to pylon strikes.

In work zone lane closures, orange drums or cones are used along lane lines to separate lanes that are open to traffic from lanes that are closed to traffic. A work zone intrusion occurs when an errant vehicle unexpectedly departs the open traffic lane and penetrates a line of work zone channelizing devices. This presents a significant hazard for workers that may be located beyond the channelizing devices. Although pylons are different from work zone channelizing devices in size, shape, and color, their intended purpose is similar: to keep traffic from crossing lane lines (and intruding into the adjacent lane). A recent study of work zone intrusions included an in-depth analysis of intrusion causes and development of potential countermeasures to reduce intrusions (*27*). The intrusion analysis was based on six years (2000–2005) of data taken from the New York State Department of (NYSDOT) work zone incident database. The researchers categorized the incident reports, and then examined each report to determine the sequence of events that led to the intrusion. A summary of the findings are shown in Figure 24.

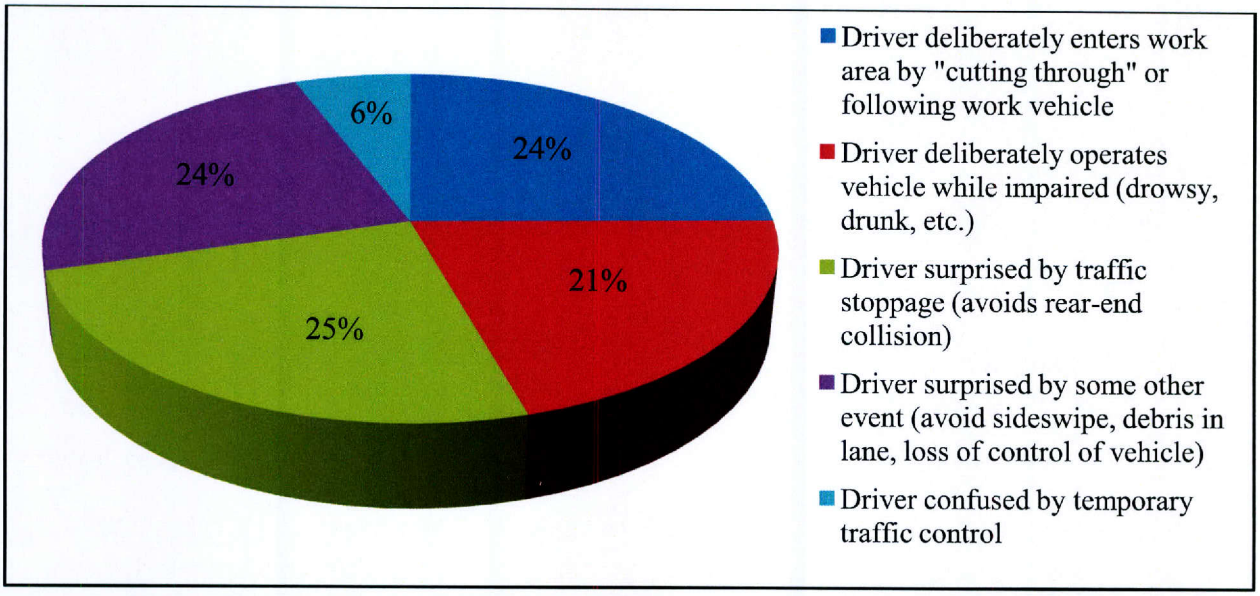


Figure 24. Factors Contributing to Work Zone Lane Closure Intrusions.

One of the major findings of that research was the recognition that many intrusions are actually the result of deliberate driver decisions and behaviors to intrude. For example, the researchers found that deliberate decisions and actions on the part of the driver accounted for almost one-half (45 percent) of the intrusions between the channelizing devices into lane closures. More than one-half of those deliberate intrusions (24 percent of all intrusions) were a result of drivers deliberately entering the work area by either cutting through the closed lane (to reach an exit, intersection, or driveway) or following a work vehicle into the closed lane. Furthermore, the fact that many of these occurred without striking any of the channelizing devices indicates that the drivers knew the channelizing devices were there and decided to cross the lane line anyway. In other words, device visibility or conspicuity was likely not a factor in these types of intrusions. It is likely that many impacts of pylons separating managed lanes and general purpose lanes are likewise deliberate attempts by drivers to cross the dividers. Although many of the work zone intrusions examined were intentional, many others were unintentional. However, most of those were not the result of poor visibility of the channelizing devices, but were the result of crash events or crash avoidance maneuvers. In some cases (25 percent), the driver was surprised by a traffic stoppage and swerved across the line of channelizing devices to avoid a rear-end collision, or committed a rear-end collision that pushed another vehicle into the closed lane. Another 24 percent were surprised by some other event, such as another vehicle making an unexpected lane change next to them, debris in the lane in the front of them, failure to merge, or other loss of control of the vehicle. In fact, only a small percentage (six) of events was the result of the driver being confused by temporary traffic control (such as improperly placed devices or, presumably, a lack of adequate device visibility). The researchers also found that about 70 percent of intrusions occurred during daytime hours. While this would be expected since this is when the majority of work zone activity occurs, it does further support the contention that there is not a general issue with channelizing device visibility that contributes to the intrusions that occur. Again, this is likely the case with separation devices between managed lanes and general purpose lanes.

Given the above discussion, then, what does contribute most significantly to channelizing device encroachments and impacts (including pylons separating managed and general purpose lanes), if not visibility? From the discussion above, events that contribute to increased crash avoidance maneuvers, such as high merging maneuver frequency and stop-and-go traffic conditions, increase the likelihood of a vehicle veering across a lane or edge line. Generally speaking, such behavior is correlated to roadway volumes (ADTs), and so this factor is normally the main predictor of vehicle lane departure frequency. However, both horizontal and vertical curvatures have also been shown to affect lane departure rates.

Whereas the frequency with which events occur to cause a vehicle to veer from the driver's intended travel path is one indicator of work zone intrusions and impacts, another key aspect is the lateral distance of the devices themselves from the lanes of travel. Once a vehicle veers off away from the travel lane, it travels some distance laterally before impacting an object, coming to a stop, or re-directing its path and returning to the travel lane. These events are referred to as encroachments. Several studies of lane encroachments were found in the literature. For example, Hutchinson and Kennedy (*28*) (*29*) conducted a study of median encroachments on rural interstate highways Illinois in the early 1960s. Although 85th percentile speeds during the study were 75 mph, traffic volumes during the study were relatively low, ranging from 1,900 vehicles per day to 6,000 vehicles per day. In addition, the roadway segment used for the study was 25 miles long and had relatively long, straight sections.

In the late 1970s, Cooper (*30*) performed a study of encroachments using a wider variety of roadway types and traffic volumes. The 85th percentile speeds ranged from 57 to 67 mph and traffic volumes ranged from 700 vehicles per day to 30,000 vehicles per day. Although data from these studies were useful in furthering encroachment research, neither study provided data for the higher volume roadways that are common today. In addition, both vehicle performance and roadway designs are much different today than they were when these studies were conducted.

In the mid-1980s, Calcote et al. (*31*) attempted to use electronic monitoring systems to collect encroachment data. Tape switches were used to detect vehicle roadway departures and still cameras recorded the events. Unfortunately, the roadway segment used for the study was very short, the number of observed encroachments beyond the shoulder was very low, and researchers were unable to correlate the events to specific driver behaviors.

The only other significant study was performed by Miaou (*32*) in the late 1990s. In this study, ran-off-road crash data were used to estimate encroachment frequency and lateral encroachment distances. Due to the limitations of existing databases and lack of funding to supplement the data, Miaou's findings are not widely acceptance. However, while crash data analysis techniques developed under this study are promising, they have not been used to predict encroachment frequencies. In summary, developing a significant database of encroachment events under a variety of modern travel conditions is an expensive undertaking.

The *Roadside Design Guide* (*2*) and in the *Roadside Safety Analysis Program (RSAP)* (*33*) are based largely on past encroachment studies. More specifically, the crash prediction module in the RSAP uses a lateral extent of encroachment distribution (shown in Figure 25). This lateral distance distribution is the basis for the clear-zone concept for roadside safety design because it describes the probability of an errant vehicle reaching specific lateral distance when a departure event occurs.

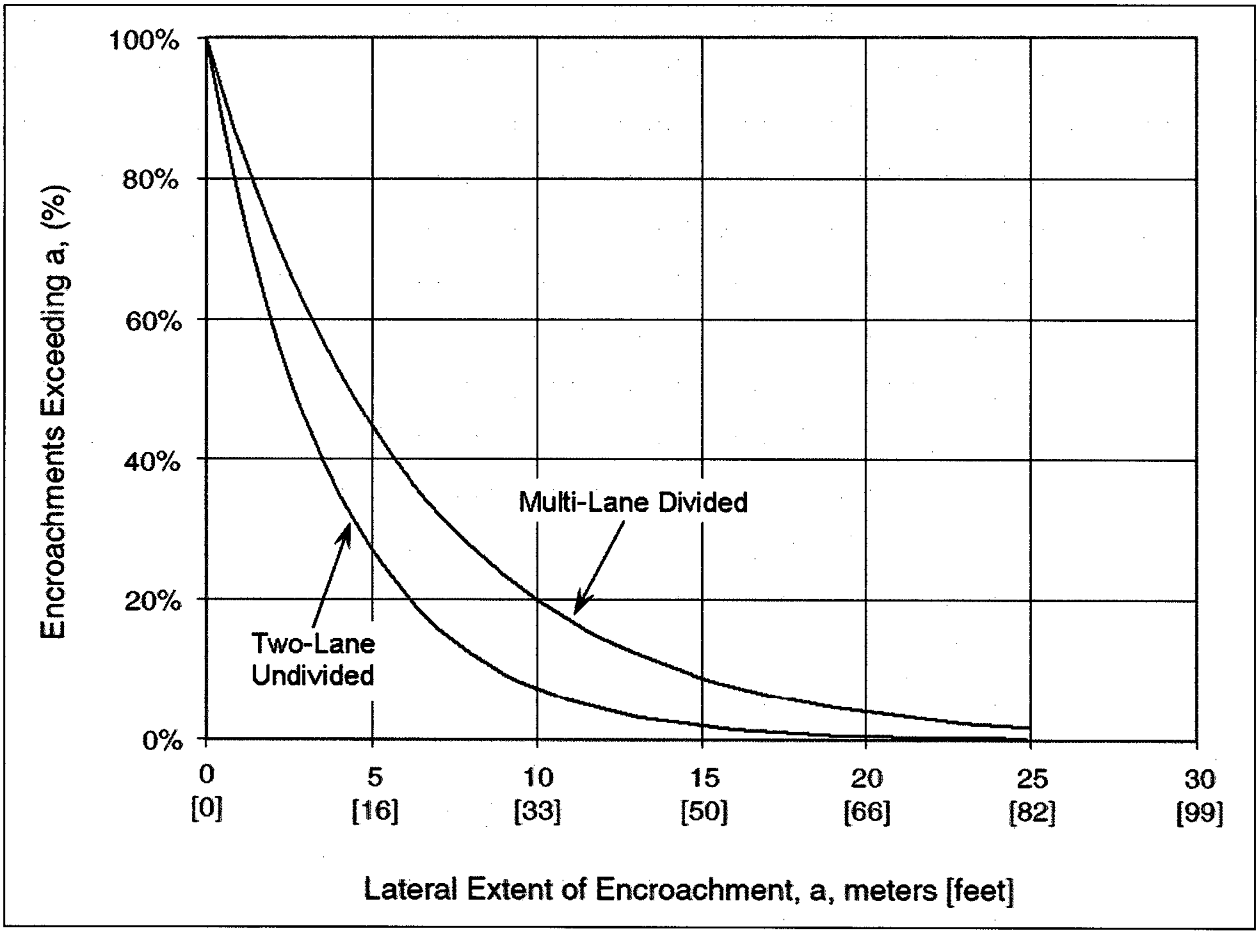


Figure 25. Lateral Extent of Encroachment Distribution (*27*).

The lateral distance the vehicle travels from the lane depends on a wide range of vehicle, driver, and roadway variables. However, as Figure 25 illustrates, the probability distribution of lateral distance travelled once an encroachment has occurred drops off dramatically the farther away from the travel lane one gets. In other words, the farther away from the travel lane a device is located, the less likely that a vehicle that veers from the lane will travel laterally enough to hit the device. According to the figure, when an encroachment occurs, the probability of the vehicle reaching lateral position *a*, in ft., decreases as *a* increases. For example, if an encroachment occurs on a multi-lane divided roadway, the probability of an object located on the edge line (*a*=0) being struck is 100 percent. If that same object is located 4 ft. from the edge of the travel way, the probability of being struck decreases to 84 percent. At 8 ft. from the edge of the travel way, the probability decreases to 68 percent; at 12 ft. from the edge of the travel way, the probability decreases to 56 percent; and at 16 ft. from the edge of the travel way, the probability decreases to 45 percent. Based on this distribution, one can infer that increasing pylon buffer space decreases the probability of the pylon being struck when an encroachment event occurs. There is no optimum buffer space, particularly when pylons are used to separate lanes of traffic. Factors such as the amount of right-of-way available (in the case of new construction) or the distance between existing lanes (in the case of retrofitting pylons into existing roadways) often predicates the placement of pylons. Because pylons typically cannot be placed far enough from the edge of the travel way to eliminate strikes by vehicles, a better approach to reducing maintenance costs may be to focus on creating a more forgiving environment, including devices that are self-uprighting after numerous strikes.

ISSUES WITH PYLON USE

Most of the pylon implementation case studies reviewed for this report indicate that pylons require dedicated and expensive maintenance. The US 75 HOV and the IH 635 HOV facilities incurred a significant number of missing pylons and broken curbs in the initial years of their operation, which resulted in large gaps for traffic to weave between the pylons, and increased road debris and significantly increased incident rates. A $650,000 per year maintenance contract was instituted by TxDOT with financial support from DART to maintain the 14-mile US 75 HOV facility. The SR 91 Managed Lane facility in California also found that maintaining the flexible pylons is expensive with an average of 1000 pylons being replaced monthly. However, the cost of maintaining pylons is justified as pylons are considered essential for the effective operation of the facility. The IH 95 express lane facility in Florida replaces about 115 percent of their pylons each year. They consider their rate of pylon replacement lower compared to other managed lane facilities using pylons in the nation. On the IH 10 Katy managed lanes, there have been no significant maintenance issues reported (*6*).

Lack of sufficient visibility of pylons at entry or exit access locations has been reported at various facilities (*6*). The IH 95 Express Lane facility changed the spacing between the pylons from 20 ft. to 100 ft. near access points. They also changed the color of the pylons for the initial 500 ft. near access points from white to orange to increase visibility. The US 75 and IH 635 facilities in Dallas, it was reported that pylon posts were lost frequently at the access points although the curb remained in place (*6*). HCTRA indicated that most of the pylon replacements on the Katy Managed Lanes occurred at entrance to the managed lanes.

Other issues identified with pylon use are 1) motorist disregard for the device and 2) lack of driver education (*6*). Since motorists are aware that the flexible pylons typically do not cause vehicle damage when run over, some motorists disregard the pylon as a delineator and drive through them to exit or enter the HOV/managed lanes. Missing pylons provide a greater opportunity for sneakers to weave between the pylons, a movement that may damage additional pylons. High crash rates on the IH 95 facility noted after the initial installation of pylons were attributed to a lack of driver education (*6*). FDOT's observation during initial operation of the IH 95 express lanes indicates that many motorists were confused about the operation of the express lanes themselves and were not aware of the specific exit access locations. This unfamiliarity resulted in many motorists crossing over the pylons to get to the general purpose lanes (*18*).

SUMMARY

Flexible pylons are relatively new traffic control and channelizing devices that are being used in several applications on roadways across the nation. There have been standard durability tests conducted on flexible pylons, which provide some guidelines for the users to select/specify appropriate products for use in different applications. These guidelines have enabled the Texas Department of Transportation and other state DOTs to generate a list of approved flexible pylon products for use in their states. The 2009 edition of the MUTCD does not specifically provide any guidance with respect to flexible pylons but provides some guidance on color and retroreflectivity requirements for channelizing devices. Since flexible pylons are used for channelizing, researchers inferred that some of the guidelines mentioned under channelizing devices in Chapters 3H and 6F of the 2009 MUTCD can be applied for flexible pylons without additional, more specific, guidance available. Guidelines regarding color and retroreflectivity available in Chapter 3F of the MUTCD pertaining to delineator posts can also be applied to use of pylons in some applications.

Information on pylon implementation on US 75 HOV, IH 635 HOV, SR 91 Managed Lanes, IH 15 Express Lanes, IH 95 Express Lanes, and IH 10 Katy Managed Lanes was reviewed and presented. Table 1 provides a summary of the pylon implementation details at these locations. Most of the facilities reviewed in this report have indicated maintenance of the pylons as an issue. Frequent loss of pylon posts, lack of visibility, driver disregard, and debris from broken curb-pylons posing safety hazards were some of the issues highlighted in the literature.

The US 75 HOV and IH 635 HOV facilities had significant issues with missing pylons, increased incidents, and curb-pylon performance during the initial years of operation. However, after establishing a maintenance contract for US 75 HOV and replacing IH 635 HOV pylons with newer and more durable curb-pylons, many of the problems have subsided. The SR 91 Managed Lane pylons also require significant replacements, however pylon barriers are considered essential for effective operation of the facility. The IH 95 Express Lane facility has experimented with different types of pylons, using orange pylons at access points to contrast concrete pavement and two different spacing lengths (20 ft. initially and then 10 ft.) between pylons. In the initial phase of operation (with 20 ft. spacing) it was reported that frequent weaving was observed and several crashes resulted due to driver confusion. Initially the pylons are being replaced at a rate of 115 percent a year at an approximate cost of $3 million per year. It appears that the narrow buffer space of 2 ft. and no shoulders adjacent to the pylons results in a significant loss of pylons at the IH 95 Express Lane facility. The IH 15 express lanes in Las Vegas, Nevada, also has significantly higher rate of pylons replacement compared to other facilities. It is estimated that about 300 percent of the pylons are replaced every year resulting in over $40,000 in pylon replacements for a 3-mile section of pylons. The buffer width for each of the facility reviewed here was plotted against the estimated pylon replacement rate. Figure 26 shows the influence of the buffer width on the yearly pylon replacement rate; a decreasing trend in the yearly pylon replacements is observed with the increase in buffer width. Some access treatments, such as use of curb mounted pylons at access were tried, but did not result in a decrease in pylon replacements.

Table 1. Summary of Implementation Details for Selected Pylon Installations.

Facility	Curb-Pylon Type	Pylon Color	Pylon Spacing (feet)	Curb Spacing (feet)	Curb-Pylon Height (inches)	Buffer Space (Right + Left) (feet)	Adjacent Lane Width (feet)	Estimated Yearly Pylon Replacement
US 75 HOV, Dallas	Curb mounted	White	12	8.3	38.5	3	11	70
IH 635 HOV, Dallas	Curb mounted	White	14	9	39.25	5	11	70
SR 91 Managed Lanes, California	Surface Mounted (pavement)	Yellow	12	not used	36	4	12	100
IH 15 Express Lanes, Nevada	Surface Mounted (pavement)	White	Initially 25 ft., now 12.5 ft.	not used	36	1.5	12	300
IH 95 Express Lanes, Florida	Surface Mounted (pavement)	White (yellow at access locations)	Initially 20 ft., now 10 ft.	not used	36 to 48	2	12	115
IH 10 Katy Managed Lanes, Houston	Surface Mounted (pavement)	White	10	not used	48	22	12	25

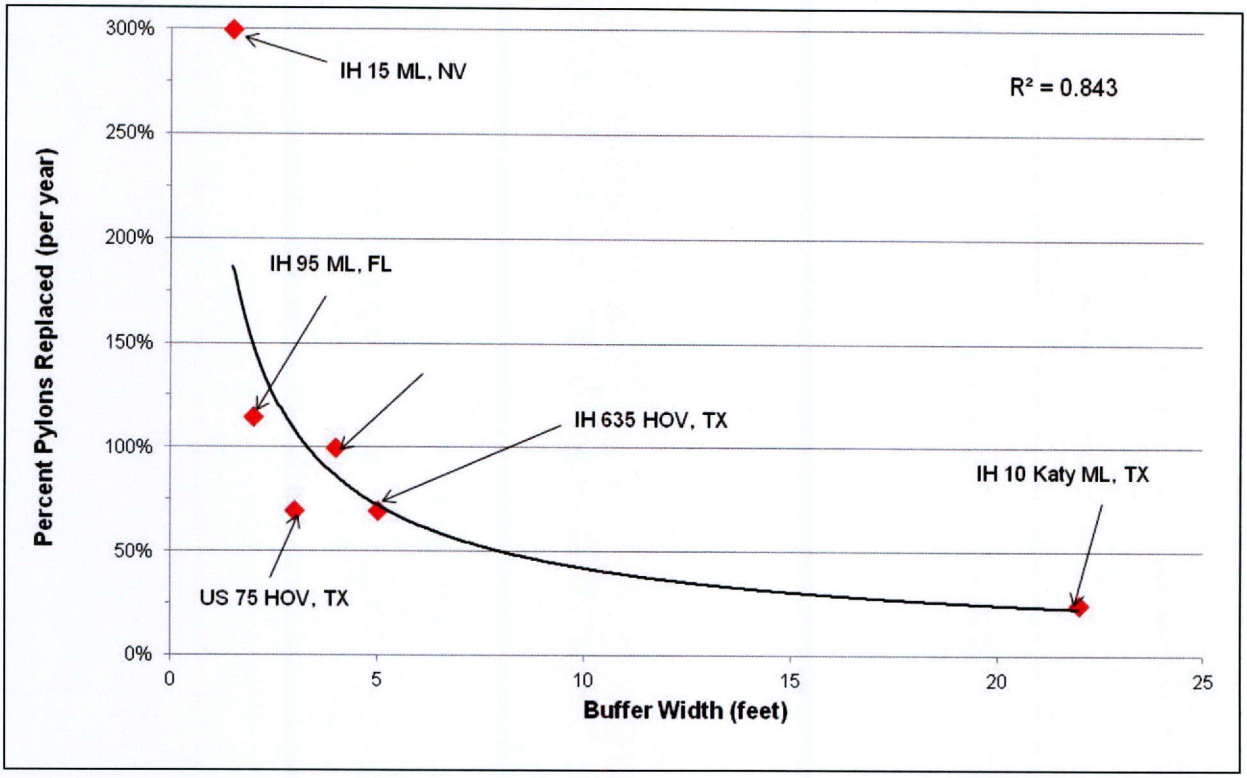


Figure 26. Buffer Width vs. Yearly Pylon Replacement Rate - Preferential Lane Facilities.

IH 10 Katy Managed Lane facilities have no significant maintenance issues. The Katy Managed Lane pylons have wide shoulders on either side of the pylons making it less likely for motorists to knock them off.

The Katy Managed Lanes have a lesser pylon replacement rate compared to other facilities reviewed. Information provided by HCTRA indicates that only about 25 percent of the pylons are being replaced annually on the Katy Managed Lane facility, and no crashes or incidents attributed to pylon use have been observed since implementation.

Limited published information exists regarding pylon implementation and performance on freeway, HOV, and managed lane facilities. Much of the available information provides insufficient details on implementation considerations, maintenance issues, or any insight into why implementation factors such as pylon spacing, buffer widths, height, and color, were made and what guidance was used. There are gaps in information that do not appear to have been adequately documented or addressed in the literature, including:

- Guidelines used for implementation of pylons regarding pylon spacing, buffer spacing, pylon height, and pylon width.
- Insufficient documentation of maintenance issues of various pylon implementations.

- Operational and/or safety evaluation of the pylon implementations.
- Proper classification based on application of pylons.

Some of these gaps in the literature were addressed through the vendor questionnaire, the survey of state DOTs and other organizations, and case studies.

CHAPTER 3: VENDOR INTERVIEWS

PURPOSE OF VENDOR INTERVIEWS

The vendor interviews were conducted for three primary purposes, including to:

1. Identify locations where pylons have previously been installed.
2. Get leads to agencies who have implemented pylons.
3. Determine if the vendors have any guidelines for implementing pylons that they share with their customers.

The deployment location information was gathered from vendors with the intent to be used in potentially selecting case study sites. The agency leads were solicited to identify agencies that had deployed pylons on various projects so that they could be surveyed for their experiences.

VENDOR SURVEY METHODOLOGY

Most state DOTs develop a list of approved vendors for many of the traffic control products used by their agencies. This list of approved products is typically termed either as an Approved Product List (APL) or Qualified Product List (QPL). The researchers conducted an online search of all state DOT websites to access the QPL of each state DOT, including the District of Columbia and Puerto Rico DOTs. Thirty-seven of the state DOT QPLs accessed had information on pylons and/or pylon-curbs. The remaining state DOT QPLs were either not accessible online or did not contain pylons on the QPL. A matrix with a list of pylon manufacturers, their products, and an indication as to which state DOTs use which products was compiled after reviewing all the available QPLs. A total of 17 pylon manufacturers and 39 different products were identified from the compilation. Figure 27 contains a summary of state DOTs who listed various pylon manufacturers on their QPLs. The annotation "T" on the top of the bar in the figure indicates manufacturers that were listed in the TxDOT QPL.

Contact information for all 17 manufacturers listed on the QPL compilation was gathered. A short questionnaire soliciting information on the pylon products, installation locations, and the agencies requesting installations was sent by email to each company. Appendix A shows a copy of the vendor questionnaire.

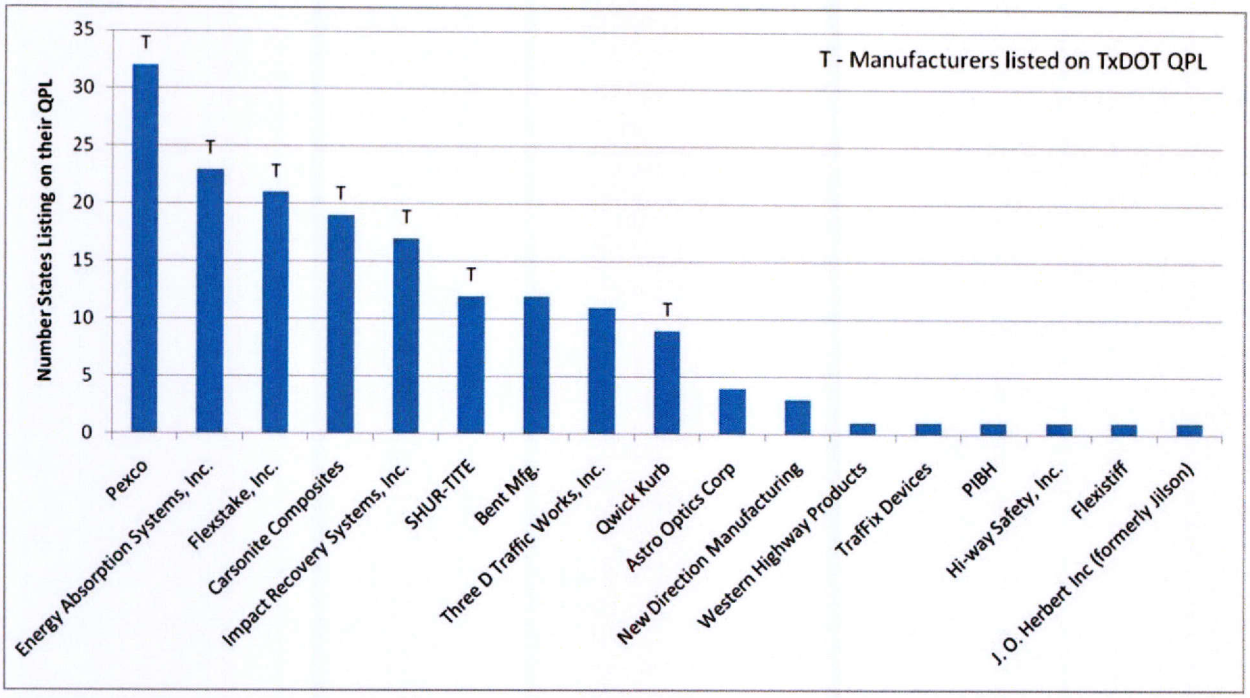


Figure 27. States Listing Pylon Manufacturers on QPLs.

SUMMARY OF VENDOR SURVEY RESULTS

Initially only five of the manufacturers responded to the questionnaire by the deadline. One of the five manufacturers responded that they no longer manufactured pylons. Four of the manufacturers provided information on major locations where their products have been installed along with leads to agencies installing their products. However the list of locations provided by the manufacturers was not exhaustive, as presented in Appendix B.

Nine of the manufacturers who did not initially respond to the questionnaire were contacted by phone. Two of the manufacturers contacted responded that they no longer manufacture pylons. Most of the others could not list the locations where their pylons were installed, either because they did not maintain such information or because they sold their products through distributors and did not know who end users were or where they were deployed. Only two of the manufacturers responded that they provided implementation guidelines to agencies. Two other manufacturers responded that they do not provide any guidelines to the agencies using their pylons and the remaining manufacturers did not provide a response to this question.

Both of the manufacturers who responded that said they provide some guidelines were contacted to solicit specific information on the guidelines. One of these manufacturers responded that they specify about 13 ft. spacing between the pylons for high speed lane separation applications (such as HOV lane separation) with curb spacing of 9 ft. This guideline was not vendor developed and driven, but resulted from feedback from agencies using their products. For low speed applications or those used to separate opposing traffic flows, the manufacturers specified approximately 3 ft. spacing and recommended that the spacing be no greater than about 6 ft. as they believe any spacing greater would allow cars to weave through the pylons. A minimum curb spacing of 3.25 in. was specified for low speed applications, which manufacturers indicated was required for drainage purposes. As for the curb height, the manufacturer indicated that the curbs are designed to create a smooth transition for the vehicles climbing over the curb while minimizing the lateral forces on the curb. The manufacturer indicated that their curbs are tested as per National Cooperative Highway Research Program (NCHRP) 350 criteria; however the curb and pylon are individually tested, not tested as a system. They stated that it was not a requirement of the Federal Highway Administration (FHWA) that the curb and pylon be tested together as some manufacturers had provisions for interchangeable pylons (of same or different manufacturer) to be attached to their curbs.

The other manufacturer indicated that they only provide guidelines regarding curb height and curb visibility. The manufacturer stated that they do not provide a recommendation on pylon spacing as it is left to the agencies to decide what pylon spacing is appropriate. This manufacturer recommends a minimum of ½ to 1 in. curb spacing for drainage purposes. They indicated that their curbs come in 1 in. and 3 in. heights and their pylon-curbs are crash tested as a whole system based on NCHRP 350 and the *Manual for Assessing Safety Hardware* (MASH) test criteria.

CHAPTER 4: SURVEY OF TRANSPORTATION AGENCIES

PURPOSE OF SURVEY

This survey gathered information on the use of pylons by various transportation agencies in Texas and the United States. The state-of-practice review revealed that that there is some guidance in the MUTCD and the TMUTCD on color and height of channelizing devices, but typically no agency-generated guidance is available on other pylon implementation factors such as spacing, buffer width, visibility, and running length.

Flexible pylons are being implemented at several locations in Texas and in other states, but it is not known if any of the agencies implementing pylons use any anecdotal guidelines for implementation. Therefore, this task gathered information on pylon implementation locations, the guidelines used for implementing pylons, and identification of potential causes for broken/missing pylons.

METHODOLOGY OF SURVEY

Survey Instrument

The survey instrument consisted of 12 questions. Most of the questions required a yes/no answer or a selection from multiple choice responses. Only two questions in the survey required the participants to write an open-ended response. The survey was designed to be completed in 10 minutes or less, to increase the likelihood of a high response rate. After the initial response was received, a follow up with specific participants was completed over the phone for clarification or to gather additional information. Appendix C provides a copy of the survey questions.

The survey asked questions regarding current pylon deployments. Respondents were asked to list pylon implementation locations, the purpose for use of pylons in those applications, and the type of roadway (high speed or low speed) on which pylons were installed. For the survey, high speed roadways were defined as facilities with speed limits of more than 45 mph and above, and low speed roadways were defined as facilities with speed limits of 45 mph and below. Additional questions asked why pylons were chosen over other devices, including concrete barriers and pavement markings. Researchers solicited information on guidelines used by the agencies to implement pylons regarding spacing, height, buffer space, running length, visibility of pylons, and presence of curbs. The survey asked several questions regarding maintenance of pylons, including whether the agency has noted issues with pylons frequently breaking or missing. If the agencies had such maintenance issues they were asked what they perceived as contributing factors toward those hits. Other questions were asked to determine if the agencies had completed any evaluation of pylon implementations, if they consider pylons beneficial for the purpose used, and if there were any other lessons or issues regarding pylon deployments that could be shared.

Survey Administration

The survey targeted three different groups. The first group consisted of the 25 TxDOT districts. The survey was sent to both the District Transportation Operations Engineer and District Maintenance Engineer at each of the TxDOT districts. Surveys were sent to both operations and maintenance engineers since the survey instrument consisted of questions relating to implementation and maintenance of pylons. The second target group was state DOTs, including the state traffic division of 49 state DOTs (excluding TxDOT), as well as the District of Columbia and Puerto Rico DOTs. State participants were primarily obtained from the members list of AASHTO's Subcommittee on Traffic Engineering. The third target group consisted of three subgroups:

- Cities in Texas with populations of greater than 50,000 per the 2010 U.S. Census.
- Tolling agencies in Texas.
- Select transit agencies that operate and/or maintain HOV lanes or possibly using flexible pylons in their operations.

To obtain the largest sample possible, the survey was sent to the participants in three formats, Microsoft Word, PDF, and online for their convenience. Participants could fill out the survey in any of the above formats. The web survey was the quickest method, but other versions provided opportunity for the participants to provide additional information if desired. Appendix D contains the project explanation and definition of terms that was sent with the survey. The survey was emailed to participants, and responses were solicited within three weeks from the date the survey was emailed. A reminder email was sent two weeks after the initial survey email to the participants who had not yet responded.

Survey Responses

A total of 169 surveys were sent out and 86 responses were obtained (a 51 percent response rate). All 25 TxDOT districts responded to the survey. More than one response was obtained to the survey from five of the districts (both operations and maintenance engineers responding). In the other 20 TxDOT districts, either the operations or maintenance engineer responded to the survey. Thirty-seven of the 51 state/territory DOTs responded to the survey, a response rate of 73 percent. Among the other Texas agencies contacted, 18 responses were obtained out of the 70 surveys sent. Of the other agencies contacted, four out of nine tolling agencies responded (44 percent response rate), two out of three transit agencies responded (66 percent response rate), and 12 out of 58 cities responded (21 percent response rate) to the survey.

Survey Follow-up

After the initial survey deadline, all the participants who responded were contacted by phone to solicit additional information as a follow-up on their responses to the survey questionnaire. The follow-up questions asked for additional details on the following aspects:

- Specific guidelines used for pylon implementation.
- Specific locations within a pylon implementation where maintenance issues were more problematic.
- Pylon inspection and replacement policies.
- Selection criteria used for pylons (low bid or durability).
- Using of (or consideration of) different specifications when selecting pylons for high speed application.
- Alternatives used and reasons for use of alternatives instead of pylons.

TRANSPORTATION AGENCY SURVEY RESULTS

This section presents the responses to the survey and provides summaries of the follow-up questions. The survey data are divided into the three target groups: TxDOT districts, state DOTs, and other agencies. The most common response to each multiple choice question is highlighted for convenient analysis. The following notes should be taken into consideration for all reported data:

- Sample sizes in the data include only those agencies who responded, not all that were contacted. Other than Table 2, which includes all respondents, all other tables in this section will only include those who responded that they use flexible pylons for lane separation and/or channelization.
- TxDOT was not included in the state DOT data; responses were segregated and reported by TxDOT districts.
- For five TxDOT districts two survey responses were received. For these five districts, the responses were compiled so that the district is only represented one time in the results.
- Not all agencies that completed the survey were available for follow-up questions.

Question 1: Does Your District/Agency Use Flexible Pylons and/or Pylon-Curb Assemblies for Lane Separation and Channelization Purposes (on High Speed and Low Speed Facilities)?

Table 2 shows the percentage of respondents from all three agency classes who indicated they use flexible pylons and/or pylon-curb assemblies for lane separation or channelization. TxDOT districts indicated more usage of pylons for these applications than the United States as a whole. Several factors may contribute to these numbers, including a lower percentage of state DOTs responding and Texas being a warmer state where frequent snow does not prevent usage in some cases. Figure 28 shows the United States map with the states color-coded by pylon usage: 1) high-speed only, 2) low-speed only, 3) both high- and low-speed, 4) do not use pylons, or 5) no response to survey. Figure 29 presents a similarly color-coded usage map of the TxDOT districts. Other Agency pylon usage on high speed roads may be lower because a majority of higher speed roadways may be operated by a state DOT as opposed to a city or county.

Table 2. Percentage of Agencies Using Flexible Pylons and/or Pylon-Curb Assemblies for Lane Separation or Channelization Purposes.

Response	TxDOT Districts	State DOTs	Other Agencies
Use on high speed facilities (Speed limit 50 MPH and above)	68%	57%	28%
Use on low speed facilities (Speed limit 45 MPH and below)	72%	57%	56%
Use on both high and low speed facilities	48%	41%	28%
Sample Size	25	37	18

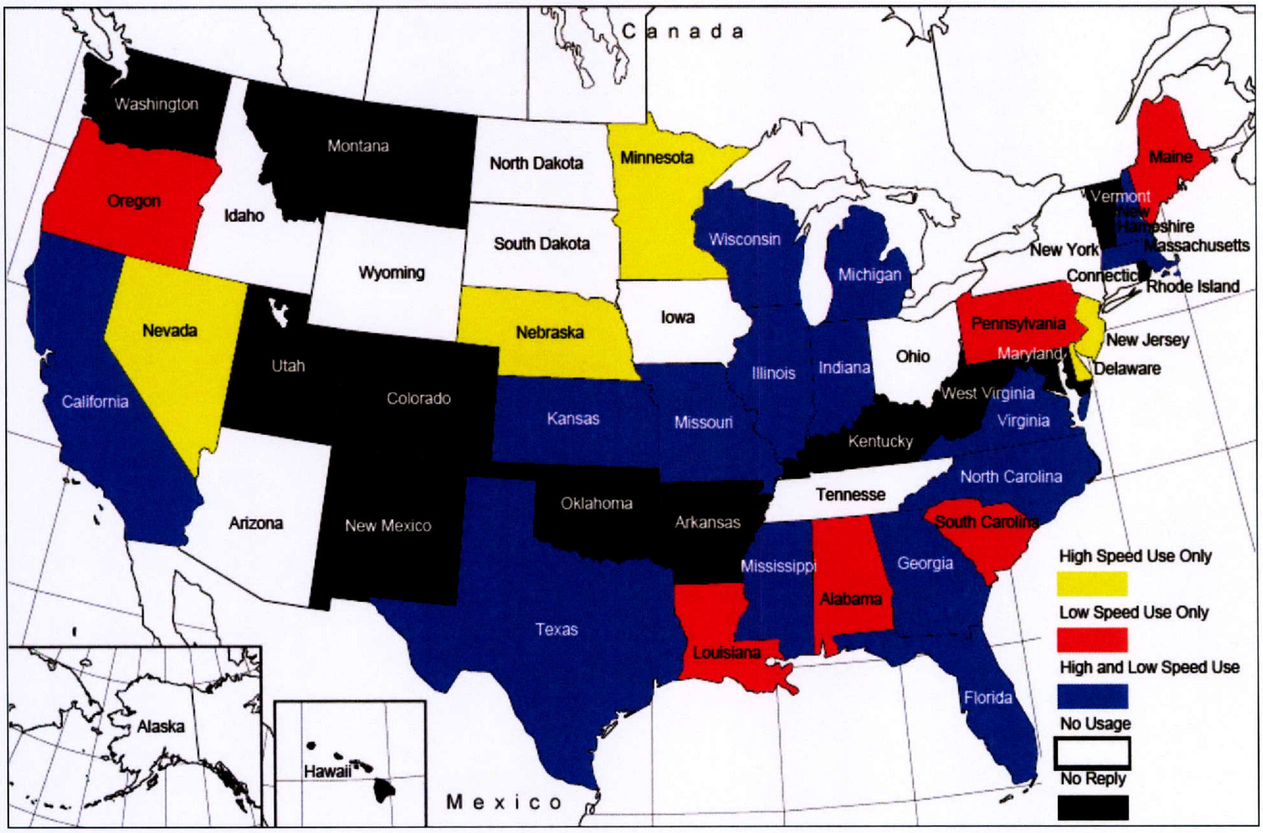


Figure 28. State DOT Usage of Flexible Pylons for Lane Separation or Channelization.

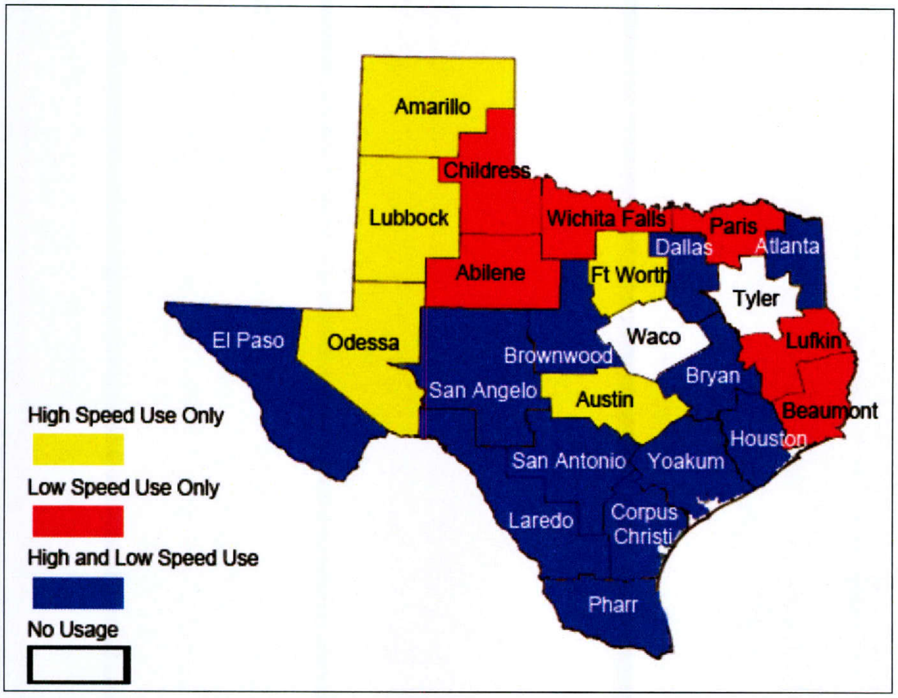


Figure 29. TxDOT District Use of Flexible Pylons for Lane Separation or Channelization.

Additional notable information includes:

- Other Texas agencies responding that they use pylons for lane separation or channelization include:
    - Metropolitan Transit Authority of Harris County (METRO).
    - Harris County Toll Road Authority.
    - City of Houston.
    - City of Beaumont.
    - City of Corpus Christi.
    - City of Waco.
    - City of College Station.
    - City of Odessa.
    - City of McAllen.
    - Capital Metro (Austin transit authority).
- Other Texas agencies responding that they do not use (or have not used) pylons for lane separation or channelization include:
    - Alamo Regional Mobility Authority (San Antonio).
    - Grayson County Regional Mobility Authority.

  - North East Texas Regional Mobility Authority.
  - City of Harlingen.
  - City of Plano.
  - City of Pearland.
  - City of McKinney.
  - Town of Flower Mound.

In follow-up interviews, the agencies who said they only use pylons for lane separation or channelization for low speed applications were asked why they did not use them in high speed applications. Overwhelmingly, the agencies responded that there currently had not been a need for high speed application. There were mixed results when these same agencies were asked whether or not they thought the flexible pylons were durable enough for high speed applications. Many agencies said they did not know since they did not have personal experience with them, some were doubtful that they would be as durable for high speed, and others were optimistic that pylons would be suitable for high speed use. Agencies that do currently use flexible pylons for high speed applications were also asked if they believed they were durable enough, and they generally responded affirmatively. However, some agencies tended to think of pylons only as a good temporary solution or a good option if you were willing to pay for the replacement.

Question 2: Why Does Your District/Agency Choose Pylons over Concrete or Other Barriers?

When asked why they choose pylons over barriers, the most common responses for all three agency classes were that pylons occupy less horizontal cross-sectional width and that they have a lower initial cost (see Table 3) as compared to concrete barriers. The response selected the least often was that pylons allow for emergency access. Each respondent could choose multiple answers, and an other option was available where respondents could leave an open ended response.

Table 3. Why Agencies Indicated they Choose Pylons over Concrete (Jersey) or Other Barriers (Multiple Choice, Can Select All That Apply).

Response	TxDOT Districts	State DOTs	Other Agencies
Lower initial cost	74%	58%	50%
Lower maintenance cost	26%	23%	50%
Allow for emergency access	13%	27%	20%
Occupies less horizontal cross-section width	83%	73%	70%
Sample Size	23	26	10

A quarter of TxDOT districts and state DOTs, and half of the other agencies indicated that lower maintenance cost would be a reason to deploy pylons. From these results and discussions during follow-up interviews, it appears that many of the responding agencies view flexible pylons as a temporary solution and may discount maintenance because their pylons may be used in applications with fewer hits. The other responses included:

TxDOT Districts

- Minimizes vehicular damage.
- Quick solution to problem.
- Supplements double white lane lines.
- Use it as test section.
- Not a permanent condition.
- Does not require end treatment.
- Safely separates traffic while minimizing vehicle damage.
- Safer for traveling motorists at these locations.
- They are safer to hit than a barrier or attenuator.
- Can be easily adjusted (lengthened or shortened).

Other States

- Can be removed during winter months.
- Flexibility in lane assignment/location, also used for short term, temporary applications.
- Less vision obstruction.

- No blunt end to protect.
- Not compromising safety with use.
- Passive protection. Safety.
- Takes up less room than a concrete barrier.
- We mainly use to help identify islands and as a physical barrier to keep traffic from making illegal movements.

Other Agencies

- Could be easily removed if needed.
- Increased visibility over raised curb or pavement markings.
- Not enough space for concrete barrier.
- Short-term solution and was quickly implementable.

In follow-up interviews, respondents were asked which of the answers they gave in Table 3 were the most important. Most commonly, agencies answered lower initial cost, followed by occupies less horizontal cross-sectional width.

Question 3: Why Does Your District/Agency Choose Pylons over Buffer and/or Paint Stripe Only?

Table 4 shows the responses to Question 3, asking why agencies choose pylons over use of a buffer and/or pavement markings alone. This question provided multiple choice selections, the opportunity to select multiple answers, and an open ended response option.

Table 4. Why Agencies Choose Pylons over Buffer and/or Paint Markings Only.
(Multiple Choice, Can Select All that Apply).

Response	**TxDOT Districts**	**State DOTs**	**Other Agencies**
Substantial physical separation	61%	46%	60%
Higher compliance (little to no crossing over line)	78%	81%	60%
Increased safety	78%	46%	80%
Sample Size	23	26	10

Across the agency classes, most respondents indicated that they chose pylons either because there is a perceived higher compliance by the drivers or they provide increased safety, although all response options (including substantial physical separation) were selected frequently. TxDOT districts chose increased safety as a reason for use almost twice as often as the other state DOTs. Other responses included:

Other Agencies

- The flexible pylons not only provide visual separation, they also create a physical obstruction to deter undesirable movement.
- Federal Rail Road Administration (FRA) requirements.
- Increased visibility.
- Trying to keep cars out of rail tracks and right of way.
- Deter lane movement.

When asked which of their responses in Table 4 was the most important, most agencies replied higher compliance or increased safety.

Question 4: Does Your District/Agency Use Any Guidelines (Standard or Anecdotal)?

Question 4 asked about which design factors that agencies had guidelines for use in implementation (see Table 5). The questionnaire provided a list of design factors, and agencies could indicate all for which they had guidelines. Appendix D contains a definition of terms that was provided to agencies along with the survey and explanation of these factors. Overall, the agency classes use guidelines the most frequently for pylon visibility but also use them often for pylon height and spacing. It appears that the agencies find the least amount of guidance for curb spacing and running length of the pylons.

Table 5. Standard and Anecdotal Guidelines Used by Agencies.

Response	TxDOT Districts	State DOTs	Other Agencies
Pylon Spacing **(distance between adjacent pylons)**	48%	58%	60%
Pylon Height **(measured from pavement surface to top of post)**	52%	73%	60%
Pylon Visibility **(includes width, color, contrast, retroreflectivity)**	57%	73%	90%
Curb Spacing **(gap between adjacent curbs for discontinuous curb)**	17%	19%	30%
Curb Height **(from the pavement surface to the top of the curb)**	22%	35%	40%
Curb Visibility **(includes color, contrast, retroreflectivity)**	43%	31%	50%
Buffer Space **(offset distance between pylons and adjacent travel lane)**	26%	15%	30%
Running Length **(length of the pylon along horizontal alignment)**	26%	4%	50%
Sample Size	23	26	10

Researchers asked respondents several follow-up questions about the guidelines they use for the various design parameters. Most respondents indicated that there are not many formal guidelines to follow but that they used engineering judgment (or trial and error) specifically for pylon spacing. Agencies turn to the MUTCD Chapters 3H and 6F for color and height standards and use the information on roadside delineators as a starting point. One agency used a combination of MUTCD delineator standards and trial and error to test three different pylon heights, deciding that 42 in. was more suitable than 36 or 48 in. to balance car damage when hit and visibility when viewed from a truck. Some agencies mentioned they follow vendor or manufacturer recommendations. Buffer space, a particular interest to researchers in this study, was rarely mentioned by the agencies, although few believed that if enough buffer existed it would decrease pylon hits and lower maintenance issues.

When asked if there were limitations to the guidelines they follow, agencies most commonly indicated that there were different considerations for high and low speed applications. Agencies responding in the survey that they did not follow any particular guidelines stated that they considered engineering judgment, existing MUTCD standards, and manufacturer recommendations when making decisions about design parameters of pylon deployments.

Question 5: Has Your District/Agency Had Issues with Maintenance, Frequently Missing or Broken Pylons and/or Pylon-Curb Assemblies?

Table 6 presents the percentage of agencies indicating they have frequently missing or broken pylons and/or pylon-curb assemblies. Table 7 summarizes why agencies perceive that pylons were frequently damaged or missing.

Table 6. Percentage of Agencies Indicating They Have Frequently Missing or Broken Pylons and/or Pylon-Curb Assemblies.

Response	TxDOT Districts	State DOTs	Other Agencies
Yes	78%	69%	100%
No	22%	31%	0%
Sample Size	23	26	10

Table 7. Agencies with Missing and Broken Pylon and/or Pylon-Curb Assemblies Major Reasons for Problems (Multiple Choice, Can Select All that Apply).

Response	TxDOT Districts	State DOTs	Other Agencies
Inattentive drivers	67%	67%	90%
Driver disregard	83%	67%	80%
Lack of contrast	0%	6%	0%
Lack of retroreflectivity	0%	11%	10%
Lack of visibility due to dirty pylons	28%	22%	20%
Emergency crossing	0%	11%	10%
Snow plowing/road cleaning	0%	22%	0%
High truck volume	39%	22%	30%
Pylons not durable	50%	44%	50%
Pylons/Curb not properly affixed	0%	28%	10%
Insufficient lateral clearance	22%	28%	50%
Large gap between pylons allowing motorists to weave through	0%	6%	0%
Sample Size	18	18	10

All agency classes indicated that it appears that the pylon damage issues stem from driver actions (mainly from inattentiveness and/or intentional disregard) rather than with the visibility of the pylons themselves. Half of the respondents also felt that the pylons were not durable enough. An open ended response provided by one agency was:

> *All of the [provided reasons apply.] When these pylons are used at decision points or areas requiring heavy weaving movement, they tend to be hit more frequently.*

> *[The] Katy Manage[d] Lanes are a good example; the majority of our pylon replacement areas are located around the tangent areas remain in good condition and have a significantly longer service life. The cause can be driver inattention, confusion, or total disregard for the desired driving movement. When the pylons continue to be hit they lose reflectivity and end up being so dirty they are no longer visible, which in turn increases the frequency of impact. It is important for an agency to select the appropriate flexible pylon system for the intended speed and placement in order to achieve the desired longevity of product.*

Other stated reasons for missing or damaged pylons as stated by respondents include:

- Kids do it for kicks.
- Wide loads impact them.
- Large vehicles do it on purpose to clear access for next time.
- Drivers deciding to exit at last minute.
- Pylons are not maintained.
- Possible vandalism.

Respondents were asked if there any noticeable trends regarding hits or traffic operations at the installations where the maintenance issues were occurring. Most respondents said that any of the pylons could be hit; it just depended on where drivers decided to cut across. Other common replies were that hits occurred near driveways and cross streets, at the first few pylons where drivers made last minute decisions, and at the last few pylons where vehicles try to cut over the first free chance they get.

The replies varied when respondents were asked if there were specific pylon applications that require more maintenance than others. Examples of applications with increased maintenance were high speed locations where turn movements were blocked such as pylons used at freeway exit ramps to discourage exiting vehicles to turn into driveways or cross streets on the frontage close to the ramps. Solutions suggested include using pylon/curb assemblies as drivers were less likely to traverse them, and using more buffer space.

The agencies were also asked if they had any other pylon maintenance issues not related to vehicle hits. Repeated responses included adhesion problems, especially when not using bolts;

leaning pylons; durability of the pylon sheeting; dirty pylons; and accumulation of dirt/debris at the base.

Agencies gave varying responses to how often their pylon implementations are inspected. Some agencies (including TxDOT districts) have formal schedules, but many replacements are more complaint-based. Responses ranged from daily inspections to once or twice a year. State DOT contacts may not have had a good feel for how often their implementations are inspected because those procedures are handled at a local rather than state level. It was also difficult to determine how often pylons were being replaced or the percentage of pylons replaced per year. Many respondents did not have a good estimate, and it is difficult to distinguish if the same few pylons are being replaced over and over or if different pylons in the implementation are being replaced all the time. The researchers infer via the follow-up that agencies with shorter or smaller implementations do not inspect and monitor their implementations as intensely as agencies with larger (or longer) implementations such as on managed lane facilities. Therefore, they could not provide the same detail of maintenance information.

Respondents were also asked if they considered the recurring maintenance cost when choosing pylons. The majority of them said they did not, which could be due to the fact that barriers were not a practical option and/or they used pylons as only a temporary solution and were not concerned with maintenance. It could also be that there was no documented experience as to the replacement requirements on other projects in a consolidated, concise source. With no published record of the replacement requirements for other projects, it would have been difficult to assess the longer-term maintenance requirements for any new deployments.

Question 6: Has Your District/Agency Performed Any Evaluation of the Pylon Implementation(s)?

Few agencies appear to have performed any evaluation of their pylon implementations (see Table 8). Within Texas, the Houston and Odessa Districts indicated they had performed evaluations, and nationwide, Florida and Indiana responded affirmatively. However, on following up, both Houston and Odessa Districts indicated that they had performed field inspection of the pylon implementations, but had no formal evaluation reports of the inspections. Indiana DOT provided three evaluation reports. These reports contained evaluation of different pylon products. Evaluations were performed to provide recommendations for use of the specific pylon products.

Table 8. Percentage of Agencies Performing an Evaluation of a Pylon Implementation.

Response	TxDOT Districts	State DOTs	Other Agencies
Yes – evaluation performed	9%	8%	0%
No – evaluations not performed	91%	92%	100%
Sample size	23	26	10

The evaluation report provided by Indiana DOT assessed the man-hours required to install a specific length of pylons, daytime and nighttime visibility, and durability of pylons in the field (from UV exposure, winter conditions, and snow plowing). However, all the evaluations were not performed under similar conditions. For example, in one of the evaluations the pylons were assessed over a period of one year to test the durability of pylons for winter conditions, while in another report pylons were subjected to four winter seasons to test for durability.

Question 7: Does Your District/Agency Consider Pylons and/or Pylon-Curb Assemblies Beneficial for the Purpose Used?

All agency classes surveyed believe the pylons and/or pylon-curb assemblies for channelization and lane separation are beneficial. Only the respondents who use pylons in channelization and lane separation applications are represented in Table 9. It appears that these agencies are very happy with the results of implementation. The State of Virginia did not answer this question, so they were the only non-yes for the state DOT responses resulting in the less that 100 percent score.

Table 9. Agencies who Consider Pylons and/or Pylon-Curb Assemblies Beneficial.

Response	TxDOT Districts	State DOTs	Other Agencies
Agencies who answered yes	100%	96%	100%
Agencies who answered no	0%	4%	0%
Sample size	23	26	10

Other Follow-up Questions

Respondents were asked if they chose low bid or durability when choosing pylon manufacturers for implementation. Most replied that policy has them choose low bid as long as the product is approved, but there may be more flexibility if it is an in-house project with a smaller order. Most agencies have some form of specification they follow for procurement of pylon products. Among those contacted, only Florida DOT had two specifications—one that requires 10 hits at 55 mph and another high performance specification that requires 50 hits at 55 mph. None of the agencies interviewed had specifications for high speed impacts (speeds greater than 65 mph). When asked how they decide to implement flexible pylons for these applications, most agencies did not have a formal process or set of requirements, but instead base decisions on complaints, accidents, observation, and past experience.

Researchers also followed up with the agencies that indicated that they do not use pylons for lane separation and channelization. The lack of usage was not due to previous unsuccessful implementation, but mainly due to a lack of need to use the device or address a particular situation. For several northern states, snowfall will likely prevent them from ever implementing pylon assemblies. Other agencies indicated that if the need arose and there was proper guidance, they would consider implementation.

AGENCY SURVEY CONCLUSIONS

A relatively high response rate (86 percent response) was obtained for the practitioner survey, which can be attributed to the survey design, response options, repeated reminders, and very good agency cooperation. The 10-minute survey was kept simple with a minimal number of questions, many of which were multiple choice format. Follow-up phone calls were made to all survey participants who responded to the survey to obtain additional more descriptive information.

Agencies were asked to provide locations in their district or state where pylons had been used for lane separation or channelization. The researchers requested photos of the locations to determine the suitability of the pylon implementation for a case study. Many of the TxDOT districts and some other state DOTs listed specific pylon locations in their jurisdictions. The majority of the pylon implementations listed in the survey responses can be classified into one of the six pylon application groups below. A total of 58 sites were initially short-listed as potential sites for the case study (see Appendix E). The number of sites short-listed in each pylon application group is noted in parentheses in the list below:

1. Managed lane/HOV applications (6).
2. Freeway main lane separation (7).
3. U-turn/right-turn channelization (11).
4. Exit ramp/frontage separation (20).

5. Entrance/frontage separation (9).
6. Median applications to block left turn (5).

The pylon application with the highest number of deployed locations was Group 4—exit ramp/frontage separation, which is the use of pylons for lane separation between exit ramp and the frontage road to discourage drivers from turning into driveways or streets soon after exiting. The short-listed sites, especially in Groups 3, 4, 5, and 6 have both low speed and high speed pylon locations for each application. The type of application and the number of sites to be considered for the case study portion of the project were determined based on availability of resources, project panel input, and feasibility of data collection at the sites.

In the survey, agencies were asked if they used any standard or anecdotal guidelines to implement pylons. Several agencies responded that they used guidelines for some or all factors (spacing, height visibility, buffer, etc.) for implementing pylons, but upon follow-up, most agencies either used manufacturer recommendations, engineering judgment, trial and error, or whatever height pylon was in their approved product list. For example, Florida DOT had tested three different heights (36 in., 42 in., and 48 in.) and found 42 in. pylons to be more suitable for their IH 95 managed lane separation application as determined by minimal damage the pylons caused to car hood upon flexing and adequate visibility of pylons from a tall truck.

When the agencies were asked why they choose to use pylons over concrete barriers, the most common reason cited by the agencies was that the pylons took less horizontal cross section width than typical concrete barriers, followed by the lower initial cost to install pylons as compared to concrete barriers. The flexibility to allow for emergency access was the least cited reason for why agencies choose pylons over concrete barriers, so it can be inferred that immediate budget issues and space constraint are the two major factors for why most agencies prefer to use pylons. When the agencies were asked why they choose pylons over pavement marking buffers only, most TxDOT districts chose higher compliance and increased safety equally (78 percent). However, among the other state DOTs, 80 percent indicated that the use of pylons results in higher compliance than just pavement marking buffer, but only 44 percent indicated that the use of pylons appear to have resulted in increased safety experience.

Nearly all agencies responding to the survey that had implemented pylons indicated that they found pylons beneficial for the purpose used. However a majority of the agencies also indicated that they had issues with pylon replacement. Pylons that get dirty and lose their target value was another maintenance issue often cited by the agencies. A majority of the agencies attributed missing pylons to driver disregard and inattentive drivers. About half of the agencies who responded indicated that pylons' not being durable was a reason for frequently missing pylons. Most of the agencies who had used pylons on managed lanes (or express lanes) knew that they lost their pylons at decision points (entrances, exits, or before interchanges). Other agencies who used pylons for short length applications thought that the pylons went missing randomly throughout the implementation. Follow-up concludes that a lot of agencies without managed lane applications rarely if ever evaluated their pylons and did not have a scheduled inspection or maintenance planned.

CHAPTER 5: VIDEO CASE STUDIES

PURPOSE

The agency survey was used to obtain general information on pylon use but not necessarily information specific to any particular pylon implementation. When agencies were asked for reasons why their pylons were getting hit, most had little quantitative information as to when and how pylons get hit and most opined that the pylon hits were random occurrences. The purpose of this case study task was to observe the actual field operation of pylon implementations at selected locations. In this task researchers have made an effort to characterize pylon hits by recording video at specific pylon deployments. Researchers observed the videos to identify pylon hits and near misses, and record traffic operations characteristics. Researchers then analyzed the data in an attempt to identify impact of traffic, speeds, and different pylon implementation factors and geometric features such as pylon spacing and buffer width.

CASE STUDY SITES

The case study portion of the project consisted of review, observation, and evaluation of 17 pylon implementation sites in Texas. Criteria used for selecting the case study sites, geographic location, and a brief description of each of the study sites are presented below.

Site Selection

Agencies surveyed listed 58 potential sites for the case studies (see Appendix E). The pylon implementations identified from the surveys covered a wide range of pylon applications; however, based on the feedback obtained from the Project Monitoring Committee, both 1) preferential lane applications and 2) freeway ramp pylon applications were identified as the deployment types of most interest for study. Researchers investigated several of the sites listed from the surveys for suitability to record video, either from existing agency CCTV or using video recorded with TTI's portable data collection trailers. After site review, 17 pylon implementations in Texas were selected for further case study. Other considerations used in selection of the case study sites were:

- Variability in buffer space.
- Variability in geographic location.

- Locations where pylons are most often replaced.
- Land use type for pylons on frontage.
- Diverse geometric conditions (access locations, tangent sections, and freeway ramp).

Cast Study Site Locations

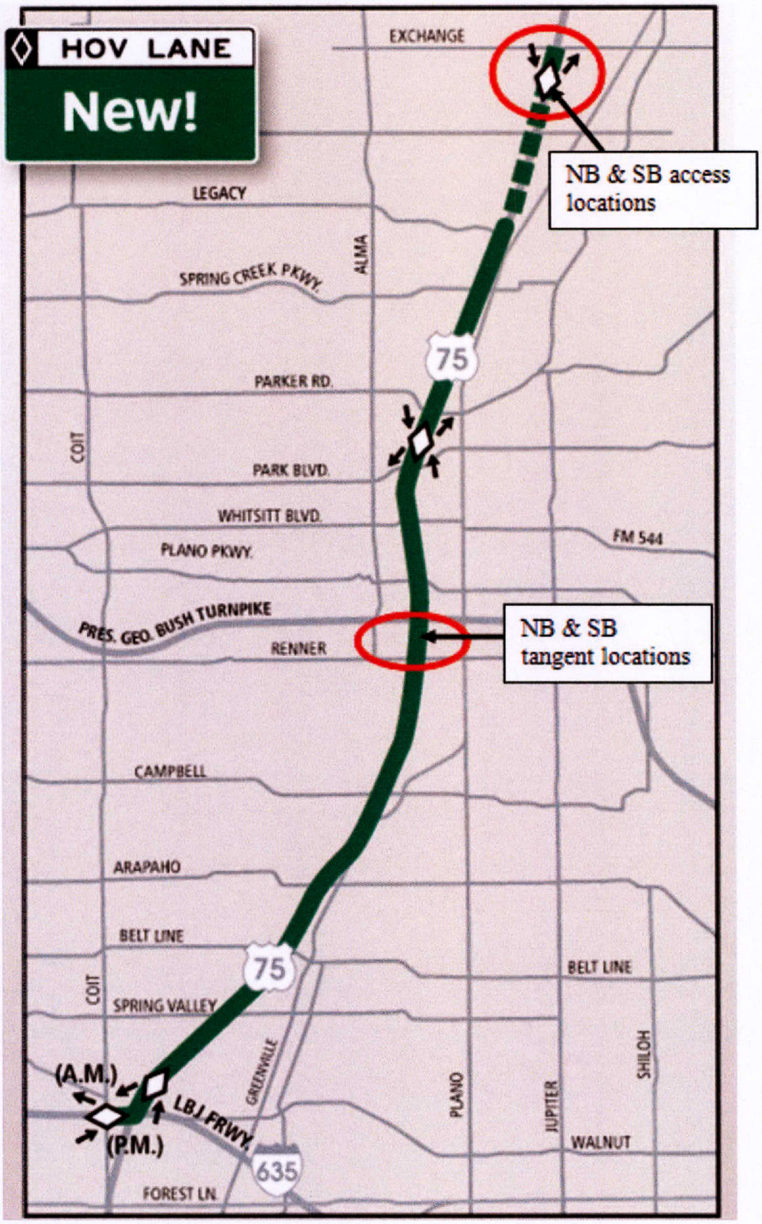
The 17 case study locations are presented in Table 10. Eight of the 17 sites were at the access (entry or exit) locations on preferential lanes. Four sites were along the tangent sections (non-access locations) of the preferential lanes. Five locations were on freeway ramps where pylons are used to separate freeway ramp lanes from frontage road lanes.

Table 10. List of the Case Study Locations.

Pylon Location	TxDOT District	Type
US 75 SB at Bethany Drive Entry	Dallas	Preferential Lane Access
US 75 NB at Bethany Drive Exit	Dallas	Preferential Lane Access
IH 635 NB at Oates Drive Entry	Dallas	Preferential Lane Access
IH 635 SB at Oates Drive Exit	Dallas	Preferential Lane Access
IH 10 WB at Silber Road Entry	Houston	Preferential Lane Access
IH 10 WB at Gessner Road Entry	Houston	Preferential Lane Access
IH 10 WB at Tully Road Exit	Houston	Preferential Lane Access
IH 10 EB at Bunker Hill Road Entry	Houston	Preferential Lane Access
US 75 NB at President George Bush Turnpike	Dallas	Preferential Lane Tangent
US 75 SB at President George Bush Turnpike	Dallas	Preferential Lane Tangent
IH 10 EB at Dairy Ashford Road	Houston	Preferential Lane Tangent
IH 10 EB at Voss Road	Houston	Preferential Lane Tangent
US 59 WB at Kirkwood Entrance	Houston	Freeway Ramp
US 59 WB at Beechnut Exit	Houston	Freeway Ramp
IH 610 West Loop SB at Woodway Entry	Houston	Freeway Ramp
SH 249 NB at Cypresswood Entry	Houston	Freeway Ramp
IH 35 NB at FM 3009 Exit	San Antonio	Freeway Ramp

Geographically, sites were located in Houston, Dallas, and San Antonio, Texas. A majority of the sites were in the Houston and Dallas areas due to the existence of pylon separated preferential lanes in these regions. Freeway ramp pylon sites were primarily selected in Houston and San Antonio due to the feasibility of collecting data using TTI's data collection trailers.

Figure 30 shows four study locations on the US 75 HOV lanes in Dallas. Access locations (southbound entrance and northbound exit) located at the north end of the US 75 HOV lanes and the tangent sections on the US 75 HOV lanes (on both northbound and southbound directions) located just south of President George Bush Turnpike were all case study sites.



NB & SB access locations

NB & SB tangent locations

(Source: DART)

Figure 30. Case Study Locations on US 75 Corridor in Dallas/Richardson/Plano, Texas.

Figure 31 shows the two preferential lane case study locations on the IH 635 HOV Lane in Mesquite, Texas. Both the locations on IH 635 are access locations at the south end of the HOV lane close to the IH 30 interchange (one entry, one exit). The sites on US 75 HOV and IH 635 HOV were selected based on the recommendations from TTI researchers in Dallas and Arlington as locations where pylons are frequently hit.

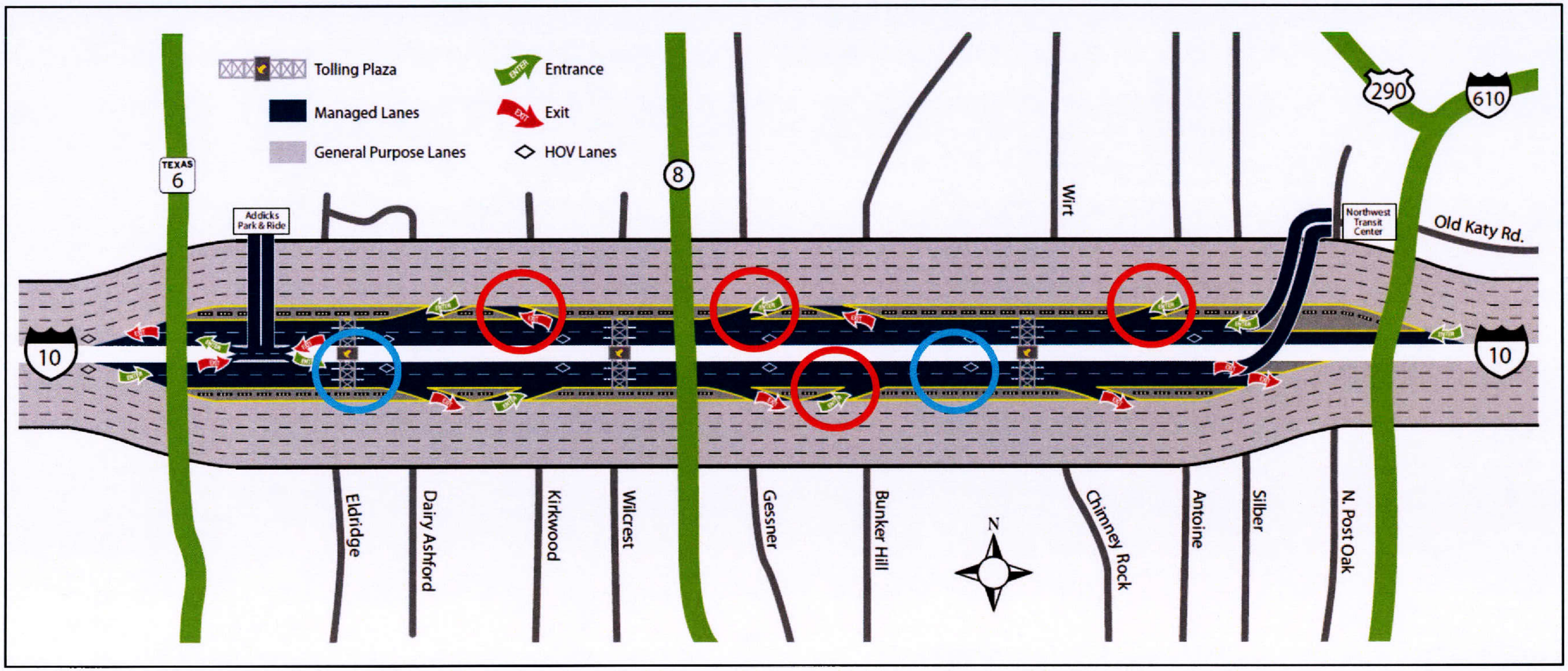
NB & SB access locations

(Source: DART)

Figure 31. Case Study Locations on IH 635 Corridor in Dallas, TX.

Figure 32 shows the six case study locations on the Katy Managed Lanes in Houston, Texas. Of these six sites, four are access locations and two were tangent locations. The sites on the Katy Managed Lanes were selected based on the information provided by HCTRA maintenance personnel.

Figure 33 shows a map of Houston with locations of the freeway ramp pylon applications selected for case study. Four of the five locations in Houston were freeway entry ramps and the other location was an exit ramp. The fifth freeway ramp location (shown in Figure 34) was an exit ramp located in San Antonio, Texas.

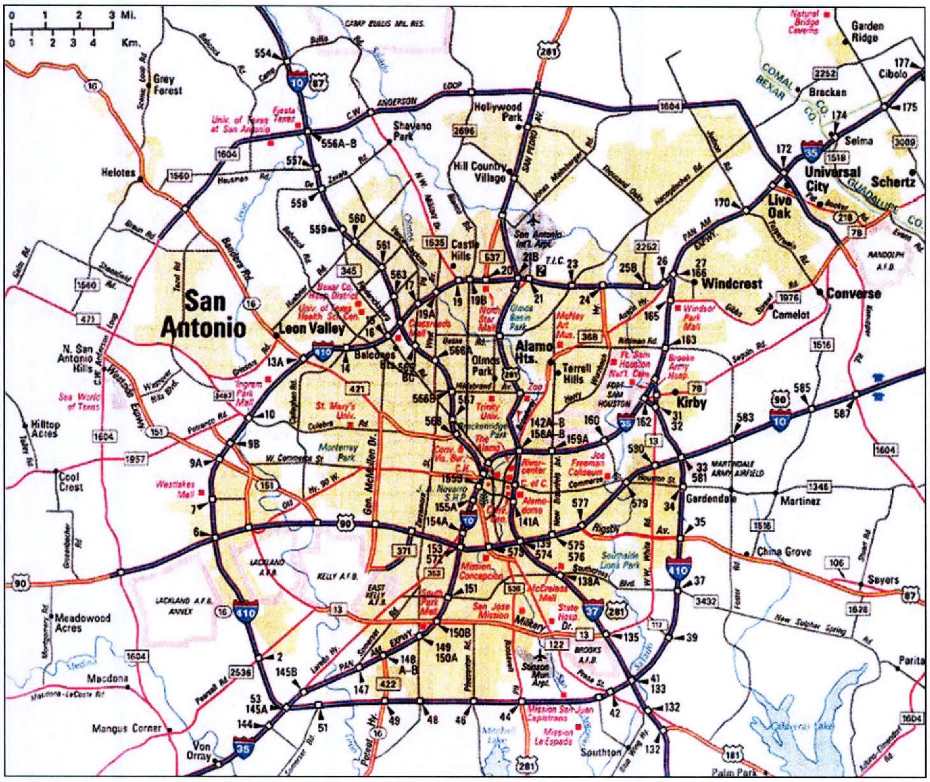


(Source: HCTRA)

Figure 32. Case Study Locations on Katy Managed Lane Corridor in Houston, TX.

(source: http://printable-maps.blogspot.com)

Figure 33. Freeway Ramp Locations in Houston, Texas.



(source: http://printable-maps.blogspot.com)

Figure 34. Freeway Ramp Location in San Antonio, Texas.

Site Descriptions

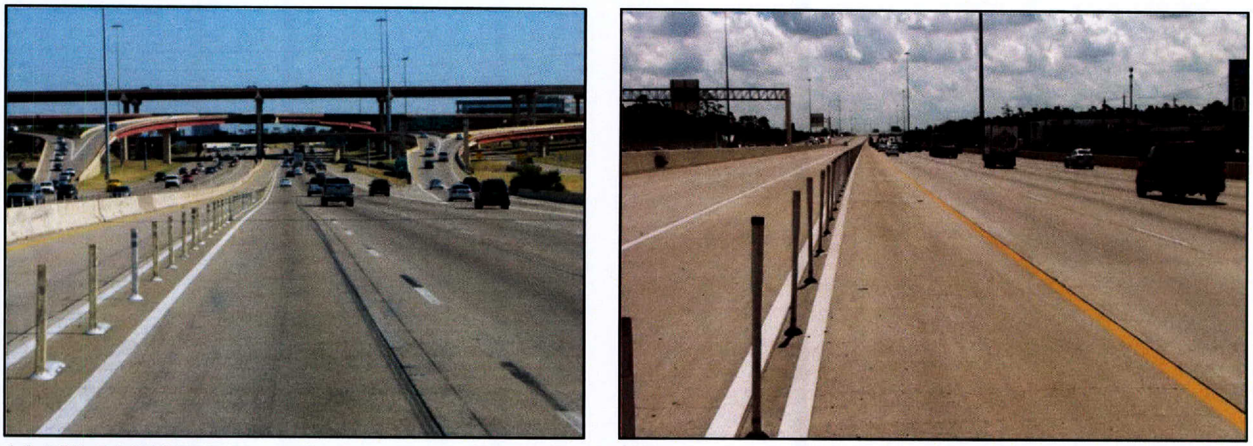
Some representative examples of the managed lane entrance, exit, and tangent locations used in the case studies are shown in Figure 35, Figure 36, and Figure 37. Photographs of all the sites considered in this case study are presented in the Appendix F. As shown in these figures, the Dallas access locations were exit (northbound) and entry (southbound) access locations at the end of the preferential lane, while the Houston access locations were all intermediate access locations with a slip ramp setup. Also seen in Figure 37, the Dallas tangent sections have a narrow buffer compared to Houston tangent sections.

(a) US 75 HOV SB at Bethany Drive (b) IH 10 ML WB at Gessner Road

Figure 35. Example Photos of Preferential Lane Entrance Study Locations.

(a) US 75 HOV NB at Bethany Drive (b) IH 10 ML WB at Tully Road

Figure 36. Example Photos of Preferential Lane Exit Study Locations.



(a) US 75 HOV NB at George Bush Turnpike (b) IH 10 ML EB at Voss Road

Figure 37. Example Photos of Preferential Lane Tangent Study Locations.

The study sites varied from each other in geometric details and and/or pylon implementation details. Table 11, Table 12, and Table 13 provide some pylon implementation and geometric details for each of the study site segregated by application type as preferential lane access, preferential lane tangent, and freeway ramps, respectively. On the preferential lane access locations, there were three sets of pylon spacing: 10 ft., 12 ft., and 14 ft. The Dallas area locations were all curb mounted while the Houston locations were all pavement mounted pylons. The height of the pylons at access locations ranged from 36 in. to 48 in. The length of the gore area where pylons are not present was also measured for all access locations—this represents the gap between the tip of the tapering gore to the first pylon on an entrance location (or last pylon on an exit location). All of the Houston access locations had the first four pylons treated with an alternating yellow and black transverse striping, whereas the Dallas are access locations did not have the end pylons treated. The entrance ramps on US 75 Southbound at Bethany Drive, IH 635 Northbound at Oates Drive, and IH 10 Westbound at Silber Road all had a shared lane on the approach to the entrance ramp, while other entrance ramps had an exclusive lane on approach to the entrance.

Preferential lane tangent sections had similar variation in the pylon spacing as the access locations. Buffer widths for the US 75 tangent section had 3 ft. buffer (1.5 ft. on either side of pylons) and the Katy Managed Lane at Voss Road had 24 ft. buffer (12 ft. on either side of pylons). The Katy Managed Lane at Dairy Ashford had no inside buffer (left buffer) and only had a 12 ft. outside buffer.

Table 11. Pylon Installation and Roadway Geometric Details for Preferential Lane Entry/Exit Access Case Study Locations.

Location	Pylon Mounting Type	Pylon Color	Pylon Spacing (feet)	Minimum Buffer Width (feet)	Max Buffer Width (feet)	Pylon Height (inches)	Ramp Lane Width (feet)	Length of Gore Without Pylons (feet)	Pylon End Treatment	24 Hour Ramp Volume
US 75 SB at Bethany Entry	Curb	White	12	3.0	3.0	36	12	215	No	5,630
US 75 NB at Bethany Exit	Curb	White	12	3.0	3.0	36	12	96	No	4,930
IH 635 NB at Oates Entry	Curb	White	14	5.0	5.0	39	11	250	No	4,140
IH 635 SB at Oates Exit	Curb	White	14	5.0	5.0	39	11	202	No	1,910
IH 10 WB at Silber Entry	Pavement	White	10	2.0	13.0	48	12	45	Yes	3,530
IH 10 WB at Gessner Entry	Pavement	White	10	12.0	19.0	48	14	149	Yes	3,900
IH 10 WB at Tully Exit	Pavement	White	10	2.5	15.5	48	14	55	Yes	2,300
IH 10 EB at Bunker Hill Entry	Pavement	White	10	1.8	15.0	48	20	71	Yes	3,930

Table 12. Pylon Implementation and Geometric Details for Preferential Lane Tangent Locations.

Location	**Pylon Mounting Type**	**Pylon Color**	**Pylon Spacing (feet)**	**Buffer Width (feet)**	**Pylon Height (inches)**	**# Pref. Lanes**	**# Gen. Purpose Lanes**	**Pref. Lane Width (feet)**	**Gen. Purpose Lane Width (feet)**	**24 Hour Adjacent Preferred Lane Volume**	**24 Hour Adjacent General Purpose Lane Volume**
US 75 NB @ PGBT*	Curb	White	12	3	36	1	4	12	11	3,600	18,620
US 75 SB @ PGBT*	Curb	White	12	3	36	1	4	12	11	4,560	20,600
IH 10 EB @ Dairy Ashford Road	Pavement	White	10	12	48	2	4	13	12	6,250	23,870
IH 10 EB @ Voss Road	Pavement	White	10	24	48	2	5	12	12	7,100	27,710

*PGBT - President George Bush Turnpike

Table 13. Pylon Installation, Condition, and Geometric Details for Freeway Ramp Locations.

Location	Pylon Mount Type	Pylon Spacing (feet)	Min Buffer Width (feet)	Max Buffer Width (feet)	Pylon Height (inches)	Ramp Lane Width (feet)	Length of Gore (feet)	Length of Pylons (feet)	Pylon Condition	24 Hour Frontage Volume	Land Use
US 59 WB @ Kirkwood Road Entry	Curb	3.0	1.0	12.5	42	14	242	130	Several Missing	29,280	Mall, Restaurant
US 59 WB @ Beechnut Road Exit	Curb	3.0	0.0	9.8	36	10	275	560	Dirty	39,150	Residential
IH 610 West Loop SB @ Woodway Entry	Curb	3.0	0.0	12.5	36	14	245	230	Initial few missing	41,560	Shopping, Residential
SH 249 NB @ Cypresswood Drive Entry	Curb	3.0	2.8	12.5	36	12	275	207	Couple Missing	32,930	Office, Shopping
IH 35 NB @ FM 3009 Exit	Curb	3.5	7.5	11.0	42	11.5	312	180	Okay	24,670	Residential, Farm land

The freeway ramp study sites all had curb mounted pylons with white posts. There was little variation in spacing between the pylons among the sites as all Houston area sites had 3 ft. spacing and the San Antonio location had 3.5 ft. spacing. The pylons at the Houston sites were placed closer to the frontage lane than the ramp lane on the gore area. Pylons at all the freeway ramp study sites had moderate dirt accumulation on the curbs and all the freeway entrance sites had pylons missing, particularly within the first few pylons of each installation.

DATA COLLECTION

In order to capture operations at each of the study sites, one week of video recordings were conducted at each location. Different sources were used to record videos at different case study locations, either existing closed circuit television (CCTV) or trailer-mounted cameras. The videos were recorded at approximately 5–8 frames per second in order to clearly view pylon hits yet keep the file sizes manageable. The following criteria were used to determine the ideal view to record video at each study sites location:

- The view should enable researchers to determine when a pylon gets hit.
- The view should include the roadway section upstream of the pylons to enable researchers to better understand and capture traffic operations.
- The view should include all lanes (managed lanes and general purpose lanes) in the direction of travel to be able to count vehicles in each lane.

For Katy Managed Lane locations in Houston, video was recorded using permanent HCTRA CCTV cameras. For each location, the camera that provided the best view of operations was selected and a preset was created of the required view. Researchers recorded data for at least one week for each case study site. Because the cameras were still being used for roadway monitoring and incident management, occasional interruption to the recordings occurred. For all Dallas locations, video was recorded using DalTrans CCTV cameras in methods similar to the Katy Managed Lane videos. However, when significant disruptions to recording were noted, additional days of video were subsequently recorded. The video on all the freeway ramp locations were recorded using a TTI portable data collection trailer as shown in Figure 38. Researchers had some flexibility to place the data collection trailer at the most convenient location at each site to record the video with optimal settings. A total of roughly 2800 hours of video was recorded at all 17 case study locations. In all, it took researchers about 11 weeks to record video on all 17 sites from the HCTRA, DalTrans, and TTI sources.

Figure 38. TTI Data Collection Trailer Deployed at a Freeway Ramp Location in Houston.

Traffic Data

Researchers collected traffic operations information at each case study site during the same time period as video was recorded. Traffic volumes and/or speeds were collected in 15 minute intervals at all study locations. At the Dallas HOV lane locations, by-lane traffic volume and speeds were collected using the DalTrans sensor data. To confirm HOV lane volumes from the sensors, typical one day volumes were counted from the CCTV video recordings at all Dallas Locations. A typical day was defined as any Tuesday, Wednesday, or Thursday with no major roadway incidents, holidays, or prolonged severe weather conditions affecting normal commuter traffic patterns. For the Katy Managed Lane locations, typical one day volume was counted by lane (all lanes including general purpose and managed lanes in the direction of travel) from video recordings. While sensors were deemed accurate to determine the average speeds for the general purpose lane and the managed lanes, traffic volumes were not deemed to be accurate enough when collected using existing sensors. At the freeway ramp locations, traffic volume was collected using tube counters. The tube counts were not collected by lane; however separate counts were done for ramp volumes and frontage volumes (sum of all lanes). Speed data were not collected on the freeway ramp locations, but speed limits were used as a surrogate.

Geometric and Pylon Implementation Data

Geometric data and pylon deployment characteristics were measured in field by researchers at most of the study locations. A few locations, particularly at several of the Dallas area sites, it was deemed risky to field measure the site geometrics without lane closures (which were not viable). In these cases data were collected from Google Earth or from previous TTI research efforts. The geometric and pylon implementation characteristics collected at the study locations is listed in Table 14 by location type.

Table 14. Geometric and Pylon Deployment Characteristics, by Pylon Application.

Measurements/Observations	**Preferential Lane Access Locations**	**Preferential Lane Tangent Locations**	**Freeway Ramp Locations**
Pylon height	√	√	√
Pylon spacing	√	√	√
Mounting type	√	√	√
Pylon color	√	√	√
Pylon end treatment	√		√
Pylon condition	√	√	√
Pylon length	√		√
Gore length	√		√
Buffer widths	√	√	√
Number of lanes	√	√	√
Lane widths	√	√	√
Merge length on approach to entrance/exit	√		
Distance to previous and next entrance or exit		√	
Distance from driveway to tip of pylon			√

Other Data Collected

In addition to the above data, incident data corresponding to the video recording days were collected for all the corridors on which study sites were located. Incident data were collected from the Regional Incident Management System (RIMS) database for all Houston sites and from the DalTrans incident database for the Dallas sites. Since no congestion or queuing was observed in the video on any of the days at the San Antonio freeway ramp site, incident data for the period of CCTV recording were not obtained for this site. The combination of Dallas and Houston incident databases resulted in information at each of the sites documenting incident locations, type of incident, time of incident, time of incident clearance, and lanes affected.

DATA REDUCTION

The video recording for each study site was viewed and researchers noted when a vehicle hit the pylons, or if a vehicle nearly missed hitting the pylons. An incident was considered as a pylon hit if the vehicle hit the pylons, grazed the pylons, drove over the curb (even if pylons were missing) or weaved between the pylons even without physically touching the pylons. An incident was considered as a near miss if the vehicles were very close to the pylons or curb separators. In the cases of freeway ramp and preferential lane access locations, a near miss was constituted by a motorist driving on the gore area before the pylons started at an entrance or after the pylons ended at an exit. For each incident (hit or near miss), researchers noted additional information including type of vehicle, lane changes made by the vehicles before the incident maneuver, traffic conditions during the incident, and driver response before and after the incident.

Researchers observing the videos were provided with a reference sheet that provided a snapshot of the free flow conditions, moderate traffic conditions, and stop-and-go traffic conditions to fill out column 14 and 15 of the data collection sheet (shown in Appendix G). Researchers reducing the video were also provided with a maneuver diagram (show in Appendix G) to fill out columns 10 and 11. Researchers were also asked to note down any anomalies such as traffic incidents, lane closures, and others.

Researchers were able to view the video at 6x speeds during free-flow conditions, at 4x speeds during moderate traffic conditions, and at 2x speeds during peak conditions. When a hit or near miss was suspected, researchers watched the instance at slower speed to more accurately determine the nature of hit. Above process took approximately on an average 1.5 hours to reduce 1 hour worth of video and a total of about 4200 man-hours to reduce data from video collected on all the sites.

To ensure that the data were reduced consistently by several researchers and staff that were involved in the data reduction process, a sample of the data reduced for all site were verified by a single researcher. Data reduced from the videos, traffic counts, and field measurements were collated in 15 minute intervals as input for statistical analysis of the pylon hits.

DATA ANALYSIS

The video recordings analyzed to identify the nature of the pylon hit and near misses. Near misses were those vehicles who cross the gore or shoulder pavement markings without hitting the pylons themselves. The video recordings were also used to identify any other perceivable factors that appeared to influence pylon hits or near misses. The summary of the observational analysis below presents some of the researcher interpretations on the nature of pylon hits, while in the quantitative analysis an effort was made to derive any trends that may exist between pylon hits and factors related to 1) pylon implementation, 2) traffic operations, and 3) geometric characteristics using statistical methods.

Observational Analysis of Pylon Hits or Misses

Figure 39 presents both 1) the pylon hit rate and 2) near miss rate, for the preferential lane access locations. The hit and near miss rates were computed by normalizing the hits and near misses at each location by traffic volumes on the lanes adjacent to either side of the pylons. The preferential lane exit (departure from managed lanes to general purpose lanes) locations had lower hit and near miss rates as compared to the entry locations. The IH 635 HOV entrance location had a slightly higher hit rate compared to other access locations. One of the potential reasons for the higher hit rate at the IH 635 entrance at Oates Drive could potentially be due somewhat limited sight distance on approach to the entry. During the field visit to the IH 635 entrance at Oates Drive, researchers observed that there was vertical curvature at the approach of the entrance that limited the sight distance as shown in Figure 40. In addition the IH 635 northbound entry is relatively close to the IH 30 interchange. With both the eastbound and westbound direct connectors joining IH 635 from the right, and with about 3000 ft. weaving distance across four lanes between the IH 30 ramps and entrance to the HOV on IH 635, some vehicles may have to make a late maneuver to enter the HOV lane, making the choice to strike the pylons and enter the HOV lane rather than experience the delays upstream.

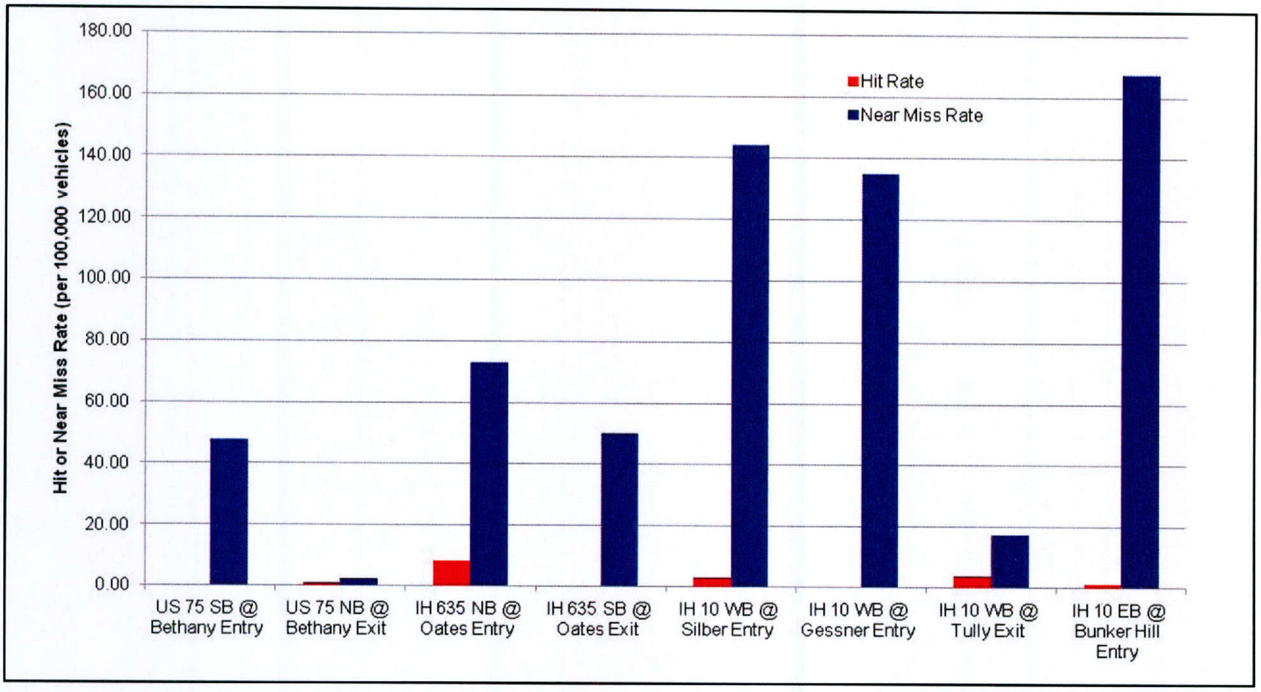


Figure 39. Hit and Near Miss Rate for Preferential Lane Access Locations.

Figure 40. Vertical Curvature on Approach to the HOV Lane Entry at IH 635 Northbound at Oates Road Study Site, Mesquite, Texas.

Figure 41 shows the hit and near miss rates for the freeway ramp locations. The Kirkwood entrance ramp to US 59 SB freeway had a significantly higher pylon hit and near miss rate as compared to the other freeway ramp location study sites. One potential reason for the higher hit rates observed at the Kirkwood entrance ramp to US 59 westbound could be the land use adjacent to this ramp, which predominantly consists of busy retail shopping and restaurants with several closely spaced driveways (as shown in Figure 42). At this location, it was difficult to extend the pylons farther east because that would have limited the weaving distance on the frontage road auxiliary lane between exit and entry ramps. This is often a consideration when deploying pylons at frontage road entry or exit ramps.

As shown in Figure 43, US 75 NB HOV south of President George Bush turnpike had the highest number of hit among the preferential lane tangent sections. US 75 HOV lane tangent sections had significantly higher hit rate compared to IH 10 Katy Managed Lanes sections potentially due to smaller buffer width on US 75 HOV compared to Katy Managed Lanes.

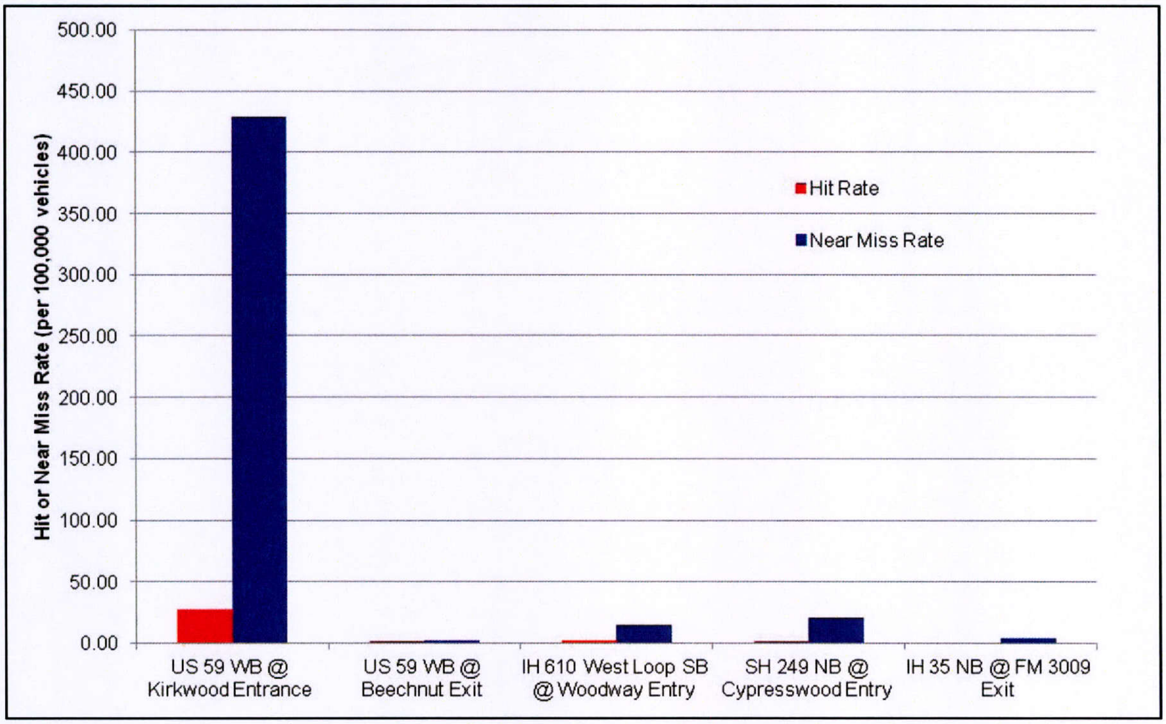


Figure 41. Pylon Hit and Near Miss Rate for Freeway Ramp Locations.

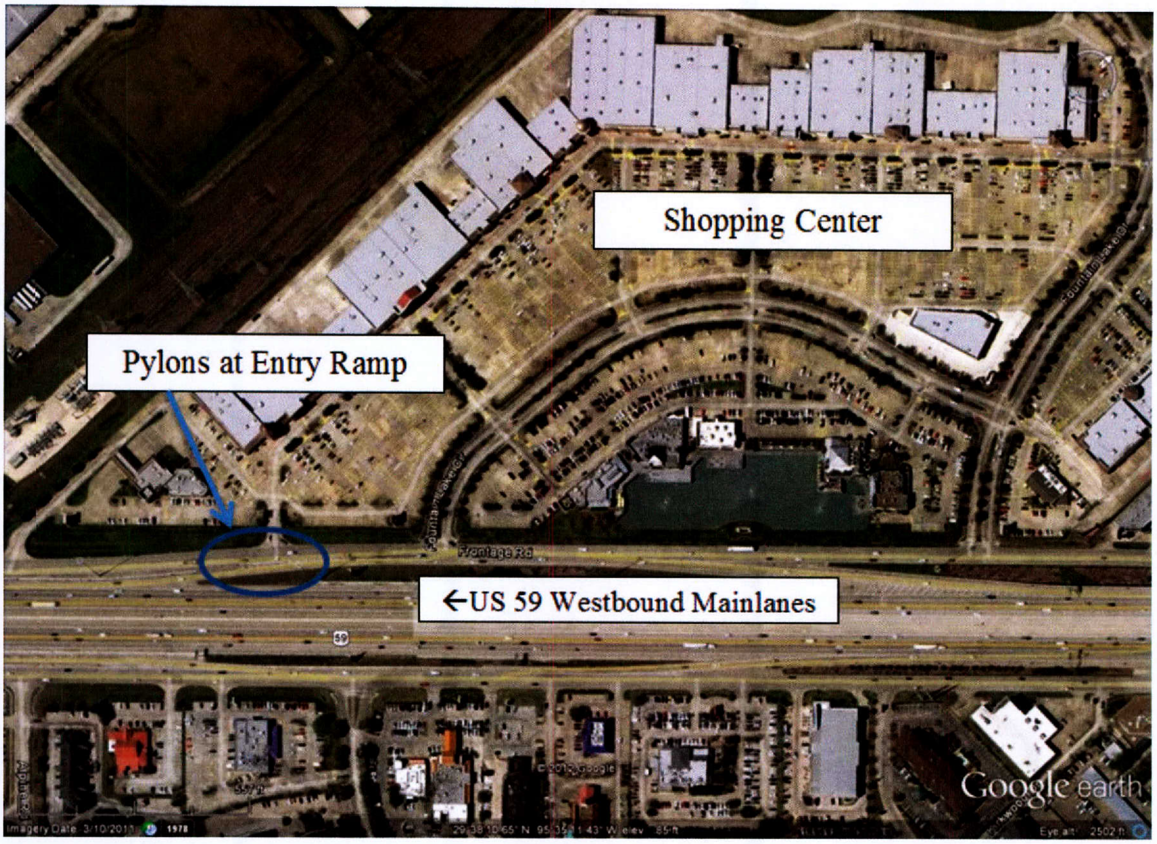


Figure 42. Land Use near Kirkwood Entry Ramp to US 59 Westbound Study Site.

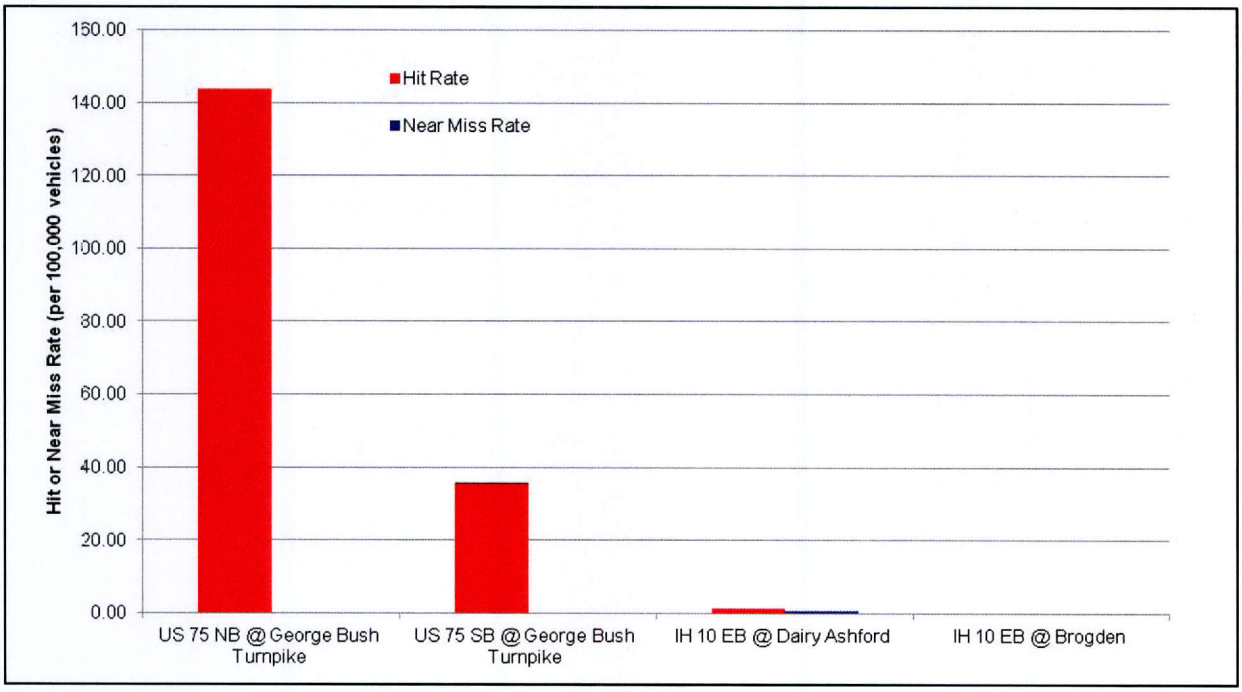


Figure 43. Pylon Hit and Near Miss Rate for Preferential Lane Tangent Locations.

As shown in Table 15, most of the hits and near misses at study sites involved light vehicles (cars, sport-utility vehicles, and pickup trucks). Observing the driver behavior from the videos, it appeared that the majority of the hits and near misses were intentional at all locations. During the observation periods, no crashes or near crash conditions were observed occurring when the vehicles made maneuvers to hit (or when they nearly hit) the pylons.

Table 15. Pylon Hits and Near Misses by Vehicle Type.

Pylon Location	Pylon Hits		Pylon Near Misses	
	Light Vehicles	Heavy Vehicles	Light Vehicles	Heavy Vehicles
Preferential Lane Entry/Exits				
US 75 SB at Bethany Entry				
US 75 NB at Bethany Exit				
IH 635 NB at Oates Entry				
IH 635 SB at Oates Exit				
IH 10 WB at Silber Entry	2	1	136	5
IH 10 WB at Gessner Entry	0	0	238	2
IH 10 WB at Tully Exit	6	0	29	0
IH 10 EB at Bunker Hill Entry	1	0	137	7
Preferential Lane Tangent				
US 75 NB at President George Bush				
US 75 SB at President George Bush				
IH 10 EB at Dairy Ashford	2	0	1	0
IH 10 EB at Voss Road	0	0	0	0
Ramp/Frontage Road Sites				
US 59 WB at Kirkwood Entrance	48	3	788	8
US 59 WB at Beechnut Exit	2	0	5	1
IH 610 West Loop SB at Woodway	5	0	28	0
SH 249 NB at Cypresswood Entry	1	0	41	2
IH 35 NB at FM 3009 Exit	0	0	7	0

The hits and near misses on the preferential lanes were observed happening primarily during heavy traffic periods with congestion in the general purpose lanes. A majority of the offending vehicles were entering the managed lanes from the general purpose lanes. Researchers noted that on the preferential lane entrance locations many motorists nearly hit the pylons as they made late decisions in taking the managed lane ramps, especially as motorists try to gauge the travel time reliability offered by general purpose lanes versus managed lanes when congestion is evident ahead on the general purpose lanes.

On the freeway ramp study sites on the frontage road, the hits and near misses appeared to be random with no perceivable increase during any specific time periods of the day. Except for a couple of hits, majority of the hits and near misses did not seem to originate from the cross street or driveway that the pylons are intended to discourage, but several of the hits appeared to originate from upstream driveway. Late decisions to enter the freeway ramp from the frontage lane adjacent to pylons were also observed in several instances.

Quantitative Analysis of Pylon Hits and Near Misses

The pylon hit data were further analyzed to find any trends in the hit or near miss pattern with respect to time of day (and day of week) by plotting frequency histograms. As examples, the charts in Figure 44 and Figure 45 show the time of day distribution of pylon hits and near misses at the US 59 Southbound at Kirkwood Road entry ramp study site and the SH 249 Northbound at Cypresswood Drive entry study site, respectively. The effect of land use on hits and near misses is apparent by observing the time of day charts for each freeway ramp sites. At the US 59 Southbound entry ramp at Kirkwood Road site, the peak of near misses was during the middle of the day as the land use drives activity near the entry ramp (retail shopping and restaurants). In contrast, at the SH 249 at Cypresswood Road Northbound entry ramp, the peak of the near misses occurs during the evening hours as commuter patterns are experienced.

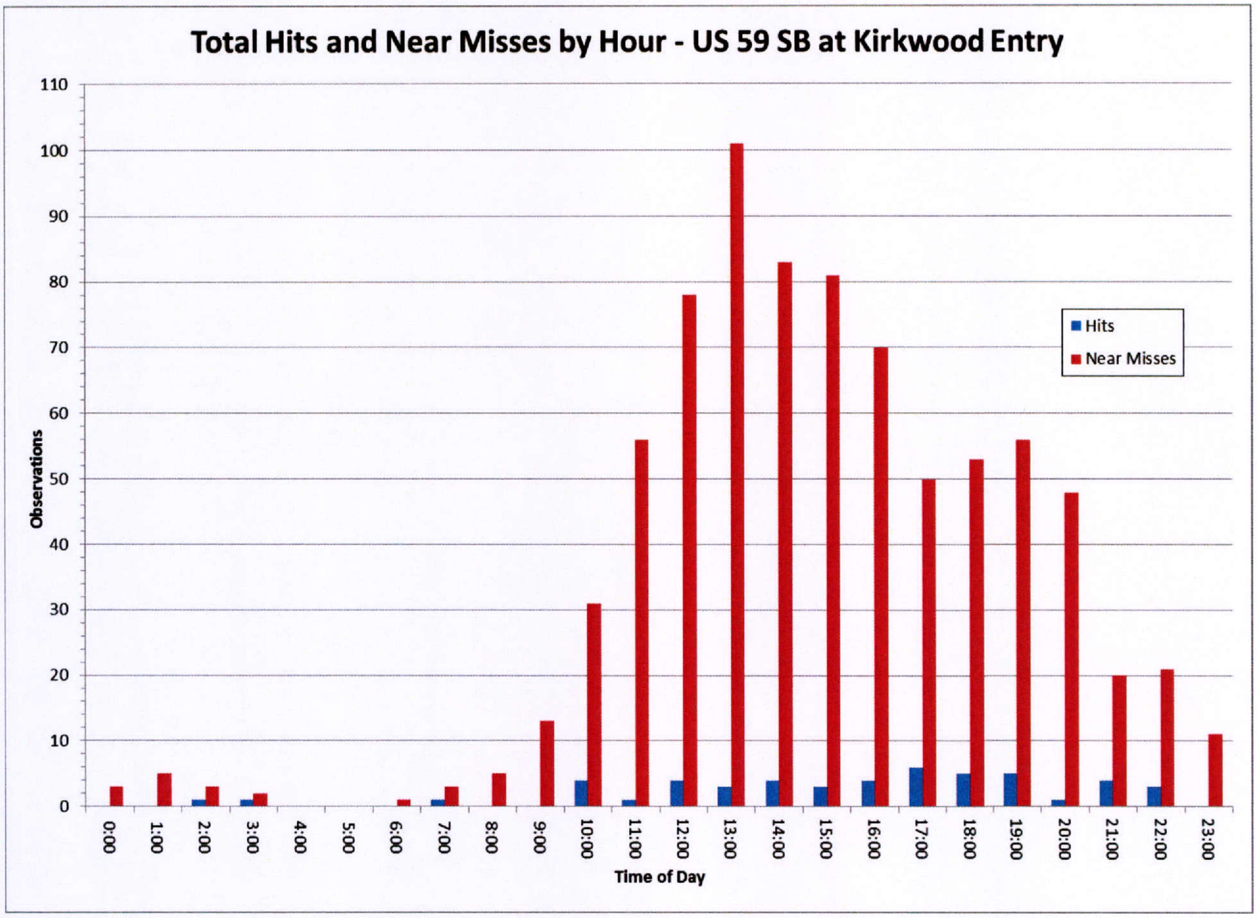


Figure 44. Time of Day Hits and Near Misses at Kirkwood Entrance Ramp.

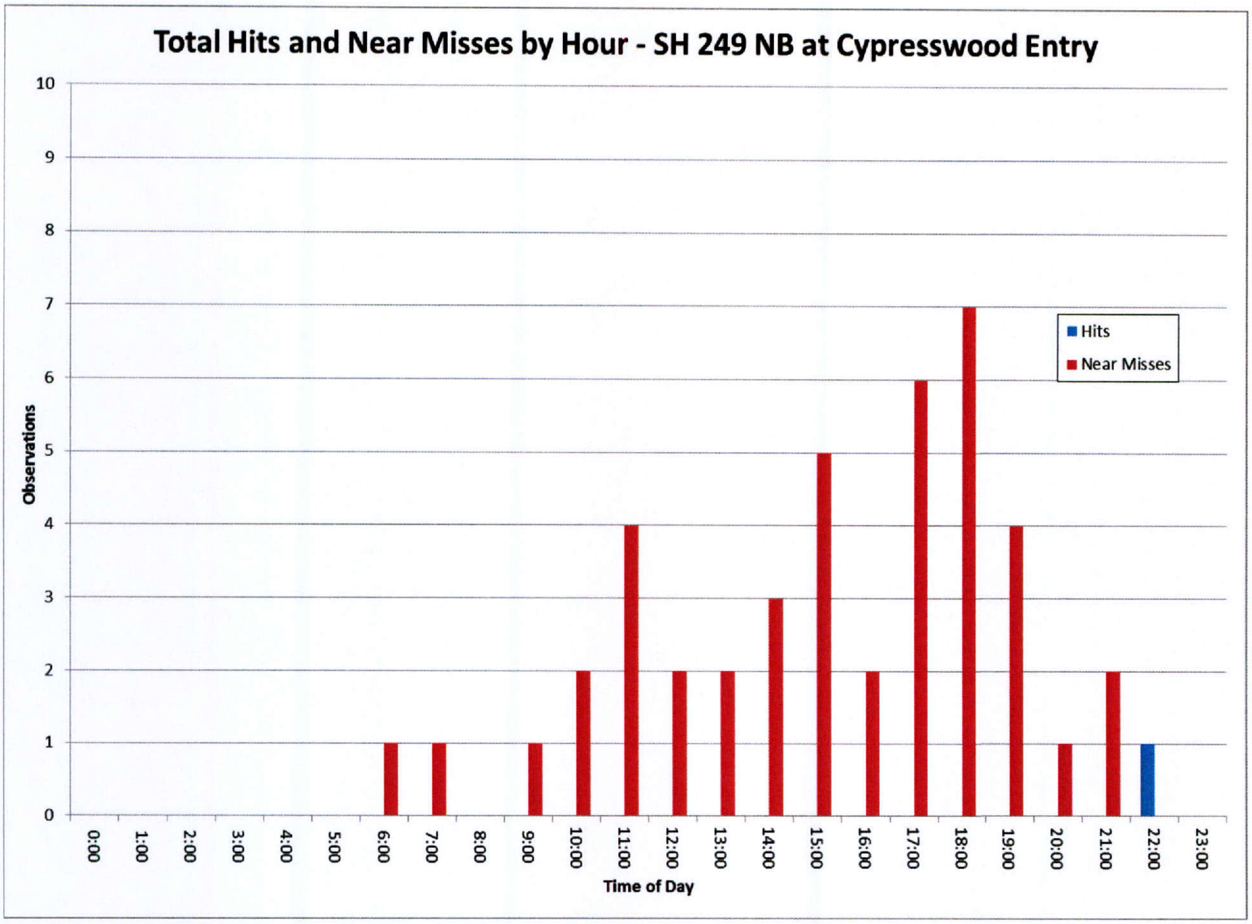


Figure 45. Time of Day Hits and Near Misses at Cypresswood Entrance.

Researchers also analyzed the data to finds trends in the hits and near misses with respect to various traffic operations-related factors, including:

- Traffic volume on the general purpose lane adjacent to pylons.
- Traffic volume on the preferential lane adjacent to pylons.
- Traffic volume on freeway ramp.
- General purpose lanes speed.
- Preferential lanes speed.
- Speed differential between preferential lanes and general purpose lanes.

Scatter plots were developed between hits and near misses against each of the above listed traffic operations-related variables for each site, aggregated by 15-minute intervals. As an illustration, Figure 46, Figure 47, and Figure 48 each show scatter plots for the Katy Managed Lanes at Bunker Hill Road Eastbound entry study site. The trend between the near misses and adjacent general purpose lane volume is shown in Figure 46. Although there is dispersion in the data points, an increasing trend in the near misses with increase in the adjacent general purpose lane volume can be seen.

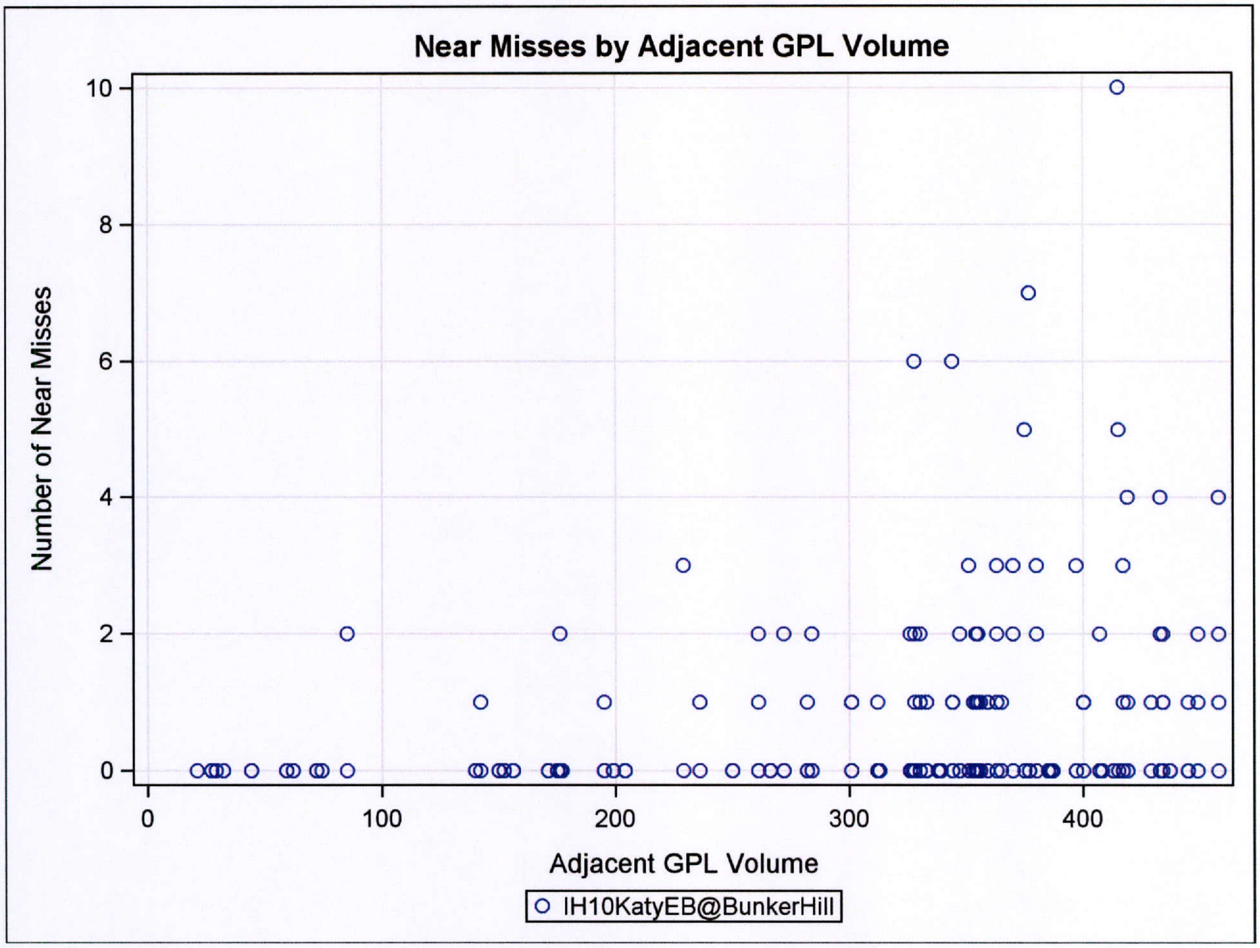


Figure 46. Scatter Plot of Near Misses vs. 15-Minute General Purpose Lane Traffic Volume, IH 10 Katy Managed Lanes at Bunker Hill Road Entry.

A similar increasing trend in the number of near misses with decrease in general purpose lane speeds can be seen from Figure 47. Also a trend between the number of near misses and the speed differential between the managed lane and general purpose lane was observed. Figure 48 shows that greater the speed between the managed lane and the general purpose lane, the number of near crashes tend to increase. However the trends in near misses as shown for the IH 10 Managed Lane entry at Bunker Hill was not consistently seen from data at all other access locations. The trends between hits and/or near misses and various traffic variables showed significant dispersion, with no clear patterns, at tangent and freeway ramp locations.

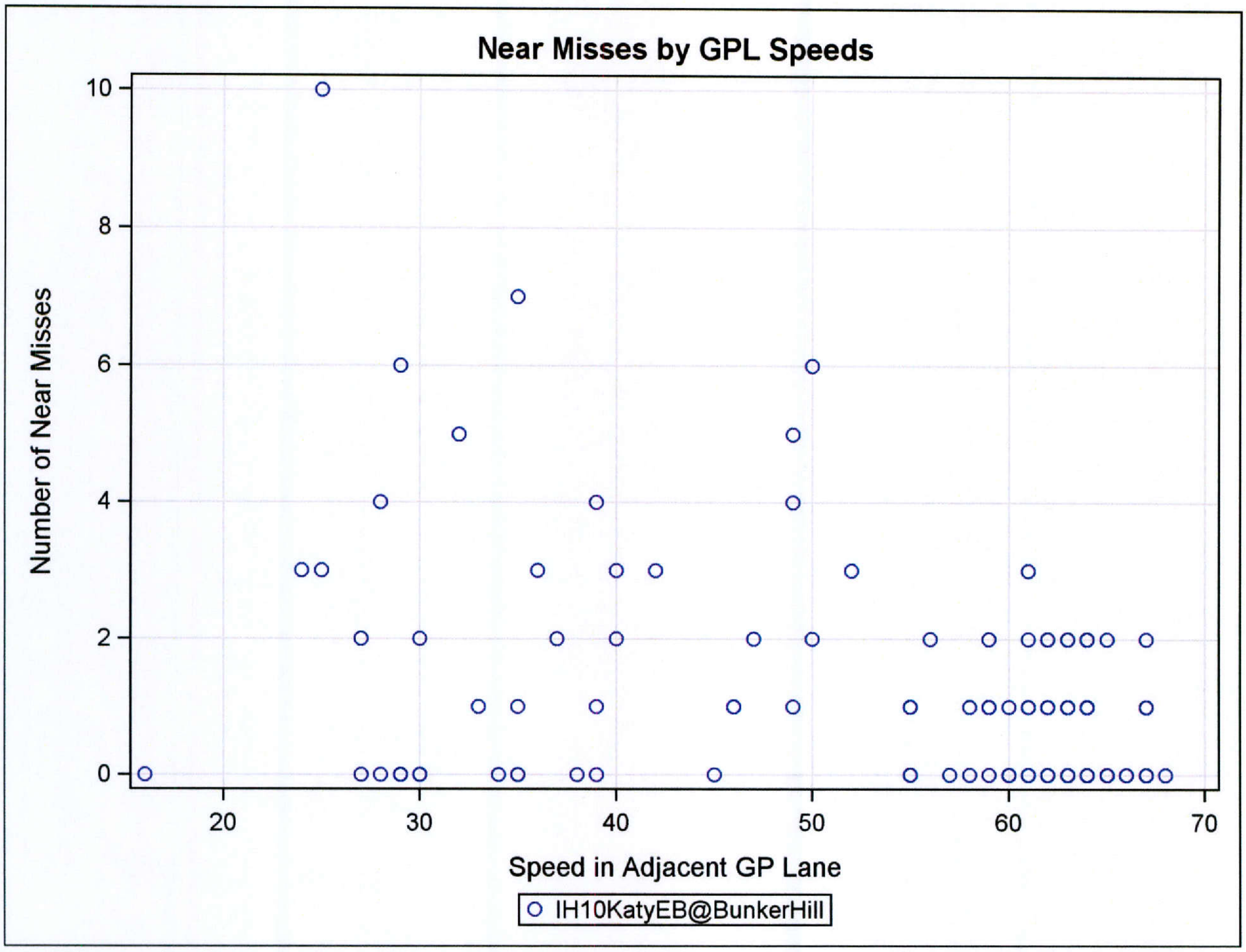


Figure 47. Scatter Plot of Near Misses vs. 15-Minute Average General Purpose Lane Traffic Speed, IH 10 Katy Managed Lanes at Bunker Hill Road Entry.

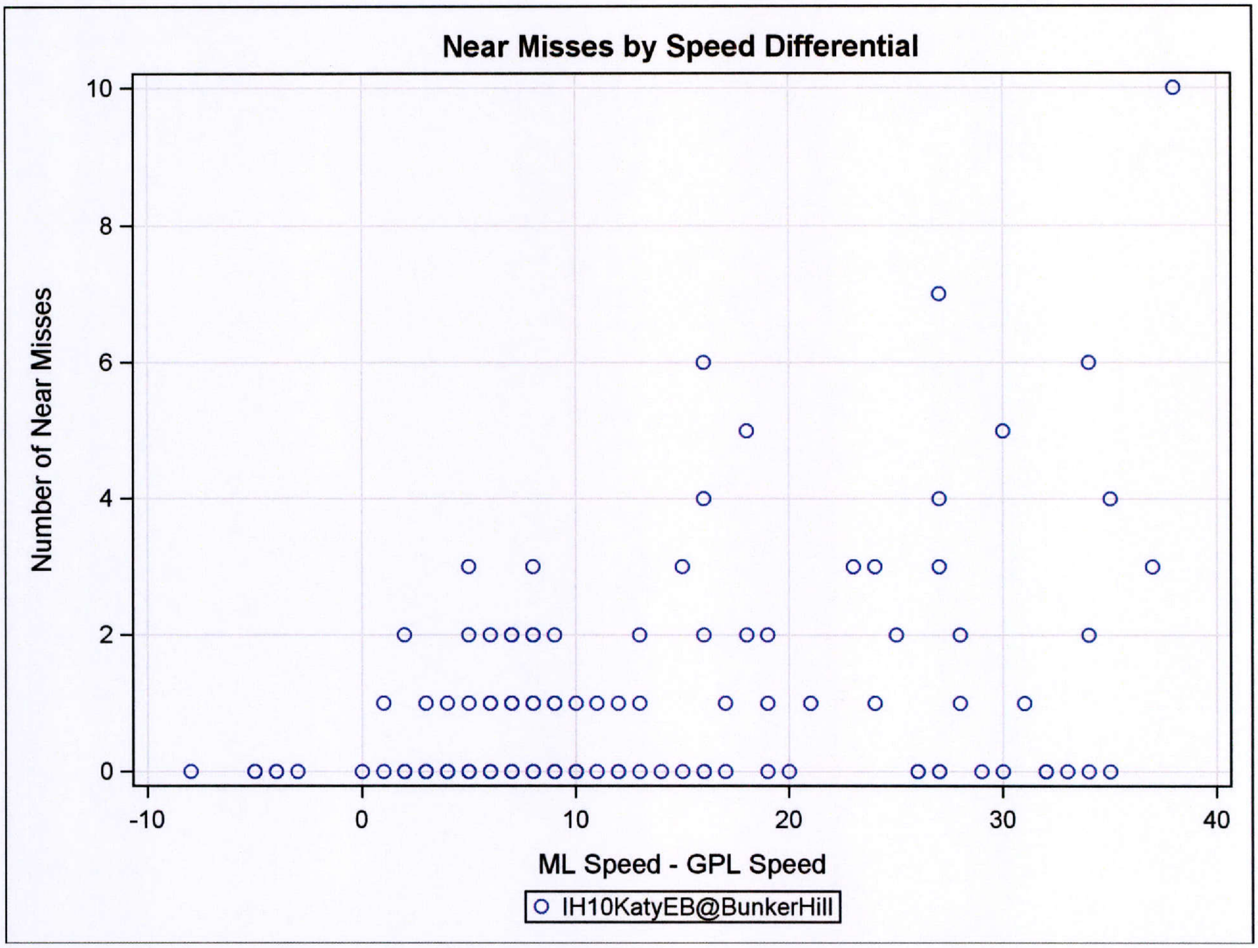


Figure 48. Scatter Plot of Near Misses vs. 15-Minute Average Speed Differential Between General Purpose Lanes and Managed Lanes, IH 10 Katy Managed Lanes at Bunker Hill Road.

Researchers also analyzed the data by correlating the average number of hits/near misses by grouping traffic variables into categories. For example, traffic volumes were categorized in bins of 25 vehicles per 15 minute interval, whereas speed and speed differentials were categorized in bins of 5 mph interval. Figure 49 and Figure 50 shows the regression scatter plots for the IH 10 Westbound Managed Lane at Bunker Hill entry and the IH 635 Northbound at Oates Drive HOV entrance. The trend between the hits and traffic factors shown in Figure 49 is more apparent compared to raw scatter plots shown in Figure 46. Regression scatter plots between hits or near misses versus adjacent general purpose lane volume and hits or near misses versus adjacent general purpose lane speed for all the case study locations are shown in Appendix H. Researchers also looked at the scatter plots by combining sites by application group (preferential lane access, preferential lane tangent, and freeway ramp) to see if there is any observable trends existed between sites. The scatter plots (sites combined by application group) of hits/near misses versus adjacent general purpose lane volume and hits/ near misses versus speed differential between preferential lanes and general purpose lane for most case study sites is shown in Appendix I.

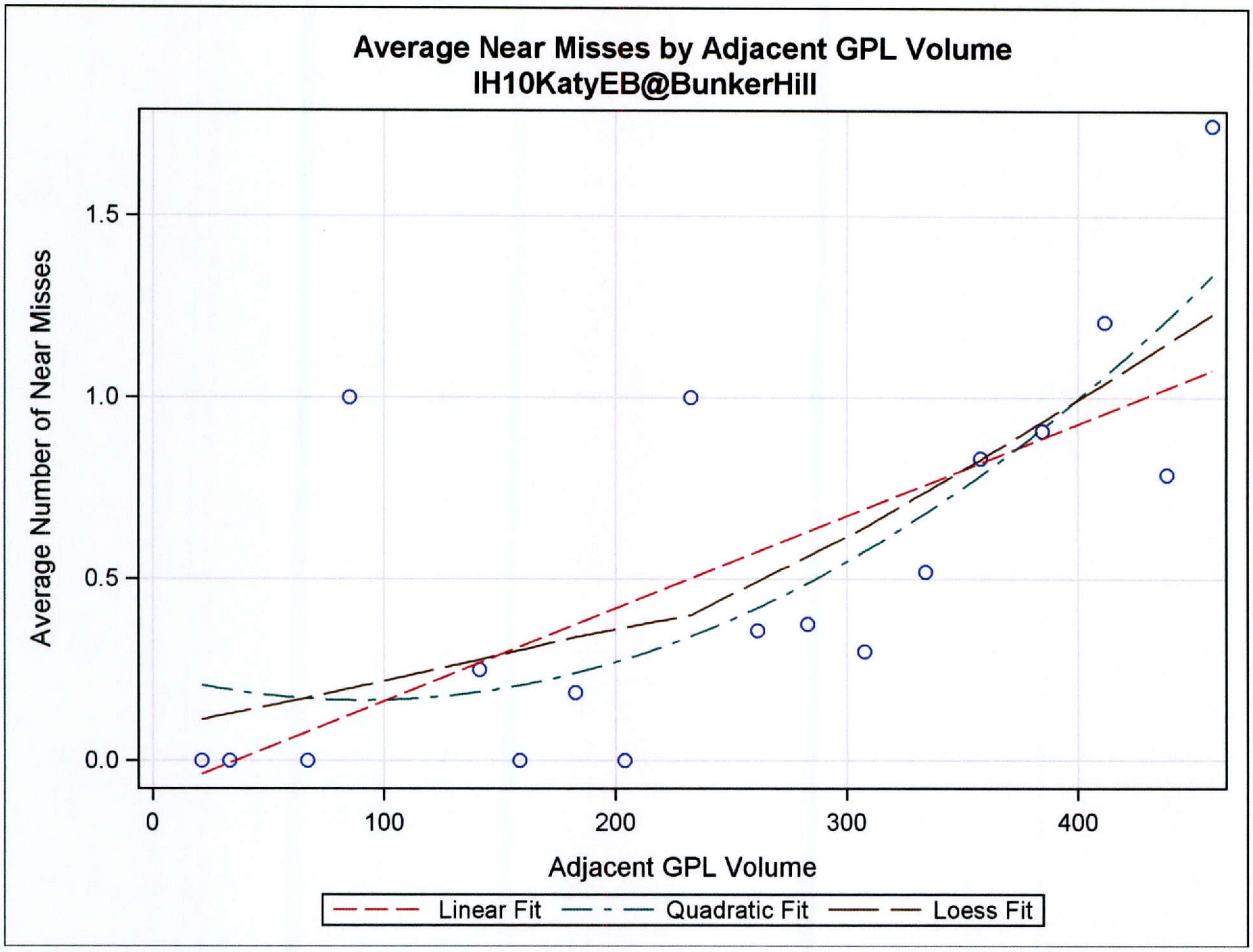


Figure 49. Trends between Near Misses and Aggregated 15-Minute General Purpose Lane Traffic Volume for IH 10 Managed Lanes at Bunker Hill.

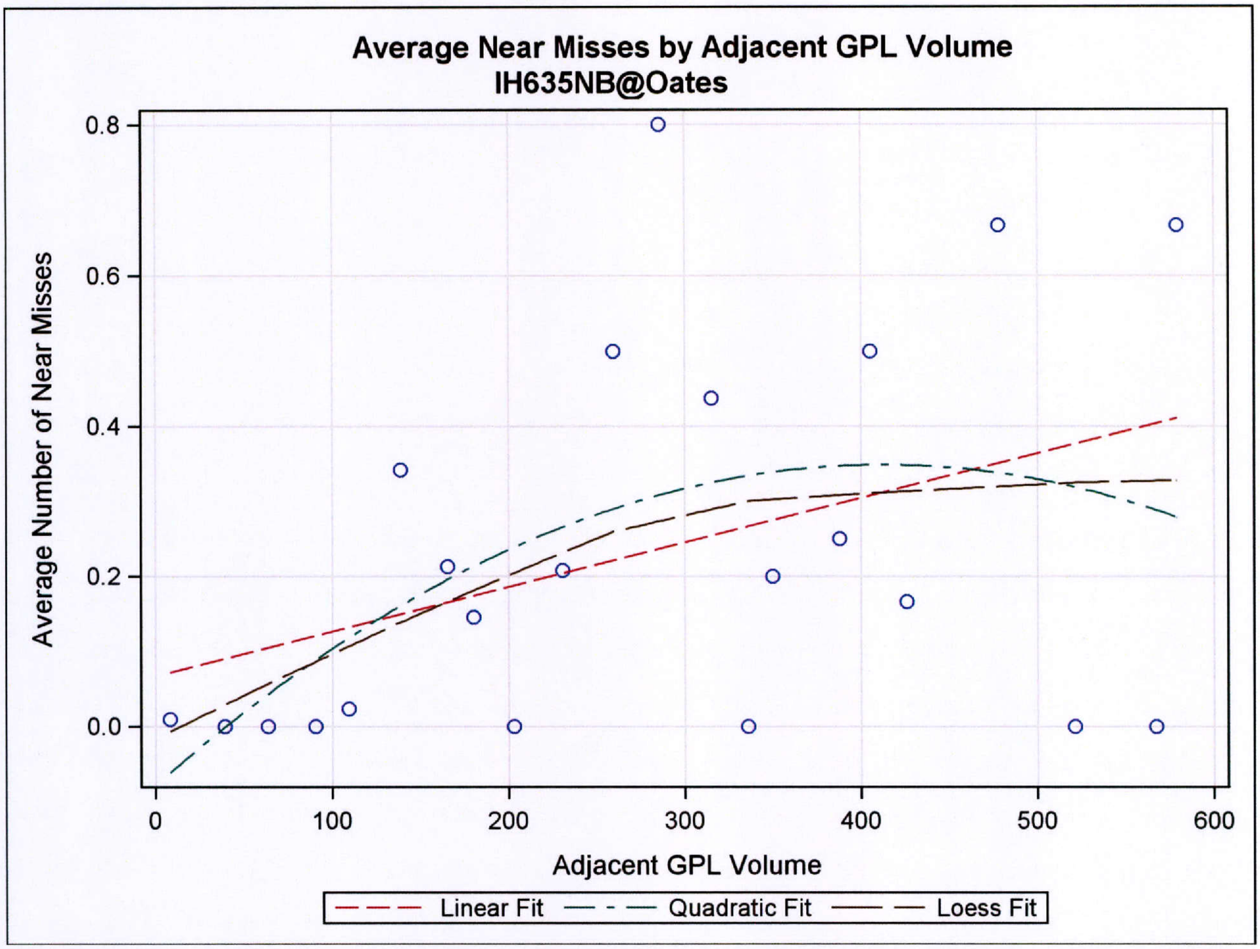


Figure 50. Trends between Near Misses and Aggregated General Purpose Lane Traffic Volume for IH 635 HOV at Oates Drive Study Site.

Researchers also developed regression models to fit the observed frequency of pylon hits and near miss using various geometric and pylon implementation factors for each group of application such as preferential lane access, preferential lane tangent, and freeway ramp applications. The following factors were used as dependent variables for each application type:

- Preferential lane access locations:
    - Minimum buffer width.
    - Pylon spacing.
    - Gore gap.
    - Access type (exit or entrance).
    - Approach or departure lane type.
    - Pylon end treatment.

- Preferential lane tangent locations:
    - Buffer width.
    - Pylon spacing.
    - Pylon mounting type.
- Freeway ramp locations:
    - Buffer width.
    - Distance from driveway.
    - Gore gap.
    - Ramp type (entry or exit).

The models were fit to several different levels of aggregation for pylon hits or near misses such as 15 minutes, 60 minutes, 24 hour and aggregation over entire data collection period. Negative binominal regression, scaled Poisson regression, and zero-inflated negative binomial regression models were fit for the above aggregations. In all cases, model fit was very poor, indicated by excessively large values in the scaled deviance and Pearson Chi-squared statistics. As an example, for data aggregated over the entire observation period, the best fit for a negative binomial regression model yielded scaled deviance and Pearson Chi-squared values greater than 3 and 10, respectively; these statistics should not ordinarily exceed unity for a model to be considered valid.

The excess dispersion exhibited by the models indicates insufficient homogeneity within combinations of factors. Indeed, each location in the study, as well as each type of pylon implementation, behaved very differently in terms of the both the frequency and the periodicity of pylon hits and near misses. The most probable explanation for the disparate behavior among the various locations is that some unknown factors not included in the analysis could be influencing pylon hit and near misses. Also the number of locations considered in each group of applications was less to identify atypical (outlier) sites that could be skewing the data.

In summary, the case study task provided some insights into trends that may influence pylon hits and near misses. However, statistically significant relationships to explain the influence of geometric, traffic operations, and pylon implementation factors on pylon hits (or near misses) could not be established at any site for any group of application (preferred lane access, preferred lane tangent, or freeway ramp/frontage road).

CHAPTER 6: SAFETY EXPERIENCE OF PYLON IMPLEMENTATIONS

In the agency surveys completed for Task 3, several state agencies and TxDOT districts indicated that when used for lane separation under specific conditions, pylons provide increased safety and higher compliance as compared to buffer and pavement markings only. One such specific use of pylon for lane separation is along frontage roads at the painted gore of a freeway exit or entry ramp. At these locations, pylons are implemented as a means to achieve better lane separation and improve safety if one or more of the following criteria are met:

- Number of crashes with ¼ mile of the ramp (5 crashes in last three years).
- Field observations by TxDOT personnel and/or public complaints related to motorists coming from side streets/driveways located in close proximity to the ramp and cutting across multiple lanes of traffic in an effort to enter the freeway.
- Field observations by TxDOT personnel and/or public complaints related to motorists exiting the freeway and cutting across multiple lanes of traffic to turn at the side streets/driveways located in close proximity to the exit ramp.

This chapter documents the safety experience of pylon implementation for separation of exit/entrance ramp and frontage road traffic at five different freeway ramp-frontage sites.

DATA COLLECTION

Researchers collected crash data from Crash Records Inventory System (CRIS) database maintained by TxDOT in Austin for the following five locations:

1. Woodway Entry Ramp at IH 610 (West Loop) Southbound (Houston).
2. Kirkwood Entry Ramp at US 59 Southbound (Houston).
3. Beechnut Exit Ramp at US 59 Southbound (Houston).
4. Cypresswood Entry Ramp at SH 249 Northbound (Houston).
5. FM 3009 Exit Ramp at IH 35 Northbound (San Antonio).

An initial query extracted all main lane, frontage, and ramp related crashes within 2000 ft. (1000 ft. each side) of the gore point, but excluding the intersection related crashes, for time periods beginning January 2007 thru June 2012. Using the results of this query, crash reports were extracted to isolate the incidents in the close proximity of the ramp area. Using the initial date for pylon installation at each location crash data were split in before and after period.

Table 16 shows installation dates and duration of before and after crash data analyzed for each site.

Table 16. Pylon Installation Dates for Crash Study Sites.

Site Name	Implementation Date	Duration of Before Data	Duration of After Data
Woodway Entry Ramp at IH 610 (West Loop) Southbound	September 2005	None	66 months
Kirkwood Entry Ramp at US 59 Southbound	February 18, 2010	38 months	28 months
Beechnut Exit Ramp at US 59 Southbound	February 28, 2011	50 months	16 months
Cypresswood Entry Ramp at SH 249 Northbound	July 7, 2011	54 months	12 months
FM 3009 Exit Ramp at IH 35 Northbound	February 2008*	13 month	53 months

*Exact date and month for this location was not available. This date was estimated based on information from TxDOT and a crash report that documented the presence of pylons at this location.

DATA ANALYSIS

Using the collision diagram and officer's narrative of the crash as available from detailed crash reports, crashes were categorized in the following types:

1. 'SS' - sideswipe due to lane changes where ramp lane is not the origin or destination.
2. 'SS-N' – sideswipe due to lane changes while trying to enter the ramp lane within the gore area.
3. 'SS-X' – sideswipe due to lane changes while trying to exit the ramp lane within the gore area.
4. 'SS-P' – sideswipe with pylons or guard rail along the ramp either when changing lanes or due to inattention.
5. 'RT' – right angle crash due to vehicles coming out of driveways/side streets and hitting a vehicle traveling straight on the frontage road lanes.
6. 'RT-N' – right angle crash due to vehicles coming out of driveways/side streets, crossing multiple lanes of traffic in an effort to enter the freeway and hitting a vehicle traveling straight on the frontage road lanes.
7. 'RT-X' – right angle crash due to vehicles coming off the freeway, crossing multiple lanes of traffic in an effort to turn at the first cross street/driveway within the gore area and hitting a vehicle traveling straight on the frontage road.

8. 'RE' – rear end crash due to inability to control speed/stop in time.
9. 'RE-N' – rear end a vehicle that was stopped in the lane next to ramp gore area in order to make a late merge or stopped in the ramp lane to allow another vehicle to make a late merge.
10. 'O' – Single vehicle accident that hit a fixed object other than pylons.

Crashes on the main lanes of the freeway and related to intersections were excluded from the dataset for the purpose of this study. As the reader will see below, it appears that as an overall conclusion from the crash analysis there is a positive influence on safety attributable to the use of pylons. However, the results were not statistically conclusive.

Location 1: Woodway Entry Ramp @ IH 610 (West Loop) Southbound

At the Woodway location, pylons were implemented to deter vehicles coming out of Uptown Park Boulevard from making multiple lane changes in an attempt to enter the IH 610 West Loop Southbound Main lanes via the Woodway entry ramp. The cross street is located at the start of the painted gore area and speed limit for this section of the frontage is 45 mph. Average traffic volumes for the entry ramp and frontage through lanes are 19,340 vehicles per day and 22,220 vehicles per day, respectively. Vehicles coming out of the Uptown Park Blvd have to travel across three lanes of traffic and gore area at right angle to the direction of traffic on frontage to use this entry ramp. The pylons at this location extend from the beginning of painted gore area to the beginning of raised curb separation between ramp and frontage lanes. Table 17 presents crash statistics for the after period at this location. No before data were available for this location.

Table 17. Crash Statistics at Woodway Entry Ramp @ IH 610 West Loop Southbound.

Time Period	Crash Types							
	SS-N	RT-N	RE-N	SS-P	SS	RT	RE	O
Before (No data available)	-	-	-	-	-	-	-	-
After (66 months)	-	1	-	-	-	1	3	1

At the Woodway entry ramp southbound location, there were a total of six incidents in the after period of 66 months and only one right angle crash of the type that the pylon implementations are intended to deter. The collision diagram and crash narrative for that one incident suggests that the crash occurred when a vehicle coming out of Uptown Park Boulevard and headed for the IH 610 West Loop entry ramp hit another vehicle that was traveling straight in the left most through lane next to the entry ramp. The crash occurred in the lane next to the entrance ramp gore area, and there is no mention of the vehicle hitting or crossing the pylons.

Location 2: Kirkwood Entry Ramp at US 59 Southbound, Houston, Texas

At the Kirkwood location, pylons were implemented to deter vehicles coming out of a commercial and retail center driveway located across from the middle of painted gore area. In this section of the frontage road, average traffic volumes for the entry ramp and frontage through lanes are 9,480 vehicles per day and 19,800 vehicles per day, respectively, and the speed limit is 45 mph. Vehicles coming out of the driveway have to travel across three lanes of traffic and turn right at the gore area to access the entry ramp. The pylons at this location extend from a point in the painted gore area located across from the beginning of driveway radius to the beginning of raised curb separation between ramp and frontage lanes. Running length of pylon implementation at this location is approximately 140 ft. Table 18 presents crash statistics by crash types for the before and after periods at this location. At this location, there were three incidents (0.95 crashes/year) in the before period and three incidents (1.3 crashes/year) in the after period. Both in the before and after period, type of crashes identified at this site are not expected to be influenced by the presence of pylons. Thus no conclusion regarding the safety impacts of pylons can be deduced at this site.

Table 18. Crash Statistics at Kirkwood Entry Ramp @ US 59 SB.

Time Period	Crash Types							
	SS-N	RT-N	RE-N	SS-P	SS	RT	RE	O
Before (38 months)	-	-	-	-	1	-	1	1
After (28 months)	-	-	-	-	-	1	2	-

Location 3: US 59 Southbound Beechnut Exit Ramp, Houston, Texas

At the Beechnut location, pylons were implemented to deter exiting vehicles from making the right turn maneuver at Tours Street located approximately 250 ft. away from the end of painted gore area. In this section of the frontage road, average traffic volumes for the exit ramp and frontage through lanes are 18,010 vehicles per day and 21,140 vehicles per day, respectively, and the speed limit is 45 mph. Vehicles exiting the freeway have to make two consecutive lane changes in a short distance of 250 ft. while looking for adequate gaps in the through traffic, and have to slow down sufficiently to make the right turn, thus posing safety issues for themselves as well as other motorists. The pylons at this location extend from a point across from the beginning of Tours Street to the beginning of raised curb separation between ramp and frontage lanes. The running length of pylon implementation at this location is approximately 560 ft. at this location. Table 19 presents crash statistics by crash types for the before and after periods at this location.

Table 19. Crash Statistics at Beechnut Exit Ramp @ US 59 SB.

	Crash Types						
Time Period	**SS-X**	**RT-X**	**SS-P**	**SS**	**RT**	**RE**	**O**
Before (50 months)	1	-	-	1	1	-	1
After (16 months)	-	-	-	-	-	1	-

At this location, there were a total of four crashes in the 50 month before period for which crash data were analyzed (0.96 crashes/year) and only one crash in the 16 month (0.75 crashes/year) after period. Out of the four total crashes in the before period, one crash was sideswiped due to a vehicle coming from the freeway and cutting in-front of the vehicle involved in the crash causing vehicle that was cut-off to swerve to the right and side wipe another vehicle. In the after period, the only reported crash in the vicinity of the ramp is of a type that would not be expected to be impacted by the pylon implementation. Absence of sudden lane change type crashes in the after period suggests positive safety impacts; however the relatively brief after-period and small number of relevant crashes in both the before and after period make it difficult to draw any conclusions at this time.

Location 4: SH 249 Northbound Cypresswood Entry Ramp, Houston, Texas

At the Cypresswood location, pylons were implemented to deter vehicles coming out of Vintage Preserve Parkway from making multiple lane changes in an attempt to enter the SH 249 NB main lanes via this entry ramp. The entry ramp is located approximately 200 ft. away from the Cross Street and speed limit for this section of the frontage is 50 mph. Average traffic volumes for the entry ramp and frontage through lanes are 6,420 vehicles per day and

26,460 vehicles per day, respectively. Vehicles coming out of the Vintage Preserve Parkway have to weave across four lanes within a distance of 200 ft. to use this entry ramp, which poses operational and safety concerns at this location.

At this location pylons have been installed along the ramp gore separating the ramp lane from frontage lanes as well as along the far right frontage lane such that traffic entering from Vintage Preserve Parkway is forced to turn into the far right lane of the frontage and is not allowed to change lanes until past the gore point of the entrance ramp. Table 20 shows crash statistics at the Cypresswood entry ramp location for the before and after periods by crash types.

At this location, there were a total of six crashes in the 54 month (1.33 crashes per year) before period for which crash data were analyzed and no crashes in the 12 month after period. Of the six total crashes in the before period, three were ramp related (with two incidents of sideswipe due to last minute lane changes on the gore area and one incident where a vehicle hit the guard rail on the left of the ramp). Examining the crash dates shows there was at least one crash per year in the vicinity of the ramp in the before period. After installation of pylons, no crashes have been reported in the one year since, suggesting a positive safety impact of pylon installation.

Table 20. Crash Statistics at Cypresswood Entry Ramp @ SH 249 NB.

	Crash Types							
Time Period	**SS-N**	**RT-N**	**RE-N**	**SS-P**	**SS**	**RT**	**RE**	**O**
Before (54 months)	2	-	-	1	-	-	2	1
After (12 months)	-	-	-	-	-	-	-	-

Location 5: FM 3009 Exit Ramp @ IH 35 Northbound, San Antonio, Texas

At this location, pylons were implemented to deter vehicles exiting the freeway from making lane changes on the painted gore area to turn at Plaza Drive, located only 250 ft. from the end point of concrete barrier separating the ramp from the frontage. The pylons have been installed for a length of about 125 ft. from the end of painted gore to the middle of painted gore thus leaving a distance of approximately 125 between the end of concrete barrier and the beginning of pylons where vehicles can still exit the ramp lane, travel over the painted gore and get in the frontage through lane, and turn at Plaza Drive. This is a two-lane frontage road section with one lane coming from south of the ramp and the second lane being added by the exit ramp. Average traffic volumes for the exit ramp and frontage through lanes are 17,380 vehicles per day and 7,290 vehicles per day, respectively. Table 21 shows crash statistics at FM 3009 exit ramp location for the before and after periods by crash types.

Table 21. Crash Statistics at FM 3009 Exit Ramp @ IH 35 Northbound.

Time Period	**Crash Types**						
	SS-X	**RT-X**	**SS-P**	**SS**	**RT**	**RE**	**O**
Before (13 months)	-	-	-	-	1	1	-
After (53 months)	-	-	2	1	-	4	2

A review of the crash statistics at this site shows there were two crashes in the 13-month before period (1.85 crashes per year) of the type correctable by use of pylons. In the after period, there were a total of nine crashes in the 53 months (2.03 crashes per year), out of which seven were of the type unrelated to the presence/absence of pylons. However, crash reports indicated that two vehicles crashed in separate incidents due to actually hitting the pylons. Since both of these crashes occurred within two months (February and March 2008) of pylon implementation, thus it is plausible to say that these vehicles did not notice the new lane separators recently put in place. Since March 2008, no other crashes involving pylon hits or of the type correctable by using pylons have been reported at this location.

CHAPTER 7: MAINTENANCE EXPERIENCE OF PYLON IMPLEMENTATION

Ongoing maintenance is a critical issue for an agency to plan for and execute. Pylons were identified as an ongoing maintenance items from most agencies surveyed. Case study interviews expanded on the questions about maintenance and are presented below. Maintenance supervisors from TxDOT (*34*), HCTRA (*35*), and METRO (*36*) were interviewed to gather information on their activities and costs related to pylons.

METHOD

Prior to in-person and phone interviews, researchers provided several agency maintenance supervisors and field personnel with questions intended to gauge the level and parameters of different maintenance activities. This maintenance task is a compilation of several interviews. The interviews can be characterized as a series of questions and answers, with an informal discussion of the practical experiences of their respective agencies. Most interviews did not follow a script but were more conversational in nature. A summary of key questions and answers are presented below. Generally pylons are not the largest maintenance items; typically mowing and snow removal is the largest expenditures.

SUMMARY OF RESULTS

Question 1. What Are the Top Three Operational and/or Maintenance-Related Items that You Spend (or Spent) Time on?

Delineators were always listed in this category. The list below summarizes the responses from the agencies.

1. Delineators.

    - Entry/exit points of managed lanes were noted as the most problematic with the highest amount of hits and replacement. Entry/exit points tend to be decision points and weaving areas.
    - Off peak tangent section pylon hits on managed lanes were a result of two patterns:
        - Off peak crashes in general purpose lanes coming across the buffer.
        - Impaired drivers although typically could not be confirmed.

- Tangent section hits are greatly increased during the peak period if there is a crash in the general purpose lanes and the managed lanes are running at free flow speeds. It appears that there is some amount of crossover to the facility with free flow (either an issue in the managed lanes and the general purpose lanes are running free flow, or vice versa). The congestion cross over issue has historically been more prevalent on the facilities, where smaller buffer areas are employed.
- Shorter and thicker delineator posts are surmised to be more durable over time. They have been used on other parts of the HCTRA system in advance of taller, thinner posts to reduce maintenance and reinstallation occurrence.
- Raised pavement markers or profile markings could potentially be used prior to the pylons to provide a tactile warning to drivers within, or in advance of the buffer area.

2. Pavement Markings.

- Retroreflective tape has come up over time in some areas around the pylons. The tape tends to curl up on the edges if no traffic is running on top of the tape as the case for typical lane or edge lines.
- Tape failure is accelerated as sweeper truck brushes contact the curled up sections of pavement marking. Thermoplastic pavement markings might be a better alternative for these applications.

Question 2. What Are the Top Three Items that You Spend Money on?

Toll operators and their paying customers both have the similar expectation or perception that if travelers are paying for the facility that the system should be kept to a higher standard in both appearance and operation than is provided by other agencies. More intense maintenance activity then occurs to address:

1. Sweeping – two times per month.
2. Debris pick up – daily.
3. Delineator Replacement – weekly.

Question 3. How Much of the Maintenance Work Is Being Outsourced? Is It a Good Value?

- Most agencies are outsourcing all pylon maintenance activities. The HCTRA contract, for instance, has multiple skill level workers and the work is assigned by task.
- The maintenance contract is a good value. It offers efficiency as multiple tasks can be done by one crew with one pass through the corridor. For example, while replacing delineators, the contractor would also pick up debris. With an unconsolidated maintenance contract approach, two crews would be used, and separate trips made to pick up debris and replace pylons.
- Managed lane facilities have a lower maintenance cost than other parts of the system. This is partially due to the age of the system, but also because there is no mowing, there are fewer signs, and there are fewer crash attenuators.
- Annual per-mile maintenance costs on the Katy Managed Lanes are about $11,000 per/lane mile versus the average cost of the rest of the toll system is about $24k//lane mile.

Question 4. Do You Have Working Relationships with Other Agencies Maintenance Staff?

- Agencies indicated good working relationships with other local agencies' maintenance and operations staff.
- Quarterly meetings are held to coordinate and discuss operational, maintenance, and other related issues.

Question 5. What Is the Cost per Pylon?

- On average, HCTRA's replacement cost per pylon is about $30 (furnish and install). The $30 per unit cost is generally the average cost for furnish and install as provide by other agencies.

Question 6. What Area or Location (Gore, Tangent Section, Declaration Point, and/or Toll Booth) Has the Most Pylon Hits and/or Replacement? What Is Typically the Cause of Hit or Replacement (Crash, Distracted Driving, Visibility, or Other)?

- Entry exit gore areas have the highest impact rates and have the highest replacement rates. Anecdotally, the increased number of hits at these locations is due to the entrance being a place where the driver must often make a decision to choose between facilities.

- It is also surmised that driver distraction or unfamiliarity with the facility may play a role in the increased number of hits at the entrance and exit locations. On managed lane facilities it was believed that motorist are attempting to look ahead to determine if they should take the managed lanes.

OTHER OBSERVATIONS

During the interviews, practitioners noted several other observations regarding maintenance of managed lane facilities.

FRONTAGE ROAD ENTRANCE EXIT IMPLEMENTATION GUIDANCE

Several conditions or criteria are used to consider the implementation of pylons. The first is good design, the access management handbook and the design manual should be used to provide proper ramp spacing from side street or driveway location. The minimum spacing is not the desired spacing and driveways and streets should have adequate distance to weave across frontage road lanes before attempting to enter or exit the freeway. Many times if the desired design criteria are followed pylons are not needed. In some cases the driveway permit process is used. If a land owner/developer desires access some treatments may need to be implemented and typically those treatments (device or the driveway design must be maintain the by the developer or the driveway permit could be removed. On existing facilities operational issues are typically identified by the traveling public and local agencies. Citizens might consider a location as a dangerous or high crash location. Operations personnel typically identify a location through daily observation or citizen input.

Site Evaluation

Once a location has been identified an evaluation is typically conducted. These can include:

- Crash analysis (using 3 to 5 years of crash data).
- Site visit.

- Video surveillance.
- Weaving analysis.

Crash analysis is a systematic tool that can be used to identify a location that may have a safety problem. Crashes are random events so multiple years of data should be used for the analysis. Five crashes per year for three to five years of crash data provide a good indication of safety issues. In areas with high volumes crash rates may be more useful. Crash reports need to be reviewed to determine the nature of the crash and what type of solution could prevent or limit the crash. Crash types that are typically considered are right angle crashes and sideswipe crashes in the proximity of the area of interest.

A site visit and potentially video surveillance are also suggested to document erratic or near miss events or conflicts. This video or site visit needs to be conducted during the peak hour or at time when the issues are reported to occur. Video surveillance can be used by defining criteria such as number of vehicles making an erratic maneuver. Or number of near misses while making the maneuver or some combination or weighted criteria.

Similarly a weaving analysis can be conducted using video to determine the number of vehicles making the weaving maneuver as well as traffic volume on the frontage road. These analyses typically take more time and can be more costly. Modeling is another alternative that might be used for evaluating the conditions and a resulting solution.

Solution Alternatives

When a site has been identified and the evaluation has been conducted there are several remedies that should be considered. Some of the remedies may include education, enforcement, and/or engineering solutions. In cases where a specific group can be identified, a targeted education solution can be a long-term effective treatment. Education solutions tend to be systemic and typically take longer to see the results but have the largest widespread effect.

Enforcement can be used to with education and engineering solutions to reinforce existing laws, signs, and markings. Enforcement can be a short-term solution and typically needs to be repeated periodically. Enforcement can be used in place of pylons if double white lines are used at the entrance or exit and consistent enforcement can reduce or eliminate the dangerous and undesired movements. Smaller jurisdictions tend to be more responsive than larger jurisdictions in all cases assistance from law enforcement is dependent on priorities at the time.

Engineering Solutions

There are some techniques that can be used to prevent or reduce the number of vehicles who attempt difficult or short weave, which can be a safety problem. Engineering solutions can help in many cases but many times have an ongoing maintenance cost associated with the solution. One method is driveway treatments such as driveway diverters, two driveways (one in and one out), or an angled driveway, which reduces the ability of motorist to merge across multiple lanes. These treatments can cause issue for pedestrians due to the higher speed of the motorist entering and exiting the driveway potentially negatively impacting pedestrians. Motorists leaving a driveway typically only look toward traffic on one-way frontage roads potentially causing a conflict for pedestrians.

Pylons can be used to enhance design treatments such as the driveway diverters or the double white lines on frontage road entrance or exit ramps. Pylons make the treatment more visible and provide some degree or feeling of a barrier.

There are some elements that designers should be aware of. A common practice is to install enough pylons to extend past the location that is trying to be blocked. Some motorists will attempt to make a 90 degree turn or even go against traffic in an attempt to enter the driveway or entrance ramp. Many engineers perceive that exit ramps are more dangerous than the entrance ramp scenario due to the higher speed of the vehicles exiting the freeway. Installing pylons on the entrance and/or exit ramp can have a negative effect on weaving distance. Extending the barrier effectively reduces the length of the weaving section. This can potentially cause increased congestion and/or more sideswipe and rear end crashes by reducing the weaving section and concentrating the number of maneuvers in a shorter section.

Tradeoffs –Barriers versus Pylons

There are differing opinions on the benefits, related to the cost, of the use of pylons versus the use of concrete barrier. The true benefits of pylon access are difficult to assess due to the limited amount of data and difficulty in collecting the data to complete a comprehensive and conclusive evaluation. However, Table 22 shows various design/operational, incident management, and maintenance tradeoffs or considerations for concrete traffic barriers (CTB) versus pylons. The comparison is based on portable CTB, although most of these comparisons would be applicable to a comparison between pylons and cast-in-place traffic barriers. Table 22 provides a summary of the comparison and a more detailed description is provided in the sections below.

Table 22. Tradeoffs between Concrete Barriers and Pylons.

Design\Operational Considerations		
Feature	**Barriers**	**Pylons**
ROW/Buffer Width	4 ft. minimum	1.5 ft. minimum (maintenance is exponential)
End Treatment	Requires Crash Attenuator	None Required but Higher Maintenance at Entrance and
Sight Distance	Perceived Limitation	Perceived Improvement - no wall to present obstruction
Encroachment	None	High Potential
Congestion	ML Not Affected by GP Congestion	ML Affected by GP Congestion - Also Potential Cross Over
Driver Perception	Feeling of Safety, sometimes confined	Potential false feeling of safety; open feeling
Lane Compliance	Excellent	Dependent on buffer width, enforcement, others factors
Enforcement (lane line violation)	No Lane Line Violation	Roving - difficult and costly
Ease of Enforcement	Occupancy - Dependent on Width	Occupancy - Dependent on Width
Installation Cost	High $16/lf	Low $3/lf
Crash Protection	Redirect Traffic	None

Incident Management		
Feature	**Barriers**	**Pylons**
Motorist Breakdown	Dependent on Width	Dependent on Width
Emergency Vehicle	Limited Access	Very Accessible
Roadside Assistance Vehicle	Limited Access	Very Accessible
Major Incident	Limited Access - Can't get traffic into or out of ML	Very Accessible - Can get traffic into or out of ML

Maintenance		
Feature	**Barriers**	**Pylons**
Lane Closure Cost	Typically Annually and may not be required	Higher Cost / Dependent on Buffer Width/ Frequency
Worker Safety	High - Limited maintenance & protected by CTB	Low - Higher need for maintenance & no barrier protection
Annual Maintenance Cost	Low -Barrier Alignment Annually if Portable CTB	Moderate/High - Dependent on Buffer Width
Crash Cost	Dependent on Severity	Dependent on Severity - could go through pylons and hit CTB

Design and Operational Considerations

There are many differences between the pylon and barriers that affect design and operations. Designers and operators will need to carefully consider these tradeoffs early in the project development process because some elements are very difficult and costly to change later and potentially may have an impact on how the facility operates.

ROW/Buffer Width

Right of Way (ROW), in the context of this discussion, is the amount of space required for the type of barrier separation provided, which can be also referred to as buffer width. Buffer width was defined above and refers to the lateral space between the pylon and the moving lanes of traffic. TxDOT Research Project 0-6643 found a high correlation between buffer width and pylon replacement rate. From a strictly physical perspective, pylons need less width for deployment, as little as 1 ft. However, the maintenance cost increases dramatically as a function of buffer width, as shown by Figure 51. With less than 2 ft. of buffer space pylon replacement can range from 120 percent per year to 300 percent per year. CTB requires about 4 ft. of ROW as shown in Figure 52. ROW can be one of the largest cost items in an urban area roadway project. With respect to buffer provision, there is a tradeoff between the space and cost. Additional space can reduce the pylon replacement rate, increase the space available for incident management, and may have some impact on capacity.

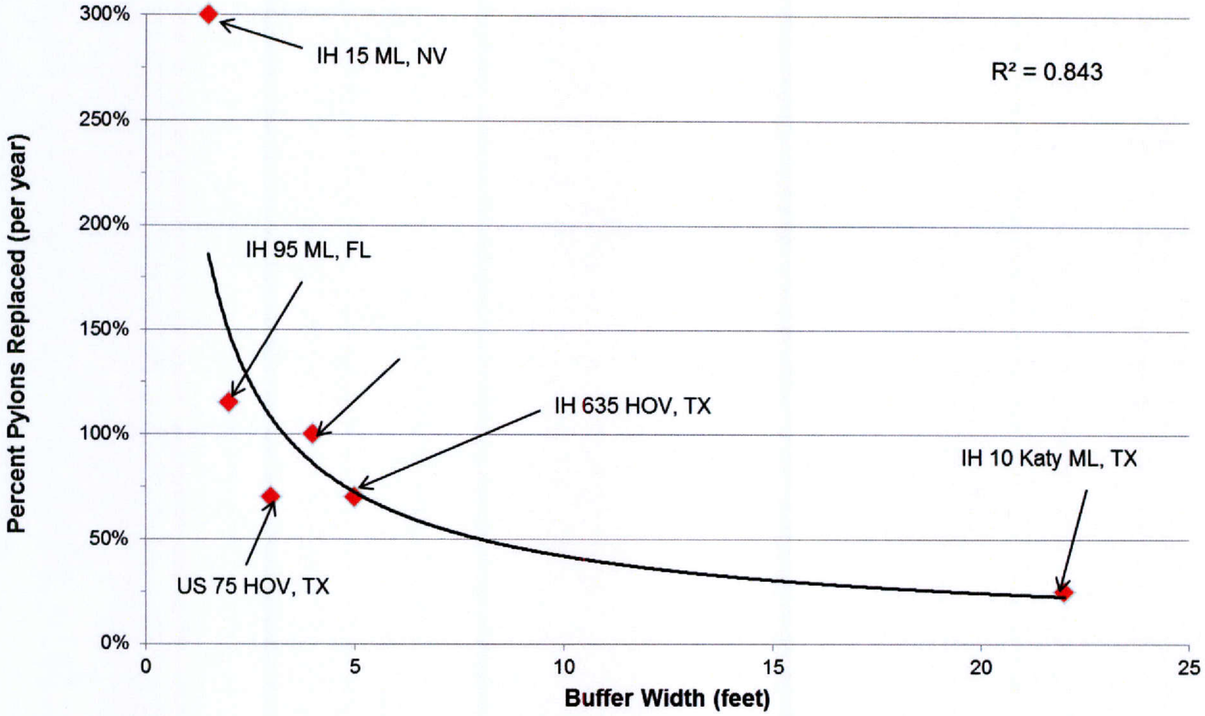


Figure 51. Buffer Width vs. Pylon Replacement per Year.

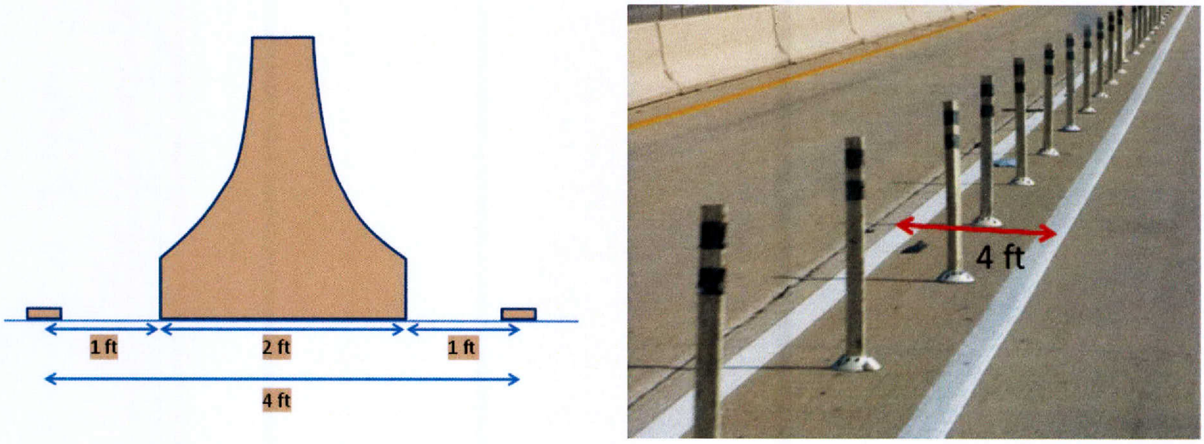


Figure 52. Space Requirements for CTB and Pylons.

End Treatment

Pylons are crashworthy and do not require a crash attenuator. CTB use requires a crash attenuator to be installed so that motorists do not strike the blunt end of the CTB. A crash attenuator will fit within a 4 ft. envelope, but with a CTB installation a crash attenuator would be installed at each entry point, increasing initial and ongoing costs.

Sight Distance and Driver Perception

While there are typically no sight distance issues with CTB deployment, agencies have noted the perception of limited sight distance or motorists feeling confined by CTB installations, particularly by motorists driving in smaller or lower-profile vehicles. Along with elimination of any perception of limited sight distance, pylons have been noted to provide a feeling of openness for motorists. However, motorists have also reported that there can also be a feeling of safety behind the CTB wall knowing that there is physical separation between lanes.

Crash Protection and Encroachment

Crash protection afforded by concrete barrier placement can have different components; mainly regarding the amount of encroachment or redirection provided:

- Encroachment - The ability to keep errant vehicles from entering or leaving the lane.
- Redirection - the ability to redirect or keep a vehicle in the lane from which it came and traveling the same direction.

The CTB typically has very little deflection upon impact. Depending on the size and weight of the vehicle and the angle of the impact of the barrier may not move at all, but if it does move it is typically less than 1 ft. In contrast, pylons do not provide any redirection capability. Pylons will not stop a vehicle from encroaching or entering/leaving the lane.

Lane Compliance

Lane compliance is how well a device prevents a motorist from crossing a double white line. This factor is based on actual compliance so it is dependent on the driver population. Some populations are more law abiding or have less penalty and will not cross double white line. Some populations need a pylon to emphasize the double white line marking and still others require an impenetrable device such as a CTB. While pylons discourage crossing the double white line concrete barriers prevent the movement.

Enforcement and Ease of Enforcement

Enforcement may be more of a factor on some facilities as opposed to others, but there are several factors related to enforcement that are needed on preferential lanes, some elements of which will enhance the ability to enforce lane compliance, lane restrictions, and other traffic laws. The choice of barrier can impact:

- Ability to confine motorists to enter and exit at designated locations.
- Occupancy verification (or checking to see if vehicles are in the required lane for HOV or toll declaration).
- Type of enforcement (stationary or roving).
- Space to perform enforcement.

If enforcement is present it boosts compliance regarding many regulations, including lane violation, occupancy, and speeding. If there is little enforcement (whether due to cost, perceived effectiveness, or space) motorists will typically push the limits of compliance. Providing space for enforcement makes these activities more efficient and effective allowing an officer to observe one section of the facility. While pylons reinforce pavement markings, CTB provides positive separation with little chance of evading enforcement.

Incident Management

Incidents are a common occurrence on urban roadways. The ability to detect, verify, and clear incidents can significantly enhance the operational effectiveness of the facility. Pylons are a benefit to incident management activities as they allow emergency responders to cross the buffer and access to both the ML and the GP lanes. In contrast, the use of CTB restricts the ability of incident personnel to directly respond to an incident in the GP lanes by utilizing the travel time efficiency of the ML (and vice versa). The use of CTB could also require the incident responders to wait in traffic or travel against traffic in the ML to get to an incident or remove a disabled vehicle. In the event of a major crash on the ML or GP lanes a pylon deployment enables transportation management personnel to directly maneuver a response vehicle across the pylons, into (or out of) the ML while a CTB restricts that ability.

In the event of an incident or vehicle malfunction the ability of the motorist to withdraw from the moving lanes of traffic is ideal. Adequate shoulders width adjacent to the travel lanes provides such refuge. Removing the vehicle from the travel lanes reduces the other motorist back up thus reducing the potential for secondary crashes and enhances the safety of the stranded vehicle reducing their exposure to moving traffic.

Congestion

When GP lanes are congested and the ML are separated by a narrow buffer, there can be a resulting slowdown in the ML. The slowdown in the ML is a result of a natural driver behavior to react to a high speed differential in adjacent lanes (and vice versa). The slowdown can be from a motorist's perception that it would be possible for a cross facility weaving movement to occur. Figure 53 illustrates the maneuver described above. The use of CTB prevents motorist from making a cross facility weave so the speed in the ML is typically not affected by GP incidents.

Figure 53. Example of GP Cross Facility Weave to ML (US 75 Dallas).

Maintenance

Lane Closures

Lane closures for maintenance activity are typically costly and given the potential to cause congestion, typically limited by time of day. Lane closures can be very expensive, with estimates ranging from $750 to $5,000 per lane mile per day. With narrow buffer widths a lane closure could be required on both the ML and the GP to repair or replace pylons or perform other maintenance activities. On some facilities, this maintenance is done on a weekly basis, thus resulting in a significant annual cost. The CTB treatment requires the barriers to be realigned every one to two years depending on the number of critical vehicle strikes, resulting in fewer lane closures and less cost over time.

Worker Safety

As the maintenance intervals associated with CTB are fewer, there is a resulting limited worker exposure when CTB is used to provide lane separation. Maintenance is conducted less frequently than with pylons and typically, when it is performed it is from within the managed lane and during off-peak time (nights and weekends). Repairing pylons on a narrow cross section, or narrow buffer, can require both a lane closure on the ML and the GP lanes, leading to more worker exposure. Even if there is a modest amount of shoulder the exposure rate for maintenance workers is higher since the workers are conducting the maintenance more frequently. In addition pylon maintenance is directly related to buffer width (0-6643) the larger the buffer width the less frequently the pylons get hit the less workers are exposed to traffic. Crash cost, the cost of repairing or replacing the CTB is typically handled during the annual realignment so there is little to know crash cost maintenance. Pylons will not stop the vehicle and will need to be inspected repaired and or replaced after each crsah and is typically done as part of the weekly maintenance.

Lifecycle Cost: Pylons versus CTB

This section describes the cost comparison between Pylons and CTB. There is a tradeoff between initial (or capital) cost compared with maintenance cost of each application. Portable CTB may have a higher capital outlay but a lower periodic maintenance cost. Several tables below describe the per mile cost based on varying buffer width, with the last table presenting the example of the Katy Managed Lanes. Below are the assumptions of the cost analysis:

- CTB Assumptions:
    - $30 per linear foot furnish and install capital cost (Portable CTB).
    - 20 year life (30 to 50 year possible.)
    - Barrier realignment $5.77 per linear foot.

  - $8,700 per crash attenuator.
  - One attenuator per two miles.
  - $3,500 to reset attenuator.
  - Reset attenuators 10 percent per year.
  - Katy ML assumed to require 11 crash attenuators.
- Pylon Assumptions:
  - 10 ft. pylon spacing.
  - $30 per pylon to furnish and install.
  - Buffer width 2, 4, 8, and 20 ft. buffer width assumed for the per mile and 20 ft. buffer on Katy for 12 miles.
  - 120 percent, 2 ft.; 70 percent, 4 ft.; 50 percent, 8 ft.; and 20 percent, 20 ft. (% pylon replacement per year, buffer width) and 120 percent pylon replacement on Katy a no difference in ROW (buffer) cost.
  - No total replacement of all pylons.
  - $750 per lane (with two lanes) Lane Closure cost (cost may range from $750 to $5,000 per lane).
  - Pylons maintenance monthly.

A cost comparison was made of the two treatments with the following financial assumptions:

- 3 percent inflation.
- 20 year life.
- All costs brought to net present value.

The cost for each treatment was calculated based on a per-mile of treatment. Table 23 through Table 26 examines the relationship between buffer width and the resulting increase in maintenance cost. The cost for each treatment type was calculated for the KML and is presented in Table 27. KML has a much lower maintenance cost due to the large buffer width and the resulting reduction in pylon replacement. The cost to provide the additional ROW for the different options was not included in the cost calculation. Lane closure costs were not included in the cost to replace pylons for KML or the 20 ft. buffer spacing since a lane closure is not typically necessary. The per-mile comparisons with buffer less than 8 ft. assumed that the entire lane would need to be closed both on the KLM and the GP lanes.

The tables cannot be directly compared since the buffer width and the resulting maintenance and replacement costs are different. The Katy and per-mile costs cannot be compared since Katy has a large buffer, not requiring lane closures, and thus has a lower maintenance cost

Table 23. CTB vs. Pylon per Mile Cost Comparison for 2 Foot Buffer Width.

Options	$/Lf*	Per Mile Install Cost	Maint**	$ Maint.	Total	% CTB
Portable CTB	$ 30	$ 163,000	50.0%	$ 302,600	$ 465,300	100%
Pylon (7 yr life)	$ 3	$ 15,800	120%	$ 251,500	$ 267,400	57%
Pylon (20yr life)	$ 3	$ 15,800	120%	$ 491,400	$ 507,300	109%

*$30/pylon/10ft **Based on buffer width curve

Table 24. CTB vs. Pylon per Mile Cost Comparison for 4 Foot Buffer Width.

Options	$/Lf*	Per Mile Install Cost	Maint**	$ Maint.	Total	% CTB
Portable CTB	$ 30	$ 163,000	50.0%	$ 302,600	$ 465,300	100%
Pylon (7 yr life)	$ 3	$ 15,800	70%	$ 197,700	$ 213,500	46%
Pylon (20yr life)	$ 3	$ 15,800	70%	$ 337,600	$ 353,500	76%

*$30/pylon/10ft **Based on buffer width curve

Table 25. CTB vs. Pylon per Mile Cost Comparison for 8 Foot Buffer Width.

Options	$/Lf*	Per Mile Install Cost	Maint**	$ Maint.	Total	% CTB
Portable CTB	$ 30	$ 163,000	50.0%	$ 302,600	$ 465,300	100%
Pylon (7 yr life)	$ 3	$ 15,800	50%	$ 176,200	$ 192,000	41%
Pylon (20yr life)	$ 3	$ 15,800	50%	$ 276,100	$ 292,000	63%

*$30/pylon/10ft **Based on buffer width curve

Table 26. CTB vs. Pylon per Mile Cost Comparison for 20 Foot Buffer Width.

Options	$/Lf*	Per Mile Install Cost	Maint**	$ Maint.	Total	% CTB
Portable CTB	$ 30	$ 163,000	50.0%	$ 302,600	$ 465,300	100%
Pylon (7 yr life)	$ 3	$ 15,800	20%	$ 21,500	$ 37,400	8%
Pylon (20yr life)	$ 3	$ 15,800	20%	$ 61,500	$ 77,400	17%

*$30/pylon/10ft **Based on buffer width curve

Table 27. CTB vs. Pylon Katy Freeway Cost Comparison for 20 Foot Buffer Width.

Options	$/Lf*	Install Cost	Maint**	$ Maint.	Total	% CTB
Portable CTB	$ 30	$3,906,000	50.0%	$ 7,261,887	$ 11,167,887	100%
Pylon (7 yr life)	$ 3	$ 380,200	20%	$ 516,700	$ 896,900	8%
Pylon (20yr life)	$ 3	$ 380,200	20%	$ 1,476,300	$ 1,856,500	17%

*$30/pylon/10ft **Based on interview

As shown in Table 24 through Table 26 the application of pylons appears to have a net cost savings. ROW has not been included in these costs and only a few variations on buffer width were reported. The CTB also has a longer than 20 year life, which in reality could change the numbers to favor CTB over a longer assumed life.

A 4 ft. area is required for a CTB so the 2 ft. comparison is not valid but used for illustration. The 20 ft. buffer has a much reduced pylon maintenance cost due to the reduction in need for traffic control to replace pylons and a much lower rate of hits and replacement. The assumptions in these comparisons should be carefully reviewed when estimating for a new deployment since the sensitivity of some assumptions can result in significant differences in the estimated costs of a deployment application.

Conclusions

The above comparison gives a general idea of the differences between deployments of pylons versus CTB. This information can be used to assist designers when making decisions related to the use pylons or CTB. Some key factors to consider are:

- ROW (buffer space) and associated maintenance are two of the largest lifecycle deployment costs and can greatly influence the analysis and decision of which treatment to choose.
- ROW and maintenance are directly related Figure 51 shows the correlation between buffer space and maintenance replacement; however, this figure does not directly report costs.
- There are many other trade-offs regarding pylon versus CTB that may be considered:
  - Incident management.

  - Cost of enforcement.
  - Consistency of design in the region and state (driver expectancy).

Many of the variables are site specific and can drastically change the cost of the design depending on the location. This section should provide guidance on the factors that would influence the decision on separation types. The designer will need to evaluate the project to determine benefits and costs of the proposed treatments. The guidance provides an outline to guide the designer through the evaluation process.

Buffer Spacing

The buffer spacing is the space between the two facilities. There is a correlation between buffer width and maintenance. Wider buffers have been shown to potentially reduce number of pylon hits. HCTRA has found that even an 8 in. to 12 in. offset from the pylon to the edge of the travel lane results in a noticeable decrease in pylon replacement. Figure 54 shows an example. The same correlation between buffer space and pylon hits or replacement was found in the 0-6643 research.

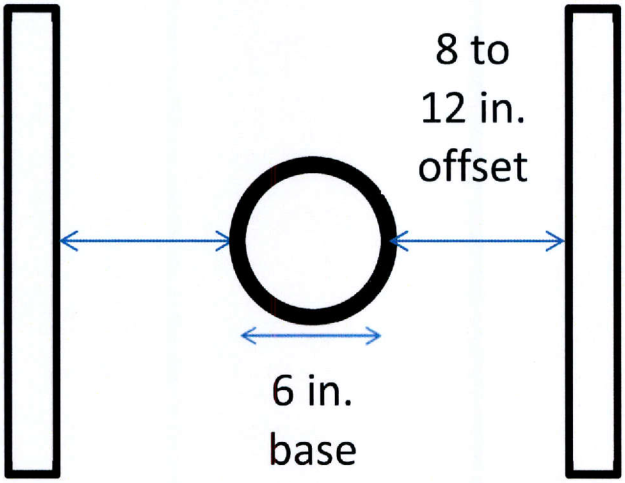


Figure 54. Increased Minimum Pylon Offset in Relation to Pavement Marking Edgelines.

Mounting Preference

The agencies surveyed prefer to use direct-pavement mounted pylons on higher speed facilities as shown in **Error! Not a valid bookmark self-reference.**. TxDOT prefers to use curbs in urban areas with lower speeds as shown in Figure 56. TxDOT indicated that they felt the curbs added more of a deterrent at the lower speeds.

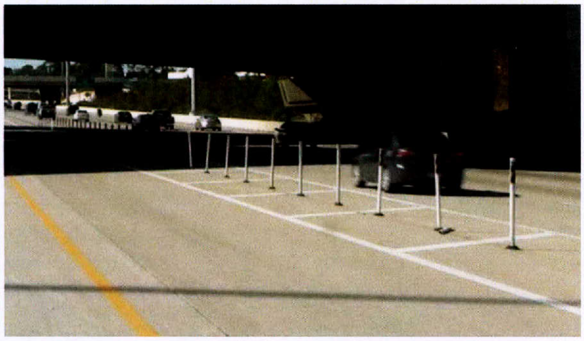


Figure 55. Pavement Mounted Pylon.

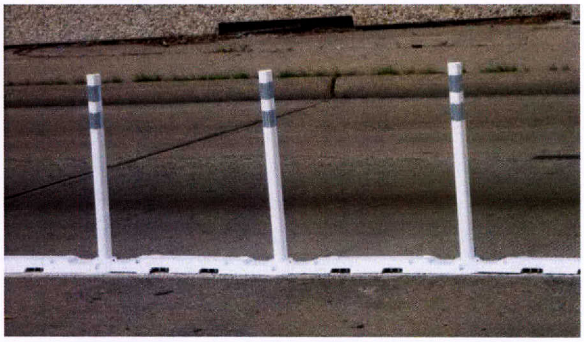


Figure 56. Curb Mounted Pylon.

PYLON CONTRAST

Contrast has been identified as a potential factor in reducing pylon replacement. Most agencies interviewed have experimented with using some sort of contrast technique such as chevron tape, different colors, or wider width pylons. The rationale to the use of contrast is that motorists have difficulty seeing the pylons at the entrance and exit locations, or that they are not conspicuous enough where other traffic control devices are present. These agencies reported no reduction in hit rate after contrast strategy was applied.

A potential strategy to increase target value could be using a black-white-black zebra or barber pole sequence. Examples of the various test patterns are shown in Figure 57. In addition to the contrast marking concept the pylon placement was also considered as part of the experimental design. Currently, the standard pattern is single file line. Figure 58 shows some alternative configurations that could be used to increase the target value of the pylon configuration. A side by side, even, soldier, or staggered pattern could double the target value (see Figure 58). These patterns could be combined with different size pylons to provide a depth component as well. Depending on the pattern and the success in reducing the number of pylon hits there could be an overall reduction in maintenance cost and activity.

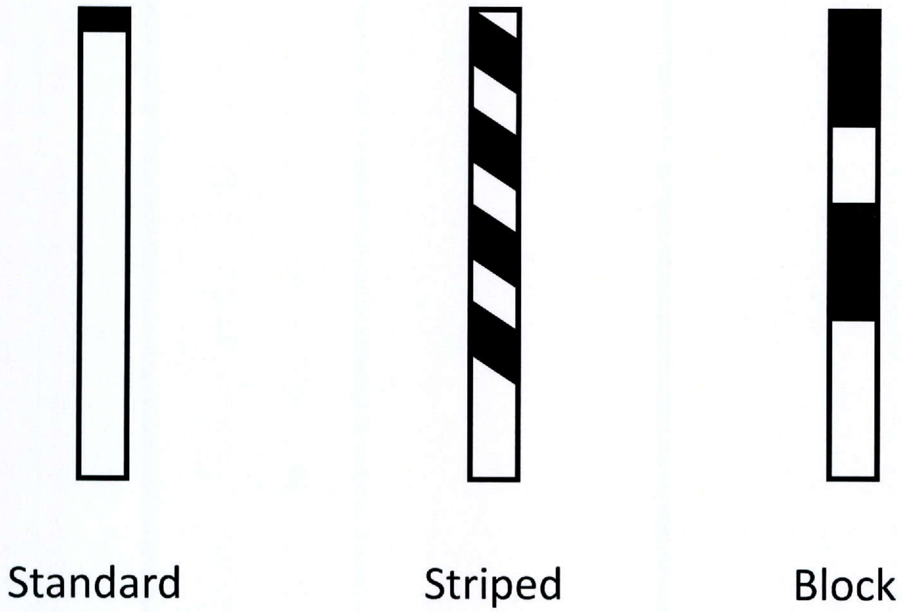


Figure 57. Potential Pylon Contrast Marking Patterns.

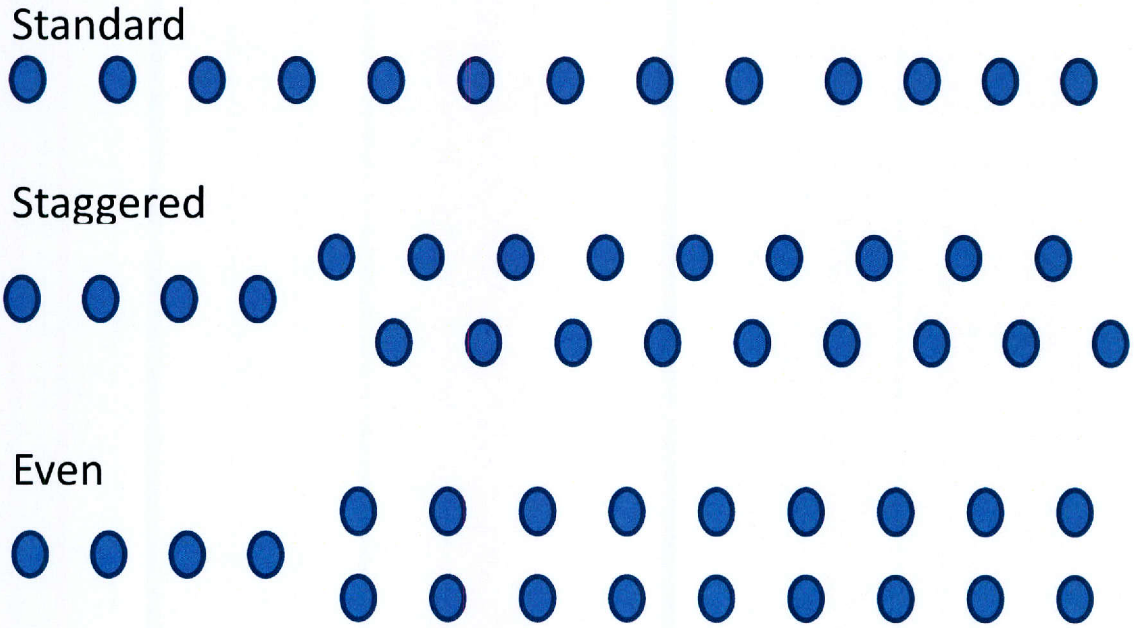


Figure 58. Potential Pylon Patterns.

Enforcement

All agencies interviewed mentioned that active lane use enforcement has resulted in a reduction in the number of pylon hits and subsequent replacement. Providing consistent enforcement and having the physical space to conduct enforcement activities were cited as beneficial elements in reducing maintenance and operational issues.

CONCLUSIONS

Several issues regarding the use of pylons on managed lanes and frontage road entrance and exit locations and possible the enhancements to existing and future facilities using them, were identified in this effort. These items included:

- Pylons were identified as one of the higher cost and higher intensity system maintenance items for managed lanes applications, and one of the items maintenance crews deal with a higher percentage of their time.
- Entry and exit gore areas typically have the higher hit rates. The causes of pylon hits in these areas are surmised to be driver workload at decision points and distracted driving.
- Enhanced enforcement can reduce the pylon hits.
- Contrast markings were perceived to be a solution for entrance and exit location pylon hits. However, no reduction was observed by the agencies.
- Pylons cost about $30 per unit (furnished and installed) for maintenance activities.
- Managed lanes typically have a lower maintenance cost due to fewer side-of-road maintenance items such as mowing, sign repair, and replacement.
- The public has an expectation that tolled facilities, including managed lanes, have a higher standard with regard to appearance, maintenance, and operations.
- Buffer width spacing of as small as 2 to 3 ft., which translates to 8 to 12 in. from pylon to edge line reduces maintenance and replacement. Experience indicates that wider buffer spacing reduces maintenance requirements further.
- Shorter, wider, and thicker profile pylons were reported to be more durable. Project 0-6772 *Development of New Delineator Material/Impact Testing Standard to Prevent*

Premature Failures Specific to Installation Application will investigate some of these aspects).

- Frontage road implementation criteria:
    - Access Management and Design Manual desired distance not minimum distances should be used to limit the impact of weaving maneuvers.
    - Evaluation can include: crash analysis, site visit, video analysis, and weaving analysis.
    - Education, enforcement, and engineering solutions should be considered.
    - Driveway diverters and pylons can be used to prevent or reduce some weaving maneuvers.
    - Most solutions have a fixed or ongoing cost, which should be considered in the selection of a solution.
- Raised pavement markings or profile markings may reduce pylon hits by enhancing the tactile and visual conspicuity of the pylon-treated area.
- Managed lane-related sign messaging, size and placement are challenging, but critical to provide safe operations and adequate warning time for motorist to make appropriate decisions. The use of pylons can reinforce the areas in which decisions can be made, but are not in themselves replacement for ineffective signing schemes.
- Retroreflective pavement marking tape was reported to have edge curl if little to no traffic runs over it to keep it down on the pavement. This can be an issue around pylons since less traffic runs over the tape near the pylons. Sweepers can significantly damage tape markings that curl, thus agencies should consider traditional paint or thermoplastic markings in these applications.
- Horizontal signing could also be utilized to reinforce the lane assignment at entrance and exit locations especially in areas were horizontal curvature can distort the lane/sign relationship.

CHAPTER 8: EXPERIMENTAL STUDY OF LONGITUDINAL SPACING OF PYLONS

This portion of the study determined the minimum spacing between pylons for which vehicles can weave between the pylons without a hit taking place. From the agency surveys, researchers found that most agencies responded that they do not have guidelines on spacing between pylons. However, many agencies have implemented pylons at 10 to 15 ft. spacing on preferential lane separation (and about 3 to 6 ft. on freeway ramp facilities) primarily on the basis of manufacturer recommendations, engineering judgment, or by trial and error. Shorter pylon spacing may tend to more discourage motorists from accessing restricted lanes, but this also increases initial and ongoing costs. Through this part of the project, researchers found it necessary to determine the minimum physical spacing between pylons that a motorist can weave without hitting the pylons at various speeds.

METHODOLOGY

The experiment was conducted at the Texas A&M Riverside facility (see Figure 59). Researchers investigated all runways for suitability to conduct the experiment. Runway 35L (shaded gray in Figure 59) was chosen based on the following considerations:

- Pavement smoothness (drive ride quality).
- Sufficiency of pavement width to perform required maneuvers.
- Unobstructed pavement length to achieve required speeds and safe stopping distance.
- Consistency of pavement color.
- Undistracted background from driver's level of view.
- Availability of facility.

Runway 35L consists of concrete pavement, with 12.5 ft. joints along the width of the runway and 20 ft. joints along the length. Concrete joints along the length were considered as lane lines for setting up the experiment. About 12 to 14 pylons were set up near the center of the runway along the longitudinal pavement joint as shown in Figure 60. Two pylons on both ends of the setup were temporarily glued to the pavement to be as realistic as possible to replicate as they are deployed in field (see Figure 61(a)), while the remaining pylons in-between were attached to 12 in. × 12 in. plywood base (see Figure 61(b)) and were deployed without gluing to the pavement so that the pylon spacing could be changed easily. As described in more detail later, drivers were asked to weave between the last gap in the pylon setup so if the test participants hit a pylon, it would be the glued pylons and not the free-standing pylons. At least 2000 ft. of distance was available on either side of the pylons (longitudinally) for motorists to accelerate to attain a certain test speed and to safely come to a halt at the other end of the test run. Table 28 shows the different combinations of pylon spacing and buffer used for different setups during the experiment. Reference markings were laid along the pylons at 5 ft. intervals, so that the spacing between the pylons could be quickly changed during the experiment.

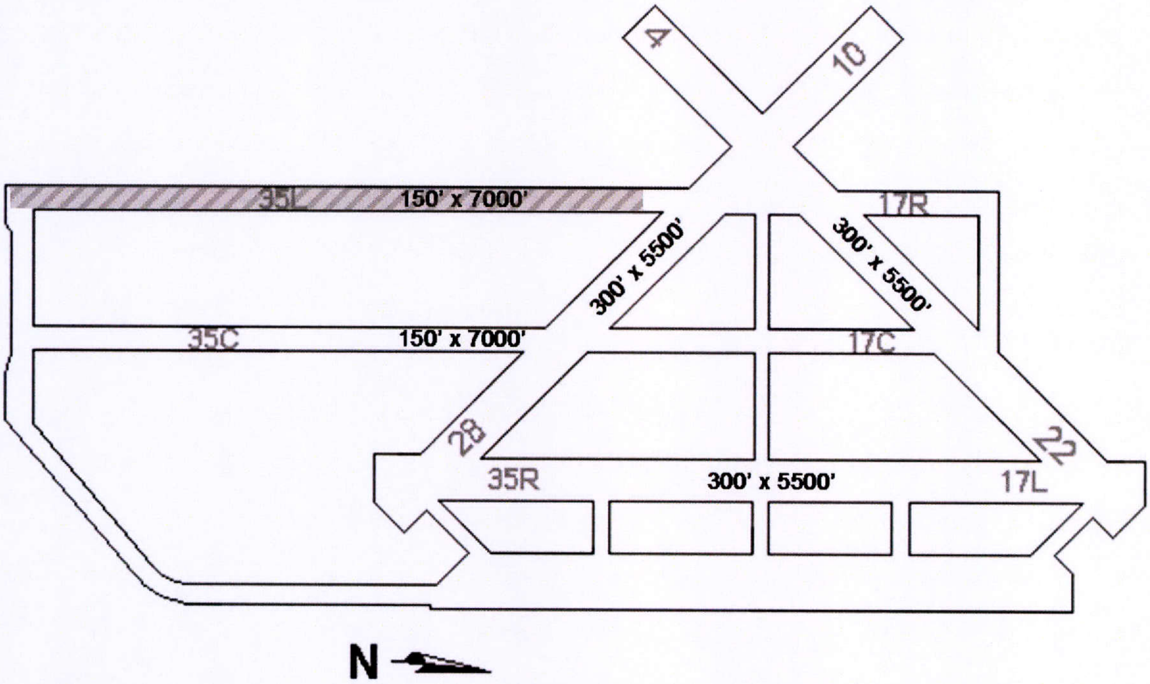


Figure 59. A Schematic of the Riverside Facility.

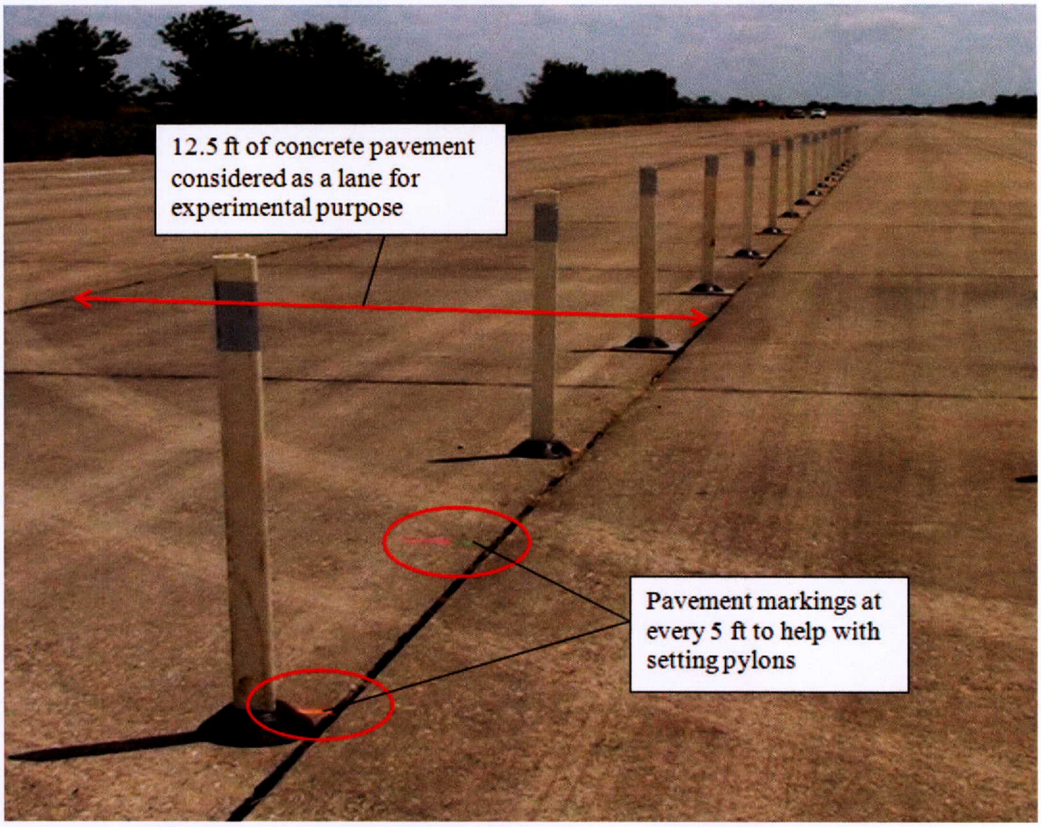


Figure 60. Pylon Setup at the Riverside Runway 35L.

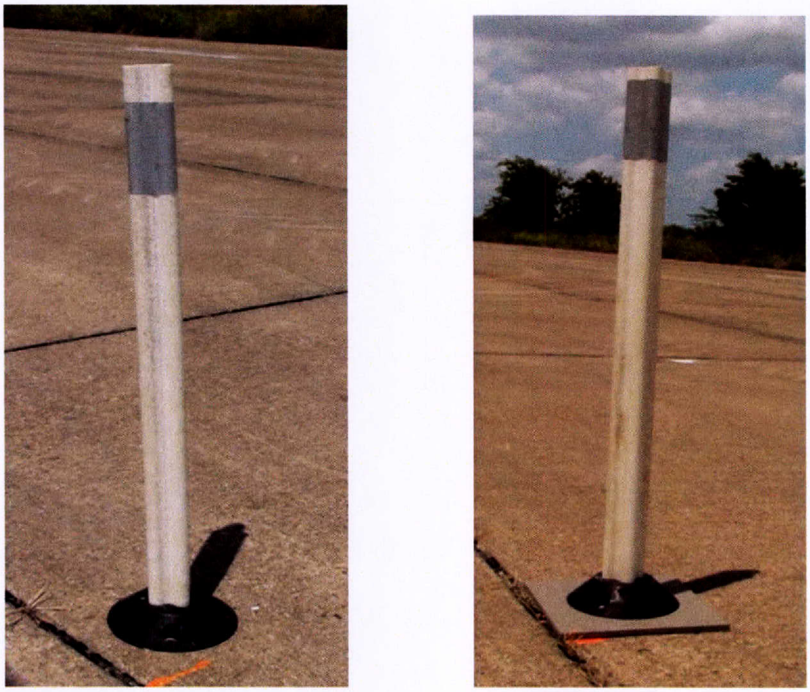

(a) End Pylons (b) Pylons fitted with Wooden Base

Figure 61. Pylons Used for the Experimental Setup.

Table 28. Pylon Spacing Buffer Combinations Used for Setup.

Pylon Spacing (feet)	Buffer Space (feet)
10	0, 6 & 12
15	0
20	0
25	0
30	0

Test Subjects

Four test subjects were used in this experiment. Two test subjects were in the age group of above 45 years and two other subjects were in the age group of less than 25 years. All the test subjects had a Texas Class C driver's license. Two subjects had prior training in high performance driving conditions, while the other two had predominantly driven under normal driving conditions. As of the gender distribution, three of the four test subjects were male and one of the test subjects was a female. The subjects will be referred to as Subject 1 to Subject 4 in order to conceal their identity.

Test Vehicles

Two test vehicles were used in this study, one was a 2004 Ford Taurus Sedan and other was a 2004 Chevrolet Trailblazer SUV. Some dimensions of both the test vehicles are presented in Table 29.

Table 29. Test Vehicle Specifications.

Measurement	2004 Ford Taurus	2004 Chevrolet Trailblazer
Overall Length	198 in.	183 in.
Overall Width	73 in.	68 in.
Overall Height	56 in.	64 in.

Source: Canadian Vehicles Specifications Database

The Chevrolet Trailblazer had an anti-lock brake system, while the Ford Taurus did not have the anti-lock brakes. Both vehicles were fitted with a Distance Measuring Instrument (DMI) to monitor speeds during the test.

Test Runs

The test subjects were instructed to drive by the side of the pylons such that the pylons were to their left, mimicking an inside-lane HOV or preferential lane situation. As the subjects approached the pylons they were asked to assess the gap between the pylons and attempt to weave between the last two of pylons without hitting or grazing the pylons. Subjects were asked to maintain a set speed during each run, and the subjects were allowed to start at any distance upstream of the pylon set up as long as they could accelerate to the required speed as they approached the beginning of the pylon setup. In addition subjects were also asked to be within the lane on the other side of the pylons after they weaved between the pylons.

Figure 62 shows a schematic of the test run scenario, wherein a test vehicle is shown traveling southbound (pylons to the left of the test vehicle), and attempting to maneuver through the last set of pylons. After weaving, the test vehicle was required to be contained within the northbound travel lane while continuing to travel south. If the vehicle could not be controlled within the northbound travel lane, then the amount of encroachment was noted.

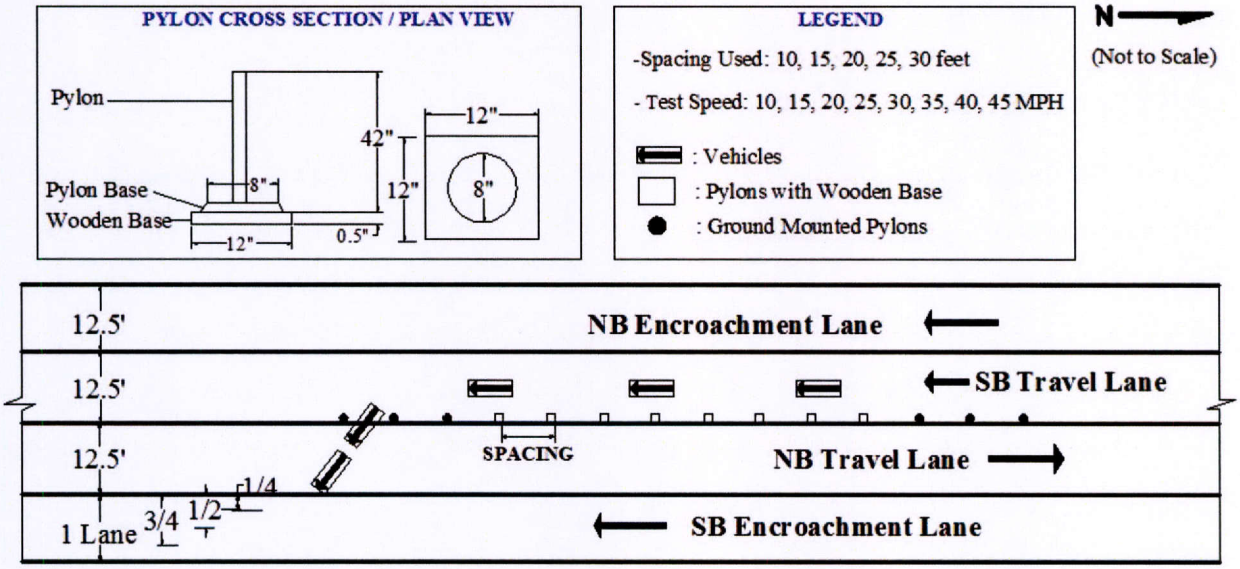


Figure 62. Schematic of the Test Run Scenario.

The test procedure involved each subject driving a test vehicle, starting with a 30 ft. pylon spacing at a speed of 15 mph. Subjects made three runs for each combination of speed and spacing. Test runs were deemed successful if the subjects could maneuver without touching the pylons or encroaching outside the travel lane. If two out of the three runs were successful, then the subject would drive the next set of three runs at an increased speed and if less than two runs were unsuccessful, then the subject would drive at a 10 mph speed (decreased speed). The lower and upper limits for speed were 5 mph and 30 mph, respectively. Speed was varied in a 5 mph increment. If the subject was successful at maneuvering between pylons spaced at 30 ft. apart at and below a certain speed, the pylon spacing was decreased to 25 ft. and subjects were asked to drive at different speeds as described previously. The lower and upper limit for pylon spacing during the test was 10 ft. and 30 ft., respectively. Pylon spacing was changed in 5 ft. intervals unless the subject was not successful in two out of three runs driving at 5 mph speed. When the subject was unsuccessful in two out of three runs then that spacing was considered as the minimum spacing a subject could physically maneuver in a given vehicle. The subject would then perform a similar set of test runs with the second test vehicle. Four subjects performed these test procedure, and in all, 334 test runs were performed over a four-day period. Tests were performed on days with clear weather, without rain or wet pavement to ensure visibility and safety was not compromised. No bias was introduced in the test results due to changes in weather or pavement conditions.

Data Collection

While the subjects drove the test vehicles, an observer was seated on the passenger side of the test vehicle to monitor DMI speeds. The passenger monitored speeds on a laptop connected to the DMI to ensure the test vehicle was travelling at required speeds along the test course. A minor change in speed (± 2 mph) just before the test subject begins to weave between the pylons was considered as an acceptable speed. But if a significant variation in speed was observed then the test run was disqualified. The passenger was also responsible to observe any hits occurred with the front pylon as the vehicle attempted to weave between the last set of pylons.

A second data collection crew was located on the encroachment lane slightly upstream of the point where test vehicles were instructed to weave between the last two pylons. Figure 63 shows a test vehicle weaving between the pylons during a test run, and an observation vehicle with data collection crew parked on the encroachment lane. The data collection crew in the observation vehicle noted any grazes or hits to the back pylons and as well noted the extent of encroachments that happened during the test run. Figure 64 shows an example of a test subject encroaching one-fourth of the lane adjacent to the travel lane after weaving between the pylons. A walkie-talkie was used to communicate test results from the passenger observing from the test vehicle to the data collection crew in the observation car. The data collection crew in the observation car was also responsible for coordinating the test runs and instructing the subjects by walkie-talkie. Table 30 shows a sample data collection sheet filled by the data collection crew.

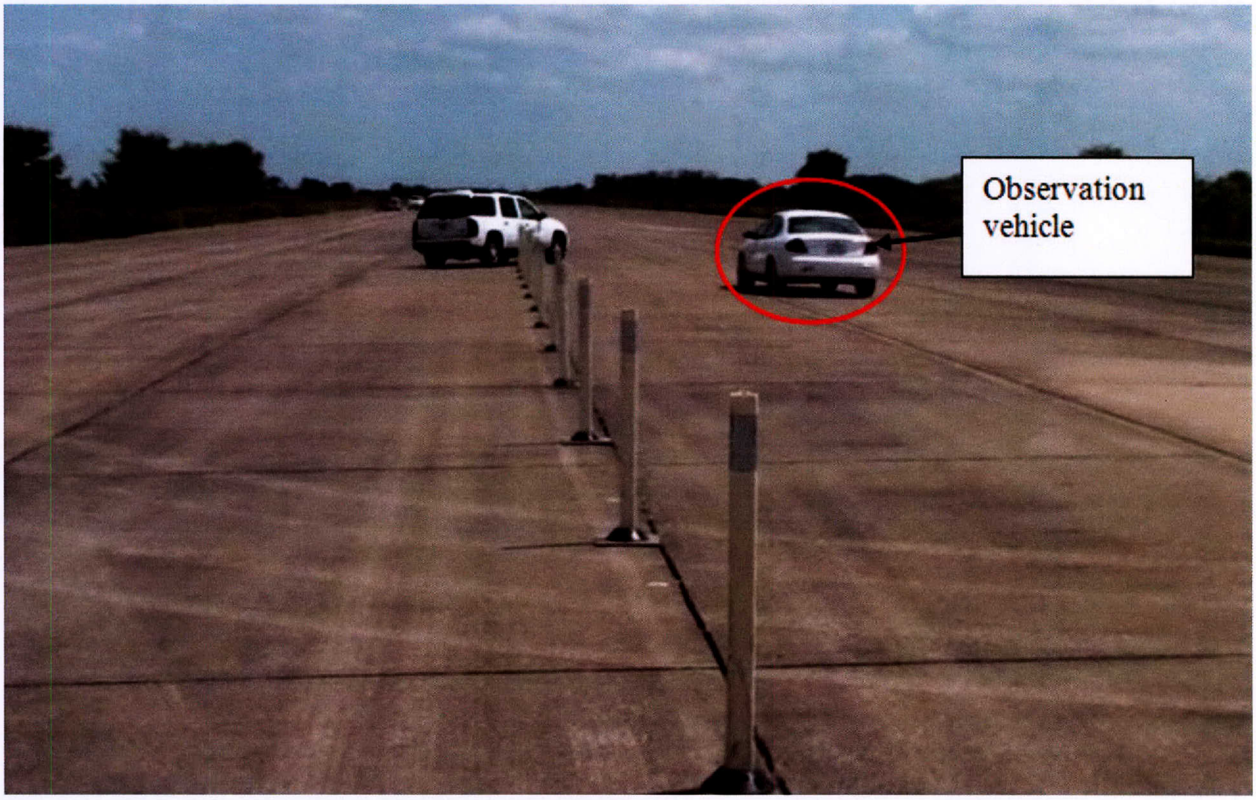


Figure 63. Data Collection from the Observation Vehicle.

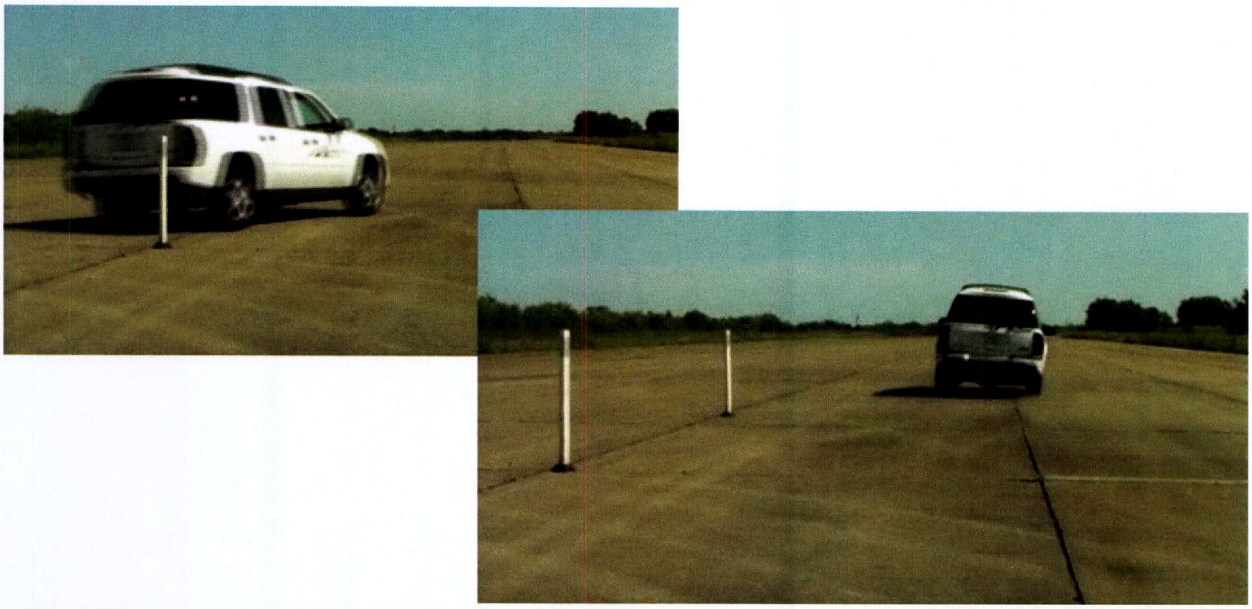


Figure 64. Test Vehicle Encroaching 1/4 Lane after Weaving between Pylons.

Table 30. A Sample Field Data Collection Sheet.

Date	Driver	Run	Spacing	Offset	Speed	Out of Lane	Back Hit	Back Graze	Front Hit	Front Graze	Travel Direction	Vehicle	Traction
6/1/2012	d	1	30	0	25	0	n	n	n	n	nb	sedan	n
6/1/2012	d	2	30	0	25	0	n	n	n	n	sb	sedan	n
6/1/2012	d	3	30	0	25	0	n	n	n	n	nb	sedan	n
6/1/2012	d	1	30	0	30	0	n	n	n	n	sb	sedan	n
6/1/2012	d	2	30	0	30	0	n	n	n	n	nb	sedan	n
6/1/2012	d	3	30	0	30	0	n	n	n	n	sb	sedan	n
6/1/2012	d	1	30	0	35	0	n	n	n	n	nb	sedan	n
6/1/2012	d	2	30	0	35	0	n	n	n	n	sb	sedan	n
6/1/2012	d	3	30	0	35	0	n	n	n	n	nb	sedan	n
6/1/2012	d	4	30	0	35	0	n	n	n	n	sb	sedan	n
6/1/2012	d	1	30	0	40	0.25	n	n	n	n	nb	sedan	n
6/1/2012	d	2	30	0	40	0	n	n	n	n	sb	sedan	n
6/1/2012	d	3	30	0	40	0.5	n	n	n	n	nb	sedan	n
6/1/2012	d	1	30	0	45	0.25	n	n	n	n	sb	sedan	n
6/1/2012	d	2	30	0	45	0.25	n	n	n	y	nb	sedan	n
6/1/2012	d	3	30	0	45	0.5	n	n	n	n	sb	sedan	n
6/1/2012	d	1	30	0	30	0.25	n	n	n	n	nb	suv	n
6/1/2012	d	2	30	0	30	0.5	n	n	n	n	sb	suv	n
6/1/2012	d	3	30	0	30	0.25	n	n	n	n	nb	suv	n
6/1/2012	d	1	30	0	35	0.5	n	n	n	n	sb	suv	n
6/1/2012	d	2	30	0	35	0.5	n	n	n	n	nb	suv	n
6/1/2012	d	3	30	0	35	0.25	n	n	n	n	sb	suv	n

EXPERIMENTAL STUDY RESULTS

Data collected from the experimental study were then analyzed and the outcome of each run was classified as either success or failure. Researchers considered two scenarios to judge the outcome of the run was successful as described below.

1. If there is no hit or a graze to either the back or front pylon and the test vehicle was completely within the travel lane after weaving between the pylons (strict criteria).
2. If there is no hit or a graze to either the back or front pylon and the test vehicle did not encroached more than quarter of a lane outside the travel lane after weaving between the pylons (relaxed criteria).

The second scenario was similar to the first scenario except a certain leeway was given in judging the success of the test runs by allowing slight encroachment outside the travel lane as in most real world scenarios motorists are not always confined to 12 ft. spacing. But in the actual test the subjects were instructed to contain within the travel lanes as much as they could. The summary of the test results for both the scenarios (strict and relaxed) is presented in Table 31 and Table 32. In Table 31 and Table 32, "n" represents the number of test runs in a particular category and shaded cells in the tables represents categories where in the number of successful test runs were greater than 50 percent of the total runs in that category.

EXPERIMENTAL STUDY FINDINGS

In Table 31, under strict conditions, none of the test subjects were able to successfully complete the run even at 5 mph speed. However at 15 ft. spacing, majority of the test runs were successful till 15 mph speed. Since somewhere between 10 and 15 ft. spacing was the cutoff spacing, researchers conducted some runs at 12 ft. spacing. Majority of the runs at 12 ft. spacing were not successful at either 10 mph or 15 mph speeds. Even at the 30 ft. spacing (maximum spacing tested), majority of the test runs were unsuccessful beyond 35 mph speed.

Under relaxed conditions also none of the test runs were successful at 10 ft. pylon spacing even when the subject drove at 5 mph speed. However at 15 ft. spacing majority of the runs were successful at speeds 20 mph and under.

Table 31. Test Results for Strict Scenario Case.

Spacing	5 mph		10 mph		15 mph		20 mph		25 mph		30 mph		35 mph		40 mph		45 mph	
	n	Success	n	Success	n	Success	n	Success	n	Success	n	Success	n	Success	n	Success	n	Success
10 ft.	6		2															
12 ft.			3	1	3	1												
15 ft.			3	3	26	15	22	9	18	3	9		2					
20 ft.							18	15	24	15	19	6	16					
25 ft.											21	17	21	6	20	2	2	
30 ft.					2	2	2	2	8	8	21	16	24	16	23	7	19	2

Table 32. Test Results for Relaxed Scenario Case.

Spacing	5 mph		10 mph		15 mph		20 mph		25 mph		30 mph		35 mph		40 mph		45 mph	
	n	Success	n	Success	n	Success	n	Success	n	Success	n	Success	n	Success	n	Success	n	Success
10 ft.	6		2															
12 ft.			3	2	3	2												
15 ft.			3	3	26	18	22	13	18	4	9	1	2					
20 ft.							18	17	24	17	19	11	16	3				
25 ft.											21	20	21	15	20	4	2	
30 ft.					2	2	2	2	8	8	21	19	24	20	23	17	19	7

At 30 ft. spacing, a majority of the runs were successful at 40 or 45 mph speed. Under relaxed conditions at 12 ft. spacing, the majority of the test runs were successful at both 10 mph and 15 mph speeds. There were some random differences in the test outcomes between the younger test subjects (less than 25 years) and older test subjects (greater than 45 years), however no specific pattern in the test results was observed between the two groups.

When a buffer space of 6 ft. was provided the under strict conditions, test runs at 5 and 10 mph were successful, but test runs at 15 mph were not successful. Increasing the buffer width to 12 ft., test runs up to 20 mph were successful. The test for the impact of increasing the buffer width in this experiment was intended to provide the driving subject additional offset to turn the vehicle closer to the pylon at less of a steep angle as opposed to if no buffer was allowed.

CHAPTER 9: SUMMARY AND RECOMMENDATIONS

This chapter provides a summary of the tasks performed in this project and findings from each task. In addition, recommendations for further research are presented in this chapter. The study design had five major tasks: 1) State of Practice Review, 2) Vendor Interviews, 3) Agency Surveys, 4) Case Studies, and 5) Experimental Study, to gather information on previous and current pylon deployments, the characteristics of and lessons learned, and measures in order to develop guidance on implementation of pylons.

REVIEW OF STUDY TASKS

State-of-Practice-Review

Researchers searched several transportation-related databases for relevant literature pertaining to flexible pylons, finding that pylons have been used for many different types of applications. Researchers also reviewed several standard manuals, including the MUTCD and AASHTO Roadside Design Guide among others, for available guidelines on implementation of pylons. While very little detail was found regarding specific guidelines for pylon design or use, some guidelines regarding the color and retroreflectivity of channelizing devices could be inferred from Sections 3H and 6F of the MUTCD. The MUTCD guidelines regarding the color of channelizing devices states that the color shall be the same as the color of the pavement marking that they supplement or shall be orange.

Researchers reviewed six preferential lane facilities where pylons have been deployed for lane separation. Information on the pylon implementation characteristics, including pylon color, mounting type, pylon spacing, buffer width, lane widths adjacent to pylons, pylon replacement rates, and estimated cost of maintenance of pylons were gathered from literature and through personal conversation with agencies maintaining the preferential lane facilities. Researchers investigated the relationship between buffer width and pylon replacement rate and observed a decreasing trend in the pylon replacement rate with increase in buffer width (see Figure 26). In addition, both lessons learned and deployment strategies used by agencies to reduce pylon hits were also documented.

Vendor Interviews

Researchers reviewed the qualified product list (or approved product list) of several DOTs and contacted 17 pylon manufacturers listed within. Questions were sent seeking information on the locations where pylons had been deployed and any implementation guidelines they provide to their customers regarding pylon spacing, buffer spacing, curb spacing, running length, pylon height, and pylon visibility. Five of the manufacturers responded to the questionnaire and two of the manufacturers indicated that they provide some guidance on pylon implementation to their customers. The following summarizes the guidance provided by the manufacturers:

- Pylon Spacing - one manufacturer indicated that they suggest 13 ft. spacing for high speed facilities and a maximum of 6 ft. spacing for lower speed facilities. Another manufacturer suggests 10 ft. spacing on preferential lane separation applications, but that 8 ft. pylon spacing performs better in terms of deterring motorists from crossing the pylons. Manufacturers said that they provide these guidelines on the basis of their experience deploying their products at various facilities.
- Pylon Height - one manufacturer recommends 36 in. tall pylons as they tend to be more durable when hit as compared to taller pylons 42 or 48 in.
- Curb Height - manufacturers responded that their curbs come in standard heights of 2.5 or 3.0 in.
- Curb Spacing - one of the manufacturers indicated that they recommend a minimum of 3.25 in. between curbs for drainage purposes, while another manufacturer said they recommend a minimum curb spacing of 0.5 to 1.0 in.

Agency Surveys

The agency surveys had two primary purposes: 1) gather information on the magnitude of use of pylons by various transportation agencies, and 2) to compile any guidance that agencies may be using to deploy the pylons. A total of 169 surveys were sent out to various transportation agencies in Texas and the United States. All TxDOT districts, state DOTs, cities in Texas with population over 50,000, and selected transit and tolling agencies in Texas were contacted. The survey consisted of 12 questions asking information on pylon use at high speed (greater than

50 mph) and low speed facilities (less than 45 mph), reasons for preferring pylons for lane separation, guidelines used for deploying pylons, and maintenance issues faced with pylon use.

In the survey, agencies were asked if they used any standard or anecdotal guidelines to implement pylons. Several agencies responded in the survey that they used guidelines for some design factors for implementing pylons, but upon follow-up, most agencies either used manufacturer recommendations, engineering judgment, or the pylons available in their approved product list. When agencies were asked why they choose to use pylons over concrete barriers, the most common reason cited by the agencies was that the pylons took less horizontal cross section width than typical concrete barriers and that they favored the lower initial cost to install pylons as compared to concrete barriers. When asked why they choose pylons over a buffer delineated by pavement marking only, most TxDOT districts chose "higher compliance" and "increased safety" equally (78 percent). However, among the other state DOTs, 80 percent indicated that the use of pylons results in higher compliance than just pavement marking buffer, but only 44 percent indicated that the use of pylons appear to have resulted in increased safety experience.

Nearly all agencies responding to the survey that had deployed pylons indicated that they found pylons beneficial for the purpose used. However, a majority of the agencies also indicated that they had issues with pylon replacement or pylons getting dirty and losing their target value. A majority of the agencies attributed hit and missing pylons to driver disregard and inattention. About half of the agencies who responded indicated that pylon durability issues were a reason for frequently missing pylons. Most of the agencies who had used pylons on managed lanes (or express lanes) knew that they lost their pylons at decision points (entrances, exits, or before interchanges).

Case Studies

The purpose of the case study task was to observe the actual field operation of pylon implementations at selected locations. Observations were made at 17 locations where pylons had been deployed. Researchers viewed the videos for each site and noted instances when pylons were hit by motorists or when motorists nearly hit the pylons. Other observations related to driver behavior before and after the hit, including traffic, weather, and incident conditions at the time of hit were noted. Other data, including geometric details, pylon installation details, traffic volumes, and speeds were gathered. Researchers observed the hits and near misses to characterize pylon hits; if the hits were intentional, conditions when pylons were hit and driver behavior before hitting the pylons were categorized. The compiled data were also analyzed for each site to identify trends in pylon hits and near misses with respect to traffic volumes and speeds. An attempt was also made to fit statistical models to correlate the frequency of hits or near misses with various geometric and pylon implementation factors such as buffer space, pylon spacing, gore gap, pylon mounting type, and pylon end treatment. Some findings from the video case study effort included:

- A majority of the hits at all locations were intentional and involved light vehicles such as sedans, SUVs, and pickup trucks.
- On preferential lanes, the majority of the hits and near misses occurred during congested periods when motorists were entering preferential lanes from general purpose lanes.
- There appears to be a clear trend indicating a decreasing number of pylon hits observed as buffer width increases on preferential lane tangent sections.
- There appears to be a clear trend that pylon hits (and near misses) increase:
    - As general purpose lane volume increases relative to preferential lane volume.
    - As speed differentials between preferential lanes and general purpose lanes increase.
- Impact of land use and proximity of driveways on the freeway ramp pylons hits and near misses was apparent.
- Exit ramps had lesser rate of hits and near misses as compared to entry ramps.

In addition to the video based analysis, researchers also did a crash analysis at five freeway ramp locations to capture the safety impacts of pylon use when used to separate ramp lanes from frontage lanes. Five years of crash data were collected from TxDOT's CRIS database. The crash reports were analyzed for all data and pylon related crashes were identified. The pylon related crash rates (crashes per year) were tabulated for each site for the before and after pylon implementation periods. At two sites, a decrease in pylon related crashes was observed but at one site an increase in pylon related crash rate was observed. At the remaining two sites either no pylon related crashes were observed or the before period data were not available. Based on the limited crash data available the effect of safety in using pylons at freeway ramps was inconclusive.

Another subtask completed for the case study task was to capture the maintenance experience of agencies in Texas with the use of flexible pylons on preferential lanes. Researchers contacted HCTRA, METRO, TxDOT, and DART maintenance personnel and sought information on maintenance costs, time expended, and other major maintenance issues. Researchers also sought information on criteria used in decision making as to when pylons should be considered for installation. Pylons were cited by all agencies as one of the top three cost and time-consuming maintenance issues among all other maintenance activities on preferential lanes. One of the agencies indicated that, as per their observation, even a small increase in buffer width resulted in significant decrease in pylon replacement.

Experimental Study on Pylon Spacing

Researchers conducted a closed-course study at the Texas A&M Riverside campus to determine the minimum pylon spacing a motorist could maneuver without hitting the pylons traveling at various speeds. This test was designed to determine the physical limits of a motorist to maneuver between pylons at different speeds. If larger spacing can be used under certain conditions (operational speeds or traffic volumes) cost savings could result.

The test setup included 12 to 14 pylons placed at a spacing that was varied 10 to 30 ft. A test subject drove a test vehicle at a set speed between 5 mph to 45 mph and weaved between the last two pylons. Test subjects were asked to weave between the last two pylons without hitting the pylons or encroaching out of the lane after weaving through the pylons. With a combination of four test subjects, two types of test vehicles (sedan and SUV), five different pylon spacing (10 to 30 ft. with 5 ft. increments), and possibly nine different speeds (5 mph to 45 mph with 5 mph increments), a total 334 runs were conducted. For each of the test runs an observer noted if the test vehicle hit the pylons or if the vehicles encroached outside the lane after the maneuver.

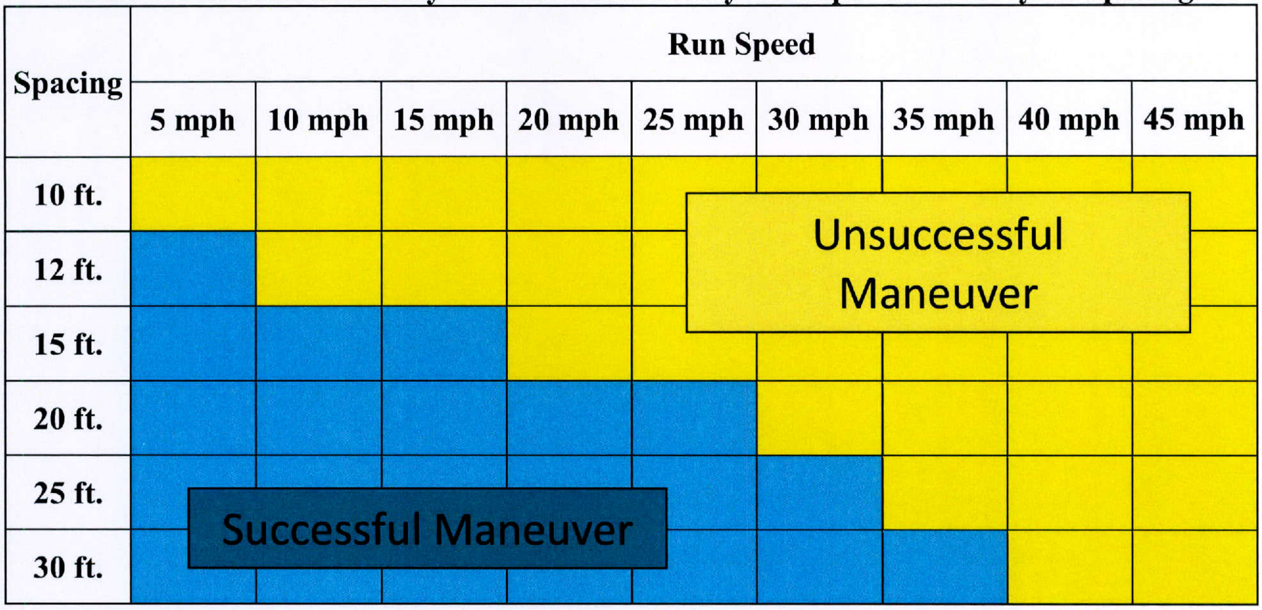
Two criteria were used to judge if a test run was successful or not:

- Criteria 1: If the test vehicle did not hit the pylon and if the test vehicle did not encroach outside the lane adjacent to the pylons after maneuvering between the pylons then the test run was deemed successful.

- Criteria 2: Similar to Criteria 1, except that if the test vehicle encroached less than a quarter lane outside the lane adjacent to the pylons then the run was considered to be successful.

For both scenarios, the percentage of successful runs for a given set of spacing and speed was tabulated. All the cells that were more than or equal to 50 percent of runs were successful and were color coded in blue; other cells were coded in yellow. The color coded tabulation for scenario 1 and scenario 2 are shown in Table 33 and Table 34, respectively. As seen in Table 33 and Table 34, in both scenarios 10 ft. pylon spacing was the minimum threshold spacing where none of the subjects could successfully weave between pylons at any speeds ranging from 5 mph to 45 mph. The speed at which motorists can successfully maneuver without hitting or encroaching appeared to increase linearly with spacing. A linear trend with proportionally increasing speeds with increased spacing was also seen with the relaxed Criteria 2. Some limited tests were performed with 10 ft. pylon spacing where test subjects drove at offsets of 3 ft. and 6 ft. away from the pylons and then tried to maneuver between the pylons (simulating as if pylons were installed with buffer width of 6 ft. and 12 ft.). At 3 ft. offset, a majority of the runs were successful (no pylon hits or encroachment) up to 10 mph speeds. At 6 ft. offset (representing a 12 ft. buffer), a majority of the runs were successful (no hits or encroachment) up to 20 mph speeds. Table 33 and Table 34 may provide TxDOT engineers guidance as to the speeds they may expect to see motorists weaving between the pylons when pylons are spaced at certain distances.

Table 33. Criteria 1: Ability to Weave between Pylons: Speed versus Pylon Spacing.

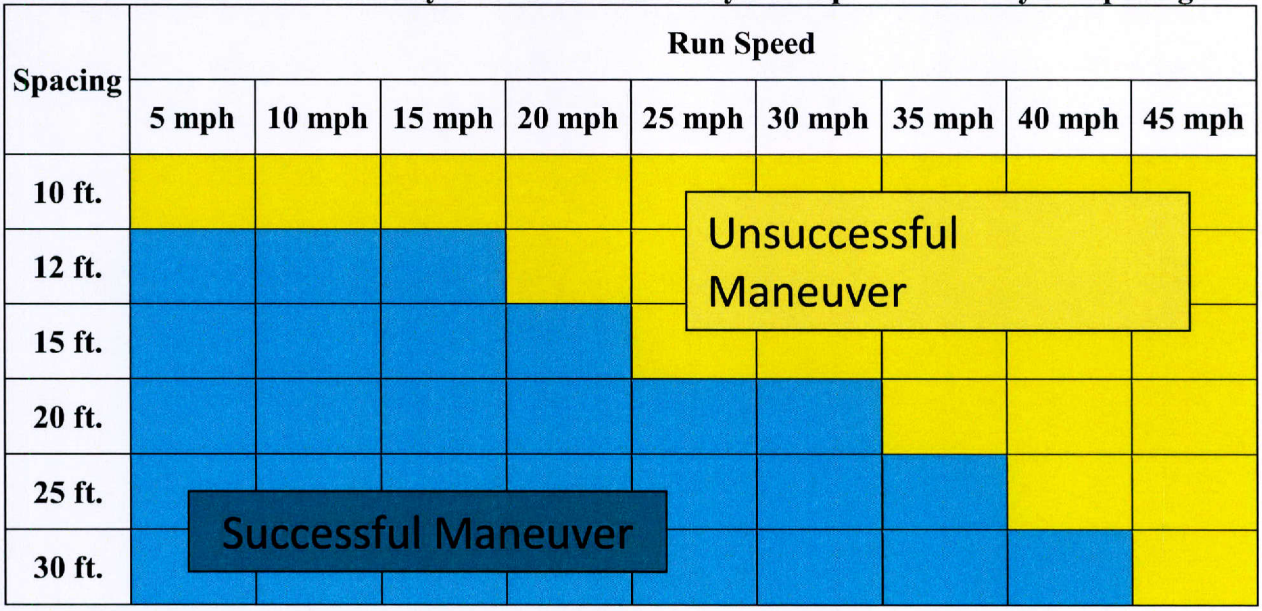


Spacing	Run Speed								
	5 mph	10 mph	15 mph	20 mph	25 mph	30 mph	35 mph	40 mph	45 mph
10 ft.	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
12 ft.	🟦	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
15 ft.	🟦	🟦	🟦	🟨	🟨	🟨	🟨	🟨	🟨
20 ft.	🟦	🟦	🟦	🟦	🟦	🟨	🟨	🟨	🟨
25 ft.	🟦	🟦	🟦	🟦	🟦	🟦	🟨	🟨	🟨
30 ft.	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟨	🟨

🟨 Unsuccessful Maneuver

🟦 Successful Maneuver

Table 34. Criteria 2: Ability to Weave between Pylons: Speed versus Pylon Spacing.



Spacing	Run Speed								
	5 mph	10 mph	15 mph	20 mph	25 mph	30 mph	35 mph	40 mph	45 mph
10 ft.	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
12 ft.	🟦	🟦	🟦	🟨	🟨	🟨	🟨	🟨	🟨
15 ft.	🟦	🟦	🟦	🟦	🟨	🟨	🟨	🟨	🟨
20 ft.	🟦	🟦	🟦	🟦	🟦	🟦	🟨	🟨	🟨
25 ft.	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟨	🟨
30 ft.	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟨

🟨 Unsuccessful Maneuver

🟦 Successful Maneuver

RECOMMENDATIONS FOR FURTHER RESEARCH

This research provides a broad understanding of potential reasons as to why, and under what conditions, pylons are hit—and under what configurations future deployments can be deployed most effectively. Researchers were also able to derive some trends between pylon hits and other factors, including traffic volumes, speed differential on either side of pylons, and buffer spacing. Qualitative guidance, as presented in Chapter 10, is provided based on the field observation, surveys, and analysis of pylon hit trends. However, precise guidelines based on statistically significant analyses were not derived in this study. However, the trends in pylon hits as observed in this study indicates that a more detailed analysis, consisting of additional data collection and statistical modeling could be used to determine statistically significant factors that influence pylon hits, albeit a larger number of sites and amount of data would need to be collected.

Researchers surmised that on some freeway ramp-frontage road pylon applications that weaving distance could be affected when pylons are used beyond the ramp gore area. A more detailed study may be warranted to determine guidelines on the weaving distance requirements to maintain when using pylons for separating ramp lane and frontage lanes. Researchers also found that agencies do use consistent criteria to deploy pylons on frontage-ramp sites. Development of a consistent criteria or guidelines as to where pylons need to be deployed should be beneficial, but was beyond the scope of this project.

Two other items of potential research could be: 1) the impact of pavement marking enhancements on approach to a preferential lane exit and entrance locations (especially where sight distance to preferential lane entrance is limited due to a vertical or horizontal curvature on the approach to the entrance); and 2) how better traveler information could be used to inform drivers of the current speeds and/or travel times on preferential and general purpose lanes so that a better decision on which facility to use could be made farther upstream, or minutes before a decision point as opposed to a last-second decision.

CHAPTER 10: GUIDANCE FOR PYLON IMPLEMENTATION

This chapter provides guidance for implementation of pylons for lane separation on preferential lanes and freeway entry and exit ramps to frontage roads. The guidance presented here are indicative in nature to enable readers to make informed decisions, or to supplement or support engineering judgment, but do not direct any specific course of action regarding pylon implementation. The scope of the guidance presented herein, along with application of engineering judgment, should allow TxDOT staff to develop policies regarding pylon use.

GUIDANCE ON PYLON COST AND SPACE REQUIREMENTS

Pylons are perceived by most transportation agencies as a cheaper alternative to other lane separation devices such as Jersey Barriers (CTB). While the initial implementation cost of pylons is considerably less compared to CTBs, the life cycle cost of maintenance of pylons may not always be cheaper compared to CTBs. Some indicative implementation cost of a typical pylons and a typical CTB is presented in Table 35. These costs may vary depending on quality of pylons, mounting type of pylons, and type of crash cushion used at the beginning of the CTBs.

Table 35. Typical Cost for Lane Separation Treatments.

Lane Separation Type	Average Implementation Cost (per linear feet)
Pylons (without curbs, 10 ft. spacing)	$30
Pylons (with curbs, xx ft. spacing)	$55
Portable CTB (without crash cushion, per linear foot)	$30
Crash Attenuator	$8,700

Some typical maintenance cost of pylons on various managed lanes is presented in Table 36. However some of the maintenance cost presented here is the overall maintenance contract for maintenance of preferential lanes and not necessarily for maintenance of pylons only. Table 36 also presents typical rate of pylon replacements on preferential lanes that will provide readers some indication of pylon replacement cost.

Table 36. Estimated Pylon Maintenance Cost.

Location	Yearly Maintenance Cost*	Average Yearly Pylon Replacement Rate (percent)	Length of Pylons (miles)	Estimated Pylon Replacement Cost Per Mile
IH 10 Katy Managed Lane, Houston, TX	$162,000	25	22	$7,400
IH 635 HOV Lane, Dallas, TX	$557,000	70	24	$23,200
US 75 HOV Lane, Dallas, TX	$650,000	70	28	$23,200
SR 91 Managed Lane, CA	$540,000	100	20	$27,000
IH 95 Managed Lane, FL	$440,000	115	42	$10,500
IH 15, Managed Lanes, Las Vegas, NV	NA	300	40	NA

Note: * indicates value of maintenance contract amount for all managed lane maintenance work.

There are other factors that are found to influence maintenance cost of pylons. Anecdotally, enforcement on the facility where pylons are installed is found to significantly reduce the number of times pylons get hit, and in-turn reduces the pylon replacement cost. Buffer width, spacing between pylons, agency maintenance or replacement policy, type of pylons used, access density, and motorists education and familiarity with pylons also influence the replacement rate and hence maintenance cost of pylons. Hence decision on the suitability of using pylons for managed lane or freeway ramp lane separation should be made being cognizant of the expected maintenance cost and in conjunction with other factors that influence pylon maintenance. For example if a managed lane is expected to have automated enforcement and violators crossing the pylons are strictly enforced then a use of pylons for lane separation is viable.

GUIDANCE ON PYLON IMPLEMENTATION

When an agency determines that pylons may be a suitable device to provide lane separation on a preferential lane or a freeway ramp, there are several aspects of using these devices that need to be considered to implement pylons in the most efficient manner. The initial decision is whether to use a curb-mounted pylon or a directly mounted to pavement assembly. Subsequent decisions regarding pylon spacing, buffer width, pylon height, pylon color, pylon retroreflectivity for night time visibility, and running length (mostly for freeway ramp to frontage road installations). This section provides guidance on various pylon implementation factors may be considered when implementing pylons on preferential lanes or freeway ramps.

Curb-Mounted vs. Pavement-Mounted Pylons

The use of curb-mounted pylon assemblies is often preferred on freeway ramp installations to provide separation or access restriction at frontage roads. It is perceived by many that curbs offer another dimension of barrier as compared to pavement mounted pylons. Some anecdotal experience shared in the agency surveys indicate that curbs may move, especially when used on curved sections, due to the centrifugal force thrust by the wheels when vehicles go over the curb. This condition may typically require more frequent maintenance. Even though they typically carry a higher initial cost, curb-mounted pylons are often used on shorter length situations (typically less than 1000 ft.) when engineering judgment leans to the need for an enhanced barrier feel or presence.

On preferential lanes, the use of curb-mounted pylons is perceived not to provide additional benefits. In one case, when pavement-mounted pylons were replaced with curb-mounted pylons at a preferential lane entry ramp, no reduction in pylon hits was observed. On several facilities, observation of preferential lane operation with curb-mounted pylons indicated that use of curbs does not appear to deter motorists from crossing the pylons. Given that the use of curbs on preferential lanes adds significantly to the initial implementation cost and ongoing maintenance costs, it is likely the optimal application to separate preferential lanes is using directly pavement-mounted pylon assemblies.

Longitudinal Pylon Spacing

Based on the experimental tests, no less than 10 ft. spacing is recommended for preferential lane separation applications. On preferential lane tangent sections, longitudinal spacing of 15 ft. may be acceptable where sight distance on the approach to the section is not restricted. On roadway segments with a history of a higher number of crashes or a high rate of violations, a spacing of 10 ft. is recommended. On segments of roadway where strict enforcement is provided and violations are minimal, a larger pylon spacing, up to 20 ft. may be considered.

Near the entry and exit access locations on managed lanes, a minimum of 10 ft. spacing is recommended. It is the first few pylons that are hit most at access locations on managed lanes. To combat frequent pylon hits near access locations, the following strategies are suggested:

- Use advance signing and horizontal pavement markings to provide guidance to motorists on the approach to the entry or exit access location, particularly when sight distance may be restricted due vertical or horizontal curvature.
- Avoid preferential lane access points at locations with horizontal or vertical curvature that may reduce sight distance.
- Consider moving access upstream or downstream to avoid sight distance or weaving issue when close to an interchange.
- Consider enhancements to pylons at the start of a run, such as transverse striped pylons, staggered dual row of shorter pylons, reflective pavement markers in a denser pattern, or paddle type pylons to increase visibility.

For freeway ramp-frontage road lane separation or access restriction applications, a pylon spacing of 6 ft. is acceptable in most cases. Spacing of 3 ft. may be used to provide a more restrictive barrier configuration to deter motorists from crossing the pylons. When curb-mounted pylons are used, drainage requirements at a specific site may influence the minimum spacing between the pylon units.

Buffer Width

Evidence from surveys, case studies, and the state-of-practice review unanimously indicates that larger buffer widths reduce the likelihood of vehicles hitting pylons. Wider buffer also provides opportunity for enforcement, area for maintenance, and potentially space for vehicle refuge. Several elements associated with buffer width determination are:

- Placement of pylons resulting in a distance from pylon to edge of travel lane of 4 ft. to 8 ft. should be avoided. Providing 4 ft. to 8 ft. of shoulder is discouraged as a vehicle taking refuge in a shoulder of that width partially encroaches on the adjacent travel lane, but not so much as to slow vehicle speeds in that lane. This may result in unsafe operations.
- Some respondents in the agency survey indicated concern when buffer width is more than 10 ft. on one side of the pylons as that width may be confused as a travel lane.

However, this was not seen in observation of traffic operations on the Katy Managed Lanes.

- Provision of a wider buffer width may not always be possible on facilities retrofitted with preferential lane. In such cases where buffer width less than 5 ft. is provided, anecdotal evidence from surveys suggests that heightened enforcement (rowing or automated) can reduce the violation of motorists crossing through the pylons.
- It appears that more pylon hits occur on curves when buffer width is relatively small. If geometry allows, consider providing more buffer width on curves, with unbalanced buffer as needed to provide more encroachment space on curves (e.g., on the right side of a curve to the left when the pylons are on the right; or on the left side of a curve when the curve is to the right and pylons are on the left).

Some of the strategies that have been taken to provide buffer space include reducing lane widths and/or shoulder width to gain additional space for buffer width around pylons. However, AASHTO's minimum recommended lane widths and shoulder widths to maintain the required capacity of travel lanes and safety standards should be considered.

Pylon Height

The 2009 MUTCD, section 6F.65 states that the tubular markers shall not be less than 28 in. when used on freeways or other high speed facilities. However 36 in., 42 in., and 48 in. pylons are commonly used for lane separation applications. Some anecdotal evidence obtained from surveys and interviews indicate that taller pylons are less durable when hit by vehicles. Pylons that are 42 or 48 in. in height when hit by vehicles (especially lower profile, sedan-type vehicles) can excessively flex, damaging the pylon, and bend to create dents on the front or hood of a vehicle. The forces involved in a vehicle hit on a taller pylon increase the probability of the pylon being ripped off their base. While the shorter 36 in. tall pylons are perceived to be more durable, some concerns about their visibility in taller vehicles were expressed in the surveys. Use of 36 in. pylons is suggested at locations where pylons are frequently hit, such as at entry and exit access locations to preferential lanes. On preferential lane tangent locations, the use of 48 in. pylons is suggested to provide enhanced visibility and separation.

Running Length

Pylon running length is important, particularly on freeway ramp and frontage road lane separation applications. Pylons are typically implemented within the gore area (from hard gore point to end of gore) and may extend past the gore point to discourage motorists from turning to or from driveways or cross streets, which are spaced closely to ramps. Typically, pylons are extended at least 100 ft. past (at an exit ramp), or start 100 ft. before (on an entry ramp) a side street access or driveway location. While the running length of the pylons should extend past the driveway or cross street of concern, the effective weaving area should be checked to ensure that the length of the pylons does not decrease the minimum required weaving distance given traffic volumes and speeds.

Pylon Color and Retroreflectivity

White, yellow, and orange pylon posts have been typically used for lane separation and channelization applications on roadways. The 2009 MUTCD specifies that channelizing devices used outside of the work zone shall be 1) the same color as the pavement marking being supplemented or replaced, or 2) orange. Use of yellow pylons on preferential facilities to separate lanes in the same direction of travel leads to conflict with typical motorist understanding where yellow pavement markings are used to separate lanes with opposing traffic. Hence, the use of yellow pylons for lane separation on preferential lanes (in same direction of travel) is not consistent with MUTCD compliant practices.

MUTCD Section 3H.01 states that when channelizing devices are used outside of the temporary traffic control zones, the retroreflective sheeting attached to the device shall be white if the device separates traffic flow in the same direction and shall be yellow if the devices separate traffic flows in the opposite direction. MUTCD Section 6F.65, concerning the retroreflectivity of tubular markers for work zones, states that the retroreflective material used on tubular markers that have a height of less than 42 in. shall be provided by two 3-inch wide white bands placed a maximum of 2 in. from the top with a maximum of 6 in. between the bands. Retroreflectorization of tubular markers that have a height of 42 in. or more shall be provided by four 4- to 6-in. wide alternating orange and white stripes with the top stripe being orange. Since none of the TxDOT districts or the state DOTs expressed concern over the amount of retroreflectiveness of the currently used pylons, the MUTCD specification with respect to area of retroreflectorization (of white retroreflective bands) should be used as guidance for pylons used on preferential lane separation application also. For higher conspicuity alternating black and white retroreflective sheeting can be used as needed.

Some concerns about the retroreflective sheeting not being durable enough and pylons getting dirty, decreasing the visibility of the pylons were expressed during the surveys. Hence frequent maintenance of pylons such as pressure washing dirty pylons when possible and replacing pylon post with insufficient retroreflective sheeting is suggested.

GUIDANCE ON MAINTENANCE OF PYLONS

Pylons were identified as one of the most frequent maintenance items and had the highest cost. The replacement rate is related to the buffer width, the larger the buffer width the lower the replacement rate. Replacement rates range from 20 percent per year with a 22 foot buffer width to 115 percent with a two foot buffer and 300 percent with a 1.5 foot buffer.

Entrance and exit locations have the highest hit rates. Both managed lanes and freeway entrance exit locations had the highest hits at decision points. Frontage road entrance and exit locations should use access management and design manual desired not minimum distances to limit the impact of weaving maneuver. Evaluation and installation criteria should include crash analysis, site visit, and could include weaving analysis.

Facilities with heavy congestion and small buffer widths can have high hit rates in tangent sections. The tangent section hit rates are also dependent on the driving population, with some areas experiencing a noticeable hit rate in congested conditions while others have a low hit rate in congested conditions.

Shorter, wider and thicker profile pylons were reported to be more durable. Project 0-6772 Development of New Delineator Material/Impact Testing Standard to Prevent Premature Failures Specific to Installation Application will investigate some of these durability aspects.

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APPENDIX A.
VENDOR QUESTIONNAIRE

A VENDOR QUESTIONNAIRE ON FLEXIBLE PYLON PRODUCTS AND IMPLEMENTATION LOCATIONS (PROJECT 0-6643, TASK – 2)

CONTACT INFORMATION

Name:	
Position:	
Organization:	
Email:	
Phone number:	

Texas Transportation Institute (TTI) is currently working on a research project (0-6643) for the Texas Department of Transportation (TxDOT) to develop guidelines for the implementation of flexible pylons on freeway, HOV, and managed lane facilities. As a part of this research, TTI is sending out this questionnaire to selected manufacturers/vendors to solicit information on the locations where flexible pylon products are implemented for lane separation or channelization on high speed facilities.

The flexible pylons studied in this project is also variously termed as flexible delineator post, tubular markers, flexible channelizer, curb mounted delineator, or plastic candle stick. These pylons can be curb mounted or pavement (surface) mounted. If you need any clarifications on the questionnaire please contact Mr. Robert Benz by phone or email given below.

Please complete the survey by June 3, 2011, and return the survey by email (r-benz@tamu.edu) or by fax (713-686-5396).

Mr. Robert Benz, P.E.
Research Engineer
Texas Transportation Institute
701 North Post Oak Suite 430
Houston, Texas 77024
Phone: 713-686-2971 x15118
Cell: 281-686-2971
Email: r-benz@tamu.edu

Thank you for your assistance!

1. List all locations where your flexible pylon products (pavement mounted or curb mounted only) are installed on high speed (speeds > 45 MPH) facilities for lane separation or channelization:

Location (facility, limits, city or county, state)

(Example) IH 10, IH 610 to SH6, Harris County, TX

1.
2.
3.
4.
5.
6.
7.
8.
9.
10.
11.
12.
13.
14.
15.
16.
17.
18.

Purpose

19.
20.

Separate managed lanes and general purpose lanes

2. Please provide the details for the above listed pylon implementations.

Location #	Pavement or Curb Mounted	Pylon Product Name Or Part Number	Agency for Which the Pylon Was Installed	Agency Contact (for Further Information)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Location #	Pavement or Curb Mounted	Pylon Product Name Or Part Number	Agency for Which the Pylon Was Installed	Agency Contact (for Further Information)
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				

3. Do you use any guidelines while installing or provide guidance to the agency using your flexible pylon products for the following pylon implementation factors:
    - Pylon Spacing *(distance between adjacent pylons)* Yes ☐ No ☐
    - Pylon Height *(measured from pavement surface to top of post)* Yes ☐ No ☐
    - Pylon Visibility (*includes width, color, contrast, retroreflectivity)* Yes ☐ No ☐
    - Curb Spacing *(gap between the adjacent curbs if not continuous)* Yes ☐ No ☐
    - Curb Height *(from the pavement surface to top of the curb)* Yes ☐ No ☐
    - Curb Visibility *(includes color, contrast, retroreflectivity)* Yes ☐ No ☐
    - Buffer space *(offset distance between pylons and adjacent travel lane)* Yes ☐ No ☐
    - Running length *(length of the pylon along horizontal alignment)* Yes ☐ No ☐

APPENDIX B. DEPLOYMENT LOCATIONS PROVIDED BY PYLON MANUFACTURERS

Table B-1. Pylon Locations Listed by Manufacturers/Vendors.

Location	Purpose
Hwy 36 and FM 3013, Sealy, TX	Divided interchange
IH 35 Exit to 3009, San Antonio, TX	Exit ramp division
Loop 1604 @ Kittyhawk, San Antonio, TX	Exit ramp division
IH 410 @ Valley High, San Antonio, TX	Divided access road lanes
IH 35 North Exit 184, New Braunfels, TX	Exit ramp division
Hwy 83 Access Road and Rooth Road, McAllen, TX	Protected right turn
South Staples St. @ 358, Corpus Christi, TX	Divided opposing traffic
Everhart Road @ 358, Corpus Christi, TX	Divided opposing traffic
Hwy 90 @ Brackettville Border Patrol Station	Divided lanes for station entrance and exit
Pacific Coast Highway, California	Separate opposing traffic
Route 2 Massachusetts	Separate opposing traffic
Big Dig – IH 95/IH 90, Boston	Separate HOV lane and freeway lanes
IH 90 Boston (temporary)	Create a protected ingress and egress lanes for 2004 democratic presidential convention
Northbound IH 635 HOV Lane starting near Northwest Highway Dallas County	Separate HOV lane and general purpose lanes
Southbound IH 635 HOV Lane ending near Northwest Highway Dallas County	Separate HOV lane and general purpose lanes
IH 95 Express Lanes, Miami, Florida	Separate managed lanes and general purpose lanes

APPENDIX C. AGENCY SURVEY

A SURVEY OF TxDOT DISTRICTS ON FLEXIBLE PYLON IMPLEMENTATIONS

(PROJECT 0-6643, TASK – 3)

Texas Transportation Institute (TTI) is currently working on a research project (0-6643) for the Texas Department of Transportation (TxDOT) to develop guidelines for the implementation of flexible pylons on freeway, HOV, and managed lane facilities that could help TxDOT districts minimize the maintenance cost of pylon implementation. As a part of this research, TTI is conducting a survey of all TxDOT districts that have implemented pylons on freeway, frontage, HOV, or managed lane facilities. The purpose of this survey is to systematically compile information on pylon installations, anecdotal guidelines available, and maintenance issues related to pylons.

The flexible pylons studied in this project may also be known variously by terms such as flexible delineator post, tubular markers, flexible channelizer, curb mounted delineator, or plastic candle stick. These pylons are usually affixed (glued or bolted) to the pavement or mounted on plastic curb (some examples of pylons is shown in figure to the right). If you need any clarifications on the survey or project in general please contact the project director or the project supervisor by phone or email given below.

If you are not the right person in your district/division to discuss pylon implementation, kindly forward this survey to the appropriate person(s) or please e-mail r-benz@tamu.edu the contact information of the person(s) whom you think is knowledgeable to fill out this survey on flexible pylon implementation. This survey is only two pages long and should take approximately 10 minutes or less to complete.

Kindly complete the survey by June 10, 2011, and return the survey by fax (713-686-5396) or by scanning and emailing your response to r-benz@tamu.edu.

Mr. Michael Chacon, P.E. – Project Director (TxDOT)
Texas Department of Transportation - Traffic Operations Division
118 E. Riverside Dr., Austin, Texas 78704
Phone: 512-416-3182
E-mail: MCHACON@dot.state.tx.us

Mr. Robert Benz, P.E. - Project Supervisor (TTI)
Research Engineer - Texas Transportation Institute
701 North Post Oak Suite 430, Houston, Texas 77024
Phone: 713-686-2971 x15118
Cell: 281-686-2971
E-mail: r-benz@tamu.edu

Thank you for your assistance!

Contact Information

Please list your contact information. If multiple staff members have participated in filling out the survey, please include their names and contact information.

Primary Survey Respondent Info:	
Name:	
Position:	
District/Division:	
Email:	
Phone number:	
Other staff members who contributed to the survey responses (include phone number or email as appropriate):	

1. Does your district use flexible pylons and/or pylon-curb assemblies for ***lane separation and channelization purposes (NOT as roadside delineator)***?
   a. On high speed facilities (speed limit 50 MPH and above) Yes ☐ No ☐
   b. On low speed facilities (speed limit 45 MPH and below) Yes ☐ No ☐

2. If answered 'Yes' to Question 1a or 1b, please list the locations (or if you have an electronic copy of a list of locations please email the list to r-benz@tamu.edu along with the completed survey):

Location	**Purpose**	**High/Low Speed**
Example: IH 10 between IH 610 and SH 6	*Separate managed lanes and freeway lanes*	*High Speed*
1)		
2)		
3)		
4)		
5)		

3. Why does your district choose pylons over concrete (Jersey) or other barriers? Select all that apply.
   ☐ Lower initial cost
   ☐ Lower maintenance cost
   ☐ Allow for emergency access
   ☐ Occupies less horizontal cross-sectional width
   ☐ Others (please specify)

4. Why does your district choose pylons over buffer and/or paint stripe only? Select all that apply.
   ☐ Substantial physical separation
   ☐ Higher compliance (little to no crossing over line)
   ☐ Increased safety
   ☐ Others (please specify)

5. Does your district use any guidelines (standard or anecdotal) for the following pylon implementation factors:
   - Pylon Spacing *(distance between adjacent pylons)* Yes ☐ No ☐
   - Pylon Height *(measured from pavement surface to top of post)* Yes ☐ No ☐
   - Pylon Visibility (*includes width, color, contrast, retroreflectivity)* Yes ☐ No ☐
   - Curb Spacing *(gap between the adjacent curbs for discontinuous curbs)* Yes ☐ No ☐
   - Curb Height *(from the pavement surface to the top of the curb)* Yes ☐ No ☐
   - Curb Visibility *(includes color, contrast, retroreflectivity)* Yes ☐ No ☐
   - Buffer space *(offset distance between pylons and adjacent travel lane)* Yes ☐ No ☐
   - Running length *(length of the pylon along horizontal alignment)* Yes ☐ No ☐

6. Has your district had issues with maintenance, frequently missing or broken pylons and/or pylon-curb assemblies?

Yes ☐ No ☐

7. If 'Yes' to Question 6, in your district's assessment which of the following are the major reasons for pylons being knocked down? Select all that apply.
   - ☐ Inattentive drivers
   - ☐ Driver disregard
   - ☐ Lack of contrast
   - ☐ Lack of retroreflectivity
   - ☐ Lack of visibility due to dirty pylons
   - ☐ Emergency crossing
   - ☐ Snow plowing/road cleaning
   - ☐ High truck volume
   - ☐ Pylons not durable
   - ☐ Pylons/Curb not properly affixed
   - ☐ Insufficient lateral clearance
   - ☐ Large gap between pylons allowing motorists to weave through
   - ☐ Other (please specify)

8. Has your district performed any evaluation of the pylon implementation(s)?

Yes ☐ No ☐

If yes, please email evaluation to **r-benz@tamu.edu** or attach to the completed survey.

9. Does your district consider pylons and/or pylon-curb assemblies beneficial for the purpose used?

Yes ☐ No ☐

10. Are there any lessons learned or issues or concerns with the current pylon installations or future use of pylons and/or pylon-curb assemblies you would like to share?

11. Can you send us photographs of some of the pylon implementation in your district?

Yes ☐ No ☐

If yes, please email photographs to **r-benz@tamu.edu** or attach to the completed survey.

12. Can we follow-up with you for additional information?

Yes ☐ No ☐

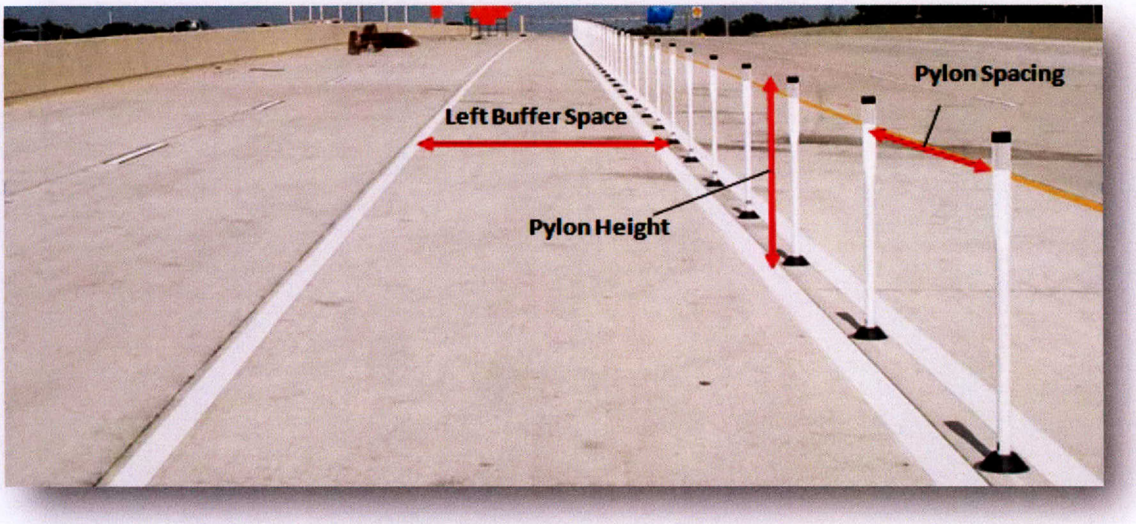
APPENDIX D.
DEFINITIONS OF TERMS

(Supplemental information sent with the vendor and agency surveys)

DEFINITION OF TERMINOLOGY USED

Pylon Spacing
Pylon spacing is the distance between the center of a pylon to the center of the adjacent pylon.

(Right or Left) Buffer Space
Buffer space is the offset distance between the center of the pylon base (or curb) to the center of the edge line of the adjacent travel lane. Any shoulder that is present between the pylons and the adjacent travel lane is also included in the buffer space. Buffer space is further classified as left buffer space and right buffer space in relation to the pylons and direction of travel.



Running Length
Running length is defined as the length of the project the pylons are used along the horizontal alignment of the roadway.

Pylon Height
Pylon height is measured from the pavement surface to the top of the pylon post. In case of curb mounted pylons, the height of the pylon also includes the height of the curb.

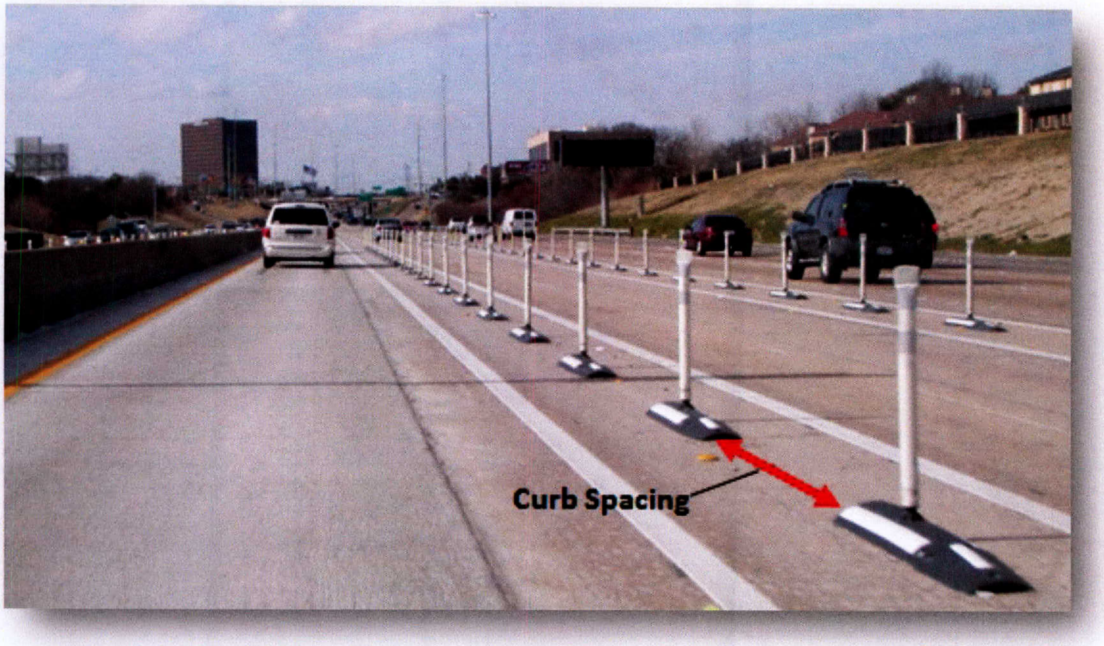
Pylon Visibility
Pylon visibility consists of four components: color, target value, contrast, and retroreflectivity. Color describes the color of the pylon, typically white, yellow, or orange. Sometimes a contrast color of black is also used (similar to a chevron). Target value describes how well a device can be seen. Contrast describes how well a device stands out from its surroundings. Retroreflectivity is essential for nighttime visibility of pylons. Retroreflectivity is usually achieved by wrapping the pylon post with retroreflective sheeting.

Curb Spacing
Curb spacing is the longitudinal gap between the adjacent curbs. Curb spacing is usually determined by drainage considerations. In cases where the curbs are interlocked longitudinally,

there is no space between curb sections. Curb spacing is usually measured from front of curb to front of curb.

Curb Height

Curb height is measured from the pavement surface to top of the curb (or top most point on the curb in case of varying height). Curb height does not include the height of the pylon post, when pylons are attached to the curb.



APPENDIX E.
POTENTIAL LIST OF CASE STUDY SITES OBTAINED FROM AGENCY SURVEYS

Table E-1. Pylon Sites Listed by TxDOT Districts and Other State Agencies.

Type	Location	Purpose	Agency	Speed
Managed Lanes/HOV				
	US 75 HOV, Dallas	Lane separation	TxDOT-Dallas	High speed
	IH 635 HOV, Dallas	Lane separation	TxDOT-Dallas	High speed
	IH-10 Managed Lanes, Houston	Lane separation	HCTRA	High speed
	SR 91 Express Lanes, Orange County, CA	Lane separation	Caltrans (OCTA)	High speed
	IH-15 Express Lanes, Las Vegas	Lane separation	Nevada DOT	High speed
	I-95 Express Lanes, Miami	Lane separation	Florida DOT	High speed
Freeway Mainlane/Ramp separation				
	IH 37 mainlane (US 77 Connector) at Ripple Road E	Discourage exiting from I-37 requires crossing miltiple lanes acros	Corpus Christi	High speed
	SH 286 mainlane near Gollihar exit	Discourage lane change and late exit	Corpus Christi	High speed
	US 59 NB going downtown at SH 288 split	Discourage late lane change	Houston	High speed
	US 59 NB at IH 10 split	Discourage late lane change	Houston	High speed
	Northbound ramp in Livingston at US 59 and BU 59	Discourage entering traffic from merging early	Lufkin	High speed
	SH 36 @ BS 36-J in Brenham, Washington Co.	Discourage early merge	Bryan	High speed
	US 54 Eastbound at I-110 On-Ramp	Separate entrance ramp lane and mainlane	El Paso	High Speed
Channelize U-turn/Right-turn traffic				
	BI 20 at JBS Parkway	to prevent traffic from using a turn-around lane "backwards"	Odessa District	High speed
	SH 361 WB @ Park Road 22, on Padre Island	Channelize right turn	Corpus Christi	Low speed
	SH 77 Frontage to FM 624	Channelize right turn	Corpus Christi	Low speed
	SH 6 NB to US 59 EB	Channelize right turn	Houston	High speed
	IH 610 westlloop FR at Hidalgo	Channelize right turn	Houston	Low speed
	US 59 NB - West of Brazos River, Fort Bend	Channelize U-turn	Houston	Low speed
	SH 6 south of Glen Lakes - near school bus barn	Channelize right turn - high bus traffic	Houston	Low speed
	Right turn from US 87 SB to RM 584	Spearate right turning traffic from through traffic	San Angelo	Low speed
	Merge of US 59 SB and SH 93 EB Thru Lanes - Texar	Spearate right turning traffic from through traffic	Atlanta	High speed
	Loop 306 FR to US 67 - right turn	Separate mainlane from acceleration lane	San Angelo	Low speed
	US 183 - Turn around @ Cameron Rd	Discourage traffic from enterimg to a drive way	Austin	High speed
Exit Ramp - Block Access on Fronatge				
	IH 410 NB FR to Valley Hi drive	Restrict traffic from turning right for a driveway	San Antonio District	High speed
	IH 35 NB FR at Fm 3009 Exit	Restrict traffic from turning right to a street	San Antonio District	High speed
	US 83/84 Exit Ramps	Restrict traffic to access	Abilene District	Low speed
	US 82 westbound exit ramp at Fairway	Discourage turning from ramp to business drive	Wichita Falls District	Low speed
	IH 37 Frontage Rd	Prevent Exit Ramp Traffic to Enter Private Drive	Corpus Christi	High speed
	US 59 SB at Tours St	Prevent drivers from accessing a street too close to ramp	Houston	High speed
	IH 610 Eastloop at US 90	prevent drivers from highway connector to enter driveway	Houston	High speed
	Loop 306 exit ramp at Alexander Street WB	Prevent exiting traffic from accesing driveway	San Angelo	Low speed
	Loop 306 exit ramp to US 87 (Eastbound)	Prevent exiting traffic from accesing driveway	San Angelo	Low speed
	Loop 306 Exit to College Hills Blvd (Eastbound)	Prevent exiting traffic from accesing driveway	San Angelo	Low speed
	US 83 EB Frontage Rd. Exit Ramp Goreeast of FM 4	Prevent exiting traffic from accesing driveway	Pharr	Low speed
	US 83 WB Frontage Rd Exit Ramp Gore west of SH 1	Prevent exiting traffic from accesing driveway	Pharr	Low speed
	US 83 EB Frontage Rd. Exit Ramp Gore west of Jack	Prevent exiting traffic from accesing driveway	Pharr	Low speed
	I-10 Westbound at Raynolds Off Ramp	Prevent exiting traffic from accesing cross street	El Paso	Low speed
	IH 40 westbound Georgia exit -- two rows of pylor	Spearate exit ramp traffic from frontage road traffic	Amarillo	High speed
	IH 35 @ Runberg Exit	To prevent hwy exiting traffic to enter side street	Austin	High speed
	US 183 @ Oak Knoll Exit	To prevent hwy exiting traffic to enter side street	Austin	High speed
	US 69 exit ramp to SH 105 northound	supplemental to double white lane lines	Beaumont	Low speed
	US 69 southbound exit ramp to Jimmy Johnson Blv	supplemental to double white lane lines	Beaumont	Low speed
	SH 191 between SL 338 and JBS Parkway	to keep traffic from making a left turn into on-coming traffic from	Odessa District	Low speed
Entrance Ramp - Block access from driveways/streets				
	US 281 SB FR entrance ramp Brook Hollow Blvd	Restrict traffic from driveways near ramp to enter	San Antonio District	High speed
	US 82 eastbound entrance ramp at McNiel	Discourage entering freeway from business drive	Wichita Falls District	Low speed
	US 287 southbound entrance ramp at City View	Discourage entering freeway from city street	Wichita Falls District	Low speed
	SH 249 at Compaq Center (two installations)	Overlapping installations to prevent drivers to access ramp from d	Houston	High speed
	US 59 NB Kirby entrance	Discourage traffic entering from driveway	Houston	High speed
	Entrance ramp on loop 306 - at Main St. WB	Discourage traffic entering from driveway	San Angelo	Low speed
	Entrance ramp on loop 306 WB - near sunset mall	Discourage traffic entering from mall driveway	San Angelo	Low speed
	On ramp to Loop 306 at Caddo street (Eastbound)	Discourage traffic entering from driveway	San Angelo	Low speed
	Loop 375 at Bob Hope On-Ramp	Discourage traffic entering from driveway	El Paso	High speed
Median application - block left turns to driveways				
	Bob bullock loop (20) NB approaching Spur 400	Median application to block left turn to Target	Laredo District	High speed
	IH 20 between JBS Parkway and Grandview exits	flex devices used as median barrier	Odessa District	High speed
	FM 1179 at Walmart in Bryan, Brazos Co	Median application - looks like to prevent left turns to walmart	Bryan	Low speed?
	FM 1179 at HEB	Median application - looks like to prevent left turns to HEB	Bryan	Low speed?
	BS 6 R at HEB	Median application - looks like to prevent left turns to HEB	Bryan	Low speed?

APPENDIX F.
CASE STUDY SITE PHOTOGRAPHS

Figure F-1. Entrance to US 75 SB HOV at Bethany Drive.

Figure F-2. Entrance to IH 635 NB HOV at Oates Drive (just North of IH 30).

Figure F-3. Entrance to IH 10 WB Managed Lane at Silber Road (just West of IH 610).

Figure F-4. Entrance to IH 10 EB Managed Lane at Bunker Hill Road.

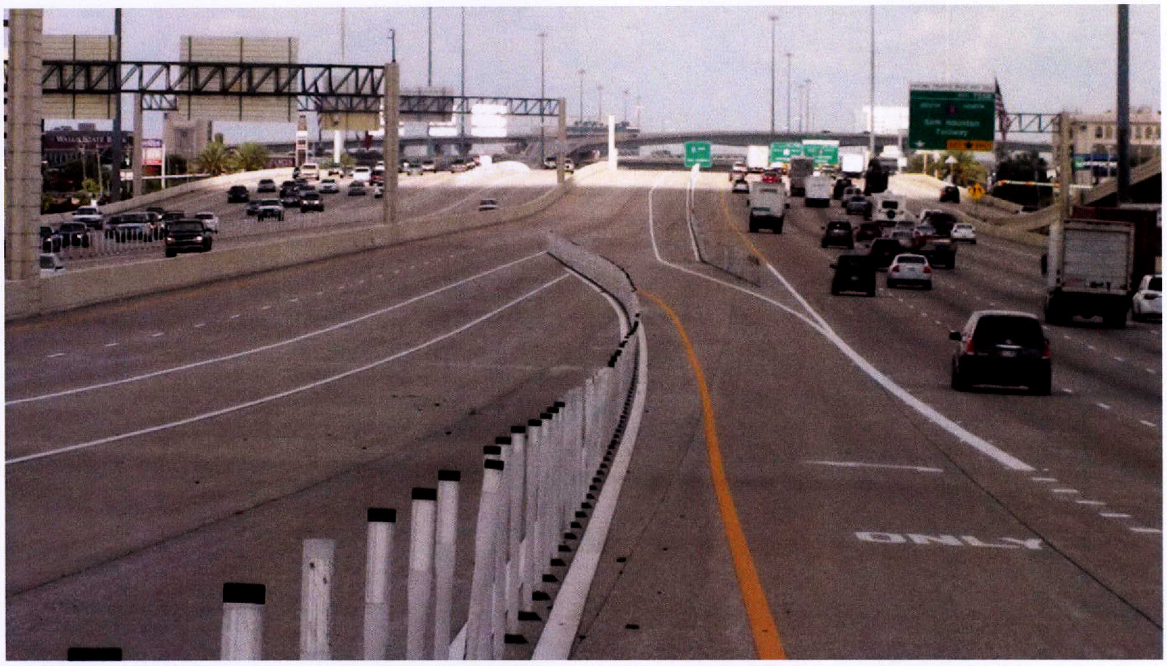


Figure F-5. Entrance to IH 10 WB Managed Lane at Gessner Road (in Houston).

Figure F-6. Exit from US 75 NB HOV Lane at Bethany Drive (Dallas District).

Figure F-7. Exit from IH 635 SB HOV Lane at Oates Drive (Dallas District).

Figure F-8. Exit from IH 10 Katy Managed Lane at Tully Road
(between Beltway 8 and SH 6 in Houston, TX).

Figure F-9. US 75 NB HOV Lane South of George Bush Turnpike.

Figure F-10. US 75 SB HOV Lane South of George Bush Turnpike.

Figure F-11. IH 10 Katy Managed Lane EB near Dairy Ashford Road.

Figure F-12. IH 10 Katy Managed Lane EB at Voss Road (between Beltway 8 and IH 610 West Loop).

Figure F-13. IH 610 West Loop SB Woodway Drive Entrance Ramp in Houston, TX.

Figure F-14. SH 249 NB Cypresswood Drive Entry Ramp in Houston, TX.

Figure F-15. US 59 WB Kirkwood Rd Entrance Ramp in Houston, TX.

Figure F-16. US 59 WB Beechnut St Exit Ramp in Houston, TX.

Figure F-17. IH 35 NB FM 3009 Exit Ramp in San Antonio, TX.

APPENDIX G.
PYLON HIT/NEAR MISS DATA TABULATION SHEET AND MANEUVER DIAGRAMS

Table G-1. Pylon Hit/Near Miss Data Tabulation Sheet - US 290 Cypresswood Entrance.

Roadway Name:	Hwy 249 Cypresswood Entrance
Direction of Traffic:	NB
Camera ID:	
Camera Name:	
Length of pylons monitored:	

Video start date - time (mm:dd - h:m:s)	Video end date - time (mm:dd - h:m:s)	Hit #	Hit date (mm-dd-yy)	Hit time (h:m:s)	Vehicle type (6)	Emergency vehicle? (7)	Vehicle hit pylons? (8)	Vehicle action before hitting (9)	Position of Pylon Hit (10)	Manuver Type (11)	Vehicle response after hitting (12)	Pylon Damage after hit (13)	Traffic on FR (14)	Traffic on Ramp (15)	QA/QC
6:15-10:25:00	6:15-10:59:00	End of video from 08:00:00-10:09:00													
6:15-11:08:00	6:15-11:13:00	1	5/22/2012	11:55:08	4	5	2	4	G	5	3	5	2	2	ok
6:15-11:34:00	6:15-11:38:00	End of video from 10:10:00-12:00:00													
6:15-11:40:00	6:15-11:45:00	2	5/22/2012	12:13:44	3	5	2	4	G	5	3	5	2	2	ok
6:15-11:46:00	6:15-12:06:00	End of video from 12:00:00-14:00:00													
6:15-13:00:00	6:15-13:10:00	3	5/22/2012	14:52:52	3	5	2	4	G	5	3	5	2	2	ok
6:15-13:12:00	6:15-13:21:00	4	5/22/2012	15:18:50	4	5	2	4	H	1	3	5	2	2	ok
6:15-13:22:00	6:15-13:26:00	5	5/22/2012	15:37:47	3	5	2	4	G	4	3	5	2	2	ok
6:15-13:28:00	6:15-13:35:00	End of video from 14:00:00-16:00:00													
6:20-13:07:00	6:20-13:08:00	Camera blurred from 00:00:00-02:00:00													
6:20-13:08:00	6:20-13:09:00	End of video from 00:00:00-02:00:00													
6:20-15:16:00	6:20-15:18:00	20	5/17/2012	10:46:49	2	5	2	4	H	1	3	5	1	1	ok
6:20-15:18:00	6:20-15:28:00	End of video from 10:30:00-12:00:00													
6:20-15:30:00	6:20-15:39:00	21	5/17/2012	13:09:15	3	5	2	4	G	6	3	5	2	1	ok
6:20-15:39:00	6:20-15:45:00	End of video from 12:00:00-14:00:00													
6:20-15:46:00	6:20-16:00:00	End of video from 14:00:00-16:00:00													
6:20-16:00:00	6:20-16:15:00	End of video from 16:00:00-18:00:00													

Column 6:	**Column 7:**	**Column 8:**	**Column 9:**	**Column 10 & 11:**	**Column 12:**	**Column 13:**	**Column 14 & 15**
1 - Motorcycle	1 - Police	1 - Hit	1 - Stopped	* See diagram	1 - Got back on lane same side	1 - Leaning	1 - Free flow
2 - Car	2 - Tow Truck	2 - No hit, but close	2 - Slowed		2 - Stopped on the same side	2 - Fallen down (base attached)	2 - Moderate
3 - SUV/Jeep	3 - Ambulance	3 - Attempted, no hit	3 - Accelerated		3 - Crossed pylons and continued driving	3 - Broken/chopped on top	3 - Stop and go
4 - Pickup	4 - Fire Engine	4 - Unsure	4 - None		4 - Crossed pylons and stopped	4 - Detached from base	
5 - Van	5 - None				5 - Crossed pylons and stopped	5 - None	
6 - Truck/Trailer					6 - Crossed pylons and entered driveway	6- Not sure	
7 - Bus					7 - Parked over the pylons		
8 - Unsure							

NOTES:

1. Video start and end time should be recorded as long as the subject pylons are visible (camera not moved/nonworking/blurred) and should be noted down even if no hits (will be added up to calculate exposure time)

2. Hits, near hits and attempted hits should be recorded on this data collection sheet. If unsure, also note down, so it can be verified

3. Column 10 & 12- see diagram for pylon position & manuver type enter the corresponding codes. If the manuver is different from those in the diagram, describe at the back of the data collection sheet

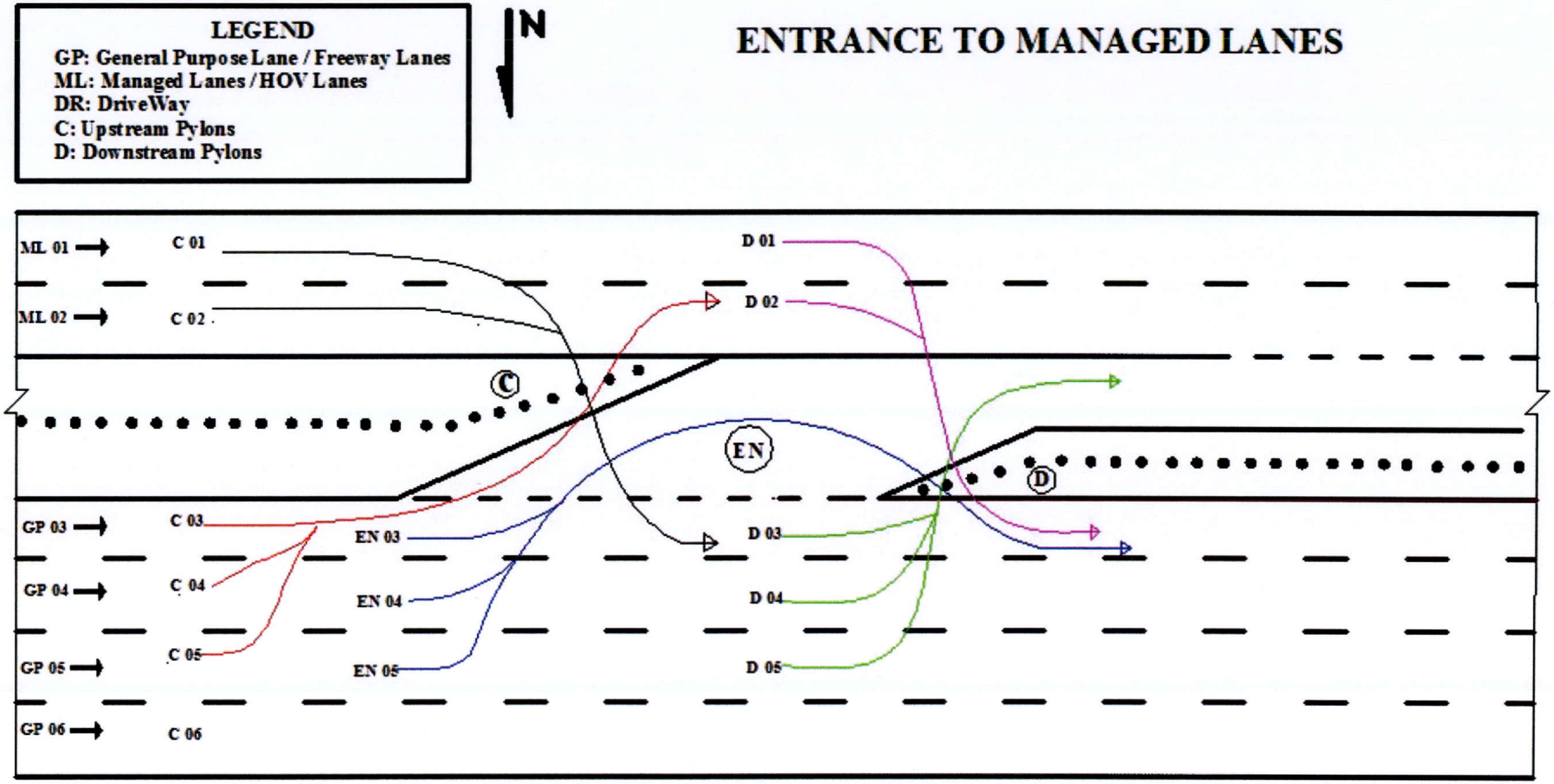


Figure G-1. Maneuver Diagram - Entrance to Managed Lanes.

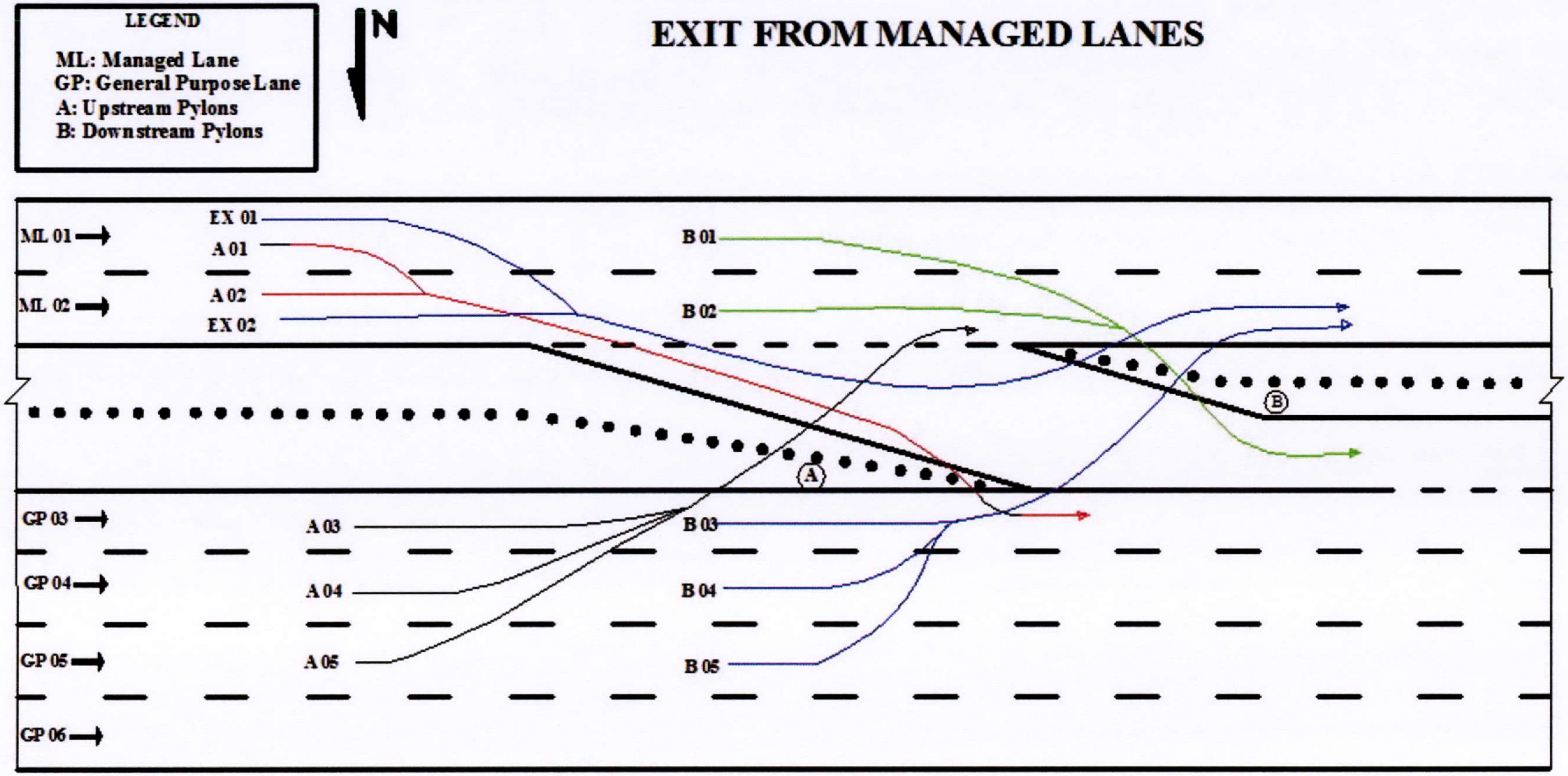


Figure G-2. Maneuver Diagram - Exit from Managed Lanes.

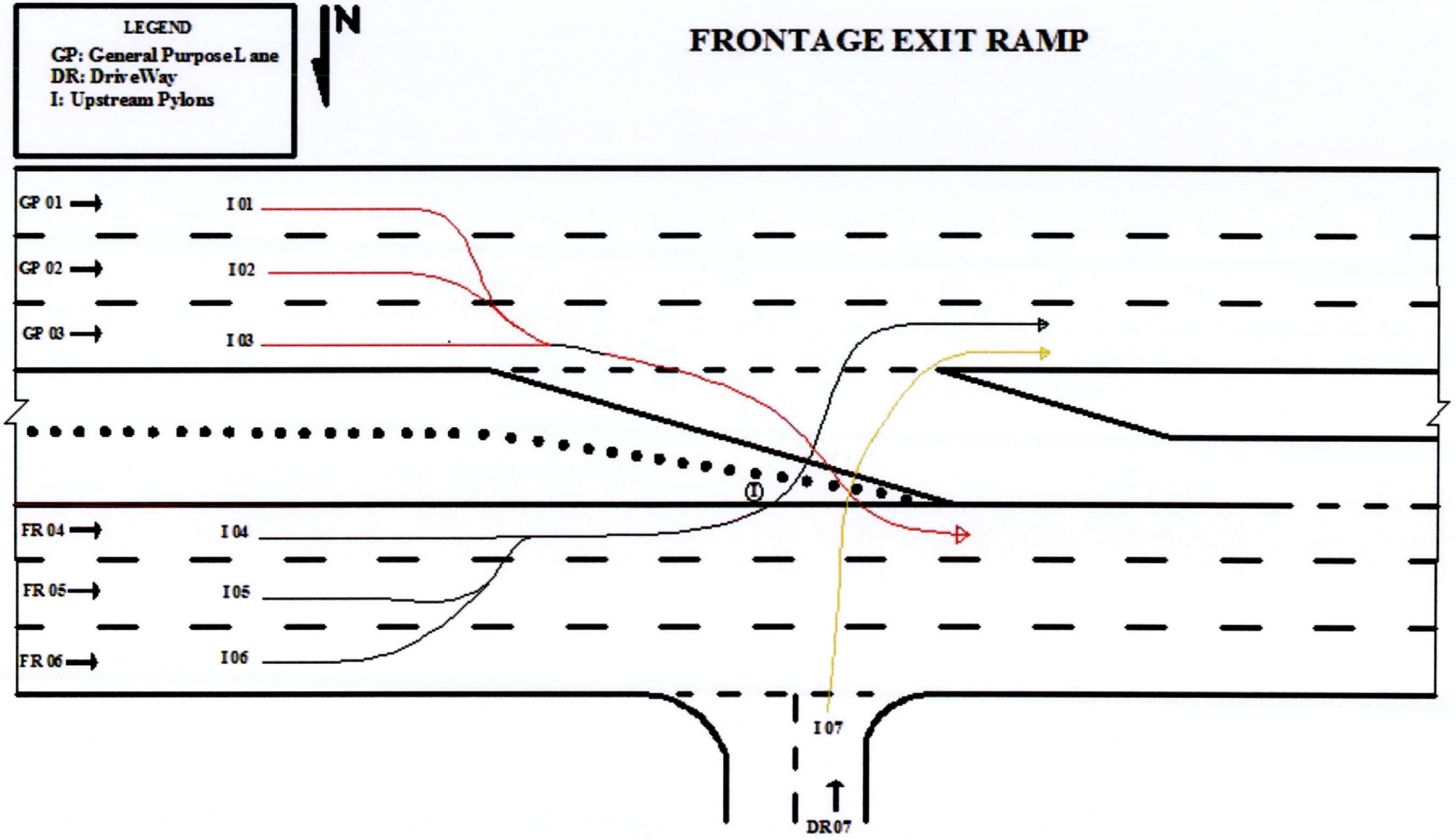


Figure G-3. Maneuver Diagram - Frontage Exit Ramp.

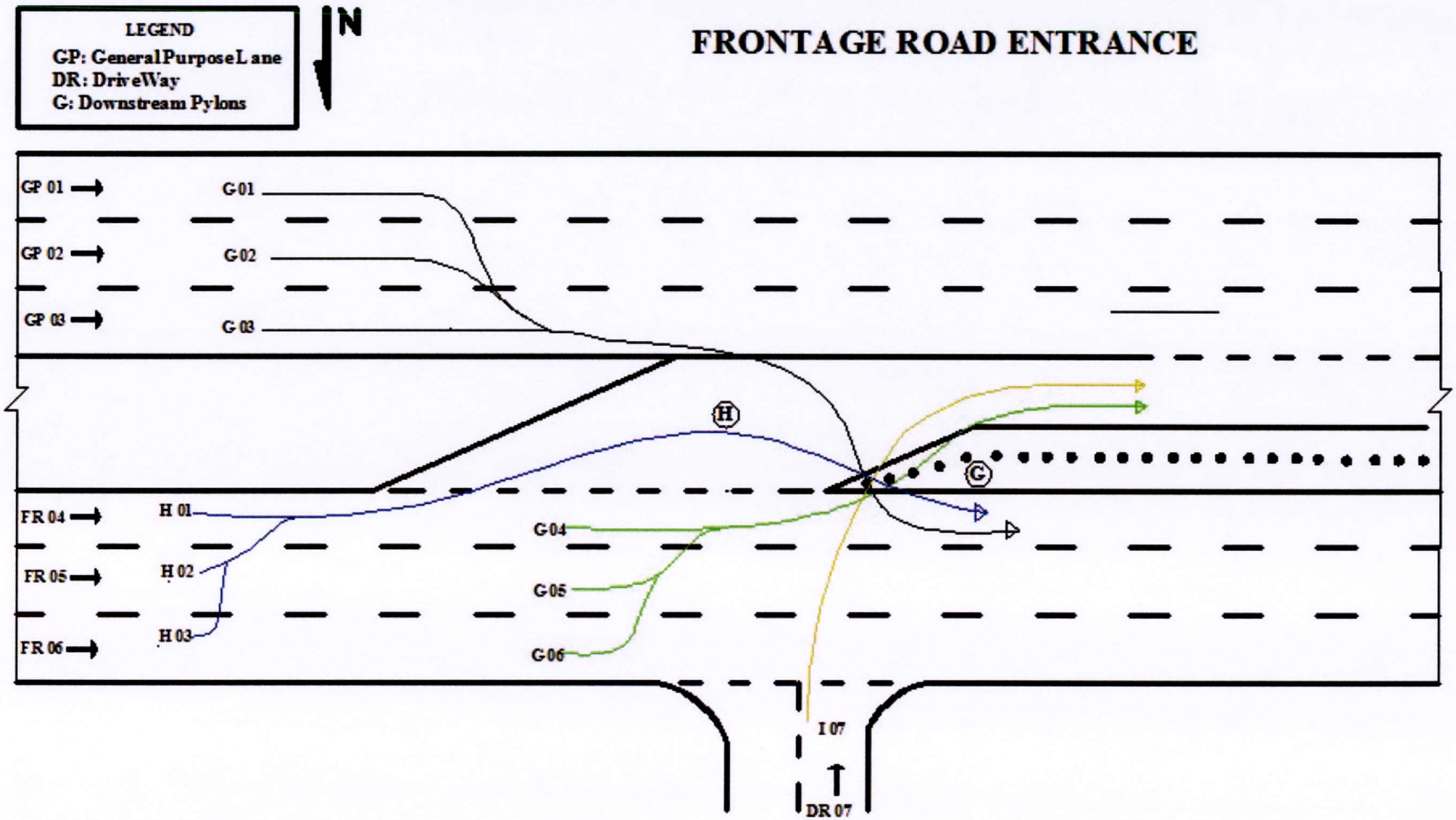


Figure G-4. Maneuver Diagram - Frontage Road Entrance.

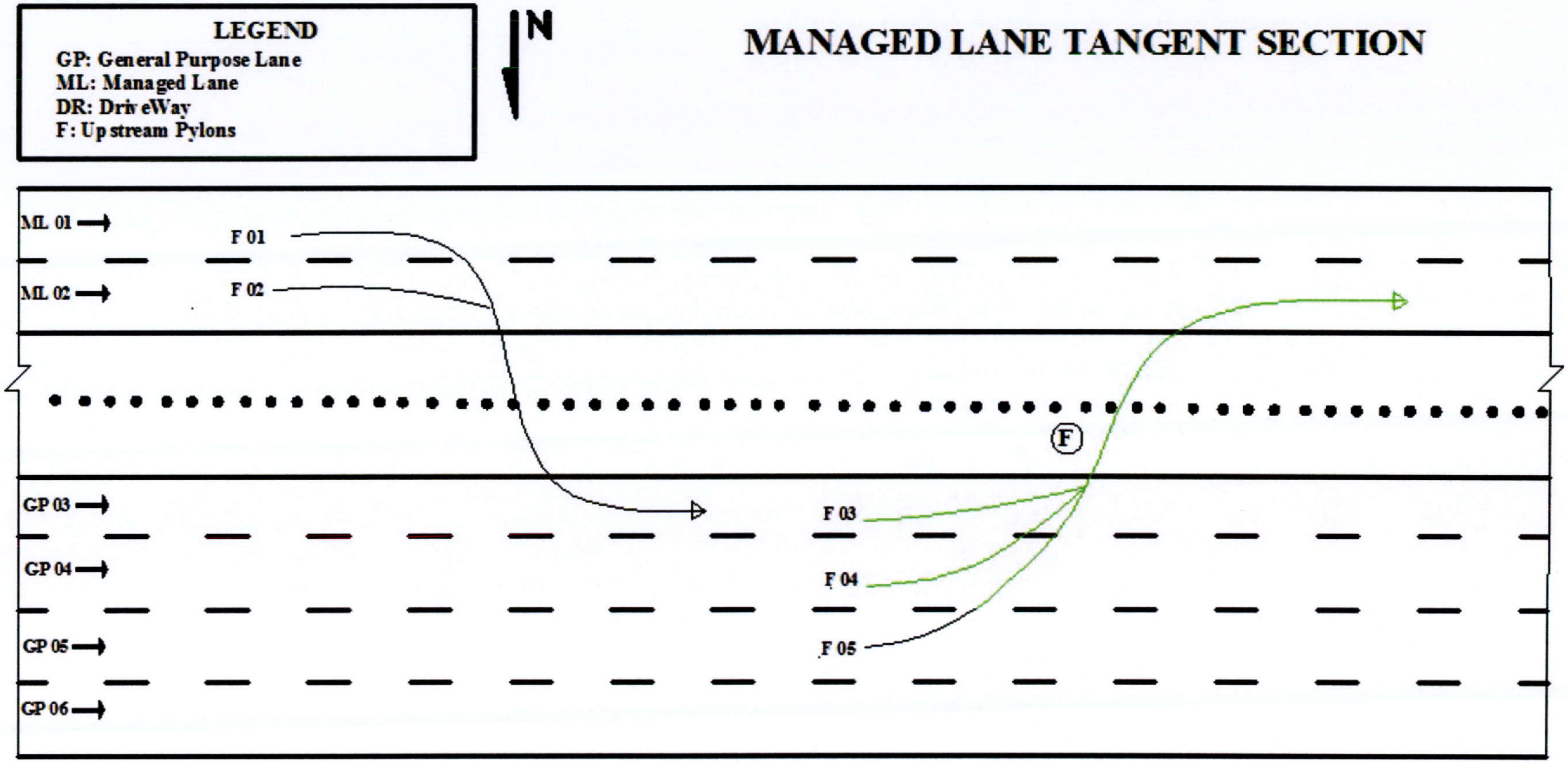


Figure G-5. Maneuver Diagram - Managed Lane Tangent Section.

APPENDIX H.
PYLON HIT/NEAR MISS REGRESSION SCATTERPLOTS FOR CASE STUDY SITES

Preferential Lane Access Case Study Sites

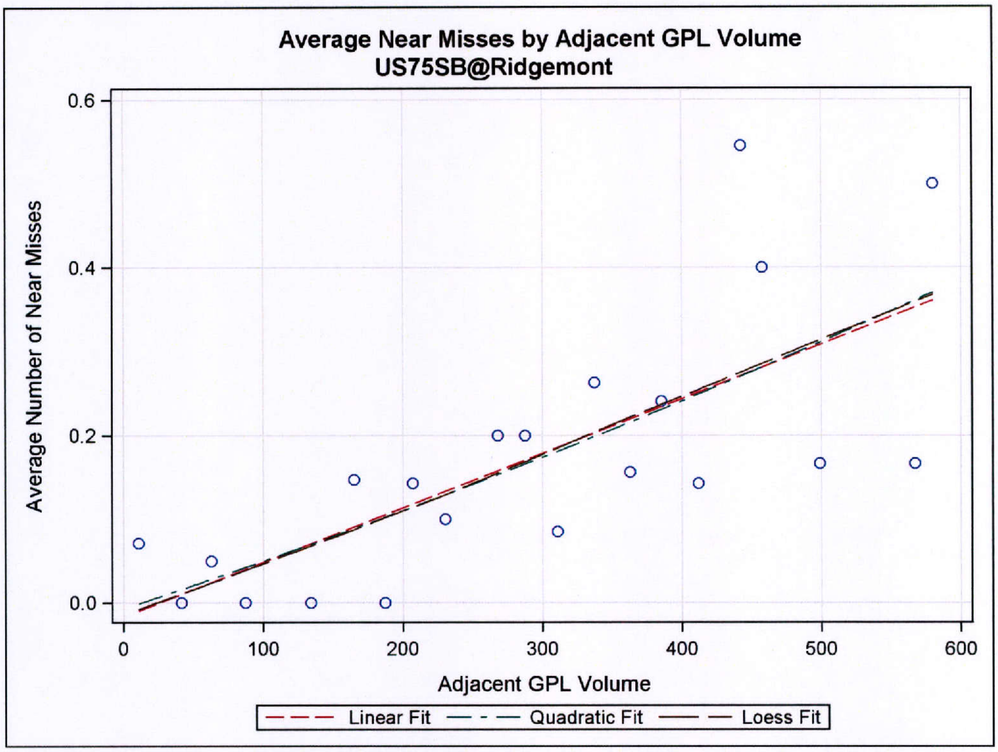


Figure H-1. Regression Trend between Near Misses vs. Adjacent GPL Volume for US 75 SB HOV Entrance at Bethany.

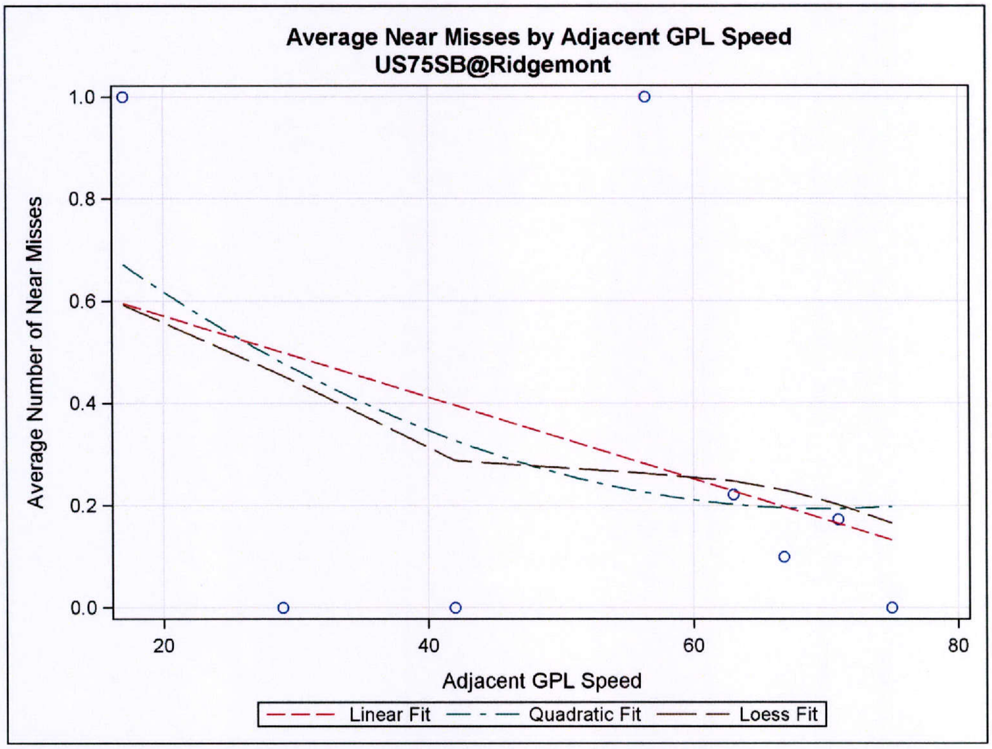


Figure H-2. Regression Trend between Near Misses vs. Adjacent GPL Speed for US 75 SB HOV Entrance at Bethany.

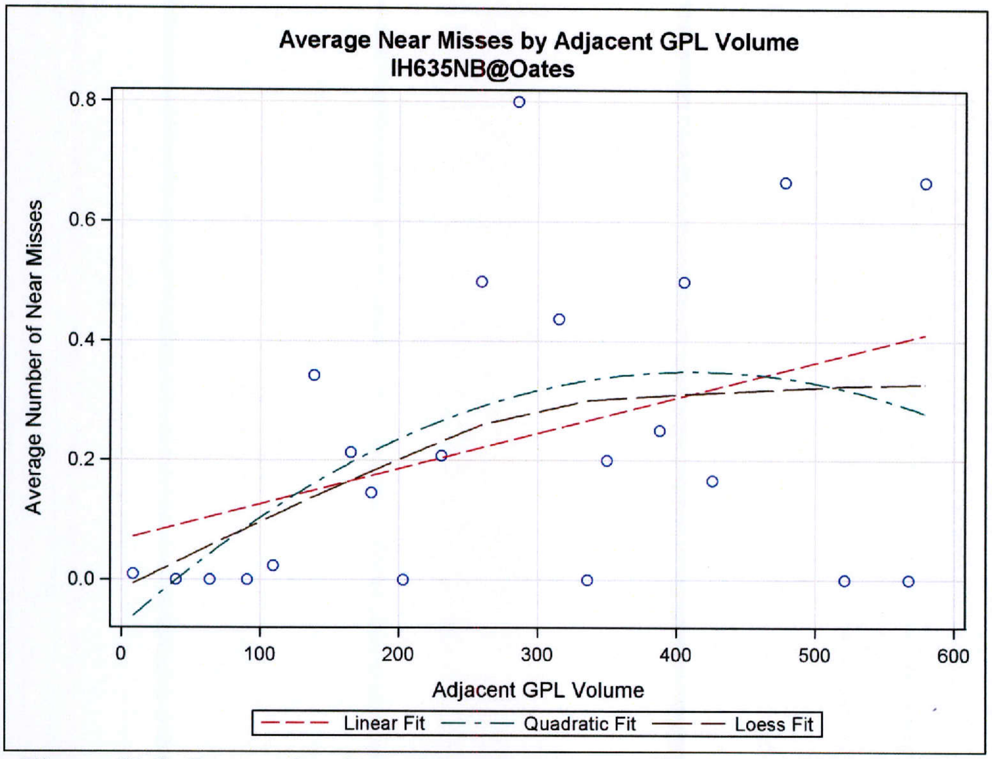


Figure H-3. Regression Trend between Near Misses vs. Adjacent GPL Volume for IH 635 NB HOV Entrance at Oates.

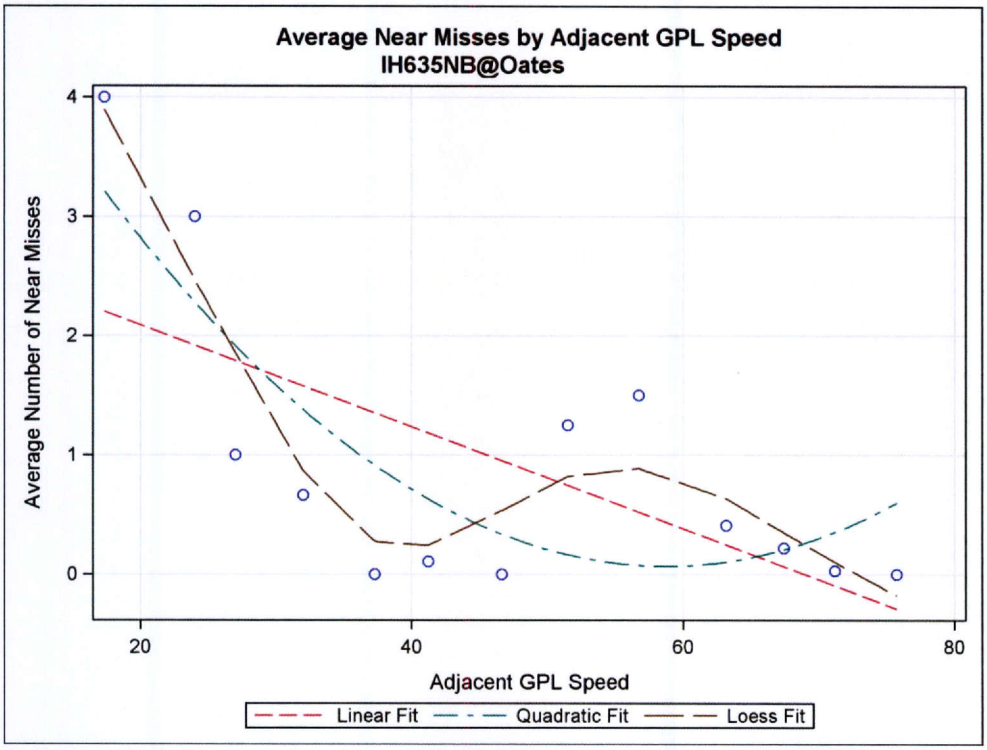


Figure H-4. Regression Trend between Near Misses vs. Adjacent GPL Speed for IH 635 NB HOV Entrance at Oates.

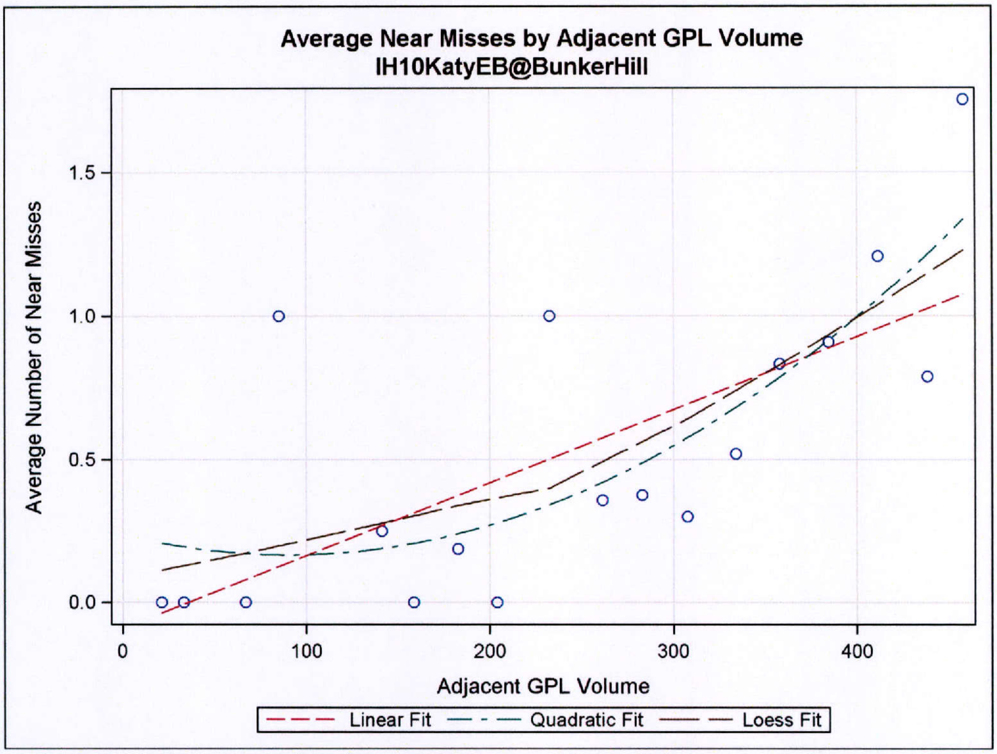


Figure G-5. Regression Trend between Near Misses vs. Adjacent GPL Volume for IH 10 EB Managed Lanes at Bunker Hill.

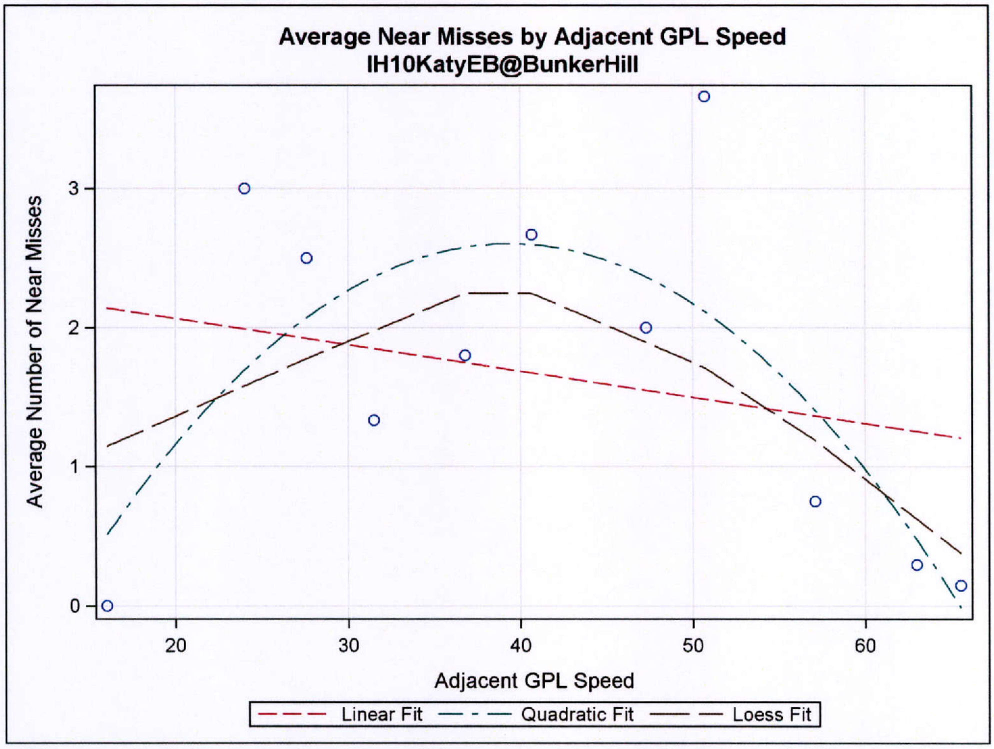


Figure H-6. Regression Trend between Near Misses vs. Adjacent GPL Speed for IH 10 EB Managed Lanes at Bunker Hill.

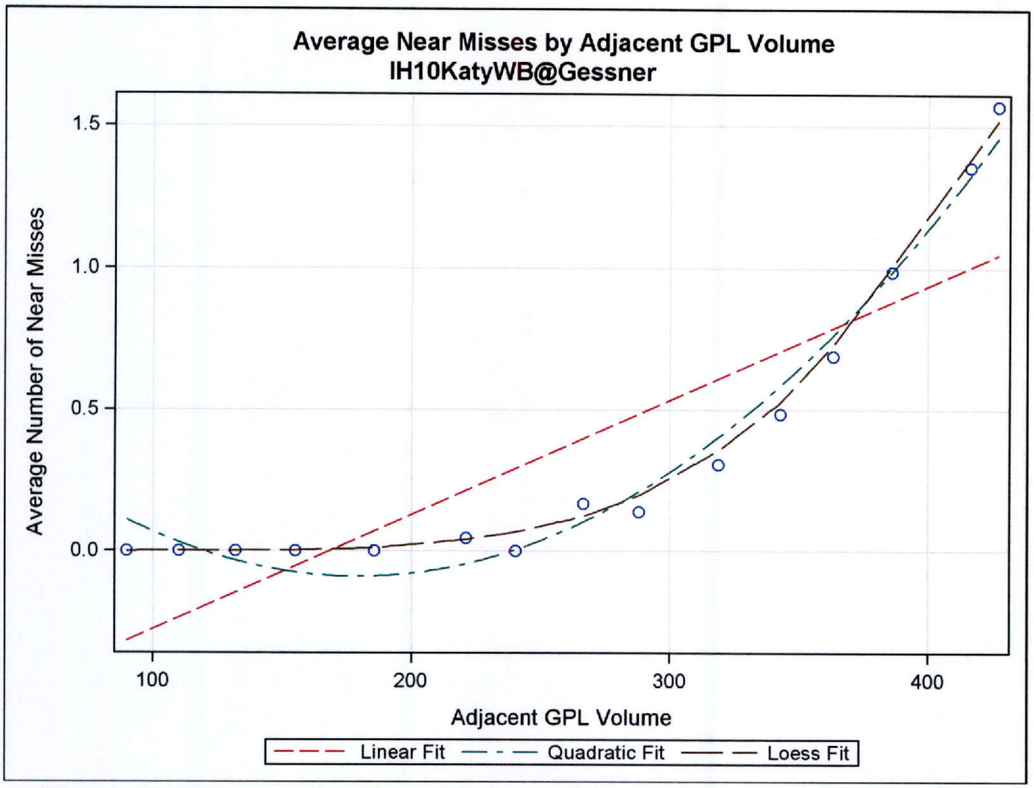


Figure H-7. Regression Trend between Near Misses vs. Adjacent GPL Volume for IH 10 WB Managed Lanes at Gessner.

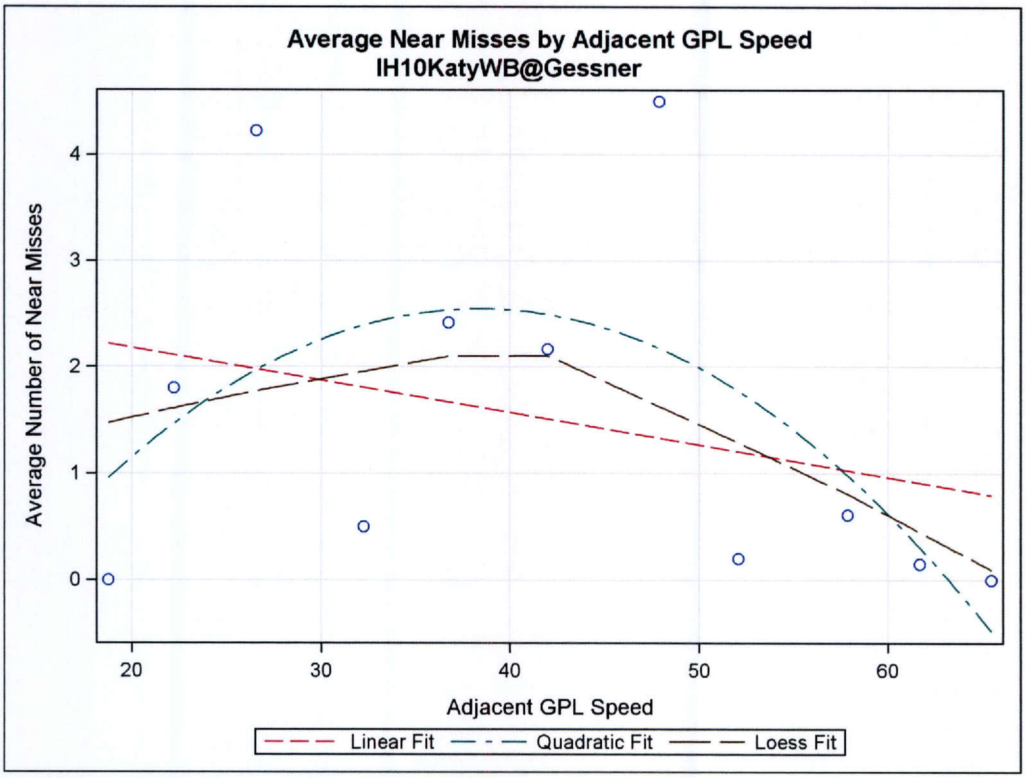


Figure H-8. Regression Trend between Near Misses vs. Adjacent GPL Speed for IH 10 WB Managed Lanes at Gessner.

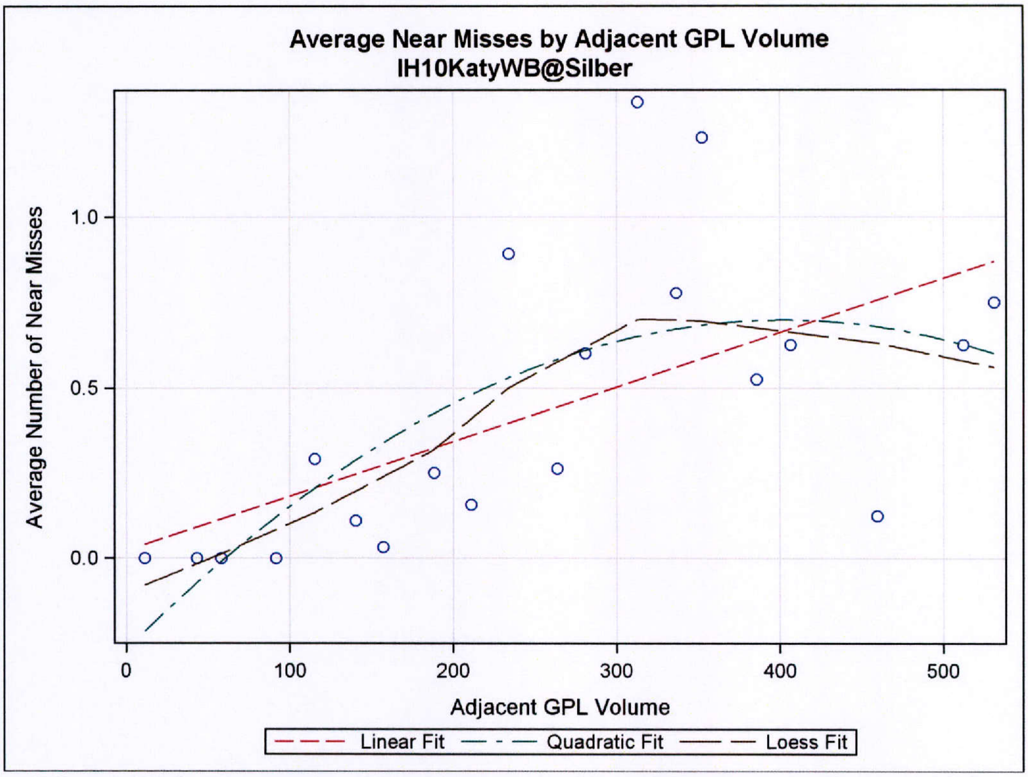


Figure H-9. Regression Trend between Near Misses vs. Adjacent GPL Volume for IH 10 WB Managed Lanes at Silber.

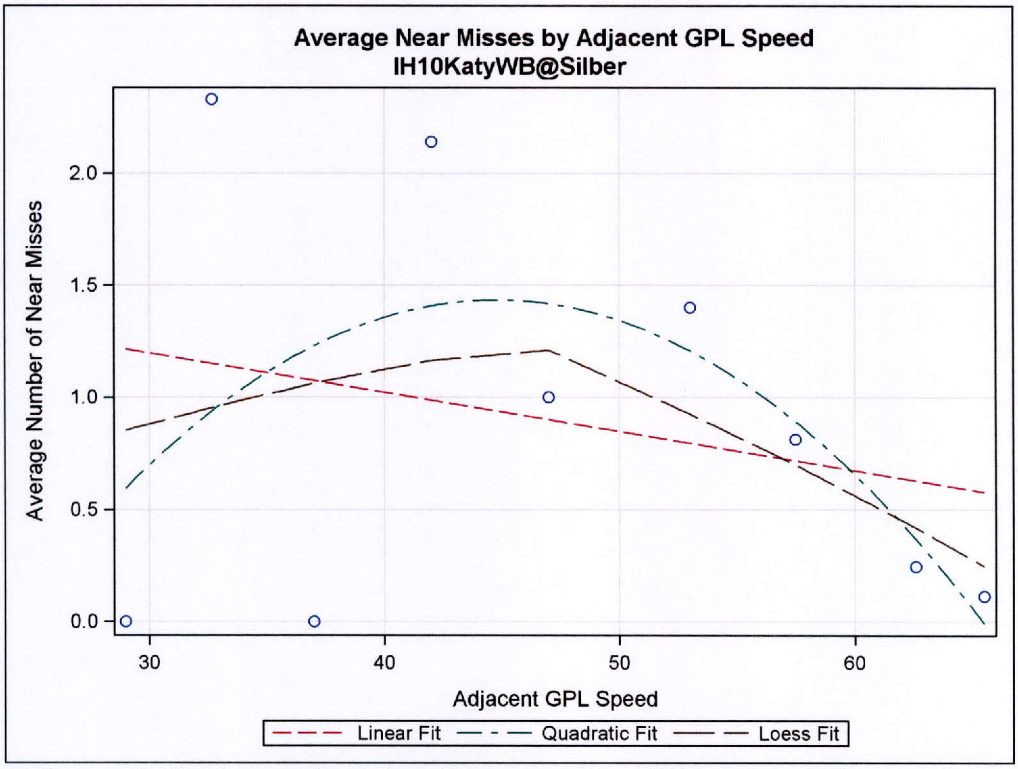


Figure H-10. Regression Trend between Near Misses vs. Adjacent GPL Speed for IH 10 WB Managed Lanes at Silber.

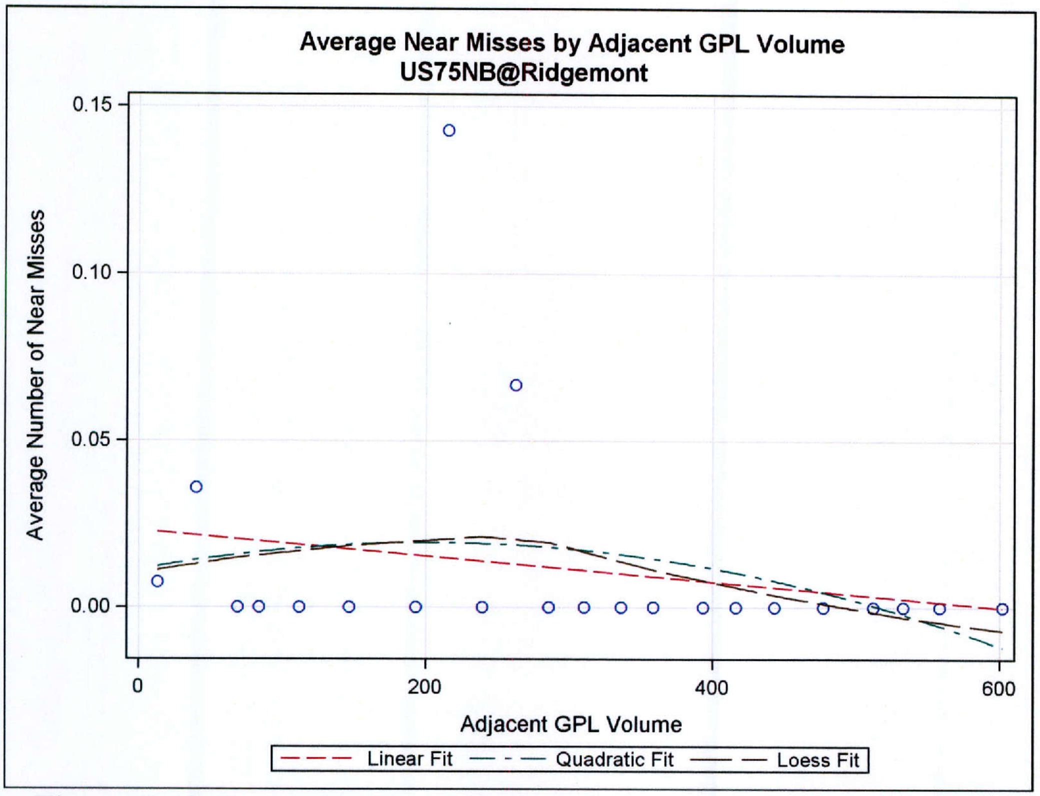


Figure H-11. Regression Trend between Near Misses vs. Adjacent GPL Volume for US 75 NB Exit from HOV Lane at Bethany.

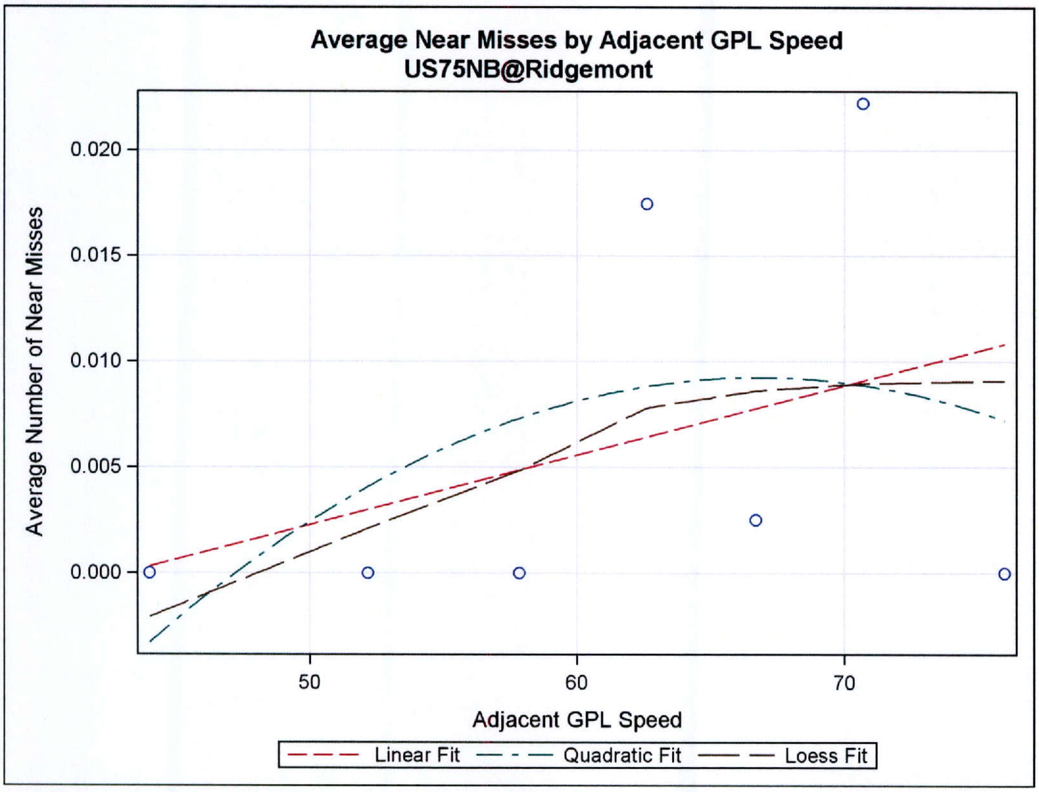


Figure H-12. Regression Trend between Near Misses vs. Adjacent GPL Speed for US 75 NB Exit from HOV Lane at Bethany.

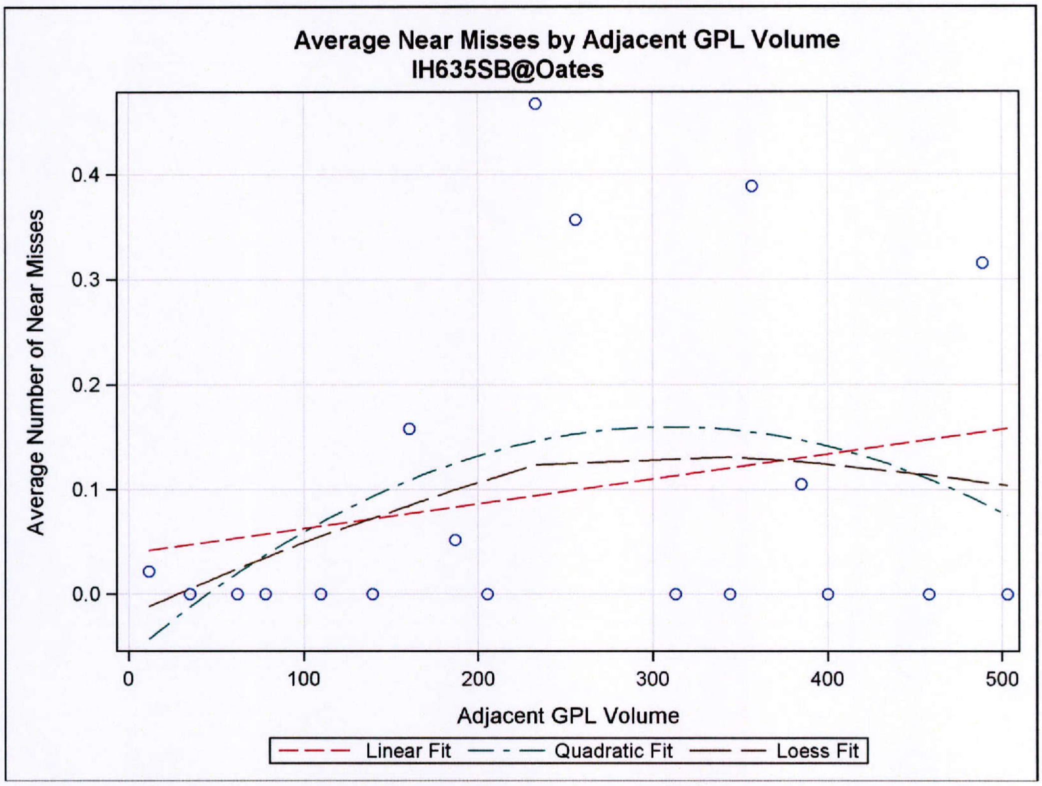


Figure H-13. Regression Trend between Near Misses vs. Adjacent GPL Volume for IH 635 SB Exit from HOV Lane at Oates.

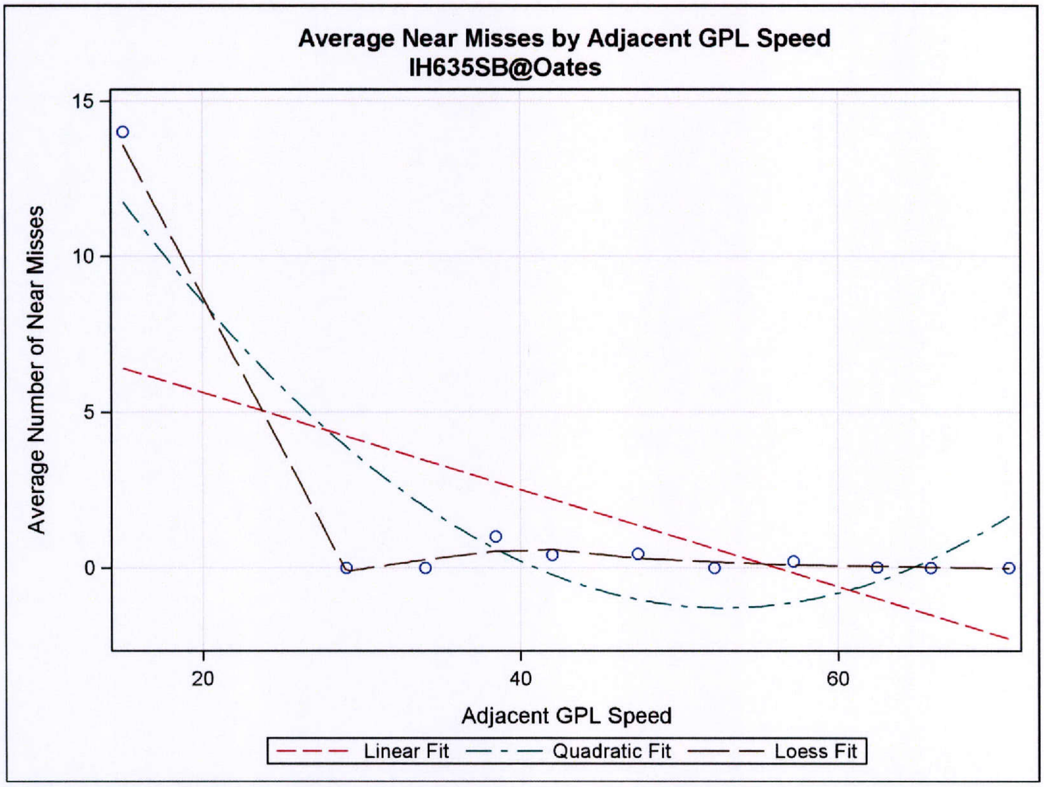


Figure H-14. Regression Trend between Near Misses vs. Adjacent GPL Speed for IH 635 SB Exit from HOV Lane at Oates.

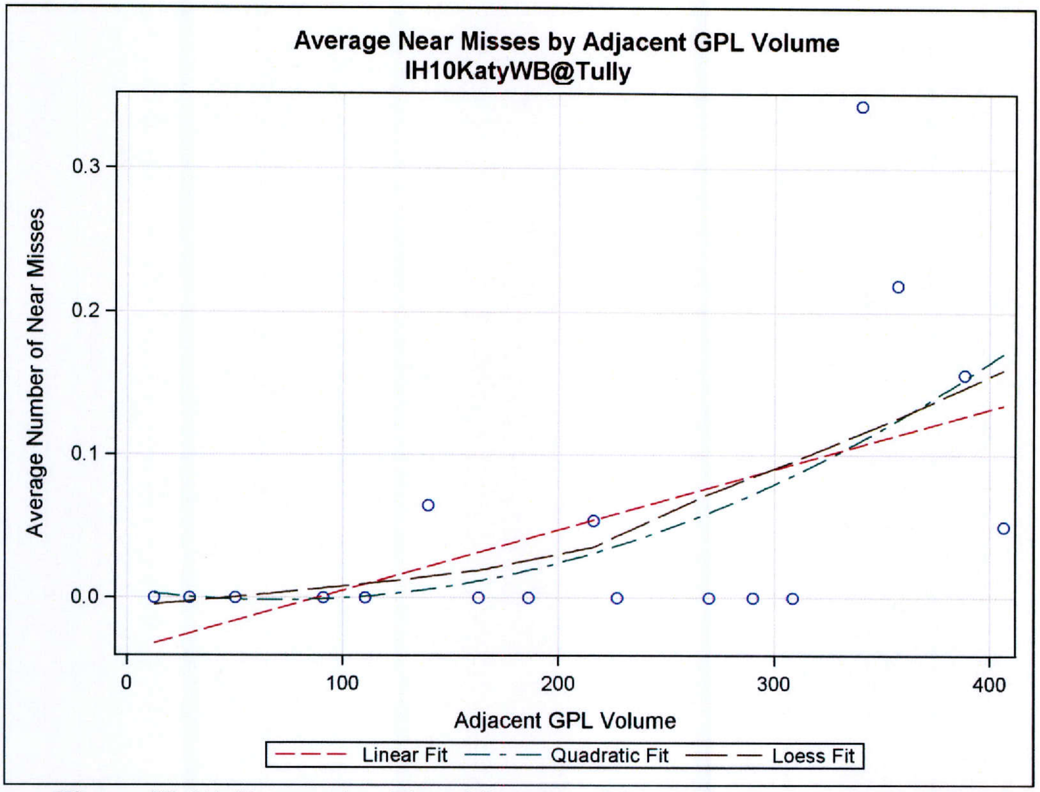


Figure H-15. Regression Trend between Near Misses vs. Adjacent GPL Volume for IH 10 WB Exit from Managed Lane at Tully.

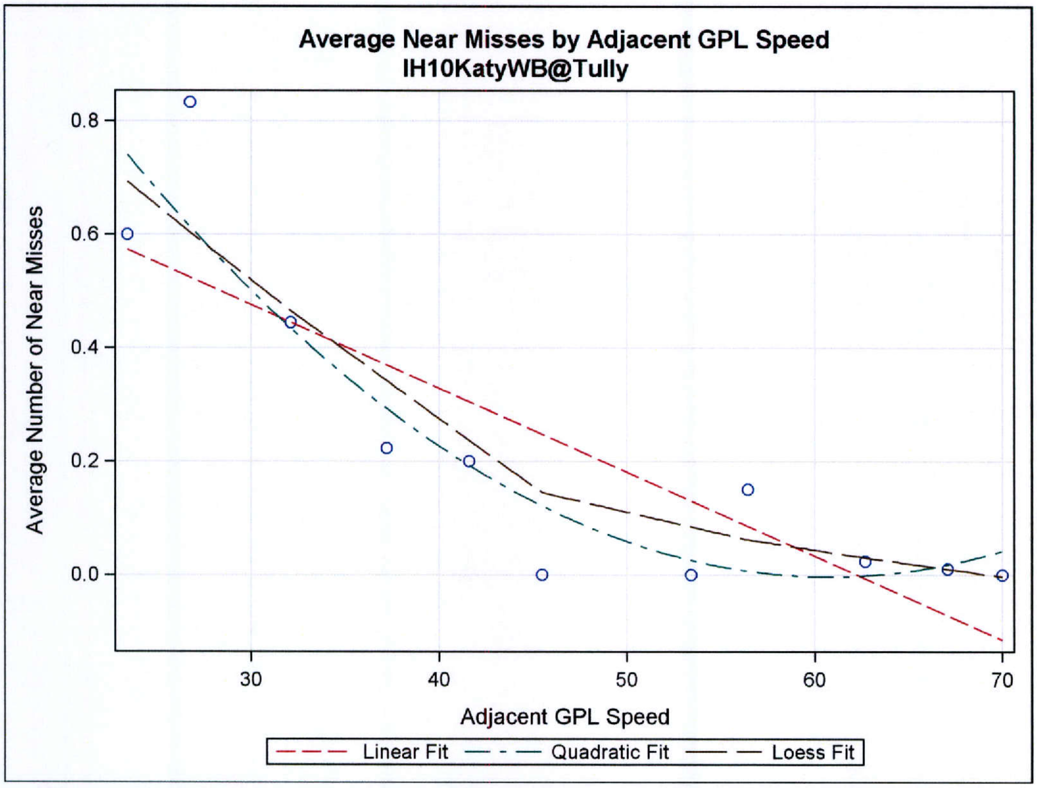


Figure H-16. Regression Trend between Near Misses vs. Adjacent GPL Speed for IH 10 WB Exit from Managed Lane at Tully.

Preferential Lane Tangent Case Study Locations

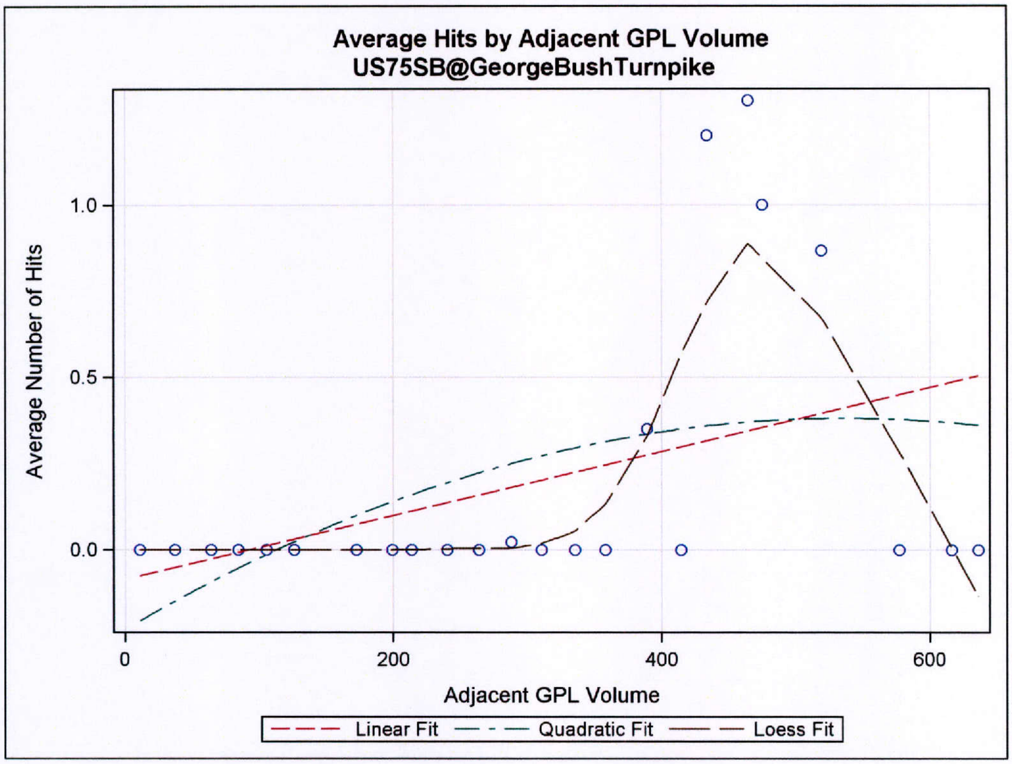


Figure H-17. Regression Trend between Hits vs. Adjacent GPL Volume for US 75 SB HOV Tangent at George Bush Turnpike.

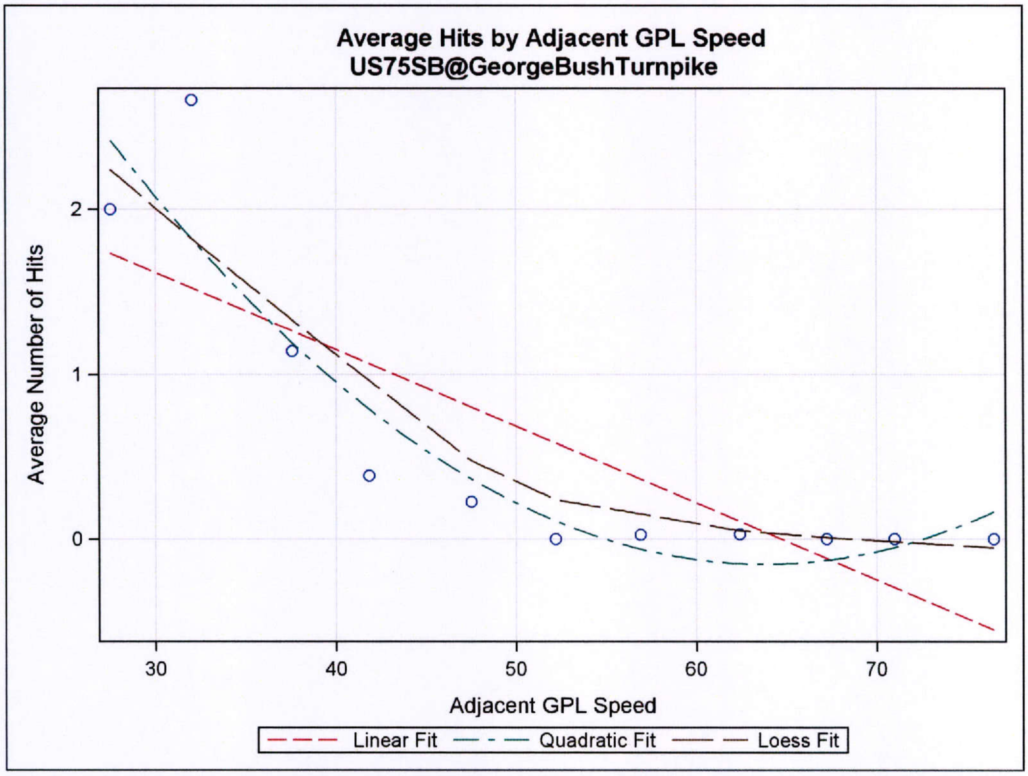


Figure H-18. Regression Trend between Hits vs. Adjacent GPL Speed for US 75 SB HOV Tangent at George Bush Turnpike.

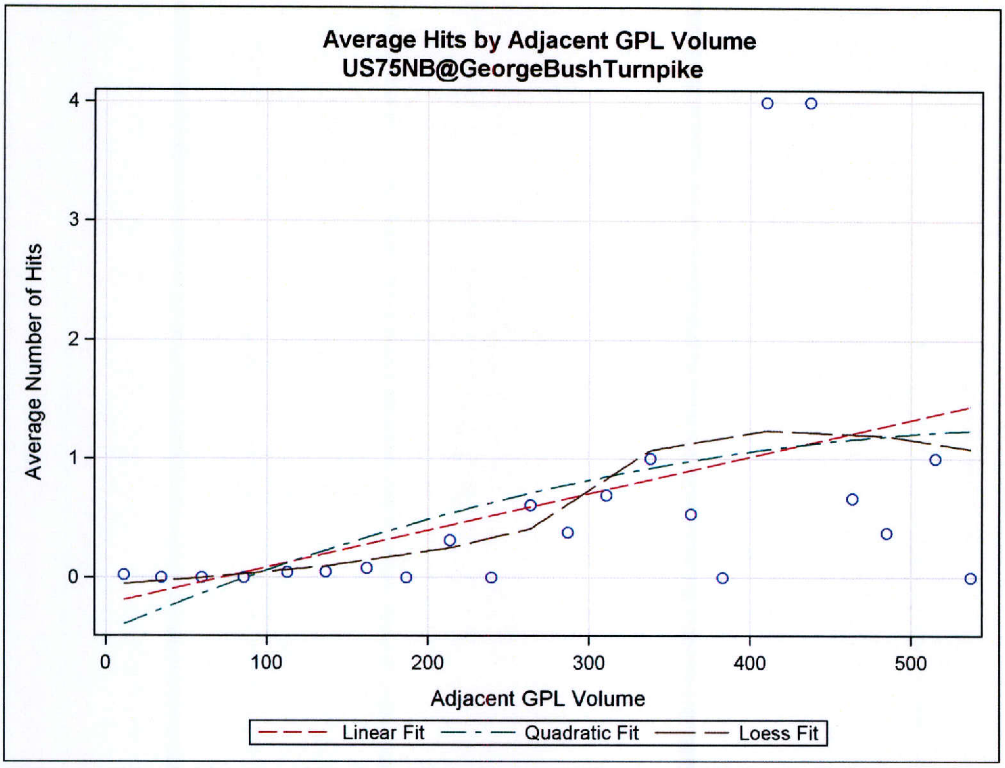


Figure H-19. Regression Trend between Hits vs. Adjacent GPL Volume for US 75 NB HOV Tangent at George Bush Turnpike.

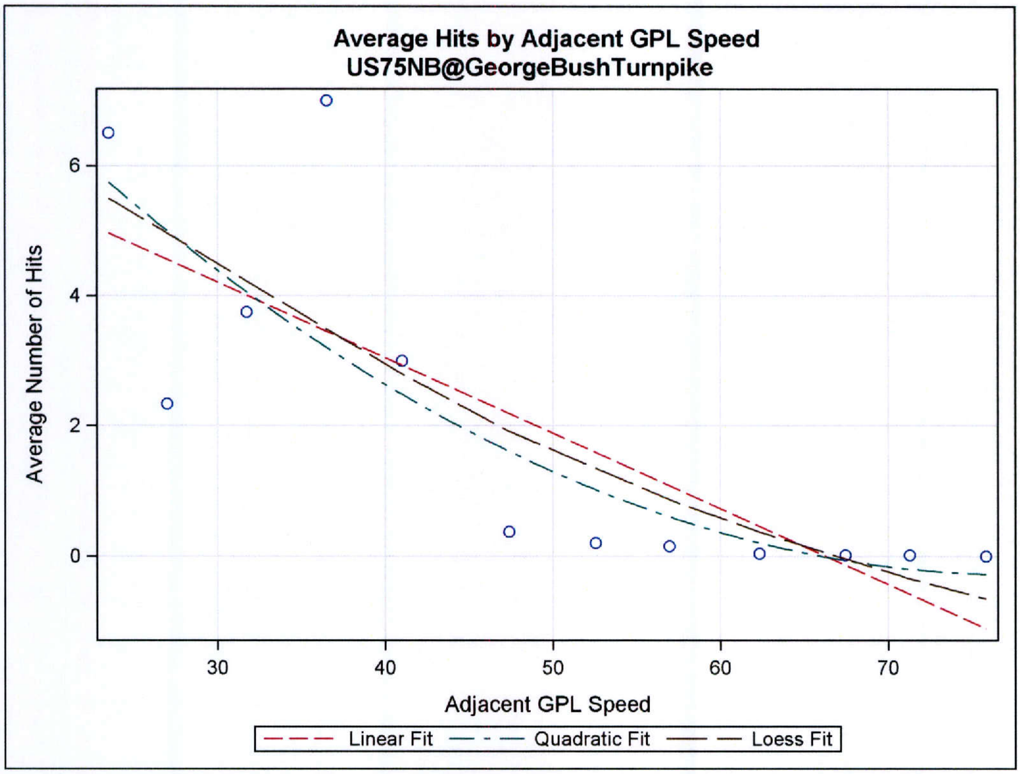


Figure H-20. Regression Trend between Hits vs. Adjacent GPL Speed for US 75 NB HOV Tangent at George Bush Turnpike.

Freeway Ramp-Frontage Case Study Sites

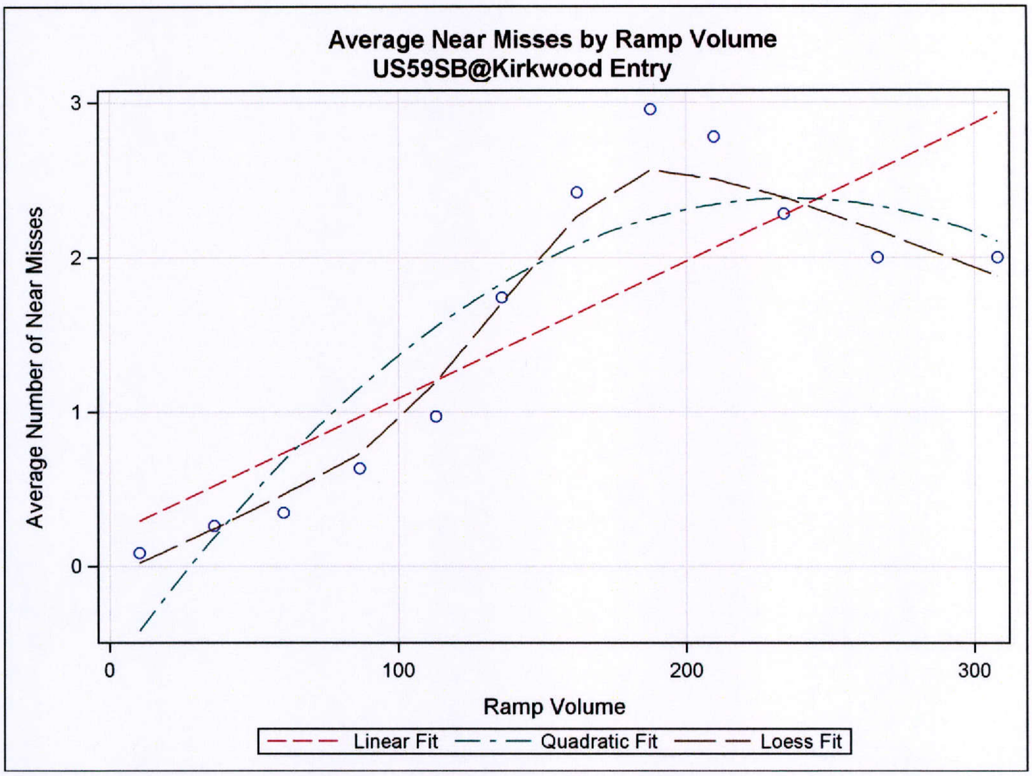


Figure H-21. Regression Trend between Near Misses vs. Ramp Volume for US 59 WB Kirkwood Entrance Ramp.

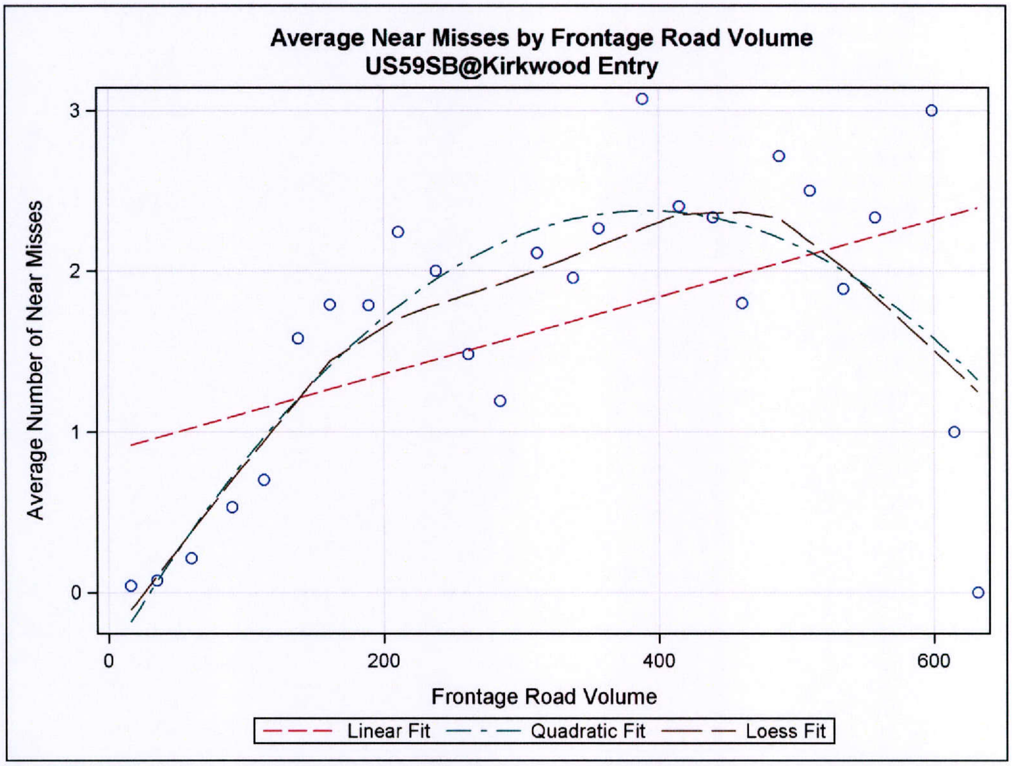


Figure H-22. Regression Trend between Near Misses vs. Frontage Volume for US 59 WB Kirkwood Entrance Ramp.

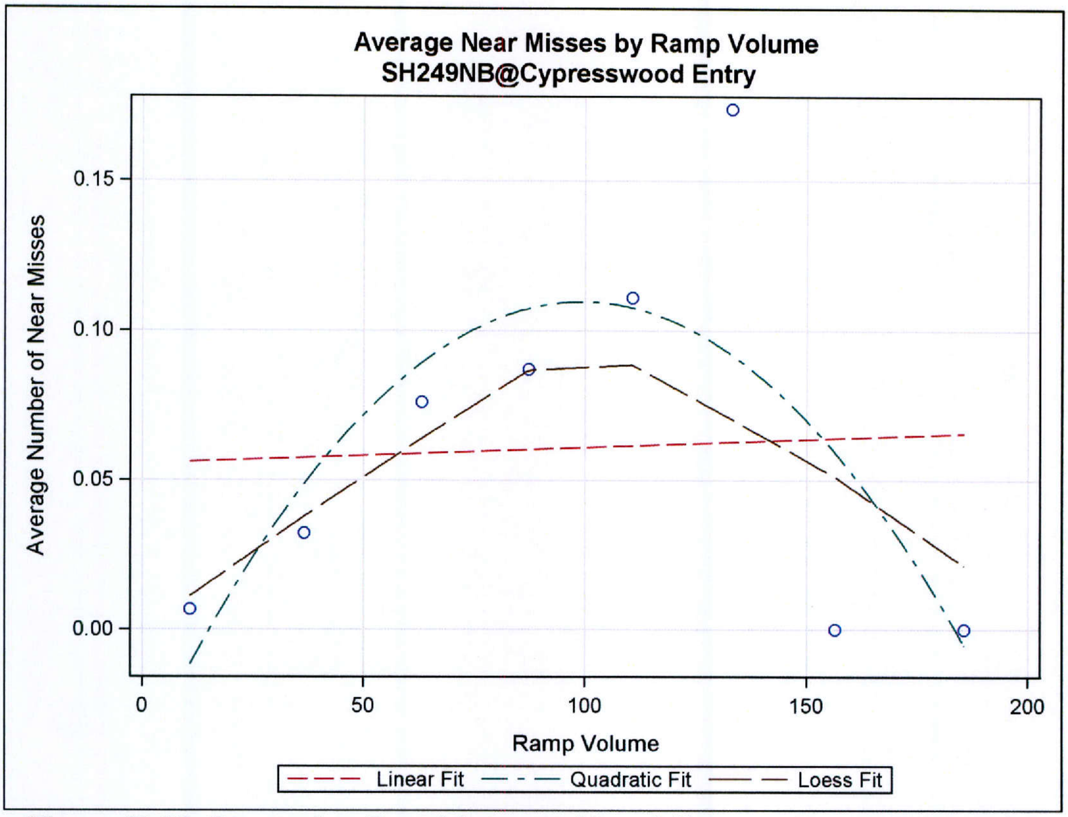


Figure H-23. Regression Trend between Near Misses vs. Ramp Volume for SH 249 NB Cypresswood Entrance Ramp.

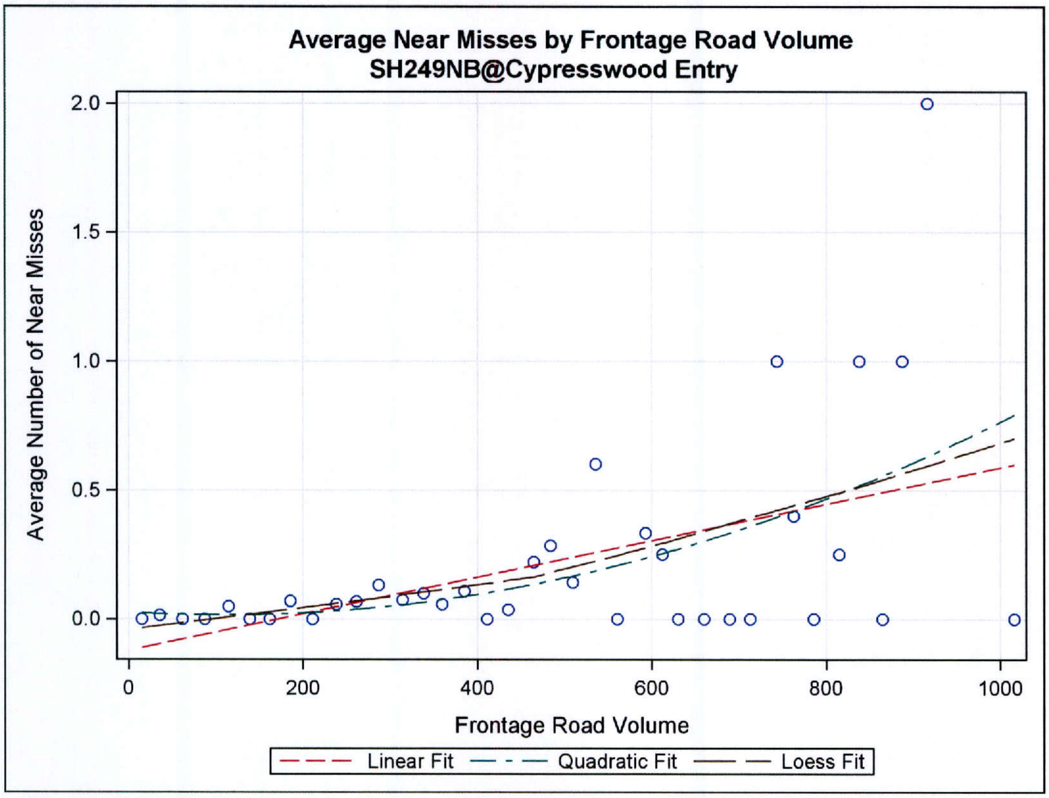


Figure H-24. Regression Trend between Near Misses vs. Frontage Volume for SH 249 NB Cypresswood Entrance Ramp.

APPENDIX I.

PYLON HIT/NEAR MISS REGRESSION SCATTERPLOTS BY APPLICATION

Preferential Lane Access Case Study Sites (Combined)

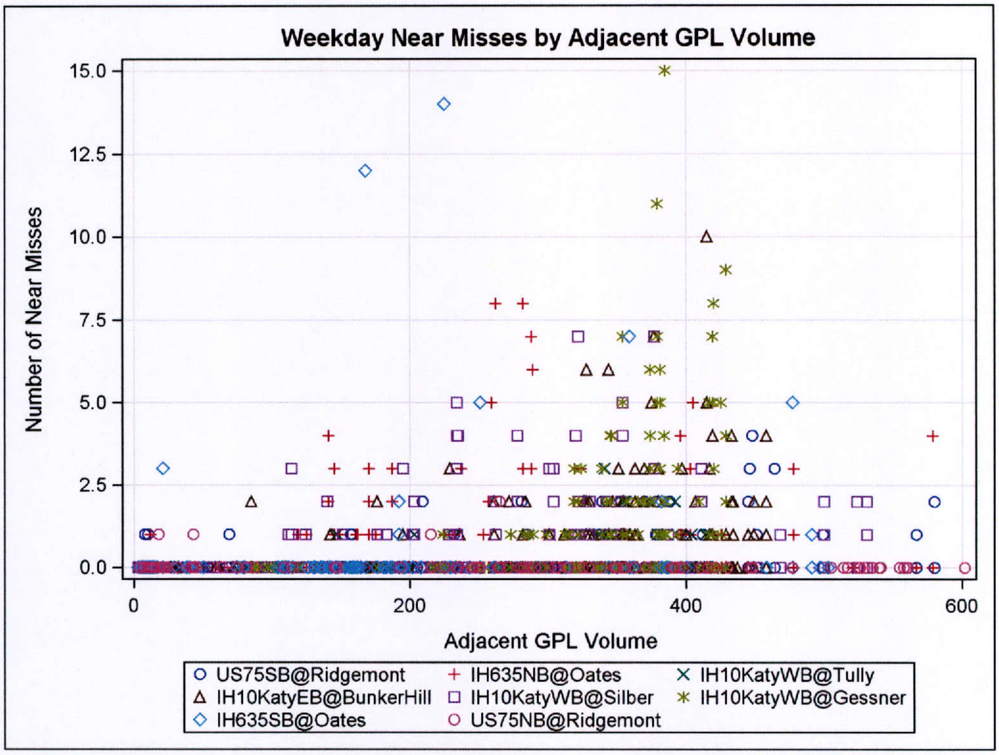


Figure I-1. Scatter Plot of Near Misses vs. Adjacent GPL Volume for Preferential Lane Access Locations.

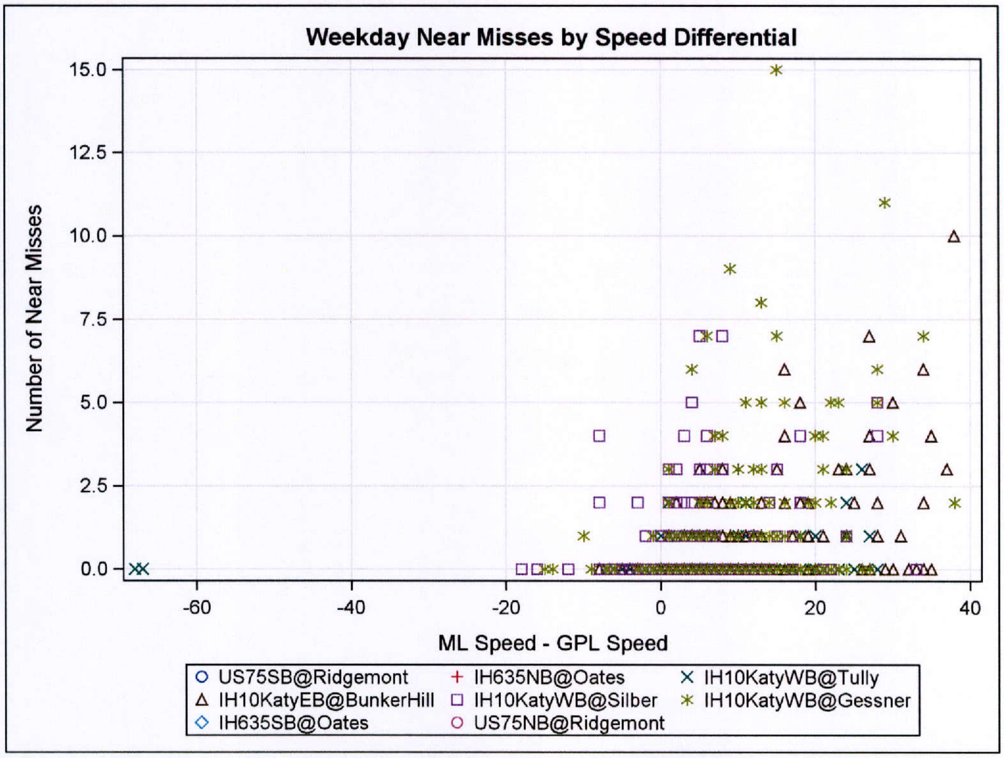


Figure I-2. Scatter Plot of Near Misses vs. Speed Differential between ML and GPL for Preferential Lane Access Locations.

Preferential Lane Tangent Case Study Sites (Combined)

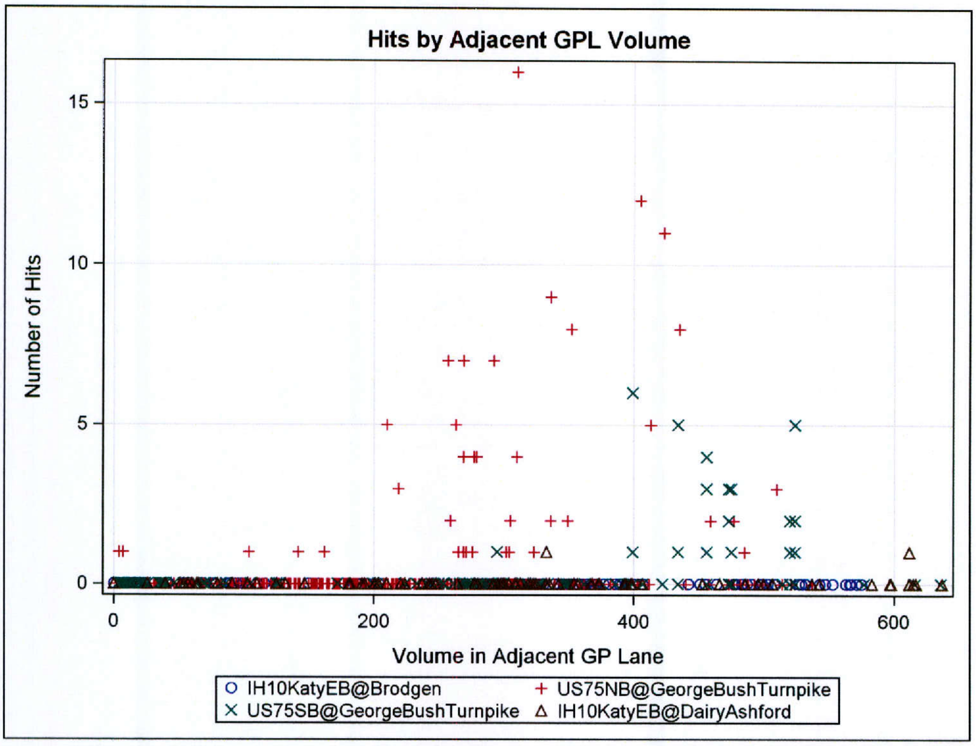


Figure I-3. Scatter Plot of Hits vs. Adjacent GPL Volume for Preferential Lane Tangent Locations.

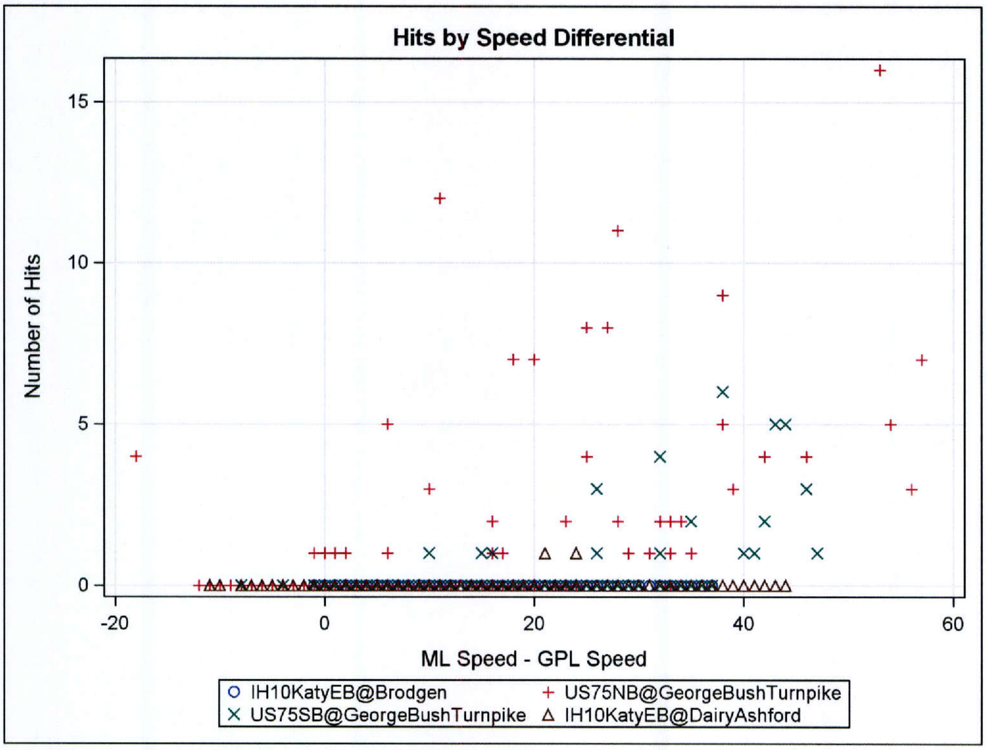


Figure I-4. Scatter Plot of Hits vs. Speed Differential between ML and GPL for Preferential Lane Tangent Locations.

Freeway Ramp-Frontage Case Study Sites (Combined)

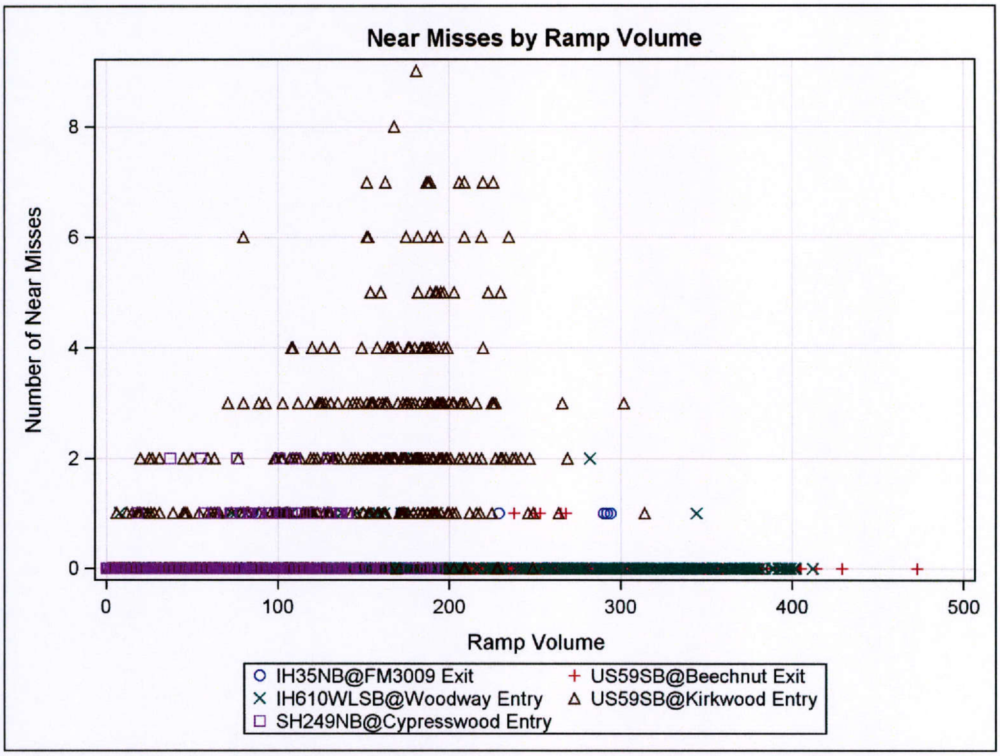


Figure I-5. Scatter Plot of Near Misses vs. Ramp Volume for Freeway Ramp-Frontage Locations.

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