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16. Abstract

The Katy Freeway Managed Lanes (KML) represents the first operational, multilane managed facility in Texas and provides an opportunity to benefit from the lessons learned from the project. This study evaluated multiple aspects of KML and the critical areas of project development, design, and operation. One sample finding is that travel time savings are approximately 5 minutes in the morning and 14 minutes in the afternoon in the peak directions, and the travel time advantage over the general-purpose lanes has increased as volumes have grown. Continual monitoring and adjustment of operating aspects of new managed lanes is required post-opening, especially during the ramp-up period in which drivers make travel adjustments to use the facility. The operating partners for the KML have continuously monitored the performance of the lanes since opening and have made adjustments in toll rates, lane configuration at the tolling zones, and access operations at the western terminus. These adjustments are critical to ensuring that the performance standards for the lanes are maintained.

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KATY FREEWAY: AN EVALUATION OF A SECOND-GENERATION MANAGED LANES PROJECT

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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, nor is it intended for construction, bidding, or permit purposes. The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because these are considered essential to the object of this report.

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CHAPTER 1. INTRODUCTION

PURPOSE OF THE PROJECT

The Katy Freeway Managed Lanes on I-10 in Houston, Texas, became fully operational in 2009. The managed lane facility, also referred to as the Katy Tollway, is the first constructed managed lane project in Texas and the first variably priced operation in the state since the implementation of the QuickRide program on US 290 and I-10 high-occupancy vehicle (HOV) lanes in Houston more than 10 years ago. The four-lane facility, which was constructed within the center of the existing freeway, can be described as a second-generation managed lanes project that is more complex than earlier-generation conversions from HOV to high-occupancy toll (HOT) lanes. In addition to the facility's unique operating characteristics, the Texas Department of Transportation (TxDOT) developed the project in partnership with other local entities in an innovative delivery process for funding, operating, and maintaining the managed lanes.

The purpose of this study is to perform a comprehensive evaluation of the Katy Freeway Managed Lanes, including aspects such as congestion, safety, enforcement, maintenance, pricing, access design, lane separation, operating policy, public perception, and project delivery mechanism. Using a combination of available data and new data collection, the evaluation will cover many of the critical areas of project development, design, and operation with the purpose of supporting successful implementation of managed lanes across Texas.

The Katy Freeway Managed Lanes represents the first operational, multilane managed facility in Texas and provides an opportunity for TxDOT and its partner agencies across the state to benefit from the lessons learned from the project. The facility is located in the Houston area, on the western portion of I-10 between SH 6 and I-610 West. A map of the facility is shown in Figure 1.

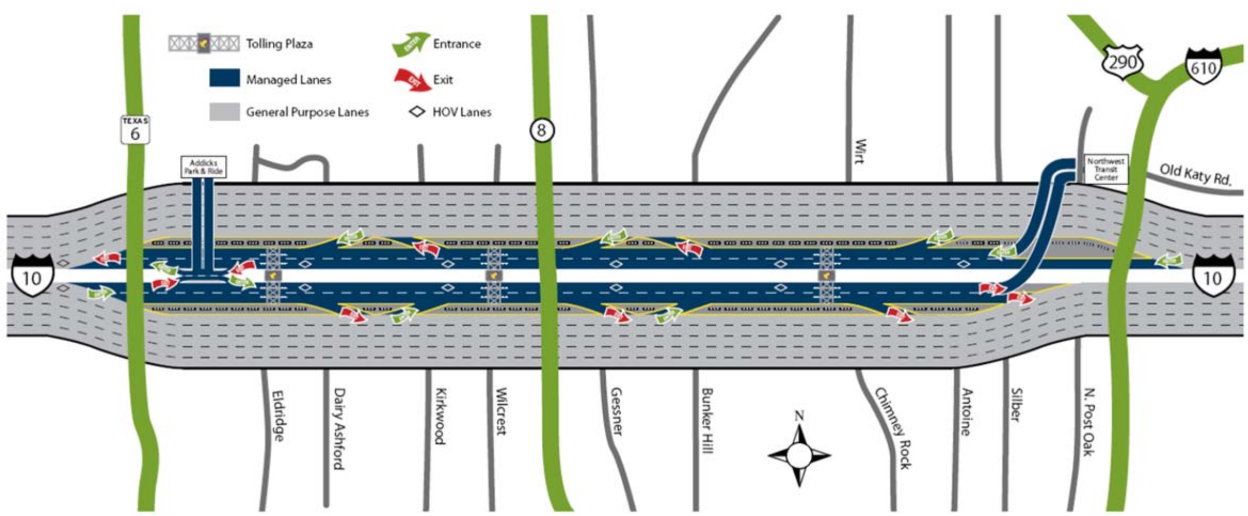


Figure 1. The Katy Freeway.

RESEARCH ACTIVITIES

In coordination with the Project Monitoring Committee, the research team developed an evaluation report framework to direct activities for the research project. They also developed 10 distinct research activities, with the framework serving as a project management tool to ensure coordination of the separate activities performed as part of the overall evaluation. These research activities are:

- Congestion and travel time.
- Safety.
- Enforcement.
- Maintenance.
- Toll and pricing.
- Access design.
- Lane separation.
- Operational policy.
- Public attitudes and perceptions.
- Project delivery.

The chapters in this report follow the order of these activities, with Chapter 2 providing a background and history of the Katy Freeway Managed Lanes. The final chapter provides findings and lessons learned.

CHAPTER 2. BACKGROUND AND HISTORY OF KATY FREEWAY MANAGED LANES

The research team gathered background information on the history and development of the I-10 Katy Freeway Managed Lanes (KML), including information about:

- Major investment study goals and objectives.
- Alternatives assessment.
- Strategic partnerships.
- Policy and business rule development.
- Project design features.

The purpose of this chapter is to provide a background and history of the Katy Freeway Managed Lanes because the decision and timing of events set a foundation for the overall evaluation. The history is summarized in Figure 2 and discussed in the following sections of this chapter.

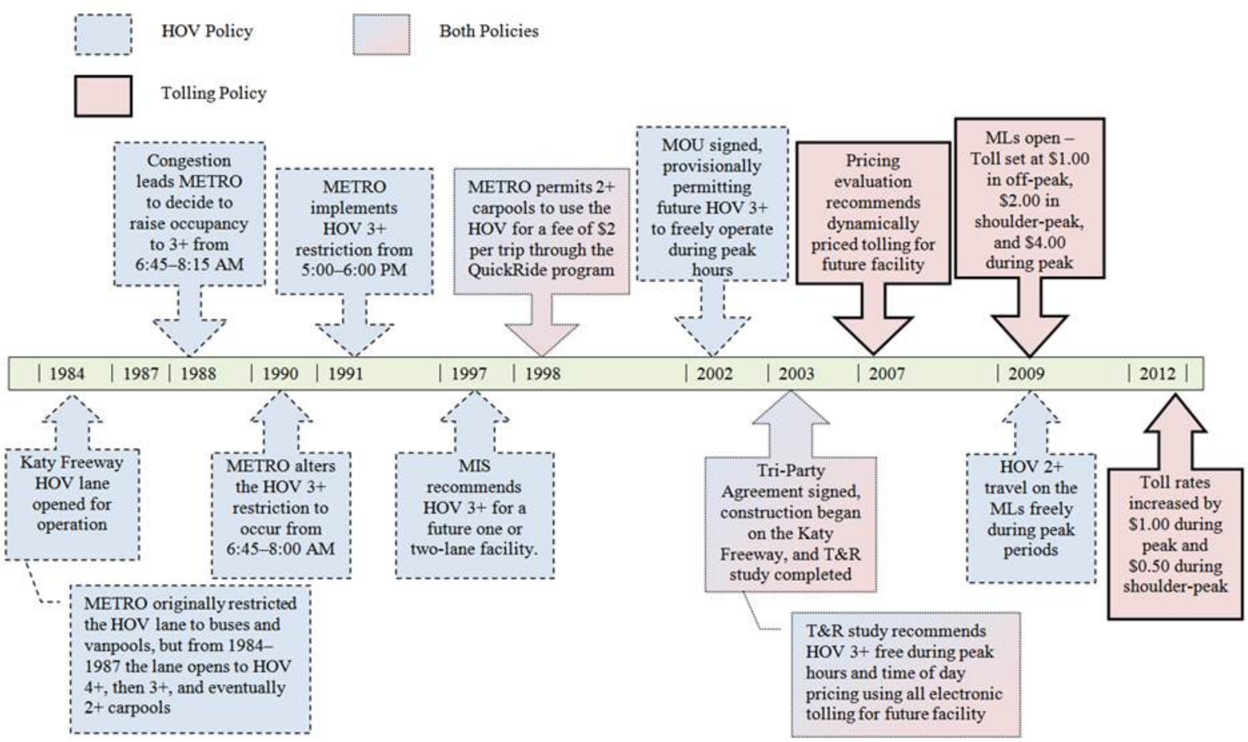


Figure 2. History of the Katy Freeway System.

HISTORY OF THE KATY FREEWAY HOV SYSTEM

The concept of an HOV lane on the Katy Freeway west of I-610 was originally conceived in 1982 when TxDOT was planning a pavement repair project that would start the following year. The Metropolitan Transit Authority of Harris County (METRO) submitted a plan to TxDOT to transform the repair into a new construction project that would convert the interior shoulders into a single reversible bus lane. The agencies used their close working relationship—originally formed when the I-45 North Freeway contraflow lanes were built during the 1970s—to finish construction from the original conception of the idea within a short 30-month time frame. The total project cost was only $12 million ($28 million, adjusted for inflation in 2011 dollars) and was completely borne by Metro's operating budget without any financial support from the federal government (*1*).

The Katy Freeway HOV Lane opened for operation in 1984 as a tool to mitigate congestion on I-10 west of Houston. The facility was originally designed as reversible HOV lane that permitted eastbound traffic in the morning and westbound traffic in the afternoon. Concrete barriers separated the HOV lane from the general-purpose lanes (GPL). At first, the HOV lane was restricted to authorized buses and vanpools, and then between 1984 and 1987, 4+ carpools, 3+ carpools, and then 2+ carpools were each systematically allowed after a continual evaluation of available capacity (*2*).

However, beginning in 1988, the Katy HOV lane experienced congestion and degradation in the quality of service when the demand for the facility exceeded capacity. Complaints from users of the system caused METRO, the operator of the HOV lane at the time, to evaluate a number of strategies to reduce demand during the peak hours of the day. Planners gave consideration to metering access, requesting voluntary travel time changes, and changing occupancy requirements. METRO ultimately made a policy-level decision to raise the occupancy requirement to 3+ during the morning period of 6:45 to 8:15 AM, keeping the 2+ rule for the afternoon period and all other times. The adjustment caused a decrease in both vehicle and person volumes of 62 and 33 percent, respectively, and an increase in the ratio of persons to vehicles from 3.1 to 4.2 during the five months after the change. In 1990, METRO slightly adjusted the time period for the morning 3+ restriction to occur from 6:45 to 8:00 AM. The following year, the 3+ occupancy rule was first implemented for the afternoon time period and was set to occur from 5:00 to 6:00 PM (*3*).

In 1998, METRO permitted 2+ carpools to use the Katy HOV lane during peak periods for a fee of $2 per trip through the implementation of the QuickRide program. The main goals of the program were to increase person throughput on the corridor, manage demand on the HOV lane without exceeding capacity, and alleviate congestion in the general-purpose lanes. Vehicles traveling as 2+ carpools had to display a hangtag and have transponders equipped to record toll transactions. A study that evaluated the QuickRide program found that demand for HOV-2 was modest and infrequent, with an average of 103 total trips per day and 0.89 vehicle trips per week. However, QuickRide was able to influence travel decisions significantly. Approximately 50 percent of the total HOV-2 volume was originally SOV trips in the general-purpose lanes (*4*).

TxDOT began an evaluation process in 1995 to assess the current condition and future needs of the Katy Freeway corridor including the general-purpose lanes, the HOV lane, and local access roads. Agency officials determined the design of the freeway to be obsolete—with maintenance costs at four times the average expressway segment in Texas—and inadequate to carry 200,000 vehicles of daily demand. A major investment study (MIS) was conducted to identify the mobility needs of the local communities and to consider a wide range of investments across multiple travel modes (*5*). This alternative was preferred because it had the potential to accommodate future growth, and the design was acceptable for TxDOT and the Federal Highway Administration (FHWA).

Reconstructing the Katy Freeway was significant in scope and project delivery in that it required a $2.8 billion investment with shared responsibility between three government agencies: FHWA, TxDOT, and the Harris County Toll Road Authority (HCTRA). The project was unique in that a local toll authority assumed responsibility for financing, constructing, operating, and maintaining the managed lanes while the general-purpose lanes remained under the jurisdiction of TxDOT. The KML was the first tri-party agreement to secure funding to operate toll lanes on an Interstate Highway in the United States. A later pact with METRO was made to allow transit vehicles to use the tollway for free as an effort to improve mobility on the corridor.

Completion of the construction phase of the program occurred in 2008, and all of the lanes became fully operational in April 2009 (*5*). When the tollway was completed, the cost to build it during a five-year construction schedule was roughly $237.5 million (*6*). The toll lanes were originally planned to operate as HOT-3+, but the occupancy requirement was lowered six months before the lanes became operational to allow 2+ carpools to travel for free (*7*). Currently, the volumes on the managed lanes are nearing the peak of 2,200 vehicles per hour (vph), and HCTRA is developing a new toll rate schedule to sustain free-flow movement without intermittent adjustment for six months following the change. The new fee structure will be similar to how tolls are displayed for the 91 Express Lanes in Orange County, California—with a fixed pricing scheme that varies by day of week, time of day, and direction of travel (*6*).

Table 1 summarizes the geometric configurations in a “before and after” snapshot.

Table 1. Katy Lane Geometry Before and After Construction.

Criteria	Before/During Construction	After Construction
Managed Lanes	One lane reversible HOV	Two lanes each direction HOV/Toll
General-Purpose Lanes	3	4
Occupancy	HOV3+ in peak hours	HOV 2+ and Toll
Hours of Operation	M-F 5AM to 11AM IB M-F 1PM to 8PM OB Sat OB & Sun IB	M-F 5AM to 11AM IB & OB M-F 1PM to 8PM IB & OB Toll 24/7/365
Separation	Barrier	Buffer with pylons
Operating Agency	TxDOT/METRO	HCTRA

DEVELOPMENT OF THE KATY MANAGED LANES

Major Investment Study Goals and Objectives

In 1995, TxDOT initiated a major investment study of the Katy Freeway corridor to examine potential large-scale changes to I-10 that could improve performance and meet the future demand and needs of a growing Houston metropolis. FHWA required the MIS as a tool to evaluate major transportation investments, as regulated by the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) and the 1990 Clean Air Act Amendments (CAAA). Additionally, TxDOT used the MIS to screen alternatives on the basis of potential harm to the environment and the possibility of public acceptance from local communities. The study had scoped a 40-mile segment of I-10 that stretched westward from the Downtown Houston Central Business District to the Brazos River (*8*).

The alternatives assessment for the MIS was guided by four principal goals that TxDOT identified, which were listed in the final report as:

- Goal 1: Improve corridor mobility and safety in a cost-effective manner.
- Goal 2: Provide a transportation system that has minimal negative impact on aesthetics, environment, and community.
- Goal 3: Provide a balanced and coordinated transportation system.
- Goal 4: Provide a transportation system that serves the regional land use/development patterns in the future (*8*).

Assessment of the Alternatives

TxDOT initially considered 11 planning concepts that integrated various elements of HOV, bus, highway, and arterial improvements. Project staff screened these concepts, which then resulted in a final list of seven refined alternatives, including the no-build option. The alternatives that incorporated major design and operational changes were conglomerates of key design and operational elements. Then, project staff swapped and combined features to build each of the alternatives. The main components included the following elements:

- Transportation systems management (TSM)/transportation demand management (TDM) techniques (e.g., ramp metering, synchronized traffic signals, incident management, etc. in the corridor).
- A general-purpose lane in each direction from I-610 to Katy and from Brookshire to the Brazos River.
- Two general-purpose lanes in each direction from I-610 to Katy.
- A two-lane, two-way HOV facility from downtown Houston to Katy.
- A two-lane, two-way HOV facility from SH 6 to Katy.
- A four-lane, two-way special-use lane from I-610 to SH 6.
- A high-level fixed transit guideway from downtown Houston to Katy, providing improved access to feeder routes and stations (*8*).

An assessment was performed as part of the MIS to gauge the ability of each option to meet the stated goals and objectives. A consensus was reached through the public involvement process that designated the no-build alternative as not viable. All of the remaining six alternatives were evaluated for performance based on the ability to:

- Encourage higher-occupancy modes of travel and a reduced reliance on single-occupant vehicles (SOVs).
- Reduce the vehicle hours of travel.
- Reduce the vehicle miles of travel.
- Reduce congestion (defined as the volume-to-capacity ratio) and improve mobility on I-10.
- Improve average speeds (*8*).

The results of the analysis indicated—at least initially—that having additional SOV and HOV lanes on certain parts of the corridor would help to meet the stated goals. Special-use lanes were also seen as a viable alternative. These lanes were defined at the time as facilities that could provide a high level of performance for HOVs, SOVs, and trucks. Moreover, special-use lanes could potentially permit HOVs to travel for free while imposing a fee on SOVs—similar to the present-day term *HOT lanes*.

The MIS identified a number of funding sources to support major construction of new facilities in the corridor, including FHWA, the Federal Transit Administration (FTA), state programs, local sources, and other revenue generation mechanisms (e.g., tolling). The financial feasibility of each of the alternatives was evaluated using estimated costs of capital, operations, and maintenance budgets. A time period of 25 years was used as the baseline assumption to calculate the life-cycle operation and maintenance (O&M) costs. The alternative with the special-use lanes was deemed to have the lowest O&M life-cycle costs at $106 million for 25 years, besides the no-build alternative and the alternative that solely used TDM techniques.

The MIS recommended an alternative, as reported in a 1997 final report, with four special-use lanes (two in each direction) from I-610 to SH 6 and an additional general-purpose lane (one in each direction) to be built as part of a large construction project to upgrade the Katy Freeway (*8*).

Strategic Partnerships: Tri-Party Agreement

A shared goal of improving regional mobility helped to strengthen the partnerships that led to the construction of the KML. When FHWA issued the record of decision in 2002, HCTRA made a proposal to assume responsibility for the four special-use lanes in the median of the Katy Freeway between I-610 and SH 6. The proposal to build, operate, and maintain the managed lane portion of the highway allowed the construction of the facility to be completed sooner and permitted funds originally designated for the corridor to be spent on other projects in the region (*5*).

The tri-party agreement between TxDOT, HCTRA, and FHWA was formed to secure funding and approval for the KML, in addition to upgrading the entire corridor including general-purpose lanes and frontage roads. Specifically, the agreement was defined as being groundbreaking and innovative because it included components not commonly involved in the delivery of major transportation investments. Some of the key traits of the tri-party agreement were:

- Having a shared operating agreement: TxDOT would own and maintain the general-purpose lanes and frontage roads. HCTRA would own and operate the managed lanes.
- Financing the construction of managed lanes on an Interstate Highway through a county-based toll operator: Up until that point, most managed lane projects were basic HOV-to-HOT lane conversions and did not have primary financial goals for operation.
- Using open road electronic tolling: No manned toll booths were planned for the KML. All tolling on the facility was to be done autonomously through overhead gantries equipped with electronic toll equipment (*5*).

A separate Memorandum of Understanding was signed in 2002 between TxDOT, METRO, and HCTRA. Before major construction on the Katy Freeway corridor began, the roles and responsibilities for the three agencies were delineated, and a basic agreement on operating principles was reached:

- HCTRA had the primary responsibilities of enforcement and maintenance.
- A level of service of C was identified to be the target for operational performance.
- Access points for transit services and an option for a light-rail corridor were drawn in the agreement.
- METRO would financially support any special signing for transit modes.
- Under the current agreement, METRO may operate up to 65 buses per hour during any time period without paying toll (*9*).

Policy and Business Rule Development

A detailed operating plan was signed in 2009 between HCTRA, METRO, and TxDOT to define the roles and responsibilities of each agency in the operation of the KML. HCTRA was given the responsibility to actively manage incidents within the tolled managed lanes with assistance from the HCTRA Incident Management Center (IMC). The system components of the IMC include vehicle detection sensors, a call center for the roadside assistance program, and a closed-circuit television network with cameras fixed on the lanes. The HCTRA IMC operates independently of the Houston TranStar system, which has the primary responsibility of detecting and responding to incidents on the general-purpose lanes. TxDOT operates the Houston TranStar system (*10*).

An operating committee was formed to address continuing issues outlined in the operating agreement and is composed of officials from HCTRA, METRO, and TxDOT. The position of committee chair is designated to be an individual from TxDOT. The committee is charged with reviewing operating procedures related to the operations, safety, incident management, and scheduled maintenance or closure events of the managed lane facility. An operations report that provides a basic overview of data elements from all of the parent agencies is required to be released quarterly by the operating committee. Any request for closure of the general-purpose or managed lanes due to special events has to be provided to the operating committee at least one week before the event (*10*).

Project Design Features

After the construction process was complete, the KML extended from SH 6 to I-610 along a 12-mile corridor. Two managed lanes operate in each direction in the median of the facility, bound by eight general-purpose lanes, with four traveling eastbound and four traveling westbound. The Addicks Park and Ride Lot and the Northwest Transit Center are located at opposite ends of the managed lanes and provide services for users seeking carpools and transit modes. Three ingress ramps and three egress ramps on each side of the corridor provide access to the managed lanes, in addition to separate access ramps for the park-and-ride lot and transit center. An 18- to 20-foot buffer with white pylons spaced at 10-foot intervals separates the managed and general-purpose lanes.

Three tolling plazas exist on the corridor, with electronic gantries detecting vehicles in each direction at the crossings of Eldridge Parkway, Wilcrest Drive, and Wirt Road. An HOV declaration lane is present on the right side during peak periods, as indicated by a dynamic message sign that displays “HOV only” overhead at each of the toll plazas. SOVs and commercial vehicles that are permitted to use the managed lanes travel on the left side of the managed lanes during peak periods. HOVs are allowed to use the managed lanes toll-free, but only during peak periods in the peak direction of flow, specifically from 6:00 to 11:00 AM in the eastbound direction and 2:00 to 8:00 PM in the westbound direction. A wide inside shoulder at the tolling plazas gives enforcement vehicles a place to manually observe HOV requirement compliance since HOVs are not required to have transponders to use the managed lanes.

CHAPTER 3. CONGESTION AND TRAVEL TIME

The research team documented the operational conditions on the Katy Freeway Managed Lanes and analyzed traffic volume and travel times over time. Traditionally, the peak hour or peak period in the peak direction is evaluated. The KML is unique in that the off-peak direction has shown a significant growth in volume and travel time savings, so the off-peak direction was evaluated as well. This chapter focuses on the pre-construction, during-construction, and post-construction time frame of the KML but includes operational data back to 1994. Researchers looked at changes over time in traffic volume, travel time, and transit usage within the HOV and managed lanes using data obtained from several sources, including TxDOT, METRO, HCTRA, and the Texas A&M Transportation Institute (TTI). An examination of the historical trends presents the magnitude of the changes.

Within this report, several comparisons are made between the previous HOV lane and the new Katy Freeway Managed Lanes. However, some of the operations, maintenance, and other aspects offer no true comparison. The original HOV lane was a one-lane reversible facility, servicing eastbound (EB) traffic in the morning and westbound (WB) traffic in the afternoon. The new KML now has two lanes in each direction, basically quadrupling the capacity of the original HOV lane. The original HOV lane was barrier-separated from the general-purpose lanes, and the new KML facility uses pylons as a lane separator from the general-purpose lanes. The use of pylons impacts enforcement and maintenance requirements on the facility.

DATA AGGREGATION TOOL

To mine the operational speed data from the Houston TranStar automatic vehicle identification (AVI) system, the research team developed a data aggregation tool to query the large travel time datasets. The Houston Regional Traffic Data Generator (HRTDG) allows researchers to quickly generate travel time scenarios, and it could be useful for ongoing monitoring of the KML. Figure 3 shows the web-based graphical user interface that allows the user to query travel time data using the HRTDG tool. The HRTDG produces a comma-delineated file that can be further analyzed using a spreadsheet, database, or statistical program.

The user has the ability to select roadway, direction, date, and time range. The user can also select days of the week, or a combination of days, to allow for analysis of the differences between days. For example, a user can compare the travel times of eight consecutive Mondays with those of eight consecutive Tuesdays. The tool was designed to be very flexible, with the ability to add other data sources. The user can select output to provide an average for a given time period or a daily summary in 15-minute increments, and can also exclude selected days from the analysis. Often it is desirable to exclude days in the summer months that may have different characteristics than days during the fall and spring when school is in session. It may also be desirable to exclude holidays, major traffic events, or significant weather events. The TTI Houston office maintains an inventory of major traffic and weather events.

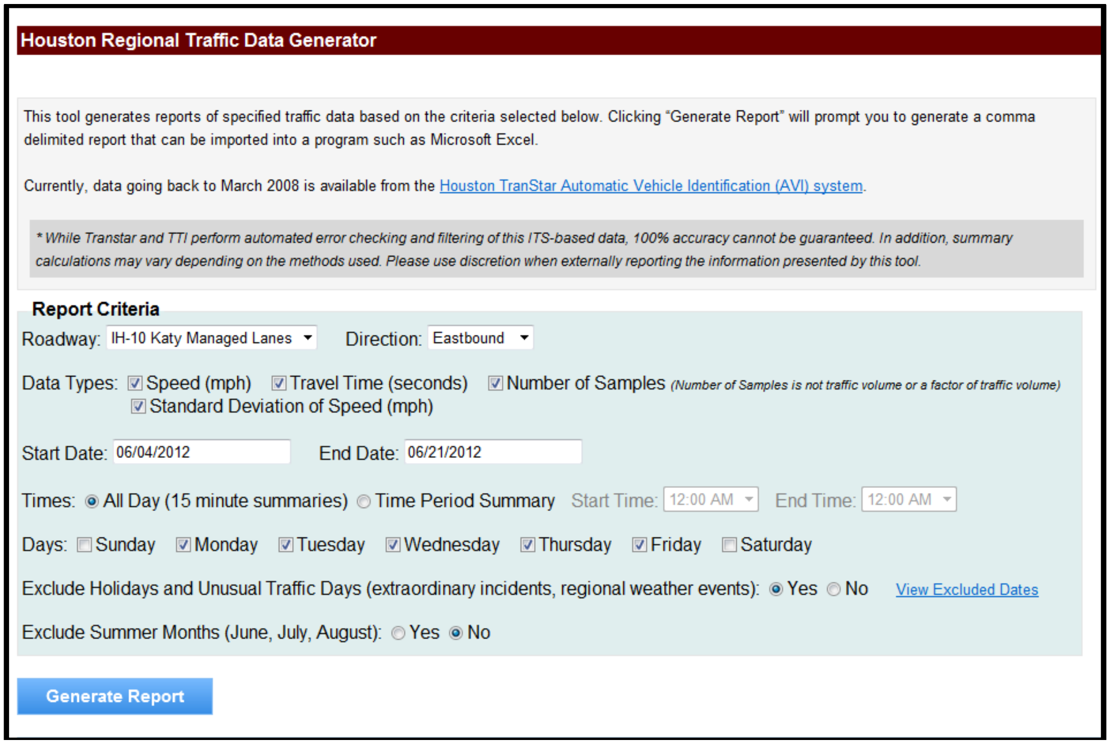


Figure 3. Graphical User Interface of the HRTDG.

TRAFFIC VOLUMES

Traffic volume information is collected quarterly from both manual and automatic tube counts as part of an ongoing monitoring of the Houston HOV lane system. TxDOT and METRO conduct these counts jointly and have collected them since the inception of the Katy HOV lane in 1984. Manual counts are conducted for the AM and PM peak periods at the Wirt toll plaza, while tube counts are typically conducted for seven days to capture weekend traffic volumes.

Figure 4 shows that the daily traffic volumes on the managed lanes were fairly consistent from about 2001 through 2008, even during the construction period from 2004 through 2009. In 2009, after construction was complete, a dramatic increase in vehicle volume was observed, essentially doubling volumes over pre-expansion levels. The two primary trend lines shown in Figure 4 are *total volume* and *carpools*. Carpools (and now toll vehicles) make up over 95 percent of the traffic volume and carry about 75 percent of the passenger volume on the KML. Conversely, buses, vanpools, and motorcycles are 5 percent of the traffic volume but carry about 25 to 30 percent of the passenger volume. As seen in Figure 4, over time there are quarterly variations, which are believed to be influenced largely by seasonal activities, as well as general economic conditions and fuel prices. However, these variations rarely last more than a quarter. In the past two years, there has been a noted reduction in KML traffic volumes during the summer. This trend is likely due to the reduced travel time on the general-purpose lanes, resulting in less travel time savings by utilizing the KML.

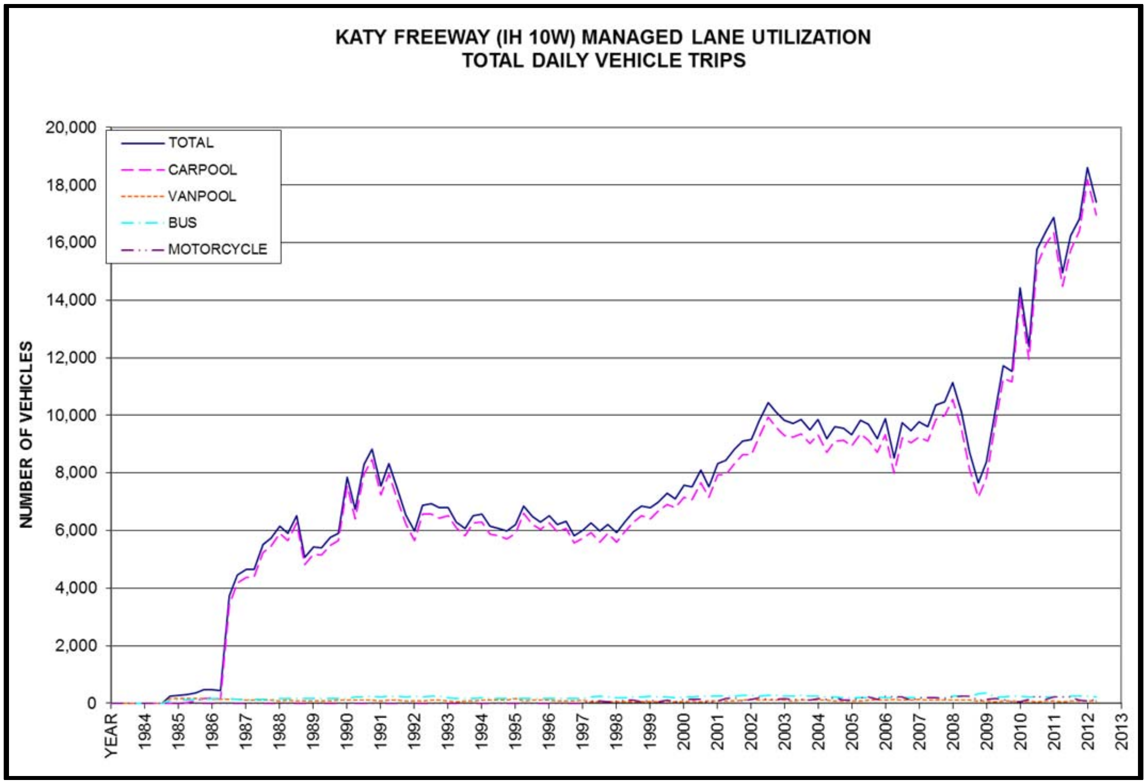


Figure 4. Quarterly KML Daily Peak-Direction (EB AM and WB PM) Traffic Volumes.

AM Peak and PM Peak

The KML AM peak-period volumes are shown in Figure 5, with the AM peak-hour volumes shown in Figure 6. The PM peak-period and PM peak-hour traffic volumes are shown in Figure 7 and Figure 8, respectively. Overall, the PM peak period has lower volumes and has not shown the summer time dips in volume like the AM peak period exhibits. The PM peak graphs also show some interesting characteristics:

- 1986: Occupancy drops to 3+ (increase in volume to over 4,000 vehicles per day [vpd]).
- 1987: Occupancy drops to 2+ (increase in volume to over 6,000 vpd).
- 1988: Occupancy increases to 3+ in peak hour (decrease in volume to 5,000 vpd).
- 2009: Two-way and two-lane operation begins (increase in volume to over 10,000 vpd).
- 2010 to 2012: Summer volume dips become pronounced (increase/decrease in volume by 2,000 vpd).

At each of these milestones, there is a corresponding reaction in the traffic volume. The AM peak period ranges between 6,500 and 8,800 vehicles for the peak period. During the peak hour, the traffic volumes are near capacity, and in some bottleneck and merge areas at the SH 6 T-ramp in the AM peak, congestion breakdown is a typical occurrence. All of the characteristics are more pronounced in both the AM and PM peak hours as compared to the peak periods.

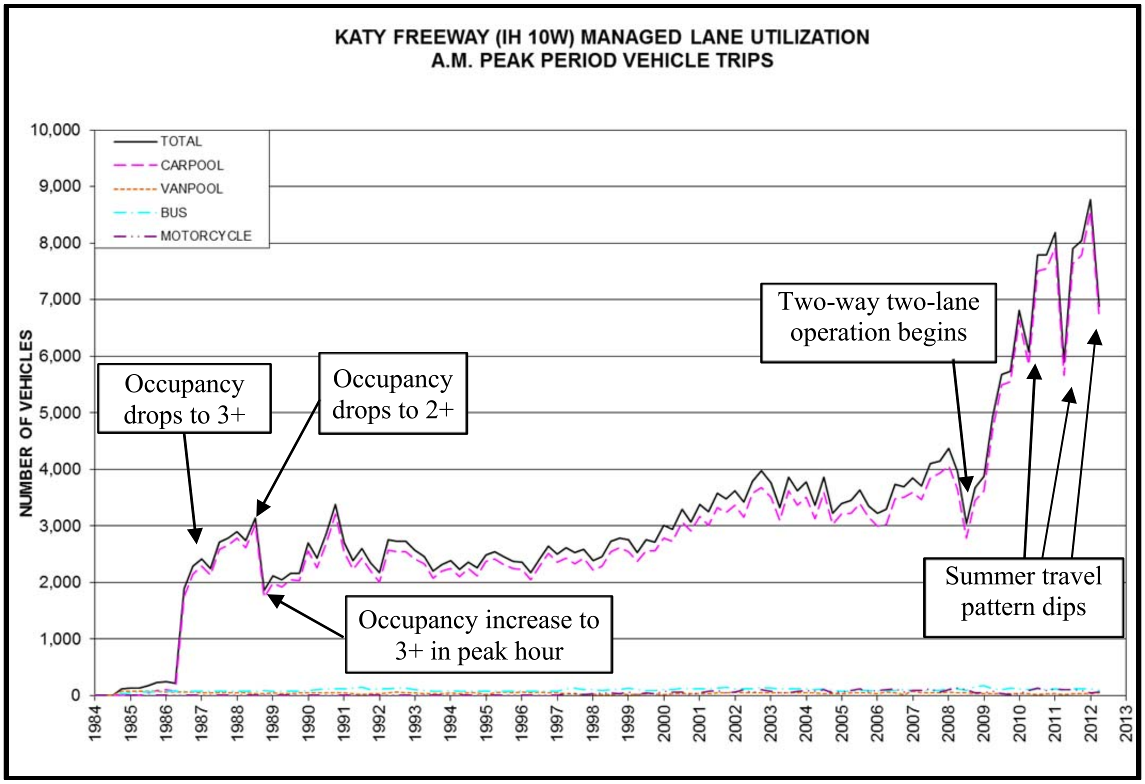


Figure 5. KML AM Peak-Period Peak-Direction (EB) Historical Volume.

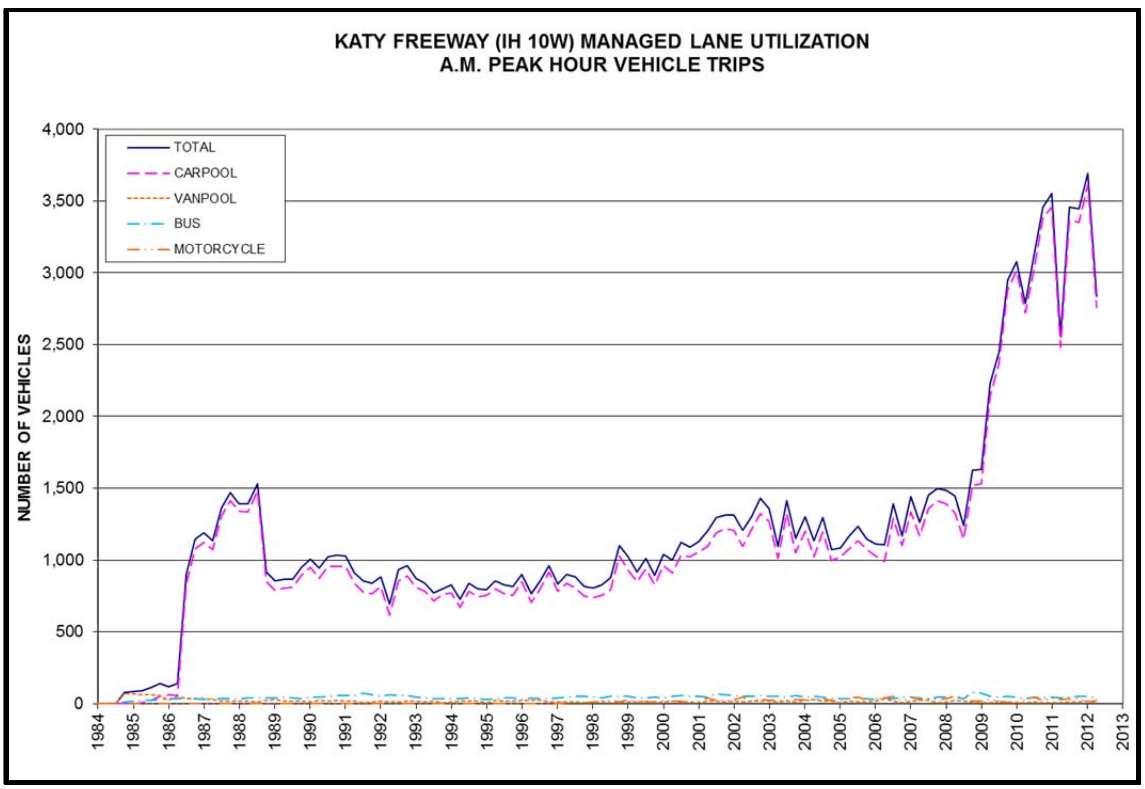


Figure 6. KML AM Peak-Hour Peak-Direction (EB) Historical Volume.

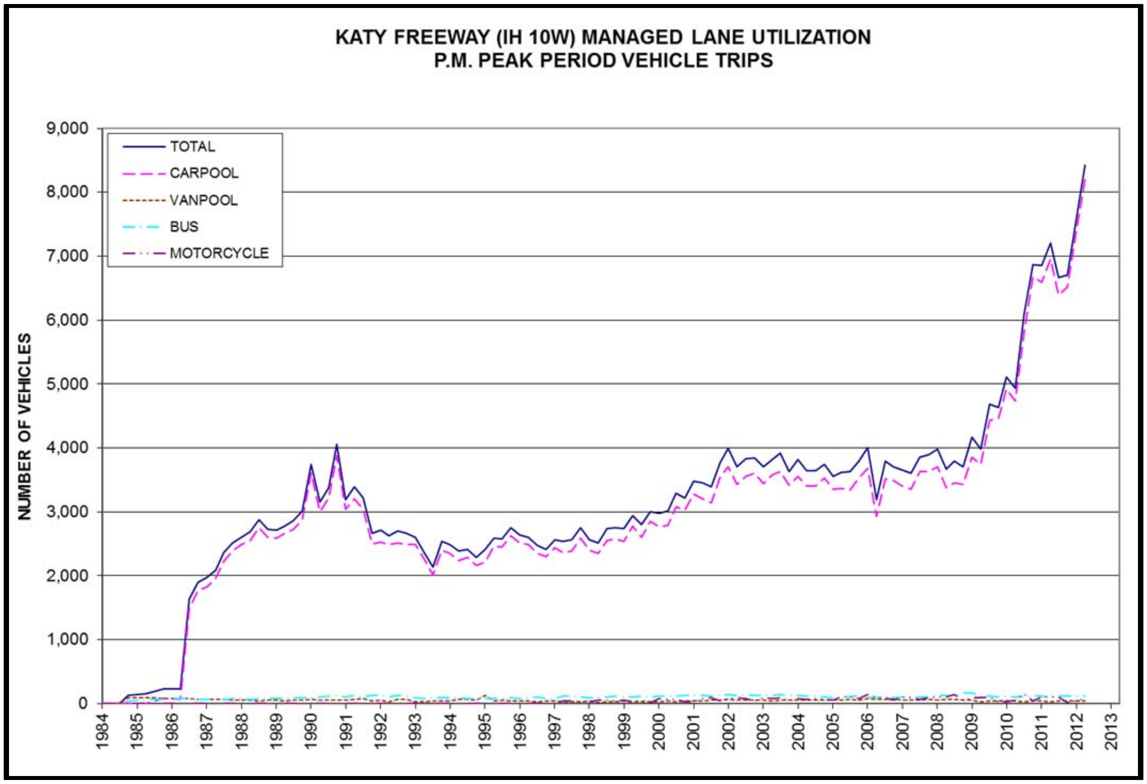


Figure 7. KML PM Peak-Period Peak-Direction (WB) Historical Volume.

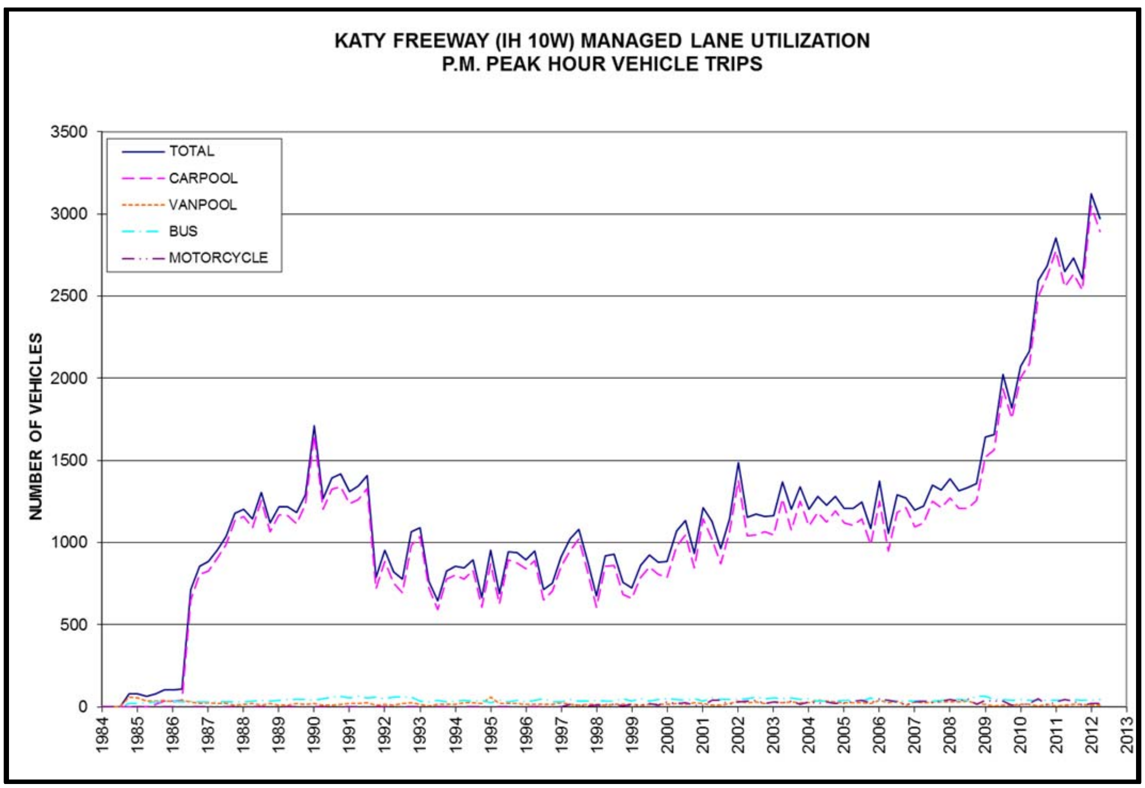


Figure 8. KML PM Peak-Hour Peak-Direction (WB) Historical Volume.

Lane Distribution

The lane distribution (or the number of vehicles in each of the two managed lanes) has been of increasing interest to the operating agencies, particularly as it impacts operations near the declaration areas. As shown in Figure 9, the amount of SOV/toll traffic relative to HOV traffic grows in the peak hour and then falls back by about 8:30 AM. This additional SOV traffic likely represents the SOV users who feel that paying the toll for a more reliable trip (and not simply a travel time savings) has value during this time of day.

The overall increase in traffic volume and periodic congestion on the managed lanes at the merge points and declaration areas has led to a proposed toll increase for fall 2012. The toll rates are being adjusted to potentially reduce traffic volumes and maintain free-flowing conditions in the managed lanes. Table 2 and Table 3 are highlighted to reflect the changes for fall 2012. Table 2 shows that the new EB toll will increase by $1.00 for a peak-period full trip, from $4.00 to $5.00, and the shoulder peak-hour rate will increase from $2.00 to $2.50 for a full trip for both directions of peak travel (EB in the AM and WB in the PM). Table 3 shows the WB peak-hour toll will now apply one hour earlier to reflect traffic demand. Off-peak rates will remain the same (*11*).

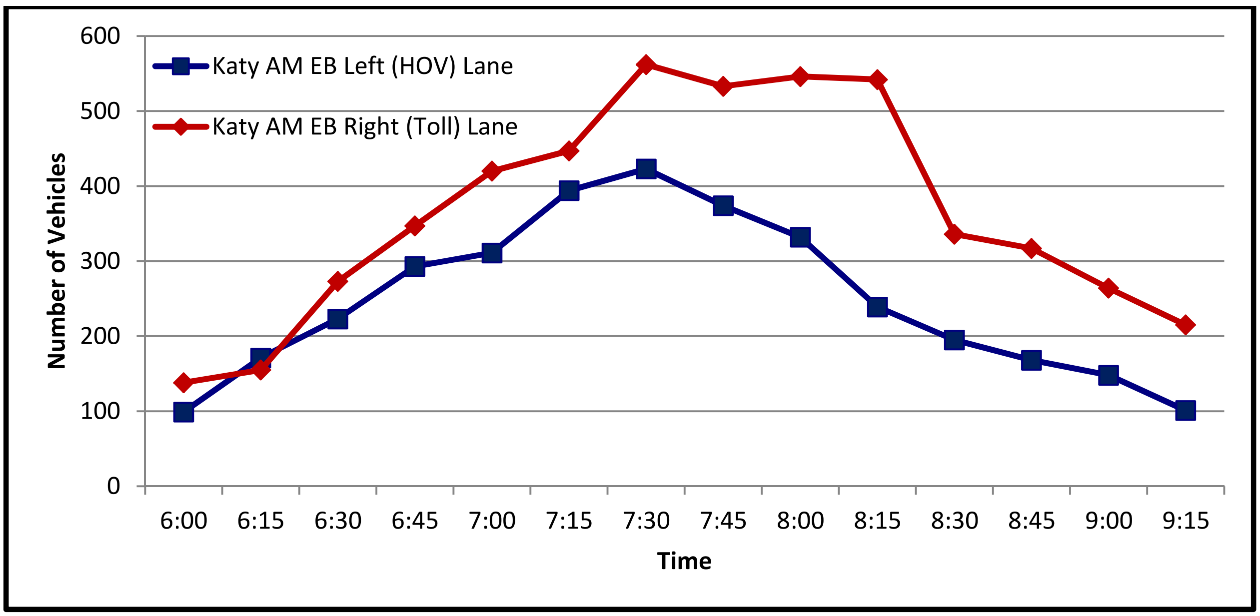


Figure 9. KML March 2012 AM Peak-Period Peak-Direction (EB at Wirt Toll Plaza) Lane Distribution by Time of Day.

Table 2. Fall 2012 Toll Rate Table Reflecting Toll Increase for the EB AM Direction.

Eastbound—AM	Old		New	
Time Period	**Hours**	**Toll**	**Unchanged**	**Toll**
Off Peak	Midnight–6:00	$1.00	Midnight–6:00	$1.00
Shoulder Peak	6:00–7:00	$2.00	6:00–7:00	$2.50
Peak	7:00–8:00	$4.00	7:00–8:00	$5.00
Peak	8:00–9:00	$4.00	8:00–9:00	$5.00
Shoulder Peak	9:00–10:00	$2.00	9:00–10:00	$2.50
Off Peak	10:00–Midnight	$1.00	10:00–Midnight	$1.00

Table 3. Fall 2012 Toll Rate Table Reflecting Toll Increase for the WB PM Direction.

Westbound—PM	Old		New	
Time Period	**Hours**	**Toll**	**Hours**	**Toll**
Off Peak	Midnight–4:00	$1.00	Midnight–3:00	$1.00
Shoulder Peak	4:00–5:00	$2.00	3:00–4:00	$2.50
Peak	5:00–6:00	$4.00	4:00–5:00	$5.00
Peak	6:00–7:00	$4.00	5:00–6:00	$5.00
Shoulder Peak	7:00–8:00	$2.00	6:00–7:00	$2.50
Off Peak	8:00–Midnight	$1.00	10:00–Midnight	$1.00

Operational Challenges

The KML generally operates very well; however, there are two locations on the facility that experience recurring congestion. EB during the AM peak period, at the SH 6 T-ramp, T-ramp traffic merges with the two managed lanes. At this location, before the T-ramp merge, the two managed lanes are near capacity during the peak hour as shown in Figure 10. For a short time in the peak hour, the T-ramp traffic has an inadequate number and length of gaps to enter the managed lanes over a minimum merge distance. The development of congestion at this location is compounded by a high number of buses coming from the Addicks Park and Ride Lot to the managed lanes. TxDOT and HCTRA are investigating modification of pavement markings at this location to extend the merge distance to give buses more acceleration distance and a ramp metering scheme at the top of the T-ramp that would potentially increase gaps in T-ramp entering traffic to reduce the potential for breakdowns in flow. In addition, the proposed toll increase may reduce traffic volumes somewhat, potentially increasing the gaps in managed lanes at the T-ramp merge point.

Figure 10. KML Addicks T-Ramp Congested Merge EB AM Peak Hour.

The other problematic location was WB during the PM peak at the North Post Oak Road entry. Previous to this point, the managed lane is only one lane from its origin inside I-610. At this point, the North Post Oak entry joins the managed lane from the left. To address this issue, the pavement markings near this merge area were modified in July 2012 to eliminate the merge and provide two lanes WB at the Post Oak Road entry. This eliminated a congestion point by allowing the traffic from inside I-610 and the North Post Oak entry traffic to each have its own lane. The entry from the general-purpose lanes (which provides access from I-10 and I-610 connectors) now has an extended merge area of about 0.5 miles.

In each of these situations, shorter merge distances and a "rolling" vertical geometric alignment contribute to higher driver workload. This, combined with higher traffic volumes (including a higher number of buses), aggravated the congestion issue. These locations are shown in Figure 11.

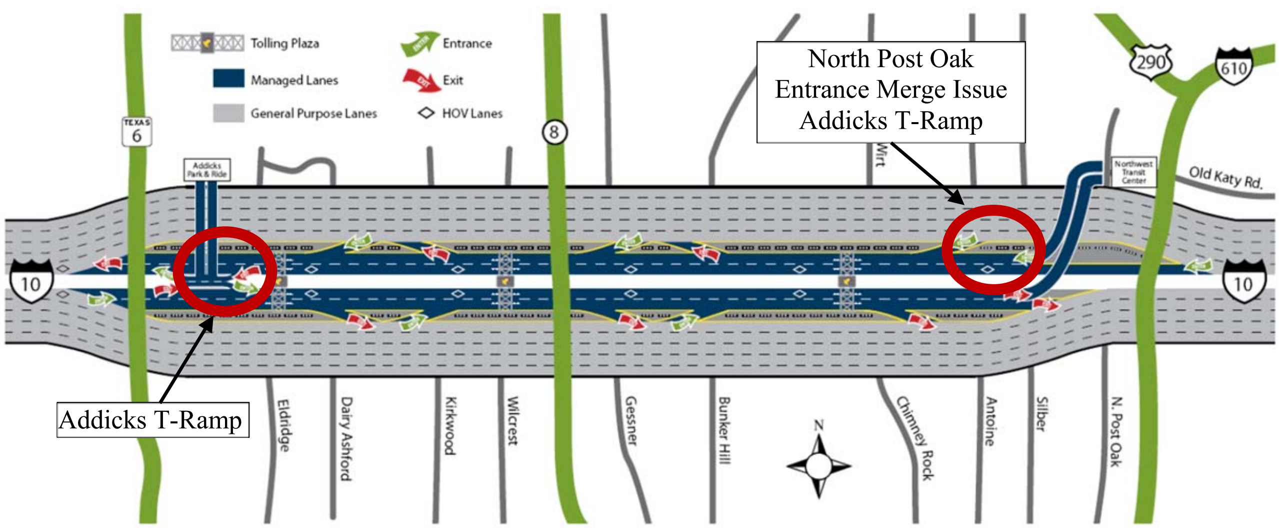


Figure 11. KML Merge Congestion Locations.

Reverse Flow Trends—AM Peak Period

The KML has two lanes in both the EB and WB directions. This allows for travelers to use a toll or HOV option (during hours when "HOV for free" is available) in both directions of travel, 24 hours per day. This lane availability was originally highly underutilized but has started to become more utilized as congestion becomes more common in the corridor.

Figure 12 and Figure 13 show the AM *peak-period* (6:00 to 9:00) traffic volume by direction and by lane distribution (left lane HOV declaration and right lane toll). HOV volume in the reverse (or WB) AM peak period shows an HOV volume that has doubled over the three-year time period since opening, with a fourfold increase in toll lane volume. It is unclear why the KML has seen the dramatic increase in off-peak-direction use; however, some potential influences may include better travel time reliability, actual (or perceived) travel time savings, or employment growth in the central and western portion of the corridor (*11*).

Figure 14 and Figure 15 show the AM *peak-hour* (7:00 to 8:00) distribution. The EB peak-hour traffic volume is approaching capacity, and the smallest incident could cause the lane to break down, resulting in congestion that typically takes 30 to 60 minutes to recover from. Large increases in the reverse direction (WB) are sharply evident.

Reverse Flow Trends—PM Peak Period

Figure 16 and Figure 17 show the PM *peak-period* (4:00 to 7:00) traffic volumes by lane. Both graphs show a steady increase in total managed lane traffic since the KML opened. Figure 18 and Figure 19 show the *peak-hour* (5:00 to 6:00) lane distribution by direction. The WB PM peak-hour volumes are approaching capacity. However, it is interesting to note the dramatic increase in EB PM traffic volume, which is the off-peak direction. The EB traffic is nearly 1,800 vehicles in the peak hour, with about 600 vehicles being HOV. This level of traffic lessens the perception of the "empty lane syndrome" because the facility provides a viable reverse commute alternative for trips from employment centers in the central and western portions of the KML corridor.

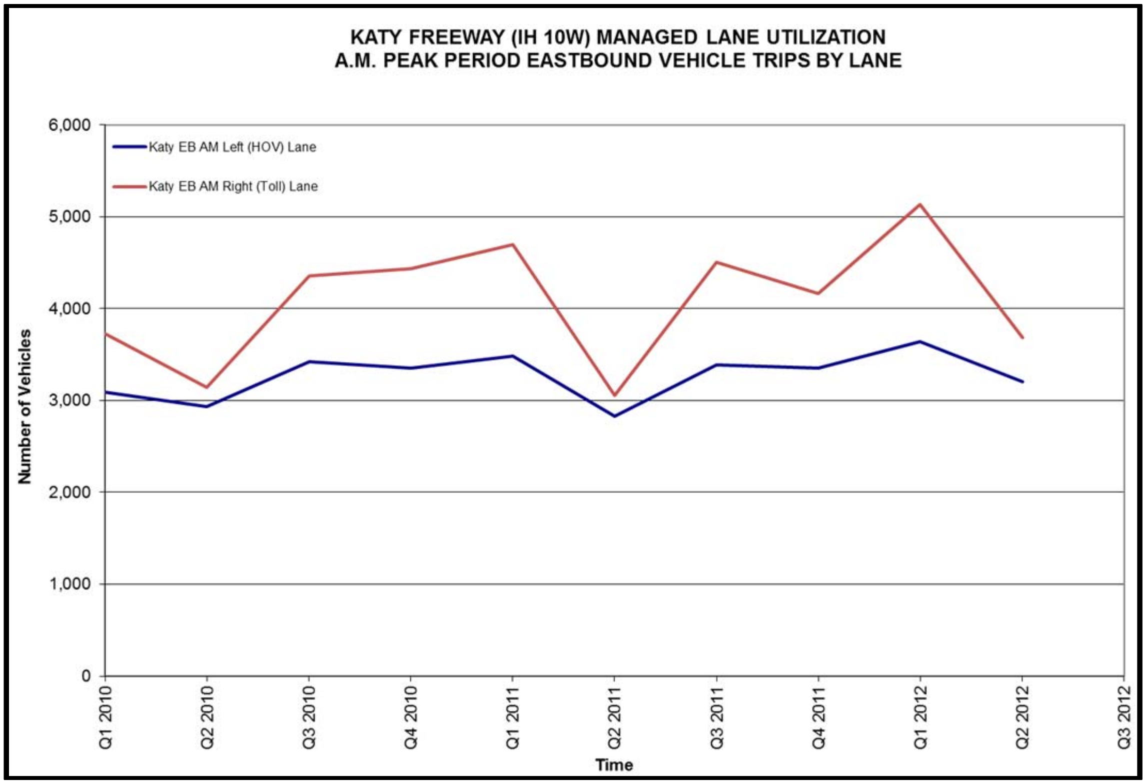


Figure 12. AM Peak-Period EB Lane Distribution.

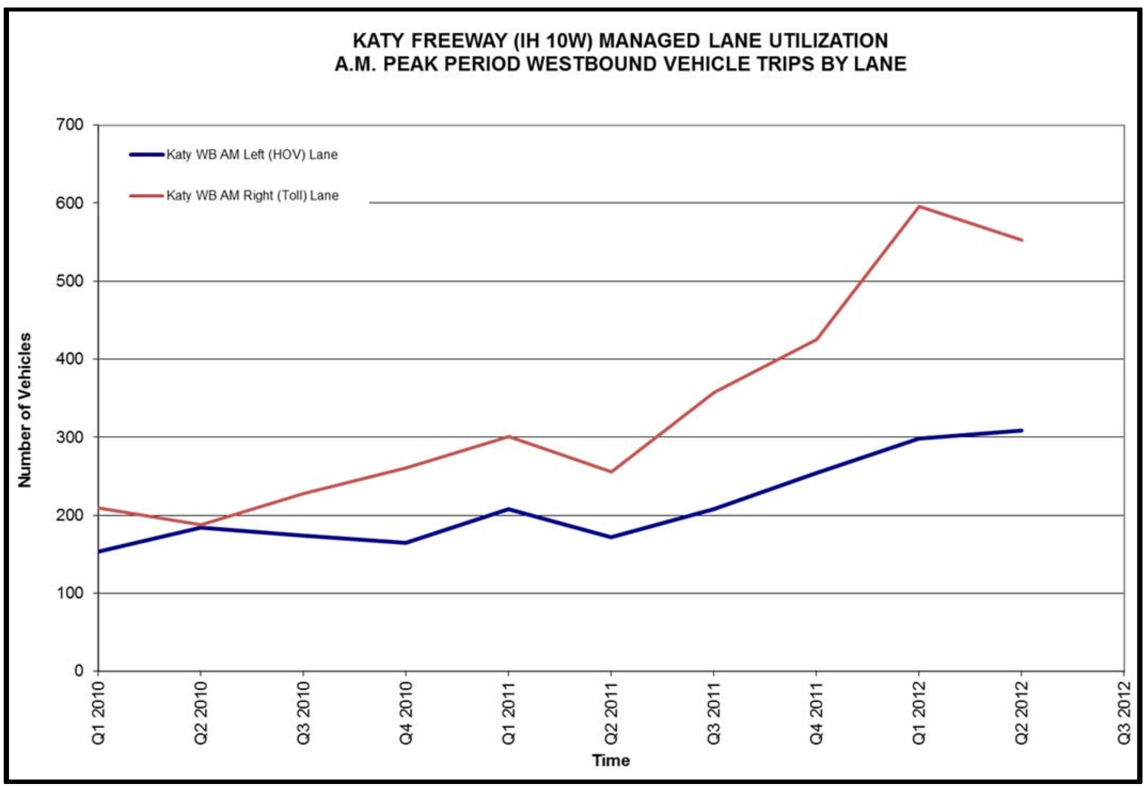


Figure 13. AM Peak-Period WB Lane Distribution.

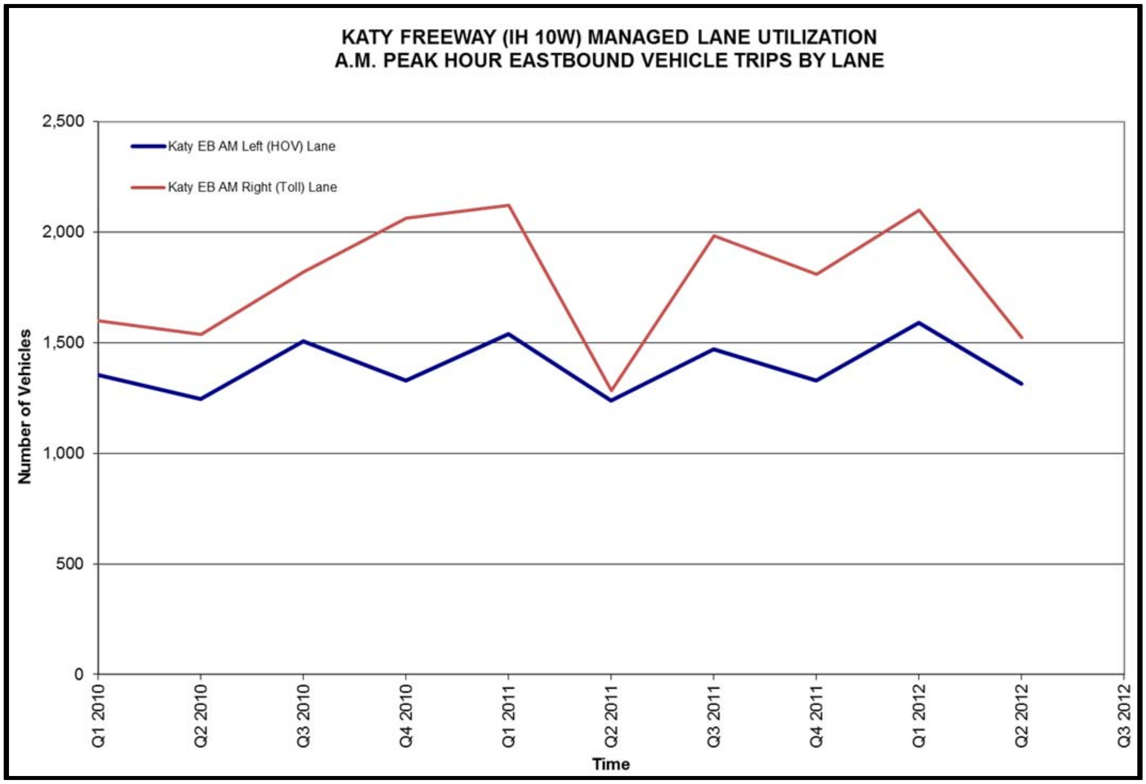


Figure 14. AM EB Peak-Hour Lane Distribution.

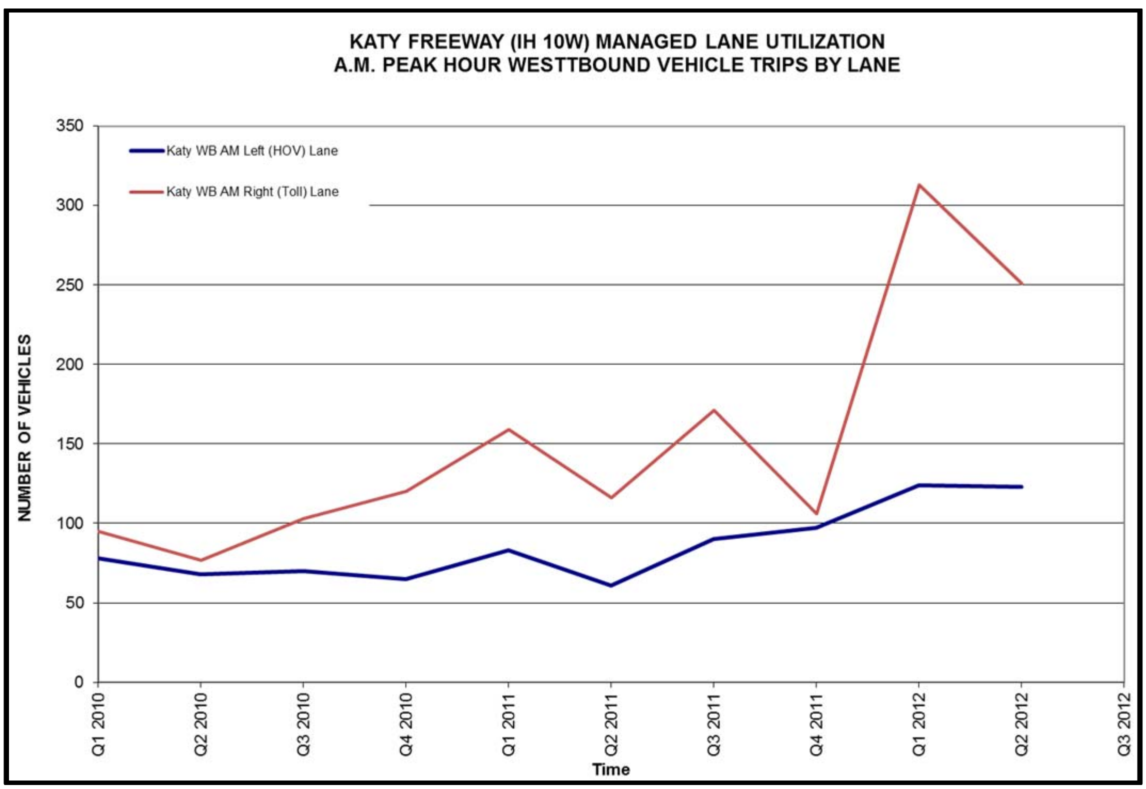


Figure 15. AM WB Peak-Hour Lane Distribution.

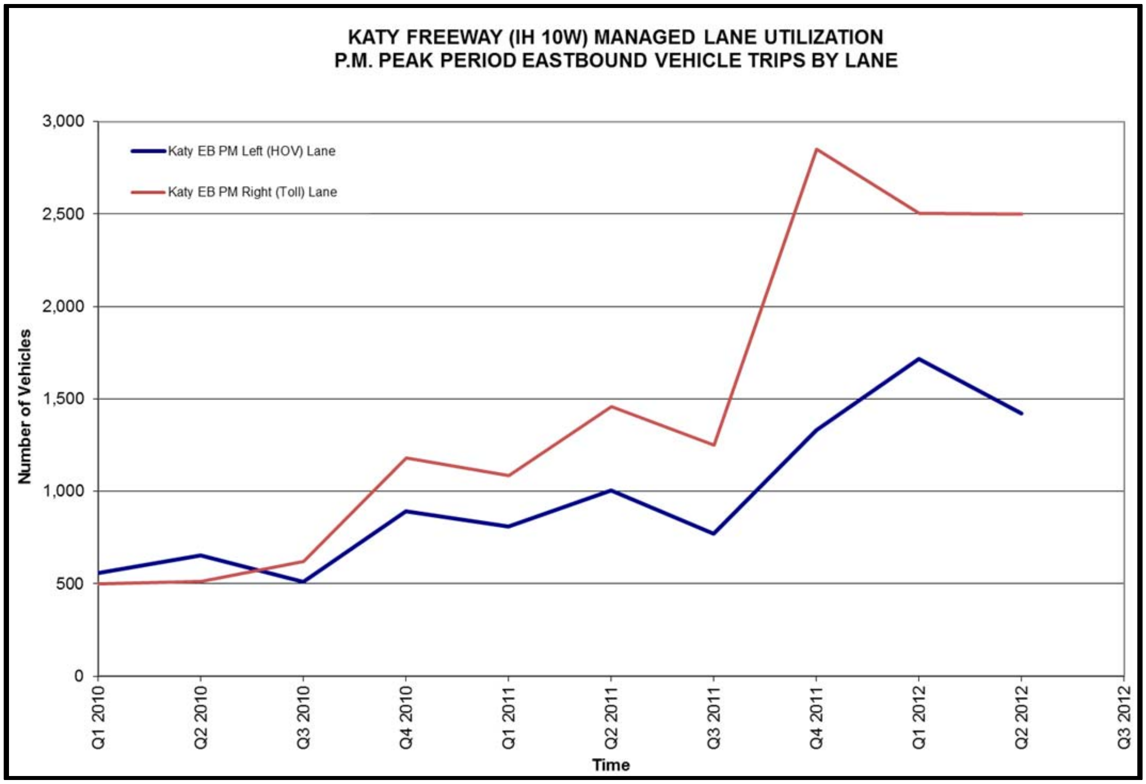


Figure 16. PM EB Peak-Period Lane Distribution.

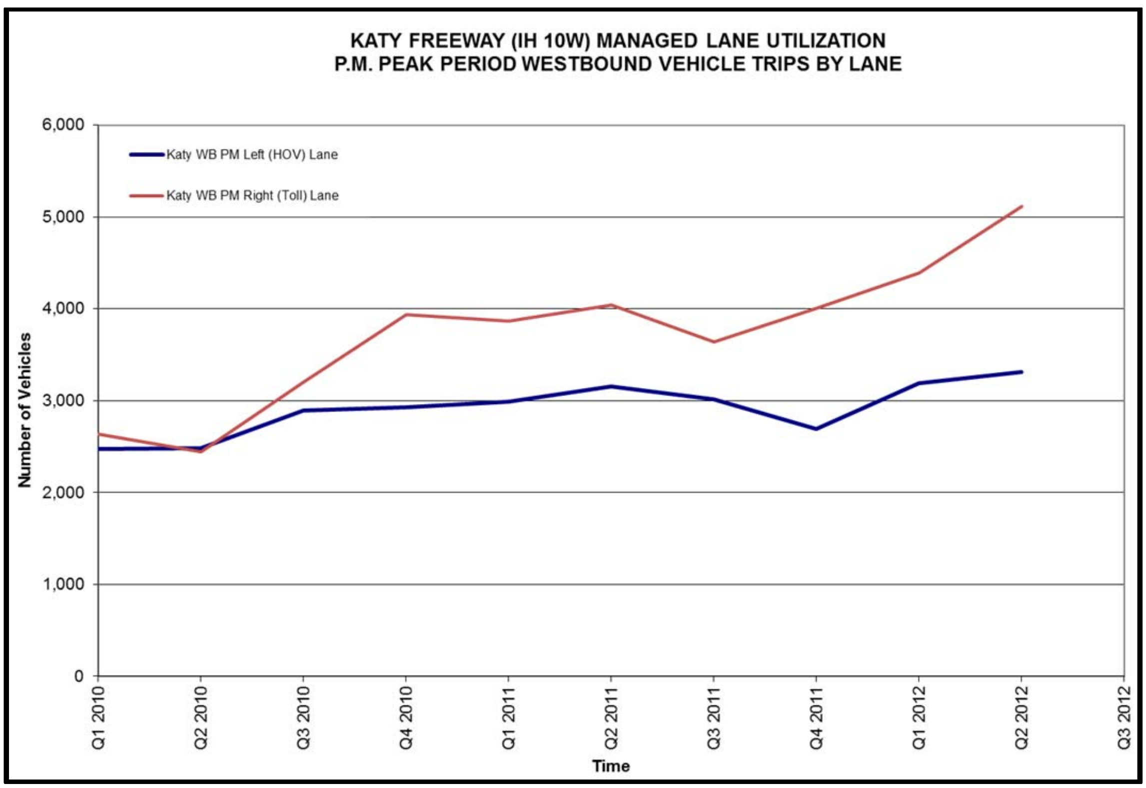


Figure 17. PM WB Peak-Period Lane Distribution.

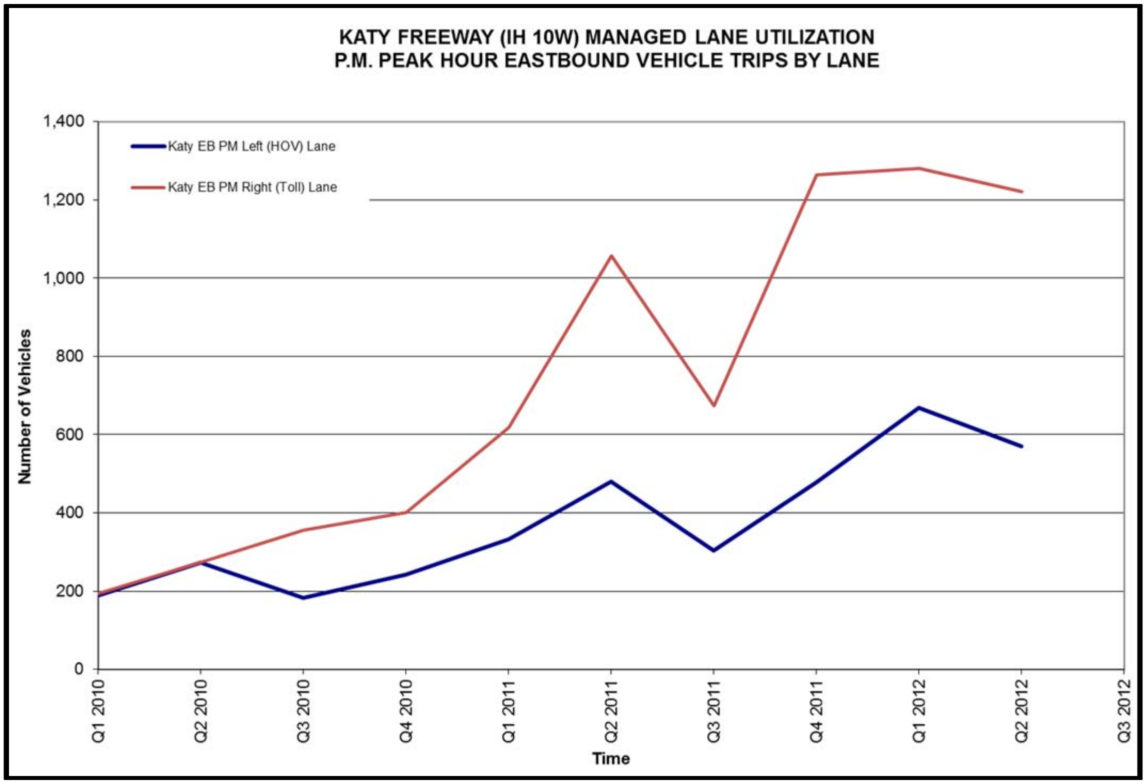


Figure 18. PM EB Peak-Hour Lane Distribution.

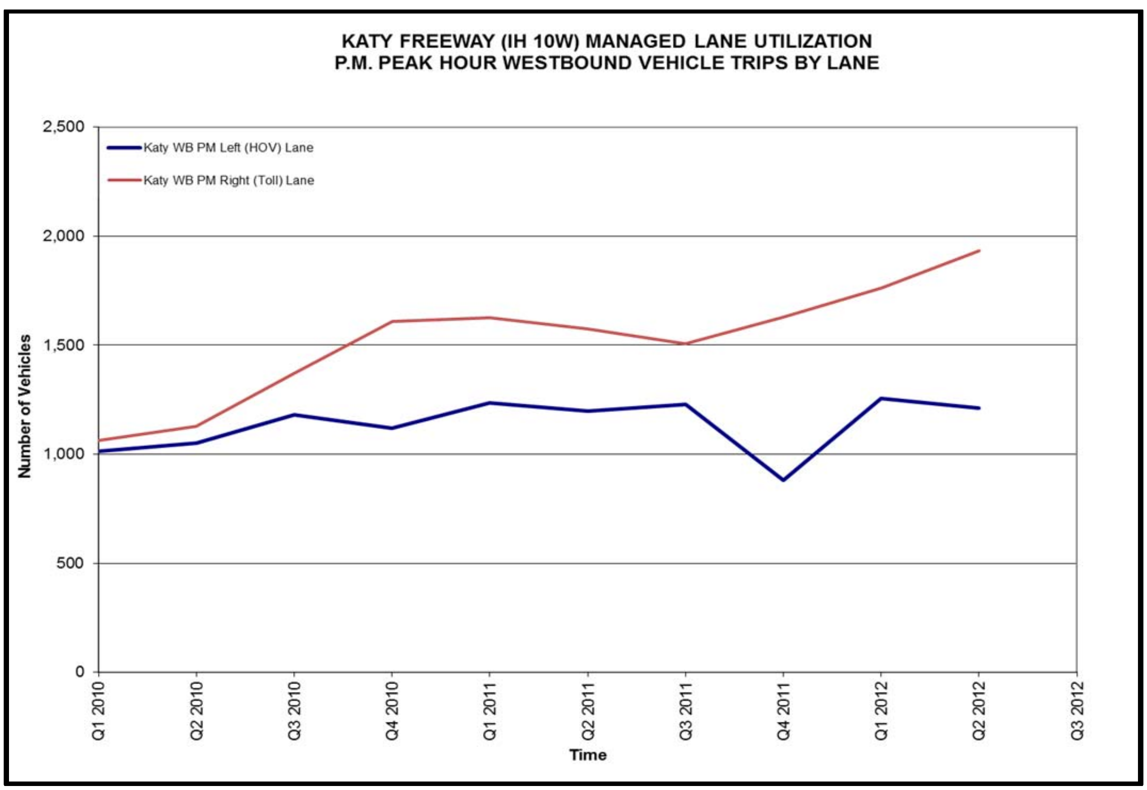


Figure 19. PM WB Peak-Hour Lane Distribution.

TRAVEL TIME ANALYSIS

An examination of travel times in the corridor was conducted using the AVI traffic monitoring system. AVI is a probe-based system that provides segment travel times (as opposed to spot speeds) primarily using toll-tag technology. A historical dataset was queried to generate the tables and graphs shown below. Graphs were developed by time of day and by lane (HOV or toll).

Data Source

The Houston TranStar AVI traffic monitoring system is used to collect real-time travel time information to present current travel conditions on Houston area freeways, HOV lanes, and HOT lanes. Houston was the first region to apply AVI technology for monitoring traffic conditions in the early 1990s. Travel time information is provided to personnel within Houston TranStar for use in detecting and managing freeway congestion. This travel time information is also provided to the public through media reports, displays on selected roadside electronic message signs, and the Houston TranStar website. In addition, travel time information is archived for planning, operations, and research tasks.

On the KML, the AVI system uses vehicles equipped with transponder tags as vehicle probes. The main source of vehicle probes is commuters using the EZ TAG automatic toll collection system operated by HCTRA (*12*).

AVI antennas and readers are installed at 1- to 5-mile spacing on structures along Houston area freeways, including the general-purpose and HOV/HOT lanes of the KML. Each reader reads radio frequency identification (RFID) tags mounted on vehicles as they pass a reader station, and the reader transmits the time and location of the probes to a central computer via fiber optic or cellular communications. As the probe vehicles pass through successive AVI readers, central software calculates average travel times and speeds for a roadway segment.

The information from the system is stored in a historical database, which includes average travel times and speeds in 15-minute increments, by roadway segment. In some cases the data are available by facility type; HOV/HOT lanes are separate from general-purpose lanes. Travel time data on segments of the system are available from 1992 to the present day. The AVI system has evolved over time, with segments having been added and modified over time with construction or for operational adjustments.

For this analysis, travel time data were queried by month for typical weekday (Monday through Thursday) traffic conditions. Major holidays, days with severe weather, and days with major incidents lasting more than three hours were excluded from the dataset. Average travel time and speed by segment were then aggregated to produce corridor travel times. The weekday peak hours were assumed to be 7:00 to 8:00 AM and 5:00 to 6:00 PM for this analysis.

Peak-Hour Travel Times

The average AM and PM peak-hour travel speeds, monthly from April 2009 to March 2012, are shown in Figure 20 and Figure 21. Several AVI segments were aggregated to develop an average travel time from SH 6 to I-610 (West Loop), a length of approximately 12 miles. Average speeds for the corridor are calculated by dividing the total average trip time by the corridor distance.

Overall, the peak-direction AM peak hour has higher peak-direction travel speeds than the PM peak hour. Over time, the AM peak hour has experienced higher speed variability, while the PM shows a more consistent declining trend in average travel speed. These trends are true for both managed lanes and general-purpose lanes. However, the afternoon has a larger travel speed differential between managed lanes and general-purpose lanes; thus, the managed lanes have typically offered a greater travel time savings in the afternoon peak hour.

The average peak-hour travel time has shown a steady decline over time. Factors that may influence the decline (and variation) of the average travel speed may include:

- Corridor diversion—Travelers from US 290 and Westpark Toll Road shift to the KML for travel time advantages versus those corridors.
- Latent demand—Trips were not made to avoid congestion, or travelers shift departure times to the peak hour instead of leaving earlier or later to miss congestion.
- Economic changes—As the Houston region's economy improves and more development occurs in the corridor, usage increases, resulting in decreased travel speeds.
- Employment—Employment in the region and in the corridor has increased, albeit slowly, influencing the rate of average speed decline in the corridor.
- Gas prices—Gas prices influence average speed variation more than the decline of average speeds over time. Gas prices tend to influence "extra" travel and induce more carpooling in the corridor.

A specific example that shows a deviation from this overall trend is the rise in travel speed in June 2011. Unemployment was at 8.9 percent, a rate not seen since June 2003, and gas prices rose to more than $3.50 per gallon. With lower employment and higher gas prices, these factors—when combined with a seasonal summer drop in commuting—resulted in a higher average travel speed. Both the traffic volume and the travel speed dips are noticeable in Figure 6 and Figure 20. Several compounding factors will influence travel patterns and travel time. The factors listed above are just some of those possible, and the correlation is not always a direct correlation; it is sometimes two or more factors.

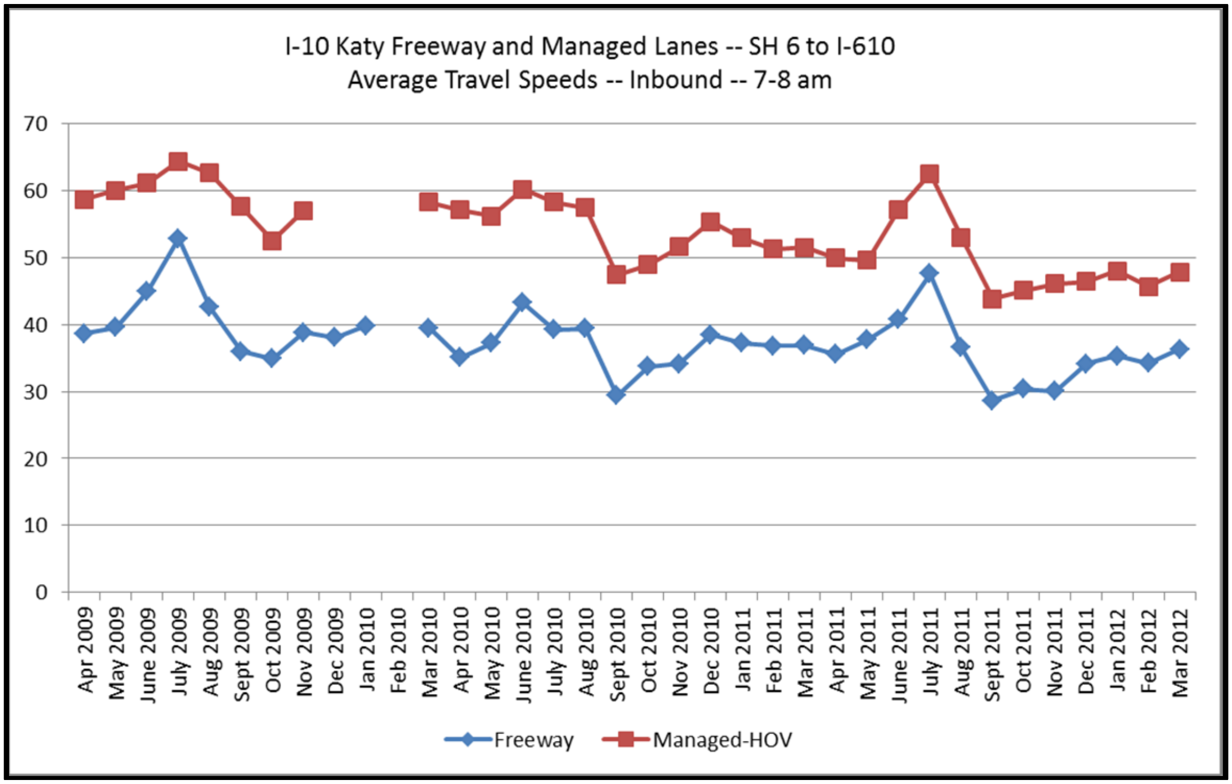


Figure 20. AM EB Peak-Hour Average Travel Time.

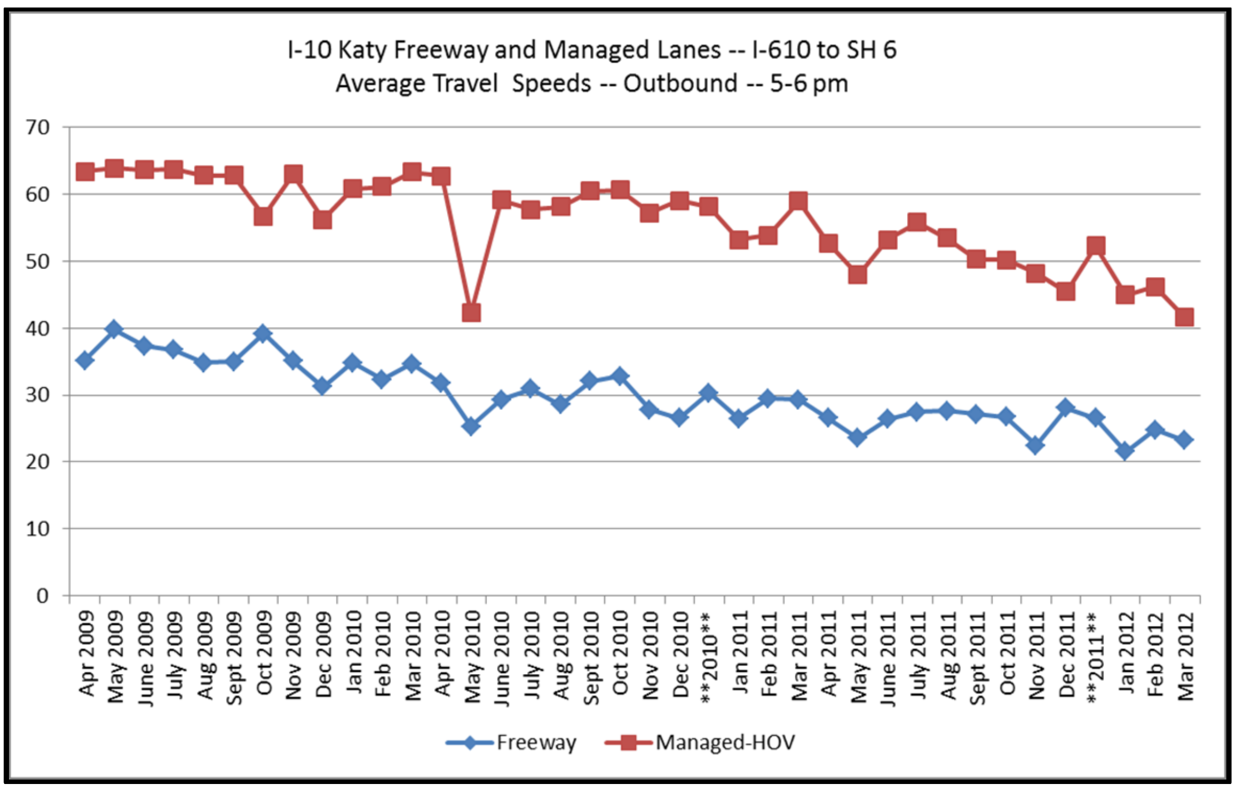


Figure 21. PM WB Peak-Hour Average Travel Time.

Travel Time Difference

Figure 22 and Figure 23 present the difference in travel time (or the travel time savings) for the AM and PM peak hours, respectively. Each figure shows the travel time savings for the peak direction (AM EB and PM WB) and the off-peak direction (AM WB and PM EB). Traveling on the managed lanes in the PM offers greater travel time savings than the AM, and the travel time savings has been growing over time. The morning travel time savings is about five minutes in the peak hour in the EB direction. The main area of congestion is from SH 99 to Eldridge. The afternoon peak-direction (WB) travel time savings is approximately 14 minutes. Congestion on the general-purpose lanes extends from the Beltway 8 (BW8) interchange to SH 6 and typically to Fry Road. High general-purpose lane volume is compounded by traffic entering from the beltway. The reverse flow AM WB travel time savings is only one minute. However, the reverse flow EB PM peak-hour travel time savings is over six minutes. Congestion at the 610 loop that propagates back to BW 8 is the main area of congestion in the EB PM peak.

This travel time savings is greater than the AM peak-direction travel time savings. Again, these are the average savings over the entire length. Some segments will yield significantly higher travel time savings. Many commuters use the managed lanes for certain segments to queue jump the congestion or to facilitate entering the freeway and thus avoiding traffic signals on the frontage roads. In the AM peak direction, the most congested segment is the furthest west near SH 6. This is partially due to the congestion before the KML and partially due to the energy corridor destination. In the PM direction, the most congested segment is again the westernmost section from inside the beltway to Fry road. High general-purpose lane volume is compounded by traffic entering from the beltway.

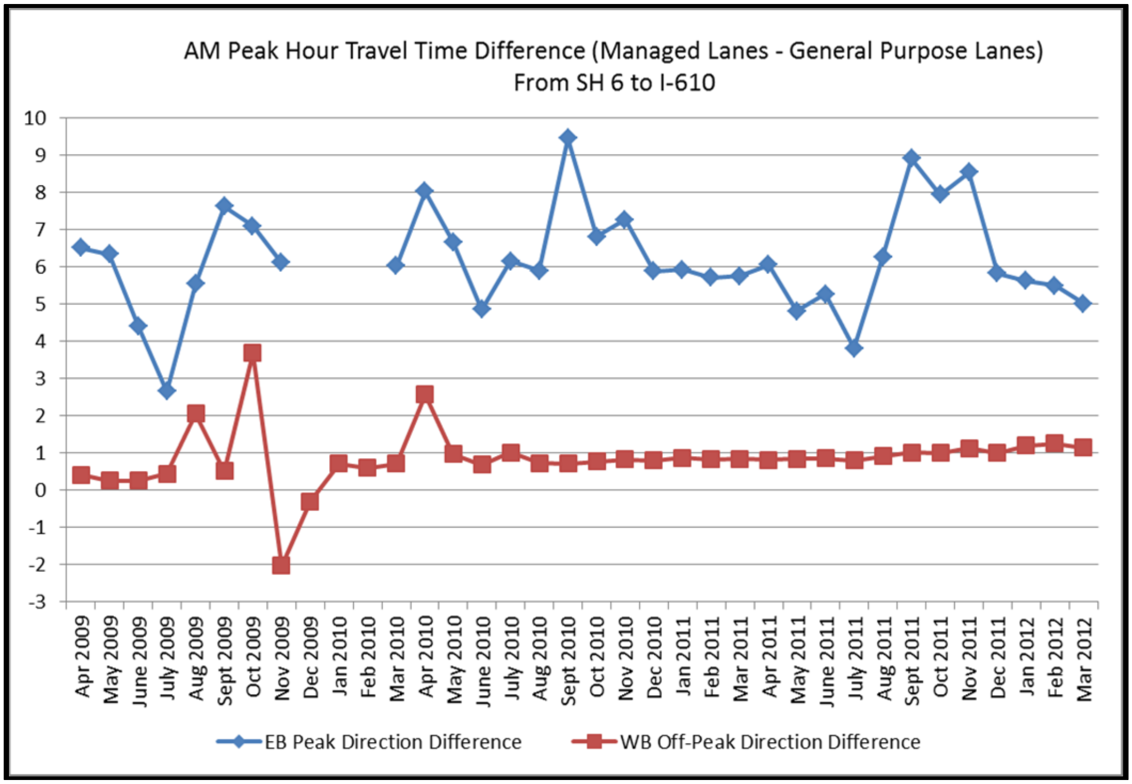


Figure 22. AM Peak-Hour Travel Time Difference, EB and WB, HOV/Managed Lanes.

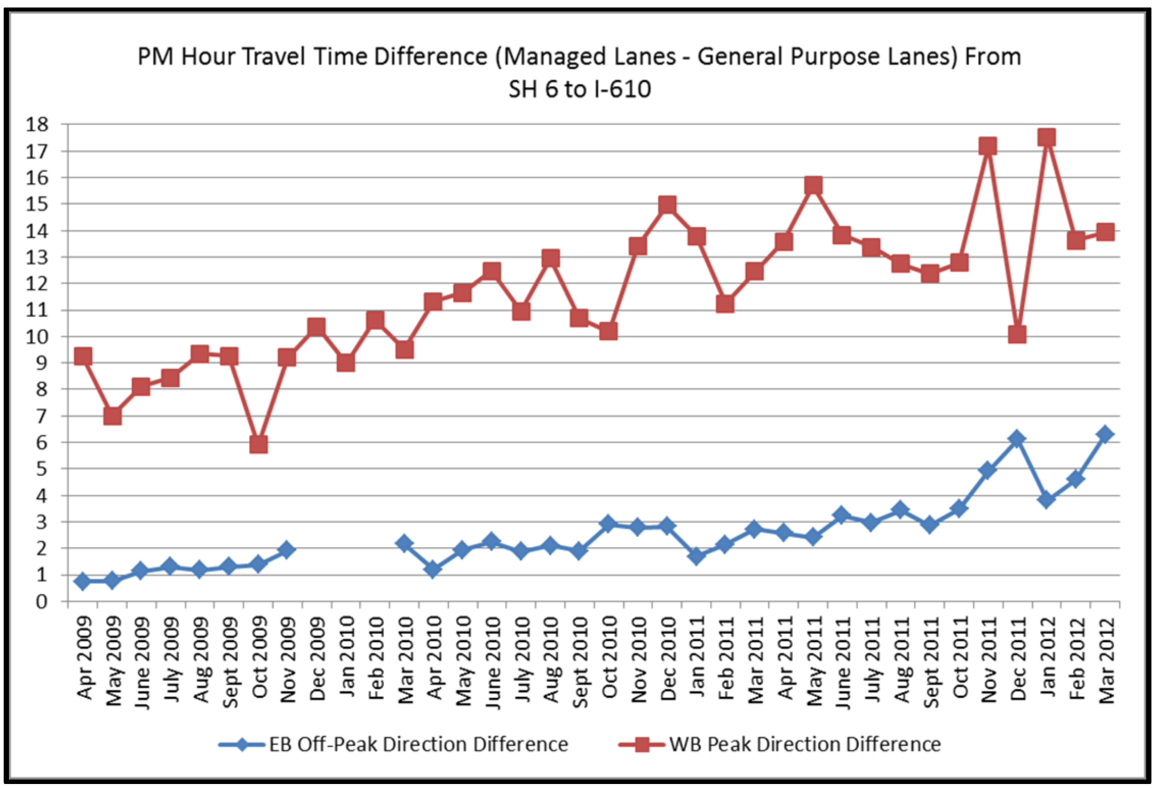


Figure 23. PM Peak-Hour Travel Time Difference, EB and WB, HOV/Managed Lanes.

AVERAGE SPEED BY TIME OF DAY

Figure 24 and Figure 25 show the average travel time trend by time of day for the entire KML from SH 6 to I-610. The EB direction shows two dips in travel time: one in the AM inbound and one in the PM inbound. This speed decrease on the general-purpose lanes is likely the cause of the increase in traffic on the EB KML during the PM peak in the reverse direction. The WB average speed has only the typical one dip in the PM WB or outbound direction. Again this is reflected in the minor use of the KML in the AM WB direction. Figure 25 also shows a dip during the noon or lunchtime period only in the WB direction.

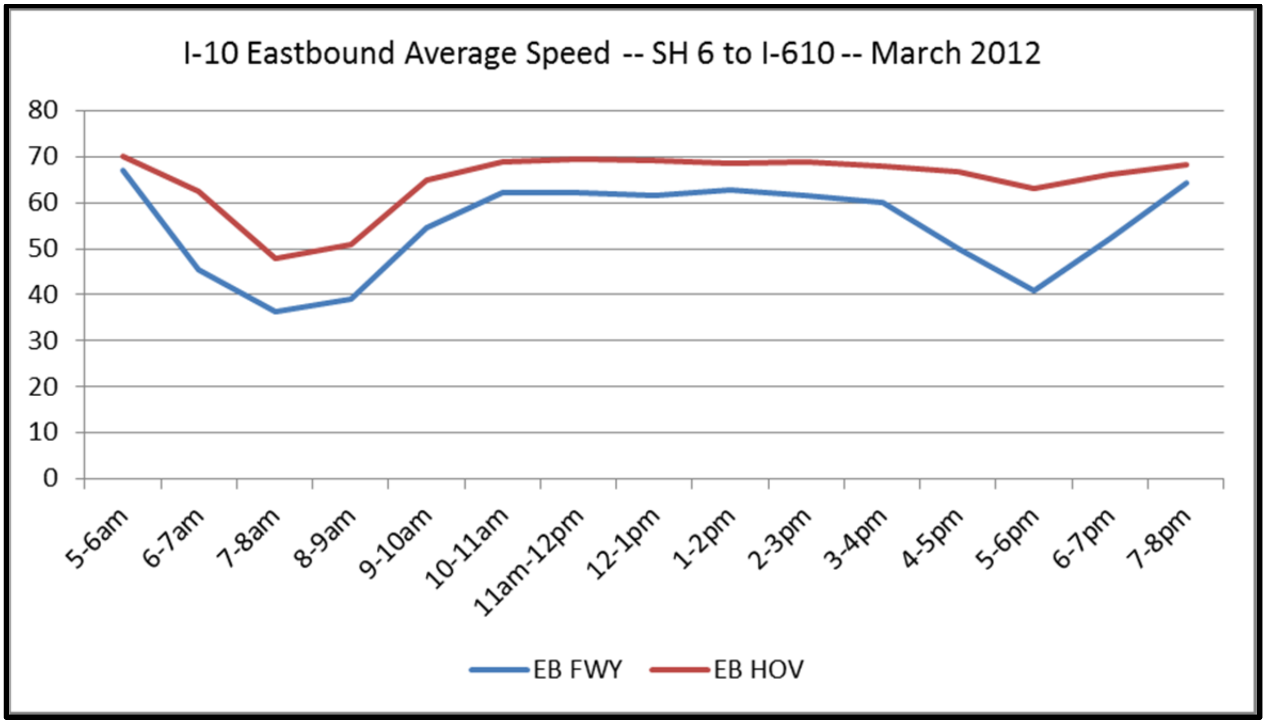


Figure 24. EB or Inbound Average Speed for March 2012.

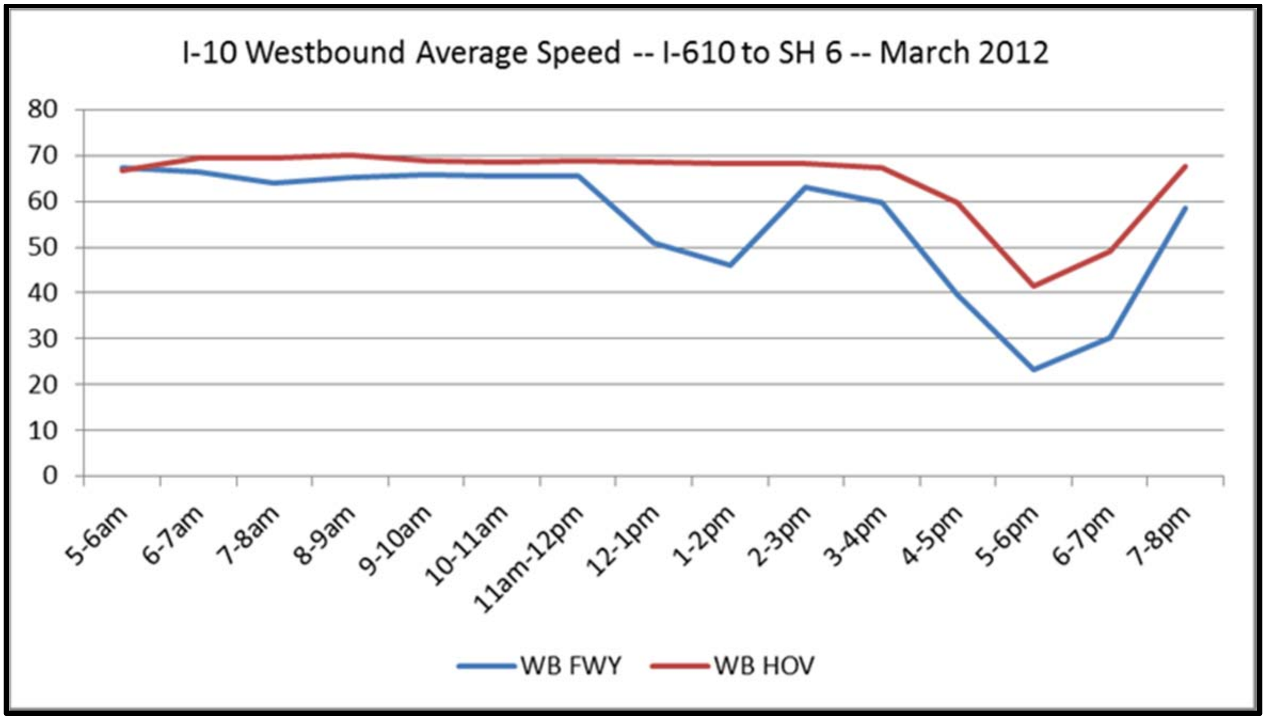


Figure 25. WB or Outbound Average Speed for March 2012.

CONCLUSIONS

Construction of the KML facility was completed in 2009, and operations since opening could be considered very successful. Peak-direction traffic volumes have more than doubled both in the peak hour and the peak period since the KML opened in 2009. Since opening, HOV volumes have increased slightly in the peak periods; however, the majority of traffic volume growth has occurred in the toll lane. The KML has seen the following trends since the opening of the facility:

- Increasing travel times are reflective of increasing traffic volumes.
- AM and PM peak-hour travel times have increased.
- Both AM and PM travel time differences (managed lanes versus general-purpose lanes) have increased in both the AM and PM peak hours, but have increased most significantly in the PM peak.
- Off-peak-direction traffic volumes have increased in the PM peak period. The HOV volume is almost as high as the peak-direction HOV volume on other HOV facilities.
- The off-peak-direction or reverse commute has been an interesting development and a trend that is growing at a rapid rate.

The facility has experienced congestion at a few merge locations. In the EB direction at the Addicks Park and Ride Lot T-ramp, the short merge distances from the T-ramp to the managed lanes contribute to congestion as buses (about one bus every five minutes in the morning peak hour), which have relatively slow operating characteristics, attempt to merge into traffic with very few large gaps. As of the date of this report, alternatives for modifications are being evaluated at the Addicks T-ramp to alleviate the condition causing congestion. In the WB direction, modifications to the managed lanes have improved the merge operations west of the North Post Oak entry ramp.

A toll increase (effective September 8, 2012) is intended to reduce volumes to help reduce congestion and contribute to better lane balance between HOV and toll users.

CHAPTER 4. SAFETY

Traffic safety is always a concern with a new type of facility, and questions often arise about what types of designs and/or elements may impact safety. To answer these questions for the Katy Freeway Managed Lanes, the research team examined crash records for the KML to quantify safety before, during, and after the implementation of the managed lane facility on I-10 in west Houston.

The research team gathered both HOV and managed lane crash information from Houston METRO and the Harris County Constable to examine before and after crash characteristics. HCTRA is the operating agency of the KML and contracts with the Harris County Constable, which provides enforcement and incident response on the managed lanes. The research team used TxDOT's Crash Record Information System (CRIS) data to conduct a before and after construction analysis for the HOV/managed lanes and the general-purpose lanes. A high-level analysis was performed to determine the overall safety of the corridor and, from a macro level, where crashes occur. Both sets of analyses used total crashes, fatalities, crash rates, and various other statistics to perform the safety analysis for this research project.

There was an anticipated difference in the type and frequency of crashes on the KML as compared to the HOV configuration because many operational aspects changed between the before and after conditions. Table 4 summarizes these changes.

Table 4. Before (HOV) and After (Managed Lanes) Operational Differences.

Criteria	Before/During Construction	After Construction
Lanes	One lane reversible HOV	Two lanes each direction HOV/toll
Occupancy	HOV-3+ in peak hours	HOV-2+ and toll
Hours of Operation	M-F 5 AM to 11 AM IB M-F 1 PM to 8 PM OB Sat. OB and Sun. IB	M-F 5 AM to 11 AM IB and OB M-F 1 PM to 8 PM IB and OB Toll 24/7/365
Separation	Barrier	Buffer with pylons
Operating Agency	TxDOT/METRO	HCTRA

Note: IB = inbound (eastbound), OB = outbound (westbound).

The changes in the I-10 facility due to reconstruction affected the roadway geometrics, traffic operations, and responsibilities among operating agencies. These changes also affected who could use the lane and the number of motorists who could use the lane, altered the enforcement priorities, and had other operational impacts. In addition, other factors affected the dynamics of the before and after data comparison that may confound the analysis. Changes in traffic volume as diversion moved from other corridors (US 290, Westpark Toll Road, and other arterial facilities) and the downturn in the economy from 2008 to 2010 are two such factors believed to impact this analysis. In general, the traffic volume is reflective of the economy. Houston had just over 4 percent unemployment toward the end of 2007 and 2008. There was a sharp rise in unemployment in 2009 to almost 8 percent. Through 2010 and 2011, unemployment plateaued after reaching a high of 8.9 percent and eventually started to decline, but was still above 7 percent.

The area from SH 6 to Dairy Ashford Road and along the Katy Freeway is known as the Energy Corridor. This area is home to several of the largest international energy companies in the world as well as 300 multinational, national, and local companies. With an educated workforce comprised of more than 78,000 employees, the Energy Corridor is the third largest employment center in the region. Changes in traffic flows can be associated with events that impacted the oil industry and the overall economy, such as the Federal constraints on drilling and the BP Deepwater Horizon explosion.

MACRO-LEVEL SAFETY ANALYSIS USING CRIS DATA

CRIS was used to do a macro-level analysis on the corridor. However, there are several limitations of the dataset. Some of these limitations occurred during the summer of 2006 when CRIS was implemented and a backlog of crashes from 2001 was entered manually. Some of the early crash records were less accurate and had less data than in later years. In 2007, the collection of crash data was transferred from the Texas Department of Public Safety (TxDPS) to TxDOT. The TxDOT Traffic Operations Division (TRF) was then responsible for the management and maintenance of CRIS. TRF scanned the database files and the original crash reports, including collision diagrams, into the database. However, a policy change in the retention of these records has limited the available crash data from CRIS to five years. The research team was somewhat able to overcome this policy because TTI researchers had retained some historical datasets, which were used to develop this analysis. Due to the differing datasets, some of the fields were not populated in some years, and thus a complete picture is difficult to construct and compare from year to year.

Some of the other limitations pertain to the original collection of the crash reports. The officer typically enters the location data, and an estimate of the nearest major cross street or hundred block is the typical convention used in positioning the crash. This leads to clusters of points at these hundred blocks and/or the nearest major intersection. Some data were filtered to segregate the crashes on the freeway and managed lanes of the facility. A detailed review of many of the crash records indicated that some crash records do not appear to be logically identified as freeway crashes because they were defined in CRIS and cannot be determined without the crash diagram. For instance, a crash involving two vehicles turning right does not make sense on a freeway since it is a limited-access facility and only entering and exiting merges are allowed, not turns. However this could be the case if exiting vehicles were miscoded as turns.

Crash data from the I-10 corridor were gathered from SH 6 to I-610 (West Loop) in Houston, Texas. The three time periods that were analyzed were the before construction, during construction, and after construction time periods:

- Before (freeway and HOV): 2003 to 2005.
- During (freeway and HOV): 2006 to 2009.
- After (freeway and managed lanes): 2010 to 2011.

The following sections describe the CRIS data and provide the overall corridor crash experience as could be gleaned from the CRIS data. Most measures described in Table 5 are shown as the "average annual measure" during the before, during, and after time periods. The "average annual measures" were estimated using available data for the time period reference. This means that the values shown for the "before" period reflect an average of the 2003, 2004, and 2005 data, while those values shown for the "during" period reflect an average of the 2006, 2007, and 2008 data. The "after" period data reflect an average of the 2010 and 2011 data. Crashes tend to be random occurrences over time and can fluctuate from year to year depending on a number of factors, including amount of traffic volume, traffic growth, and weather. In a crash analysis, some of these factors can be controlled for (or normalized), but typically three to five years of crash data are used for analysis to moderate any fluctuations in the data.

These average annual measures were used to compare the crash characteristics before, during, and after construction and reflect, as noted above, the data for the time ranges that define each analysis period. The yearly datasets were also split based on the crash dataset versions or the evolution of the CRIS database. Since 2006 data were the first version of the CRIS data, the "before" period data were based on the old crash record system, which had different data record fields. For the 2006 to 2011 data, note that CRIS evolved over the time periods used in the analysis, thus these structural changes can introduce uncertainty since fields and parameters changed over time. These changes make year-to-year comparisons difficult, particularly over a period of eight or nine years, and the results should be interpreted with these limitations in mind.

Table 5. Summary Table of CRIS Analysis.

Average Annual Measures	Before (2003–2005)	During (2006–2009)	After (2010–2011)
Rate per MVMT	128.3	81.7	57.3
Crash Frequency	1037	720	582
Severity Average Fatal	4	5.2	1
Severity Average Injury	691	298	202
Severity Average Non-injury	547	395	373
Primary Time of Day Crash	PM Peak	PM Peak	PM Peak
Traffic Control	339	N/A	90
Object Struck	102	N/A	81

Note: MVMT = million vehicle miles traveled.

Crash Frequency and Rate

As would be expected with a new facility designed and constructed to current standards, the average annual crash frequency shows a downward trend from before, during, and after construction. The year-by-year data show a higher crash frequency before construction, likely due to the higher levels of congestion that were present before reconstruction. The during-construction crash rate is lower than before construction because the facility experienced lower speeds and motorists spread their travel throughout the day.

The crashes by time of day show that the before- and during-construction crashes are more consistently spread throughout the day versus the after-construction crashes, which have a more distinct concentration of crashes in the AM and PM peak periods. During all time periods, crashes were 25 percent to 50 percent higher in the PM peak than in the AM peak. Crashes were highest on Friday as compared to other days of the week.

The crash rate (per million vehicle miles traveled) also shows the same downward pattern but with a different magnitude. The crash rate estimation entailed two steps. First, the average daily traffic (ADT) data were available quarterly; these numbers were averaged to create the "weighted average ADT." Second, the number of crashes was divided by the weighted ADT. This resulting rate normalizes the crashes by traffic volume. Figure 26 shows the ADT for the corridor over the study time period. In general, the traffic volume is reflective of the economy as discussed at the beginning of this chapter.

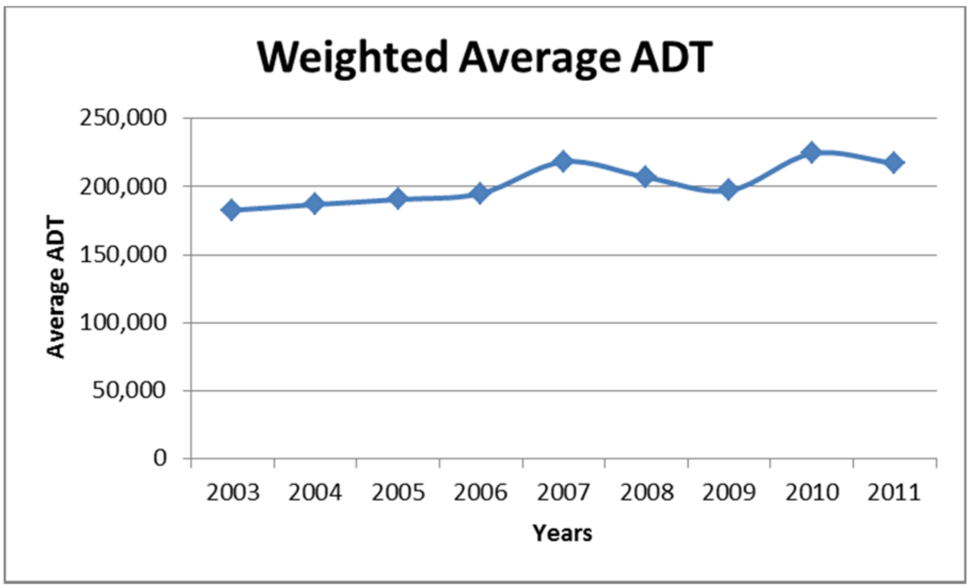


Figure 26. Weighted Average Corridor ADT.

Crash Severity

Fatalities rose during construction, but as stated earlier, crashes are random events, and fatalities have a high variance. Severity and non-injury crashes show the same downward trend as crash frequency. While these measures are important, the fatalities and injury crashes have also seen a reduction nationally due to improvements in vehicle safety, including air bags, vehicle cages, and other safety devices. Crash frequency and crash rates tend to be better measures than fatalities and severity.

Collision Type

Table 6 shows the average annual crashes by collision type. The rear-end type of collision leads all others during the analysis periods. These crashes are typically associated with congestion and are consistent with the AM and PM peaking characteristics of the crash data. The second highest occurring crash type was the sideswipe. These crashes have a variety of causes, including merging or weaving, distraction, or inattention.

Table 6. Average Annual Crashes by Collision Type.

Average Annual Frequency Crash Type	Before 2003–2005	During 2006–2009	After 2010–2011
Rear End	425.3	244.8	232.0
One Stopped	175.3	103.5	78.0
Sideswipe	208.7	157.5	139.5
Single Vehicle	197.3	145.5	129.0
Other	30.0	68.8	3.5

Traffic Control and Object Struck

The highest-cited traffic control was center stripe/divider and marked lanes. These were consistent for both the before and after conditions; the under-construction period was not available. The object-struck crashes are shown in Table 7. The object struck was typically a concrete barrier, followed by a retaining wall. These two objects are sometimes mistakenly interchanged. These crashes can be caused by distraction, weaving maneuvers, avoidance, and/or overcorrection.

Table 7. Average Annual Crashes by Object Struck.

Average Annual Frequency Object Struck	Before 2003–2005	During 2006–2009	After 2010–2011
Fixed Object	19.7	N/A	9.0
Guard Rail	41.0	N/A	9.0
Concrete Barrier	71.0	N/A	68.5
Retaining Wall	30.7	N/A	12.5
Pylon	N/A	N/A	5
N/A	815.7	N/A	439
Other	88.0	N/A	39

The last type of analysis conducted was a determination of crash density. Figure 27 through Figure 31 show the density of crashes by location. The density of crashes increases by color from green to red, with red having the largest number of crashes in a given area. The location of the red points is localized at cross streets and hundred-block increments. Police officers tend to list the nearest cross street or round hundred blocks, which concentrates the crashes at these locations. With limited information in the dataset and no collision diagram, no conclusions can be drawn about weaving areas and other related geometrics.

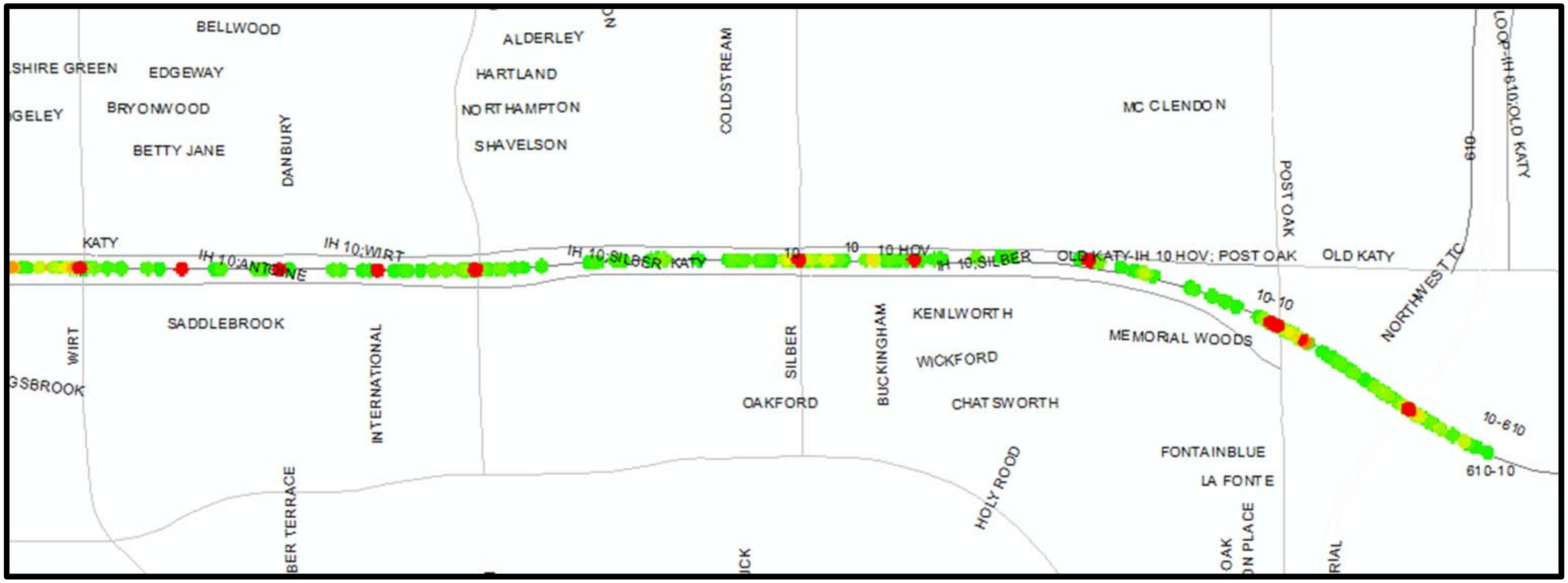


Figure 27. Crash Density I-610 to Wirt Road.

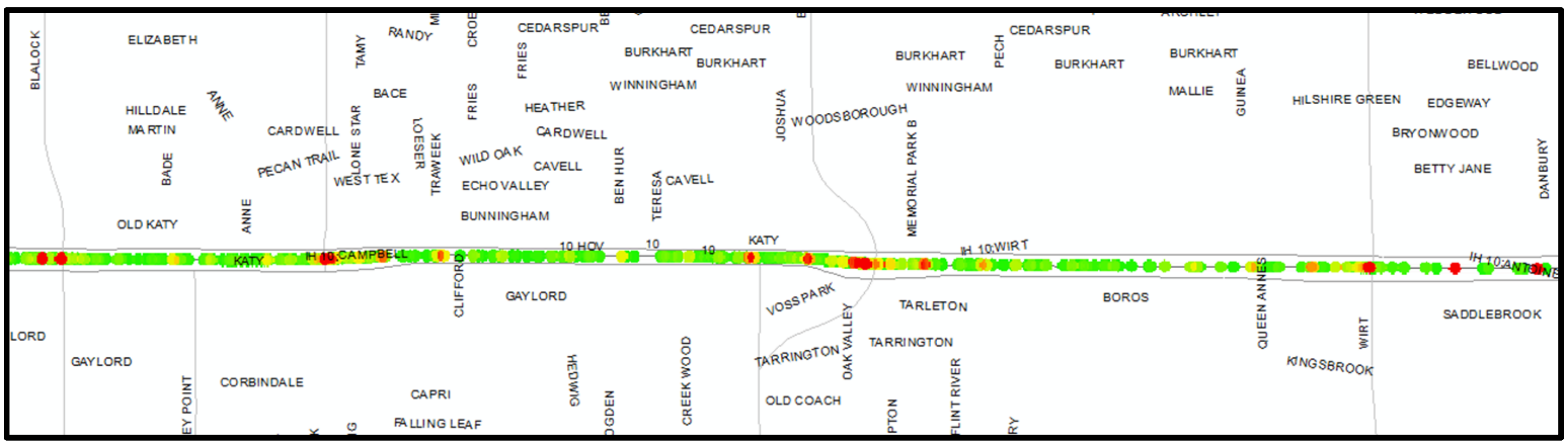


Figure 28. Crash Density Wirt Road to Blalock Road.

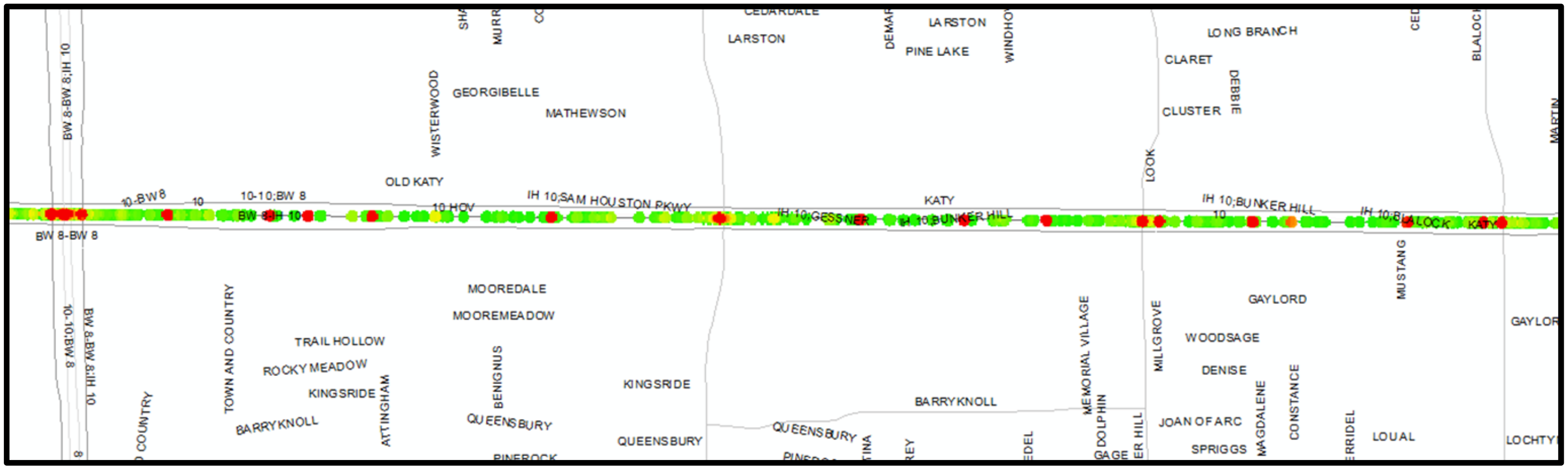


Figure 29. Crash Density Blalock Road to BW 8.

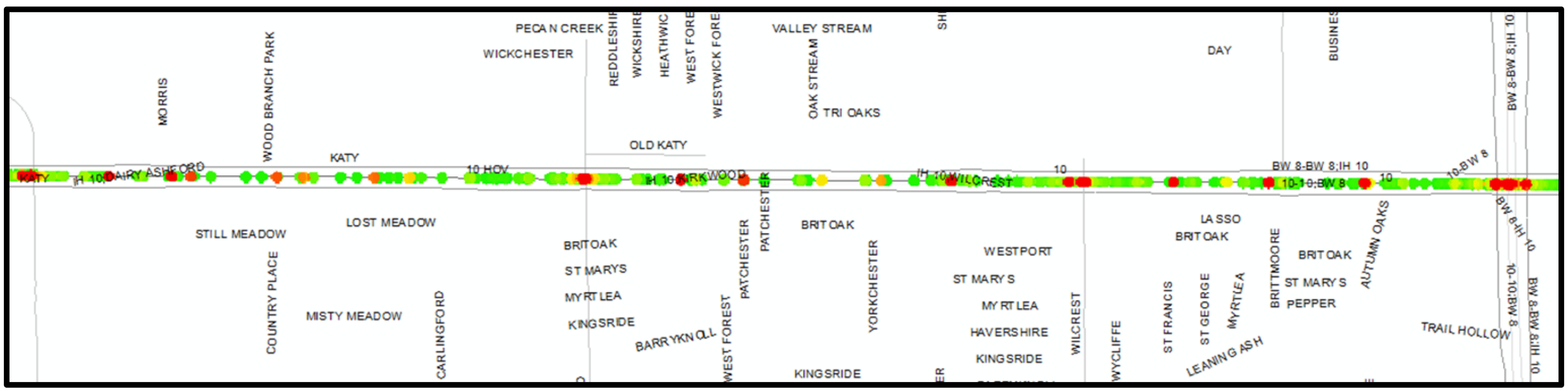


Figure 30. Crash Density BW 8 to Dairy Ashford Road.

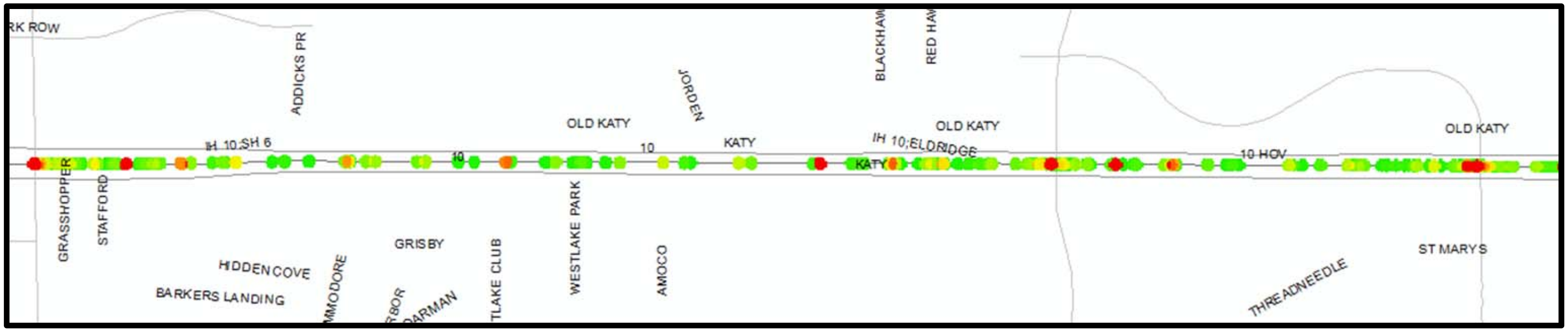


Figure 31. Crash Density Dairy Ashford Road to SH 6.

HCTRA AND METRO CRASH DATA ANALYSIS

Two additional crash data sources were used in the safety analyses: one obtained from METRO and one from HCTRA. METRO was the operator of the reversible HOV lane prior to construction of the KML. After the reconstruction of the Katy corridor in 2009, HCTRA operated the facility. HCTRA contracted with the Harris County Constable office for the enforcement of the KML.

Data Limitations

These two datasets are limited in detail but appear to have more reliable information since there are fewer crashes and the databases are used for internal operations and tracking. The HCTRA dataset consists of only crashes that originated in (or at some point involved) the KML. Only a small percentage of crashes were coded as toll road crashes in the CRIS database, resulting in a large discrepancy between the CRIS and the HCTRA datasets. A similar situation exists for the METRO crash data.

The HCTRA and METRO datasets have limited location information and have only brief descriptions of the crashes. Typically, only the nearest major cross streets were provided, and in some cases the address was provided for the location of the crash.

The HCTRA dataset also includes the number of vehicles and a description of where the crash originated: in the general-purpose lanes or in the KML. The HCTRA data were from 2008 through 2011. Unfortunately, the manner of collision is not reported, only the damage to the facility, such as damage reported to delineators, concrete barriers, etc. Occasionally, additional details are included, such as managed lanes blocked, shoulder blocked, or overturned vehicle.

The METRO dataset includes a date, major or minor crash, and a brief description of the crash, such as the number of vehicles and the manner of collision.

HCTRA Data Analysis

The HCTRA data in Table 8 show an almost equal split between EB and WB crashes. As stated previously, only major cross streets were identified in the HCTRA database, so a locational analysis could not be conducted in more detail. Table 9 shows 45 percent of the crashes were single-vehicle crashes, which typically involves crashes striking an object, such as a concrete barrier. Equally as high are the two-car crashes, which are typically either rear-end crashes (which are usually due to congestion) or sideswipe crashes (which can be due to congestion or inattentiveness). A relatively low number of crashes involved more than two vehicles or involved trucks.

Table 8. HCTRA KML Crashes by Direction.

Direction	Crashes	Percent
EB	122	49
WB	127	51
Total	249	100

Table 9. Number of Vehicles Involved in Crash.

Number of Vehicles	Frequency	Percent
1	112	45
2	110	44
3	12	5
4	4	2
18-Wheeler	2	1
Other	8	3
Total	248	100

Table 10 includes the interesting measure of where the crash originated. Forty-three percent of the crashes originated in the general-purpose lanes, and 57 percent of crashes originated in the KML. This is significant because if there was a barrier separating the KML from the general-purpose lanes, the crash rate would be almost half since 43 percent of the crashes originated in the general-purpose lanes but ultimately rested in the KML. Overall, there were more minor crashes than major crashes; however, if the crash originated in the general-purpose lanes, it was more likely to be a major crash. This would make sense since the crash was severe enough to force it across a 20-foot buffer to impact the KML.

Table 10. Crash Origination and Relative Severity.

Origination and Severity	Crashes	Percent
Originated in KML and Was a Minor Crash	97	39
Originated in KML and Was a Major Crash	45	18
Total KML Crashes	142	57
Originated in General-Purpose Lanes and Was a Minor Crash	43	17
Originated in General-Purpose Lanes and Was a Major Crash	64	26
Total General-Purpose Lane Crashes	107	43
Total Minor	140	56
Total Major	109	44
Overall Total	249	100

A relatively even distribution of crashes by day of week is shown in Figure 32. An unusually high percentage of Monday/Tuesday crashes is shown, unlike the CRIS dataset, which had a higher frequency on Fridays.

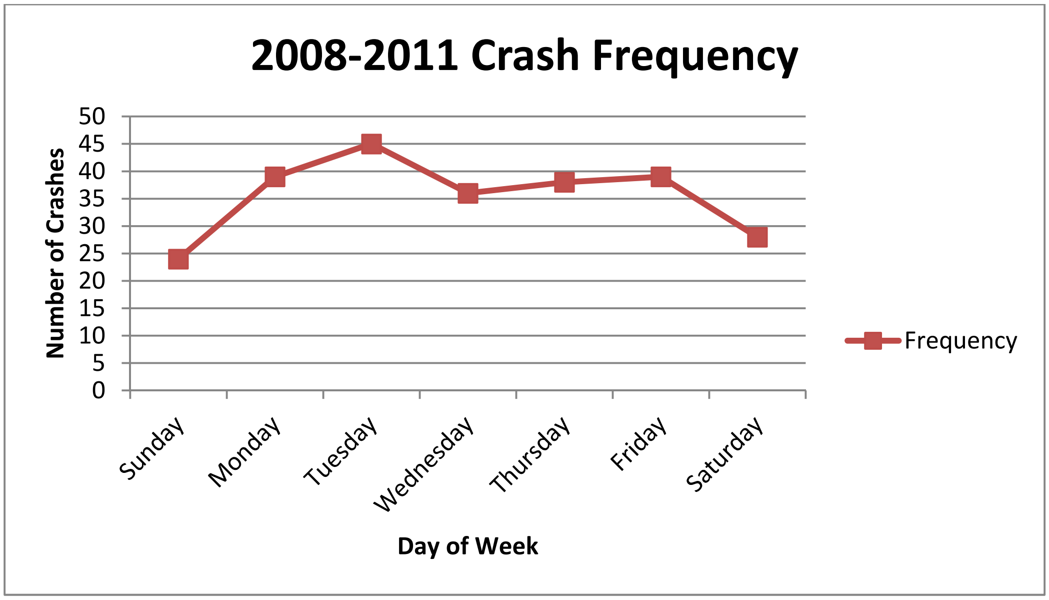


Figure 32. KML Crashes by Day of Week.

Table 11 shows the crash frequency and rate by year for all crashes associated with the KML and only those that originated in the KML. Fifty-seven percent of all the crashes originated in the KML. This applies to the crash frequency and the rate per million vehicle miles traveled.

Table 11. HCTRA Crash Frequency and Rate by Year.

Year	Frequency All	Rate	Frequency KML	Rate
2009	79	158	45	90
2010	91	127	49	69
2011	79	94	48	57
Total/Average	249	126	142	72

METRO Crash Data Analysis

The METRO dataset is from 2003 to 2008, when the HOV lane was barrier separated, and has similar limitations as the other two datasets. Location data are provided by the hundred block; however, there is some information on the manner of collision. Table 12 shows the METRO crashes by manner of collision, frequency, and rate per million vehicle miles traveled. The crash rate is provide per year and averaged by period. The highest percentage is rear-end crashes, typically a result of congestion and/or driver inattention. The next highest crash type is striking the wall of the barrier-separated HOV lane, most of which were single-vehicle crashes.

Gate crashes typically had two types as described in the crash reports: a railroad arm was struck, or a metal farm gate was struck when the HOV lane was closed. The railroad gates are in place to prevent wrong-way crashes when the lane is open. Most crashes occurred when the arm did not go up fast enough for the approaching vehicle. The farm gates are closed when the lane is closed or when the lane is in operation in the reverse direction. The first type typically has very minor damage, if any; however, the second can cause significant damage to the vehicle. Both types of gate crashes typically are single-vehicle crashes.

Table 12. METRO Crash Data, Frequency and Rate by Year.

Crash Type	2003	2004	2005	2006	2007	2008	Total	Percent
Rear End	16	13	4	10	10	7	60	34
Struck Gate	7	2	0	0	3	3	15	8
Sideswipe	11	7	5	7	4	2	36	20
Struck Wall	9	16	9	10	9	4	57	32
Other	3	1	2	2	3	0	11	6
Total	46	39	20	29	29	16	179	100
Crash Rate	109	94	49	71	67	39	N/A	N/A
Period Rate	N/A	N/A	84	N/A	N/A	59	72	N/A

The crash rates show substantial variation, which could be caused by narrow geometrics, unfamiliar users, potential congestion, and the economy. The average crash rate from 2003 to 2008 is 72 crashes per million vehicle miles traveled, which is the same as the average crash rate for only the KML.

CONCLUSIONS

The CRIS data show a lower corridor crash rate due to improved geometrics and a reduction in congestion. In general, the newer design appears to be safer than the older design when looking at the entire corridor. The same patterns of crashes are consistent, with rear-end crashes being the highest, followed by sideswipe crashes and object-struck crashes.

When comparing the HOV lane to the new KML, the crash rates are about equal. The original Katy HOV lane had high congestion, narrow geometrics, reversible flow, and fewer lanes. The new KML design has four lanes, more ingress/egress locations, and a very wide 22-foot buffer area for recovery and crash avoidance. The HOV crash patterns appear to be consistent with the overall crashes, with rear-end crashes being the highest, followed by sideswipe crashes and object-struck crashes.

Data inconsistencies prevented a more rigorous analysis. Improved data reporting from police and operating agencies could provide more accurate detail on crash location, object struck, and collision type. Crash data retention policies limit the amount of data and types of analyses that can be conducted. These improvements could provide more information for a more conclusive analysis.

CHAPTER 5. ENFORCEMENT

The research team examined the operation of the Katy Freeway Managed Lanes as it pertains to enforcement before and after the implementation of the managed lanes. Interviews and site visits were conducted to find out how the METRO Police Department and Harris County Constable Precinct 5 approached enforcement. Monthly HOV citation and toll violation statistics were compiled to calculate a measure of driver compliance.

ENFORCEMENT OPERATIONS

METRO and its full-service police unit with sworn officers and civilian personnel originally enforced the Katy Freeway HOV lane. The METRO Police Department began in 1982, and its peace officers are fully authorized in Texas to enforce all laws. METRO has enforced all of the managed lanes that the authority operated in the Houston region, including the Katy Freeway before the managed lanes were finished in 2008. Regarding the HOV lane facilities, the primary mission of the METRO Police Department was to enforce HOV rules and regulations at specific locations on the corridor, without impeding the flow of traffic.

Harris County Constable Precinct 5 took over enforcement responsibilities of the KML once major construction was completed in October 2008. A special toll road division within Precinct 5 handles citations on the managed lanes. The goal of the toll road division is primarily to facilitate the flow of traffic while providing security for users. Officers enforce all traffic laws on the managed lanes and provide disabled motorist assistance when necessary.

The management of enforcement operations on the KML is guided by the prevailing principle that "mobility has to be balanced with enforcement." Ensuring mobility with proper enforcement is difficult because the two concepts are often contradictory. For example, the presence of officers on a highway can encourage drivers to slow down near enforcement vehicles, thereby indirectly influencing congestion. Officers realize this relationship and adjust their protocol to mitigate their impact on the highway. All incidents and calls on the highway are addressed in a safe and rapid manner to ensure that unsafe risks do not escalate into larger concerns. The department takes specific measures such as conducting HOV occupancy checks behind toll gantries, out of plain sight, and handling incident management calls at off-site locations.

The approach to handling crashes is to "never place a pen on paper while on the road." After a crash occurs, an officer approaches the driver of the damaged vehicle, takes the driver license, and leads the drivers to an off-site location where an incident report can be produced and insurance information can be exchanged between drivers, if necessary. Officers take the driver license away, at least initially, as an incentive to keep the driver—and the corresponding vehicle—with the officer as they travel to an off-site location. Harris County has a standard of dispatching two officers with two separate vehicles to crashes because they found that it took less time to get an impaired vehicle off the road.

Enforcement areas are adjacent to toll plazas on the KML. At each toll plaza is a declaration lane for HOVs, which is located on the inside lane in both directions of the facility and is separate from the toll lane. The enforcement area is situated directly behind the toll plaza in the space between the barrier of the median and the managed lanes. During periods of HOV-2+ toll exemption status, an officer is typically in the enforcement area physically observing vehicle occupancy in the HOV declaration lane.

To monitor enforcement, officers park their patrol vehicles in the enforcement zone at an angle and stand on the side of the vehicle that is farthest from the active lanes of traffic. This choice of position is used to help protect officers from being hurt or killed by traffic incidents. Officers use binoculars to peer over the roof of the parked patrol vehicle and into the managed lanes. They do not use the observation booths at each toll plaza because the time taken to exit the enclosure and enter the enforcement vehicle is too great for an officer to effectively intercept violators. Metro technicians primarily use the observation booths to collect vehicle occupancy data from the HOV lane. Figure 33 shows a typical setup of an officer from the Harris County Constable enforcing HOV compliance on the managed lanes. Figure 34 shows the location of the enforcement vehicle with respect to the physical layout of the toll plaza.

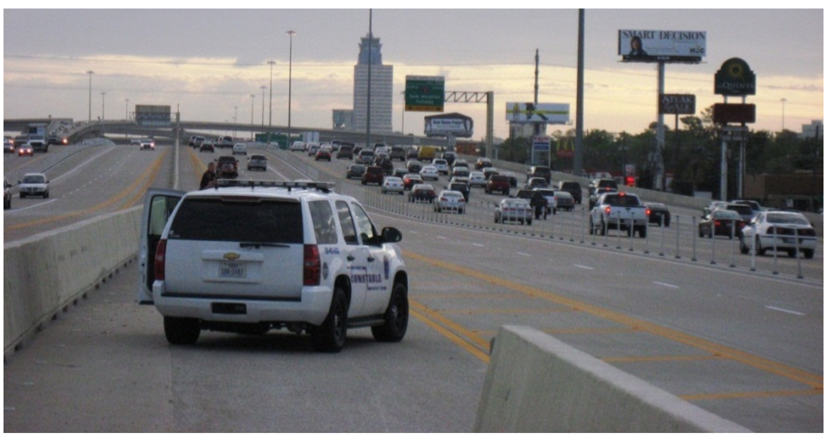


Figure 33. Harris County Constable Officer Enforcing HOV Compliance.

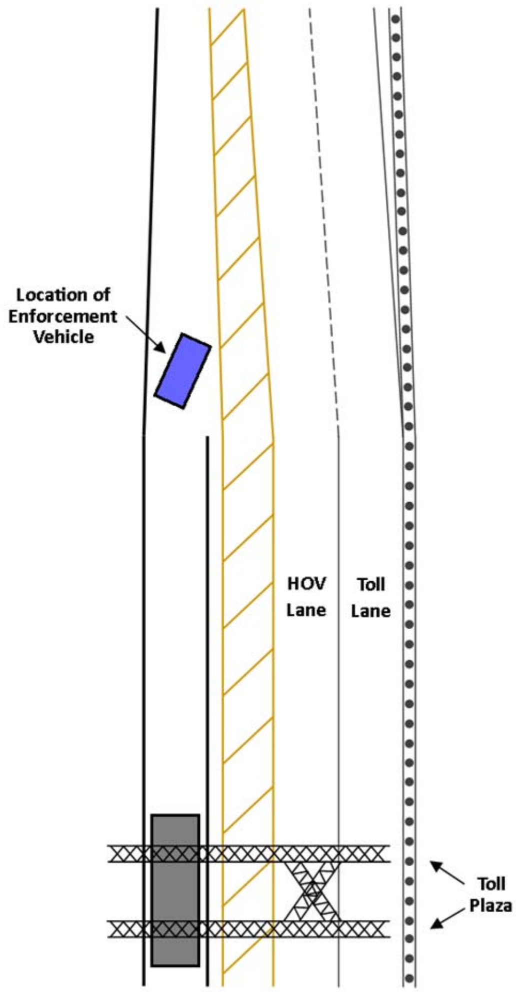


Figure 34. Schematic of Enforcement at a Toll Plaza (Not to Scale).

Enforcement on the corridor is conducted on a toll-plaza-to-plaza basis. After doing an occupancy check or issuing a ticket near one toll plaza, the officer moves his or her vehicle down to the next plaza to establish a presence there. When reaching the end of the corridor, the officer exits the managed lanes and the Katy Freeway at the nearest exit, turns around, and conducts enforcement in the opposite direction of the managed lanes.

Vehicles that are traveling in the HOV declaration lane that are not in compliance with HOV operating rules during peak periods are pulled over by officers and given citations. Officers are encouraged to pull over violators early because there is usually sufficient space on the shoulders for a pull-over near the toll plaza, as opposed to narrower locations downstream. They perform quick, close-up occupancy checks when they approach a vehicle that has been pulled over. If the vehicle is later found to have two or more occupants, the driver is quickly waived on to prevent congestion in the managed lanes. Common reasons for why vehicles may be mistaken for an HOV violation include instances of missed backseat passengers and viewing impediments due to tinted windows. Officers from the Harris County Constable believe that roughly

25 percent of all vehicles pulled over have a child in the backseat that is not clearly seen from the outside of the vehicle.[1]

HOV CITATION DATA

Citation data from METRO were used as the baseline period for analysis from January 2005 to August 2008. The METRO Police Department provided a dataset containing individual citations with a specific date and time element. The citations used in the analysis for METRO included all that the officers on the Katy Freeway HOV lane (the same segment where the managed lanes were implemented) had issued for the unauthorized use of the restricted lane and the unauthorized use of the diamond lane. No warnings, which comprise instances of when officers pulled over vehicles but did not issue tickets, were used in the analysis.

Harris County Constable Precinct 5 provided monthly aggregated values for the number of toll citations (with no detailed time and date information) issued by officers from October 2009 to March 2012. The time between September 2008 and October 2009 was not included in the dataset because this was the time frame when either the former HOV lane was closed or was part of the initial ramp-up period for the KML. An informational campaign was being conducted during this period to explain the rules for navigating the managed lane.

The Harris County Constable only enforces for toll violators in the HOV declaration lane during the hours of the HOV-2+ toll exemption. The tolling equipment is deactivated in the HOV declaration lane during times when the HOV rule is in effect. For the other time periods, the automated enforcement system that HCTRA had installed identifies vehicles without a registered transponder and issues a violation through the mail.

HOV EVALUATION FINDINGS

The monthly number of HOV and toll citations that the METRO Police Department and the Harris County Constable had issued varied from January 2005 to March 2012. Generally, the monthly number of HOV citations that METRO had given was higher than the monthly number of toll citations that the Harris County Constable had given. The average number of HOV citations from METRO during January 2005 to August 2008 was 111 citations per month compared to 24 toll citations per month from the Harris County Constable during October 2009 to March 2012. Both agencies issued citations during those periods for offenses other than HOV and toll violations. HOV citations represented 54 percent of all citations that METRO issued before the opening of the managed lanes, and toll evasion citations represented 16 percent of all citations that the Harris County Constable issued after tolling began on the facility. The Harris County Constable issued the most citations for speeding, which comprised 23 percent of all the

[1] Based on an interview with Captain Terry Allbritton of Harris County Constable Precinct 5 on March 7, 2012.

citations issued during the evaluation period. Figure 35 shows a detailed monthly distribution of the citations issued from the two enforcement agencies.

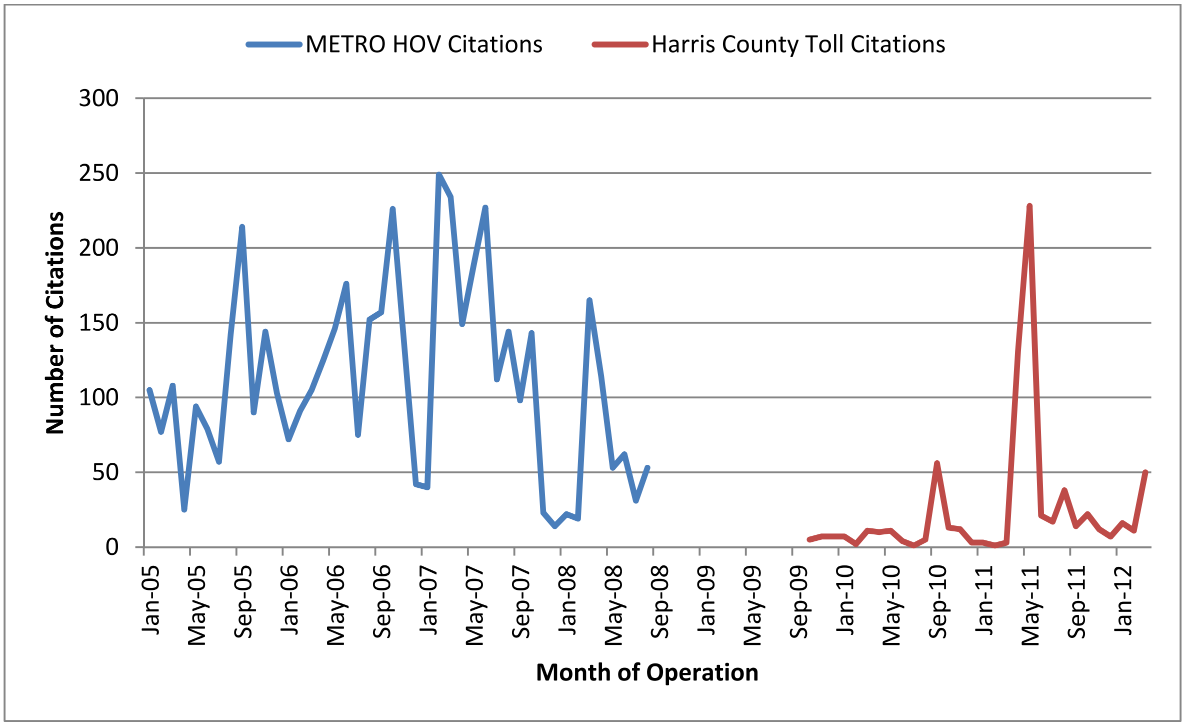


Figure 35. Monthly Distribution of HOV and Toll Citations from January 2005 to March 2012.

A reason for the significantly lower citation rate for the Harris County Constable may be the occurrence of lane jumping by violators and officers issuing citations for other reasons. When the managed lanes were introduced, the declaration lane at each toll plaza gave drivers the ability to quickly switch lanes when officers could be seen. Toll violators who travel in the HOV declaration lane are usually given citations for toll evasion. However, drivers in the outside toll lane are not given toll citations because the enforcement monitoring system from HCTRA is activated to process violations separately. The Harris County Constable does not issue a citation for the same infraction that the toll system on the corridor tracked and reported. Commonly, the officer issues a citation for an unsafe lane change maneuver or another violation when the officer sees an offender switch into the toll lane from the HOV declaration lane.

Toll citations are different from violations because citations require the offender to have a court appearance, whereas a violation can be handled through the mail or a toll agency website. Citations also incorporate a higher amount of associated fines and fees as compared to a violation.

The monthly rate at which METRO issued citations varied considerably, with a range that extended from 14 to 249 citations per month. METRO issued fewer citations per month in 2008, with a monthly average of 65 citations per month in 2008 compared to 121 citations per month from 2005 to 2007. The decrease may be due to diminishing enforcement efforts in anticipation of opening the managed lanes later in 2008. The Harris County Constable issued a fairly level number of toll citations during each month of operation, except for an unusual spike during April and May 2011—at 131 and 228 citations, respectively. A potential reason for the outlier may have been the result of the Harris County Constable's aggressive campaign to specifically target toll violators by giving evaders citations with assigned court appearance dates.

CONCLUSIONS

A significant finding from the evaluation was the difference in the prioritization of goals between the METRO Police Department when monitoring the HOV lane and the Harris County Constable Precinct 5 when monitoring the managed lanes. The METRO Police Department placed a stronger emphasis on the enforcement of vehicle occupancy requirements, whereas the Harris County Constable placed a greater priority on mobility within the managed lanes. However, METRO did recognize that its officers should "not impede the flow of traffic," and the Harris County Constable made every attempt to "balance mobility with enforcement."

Distinct differences in enforcement policies were evident in the number of citations issued by type for each agency. METRO issued more citations for not meeting vehicle occupancy requirements as opposed to other citation types, whereas the Harris County Constable issued more citations for speeding as compared to toll evasion. Specifically, HOV citations represented 54 percent of all citations issued by METRO, and toll evasion citations represented 16 percent of all citations issued by the Harris County Constable. A possible reason for fewer citations from the Harris County Constable may be the phenomenon of lane jumping. Lane jumping occurs when users merge at the last second from the HOV lane to the toll lane when officers are present, potentially to avoid a higher fine. Overall, the monthly number of citations issued was sporadic, with each agency reporting low and high monthly totals.

CHAPTER 6. MAINTENANCE

Ongoing maintenance is a critical issue for an agency to plan for (and execute) when actively managing a tolled facility. Aside from normal maintenance of the roadway itself, the agency has to be more focused on the operational status of active elements of the system: dynamic message signs, traffic flow monitoring sensors and systems, closed-circuit television, and tolling infrastructure.

Documenting the maintenance experience of both agencies could be used to potentially improve existing operations and future design for the agency, resulting in a safer, better-maintained experience for the traveling public. The information and lessons learned as documented here can provide insight to the operating agency on how to optimize maintenance investment on future facilities to maintain and improve operations on managed lane facilities.

Maintenance supervisors from TxDOT (*13*), HCTRA (*14*), and METRO (*15*) were interviewed to gather information on their activities and costs related to the Katy Freeway Managed Lanes operations. From a historical perspective, TxDOT owns the Katy HOV lane and METRO operated it. The maintenance was split between TxDOT and METRO. Table 13 shows the responsibility of each agency; METRO maintained most items inside the HOV walls, and TxDOT maintained items outside the walls, with the exception of pavement, which TxDOT maintained. Under the new model, HCTRA maintains all aspects of the managed lanes.

Table 14 shows a before and after comparison of the two facilities. These are very different, and the major differences in characteristics do not allow direct comparison.

Table 13. TxDOT METRO HOV Maintenance Responsibilities.

Description	Responsible
Concrete Traffic Barrier (CTB) Alignment	TxDOT
Vehicle Impact Attenuators	TxDOT (outside HOV lane) METRO (inside HOV lane)
Pavement Markings	METRO (normal maintenance) TxDOT (after overlay)
Reflectors	METRO
Static Signs	METRO
Gates (Farm/Vertical/Swing)	METRO
Sweep Lanes	TxDOT
Loop Detectors	METRO
Traffic Signals, Fiber-Optic Signs, Electronic Signs and Signal	METRO
Dynamic Message Signs on HOV Lanes and Metro Facilities	METRO
Closed-Circuit Television Cameras	TxDOT
Transponder Readers and Radars	METRO
Slip Ramp Control Systems (Restraining Barrier Systems)	METRO

Table 14. Before and After Facility Comparison.

Criterion	Before	After
Lanes	One lane reversible	Two lanes each direction
Occupancy	HOV only 3+ in peak hour	HOV 2+ and toll
Separation	Barrier	Buffer with pylon
Operating Agency	TxDOT/METRO	HCTRA

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 but primarily summarizes the experience of HCTRA regarding the KML in addressing these questions. The interviews can be characterized as a series of questions and answers, with an informal discussion of the practical experiences of the respective agencies.

Most interviews did not follow a script but were more conversational in nature. A summary of key questions and answers is presented below.

SUMMARY OF RESULTS

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

1. Signs and sign message:
   - The issue is how to best convey to the public what lane to be in at the declaration points: the HOV lane or the toll lane.
     - Customers' being in the wrong lane—and being charged or not being charged—directly affects the bottom line and the customers' experience.
     - Roadside or barrier-mounted signs are too small to completely convey these messages, but overhead signs are very expensive and were limited in deployment.
     - The most difficult concept to convey to the public was the difference between "entrance to the HOT" versus "exit from general-purpose lanes."
     - There were initial issues with electrical grounding on dynamic message signs. Once that was corrected, the signs have worked well.
     - Historically, METRO has had failure issues with electronic signs, but these issues have improved with improved technology.
2. Delineators:
   - Entry/exit points are problems, with the highest amount of hits and replacement. Entry/exit points tend to be decision points and weaving areas.
   - Tangent section hits were a result of two patterns:
     - Off-peak crashes in general-purpose lanes coming across the buffer.
     - Impaired drivers (although this 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 (there is 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 in the Dallas HOV lanes (*16*), 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.
   - 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.

3. Pavement markings:
    - Retroreflective tape has come up 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 is the case for typical lane or edge lines.
    - Tape failure is accelerated as sweeper truck brushes contact the curled-up sections. Thermoplastic pavement markings might be a better alternative for these applications.
4. Farm gates:
    - METRO installed farm gates at all the entrance and exit locations as a result of wrong-way movements in the early 1990s. These gates get hit periodically, and repair or full replacement were noted as the top time and budget maintenance items.

Question 2. What Are the Top Three Items That You Spend Money On?

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

- Sweeping—two times per month.
- Debris pickup—daily.
- Delineator replacement—weekly.

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

- Most agencies are outsourcing all maintenance activities. The HCTRA contract, for instance, has multiple-skill-level workers, and the work is assigned by task.
- The HCTRA labor contract is bid using a request for proposals for a one-year term with four renewable one-year terms (for a total of five years). This provides the authority and the contractor some stability if work is satisfactory and keeps a consistent cost.
- The maintenance contract is a good value. It offers efficiency because multiple tasks can be done by one crew with one pass through the corridor. For example, while replacing delineators, the contractor can 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.
- The KML has a lower maintenance cost than the rest of the HCTRA tollway system. This is partially because of 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 KML are about $11,000 per lane mile, and the average cost of the rest of the toll system is about $24,000 per lane mile.
- METRO *(15)* was not able to provide costs for HOV lane maintenance on the Katy Freeway but did provide an estimate of $50,000 to $60,000 for the approximately 110 miles of the HOV system. METRO also outsources its maintenance activities. These costs do not include the maintenance items that TxDOT performed.

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

- HCTRA 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. How Is Incident Management Handled?

Incident management is performed by the following entities, depending on the location and severity of the incident:

- HCTRA operates a full-time traffic operations center that has detection, verification, and dispatch capabilities to monitor and maintain its facilities.
- The Patron Emergency Assistance Team (PEAT), which is a service that HCTRA offered, assists motorists with minor issues such as flat tires and stalls.
- Private tow operators or SAFEClear tow operators are used when a vehicle needs to be removed from the facility. SAFEClear was an incident management strategy that Houston operated, which paid $50 for tows to get vehicles off the travel lanes and to keep traffic moving. The program started in 2005; due to budget issues, the city was not able to continue the program as of 2011.

Question 6. What Is the Cost Per Pylon?

- On average, HCTRA's replacement cost per pylon is about $30 (to furnish and install). The $30 per unit cost is generally the average cost to furnish and install as provided by other agencies.
- Pylon replacement costs about $500,000 per year, with the total maintenance contract costing about $12 million per year. However, as explained above, one crew typically does multiple tasks, so the exact cost was estimated.

Question 7. What Area or Location (Gore, Tangent Section, Declaration Point, and/or Toll Booth) Has the Most Pylon Hits and/or Replacements? 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 exit 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 exit locations. It was believed that motorists 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.

Maintenance Philosophy

HCTRA considers it advantageous to complete some routine maintenance tasks on a weekly basis. HCTRA's philosophy is that a higher maintenance standard is expected on its facilities since customers are paying for the trip. To provide enhanced services, HCTRA:

- Performs Sunday maintenance runs (outside of peak weekday and weekend traffic periods) to identify maintenance issues.
- Conducts daily off-peak debris collection.
- Sweeps the facility twice per month.
- Provides a dedicated Patron Emergency Assistance Team.

Pylons versus Concrete Barrier

There are differing opinions on the benefits, related to the cost, of the use of pylons versus the use of concrete barriers. 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, some of the benefits and disbenefits attributed to the use of pylons and concrete barriers include the following:

- Pylon benefits:
    - Incident management access—pylons are mountable/passable.
    - Emergency vehicle access—pylons are mountable/passable.
    - Lower initial cost.
    - Sight distance improvement—no wall obstruction is present.
- Pylon disbenefits:
    - Ability for motorist to cut from general-purpose to managed lanes (or vice versa) to get to better-flowing traffic.
    - Maintenance cost for repair/replacement of pylons.
    - Exposure of maintenance staff and contractors to moving traffic during maintenance activities.
    - Traffic control cost to accommodate maintenance activities (depending on buffer width).

- Concrete barrier benefits:
  - Safety benefit with respect to prevention of cross traffic cutting into or out of lane.
  - Prevention of crashes from entering or leaving managed lanes.
- Concrete barrier disbenefits:
  - Higher initial cost (for both cast-in-place and portable barriers).
  - Higher repair cost if cast in place.
  - Cost of periodic alignment of movable barriers.
  - Lack of ability for emergency vehicles to respond to an incident on the other side of the wall.
  - Inability to divert traffic from the general-purpose lanes into managed lanes if a major accident occurs.

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 the number of pylon hits. HCTRA has found that even an 8- to 12-inch offset from the pylon to the edge of the travel lane results in a noticeable decrease in pylon replacement. An example is shown in Figure 36. The same correlation between buffer space and pylon hits or replacement was found in the TxDOT Research Project 0-6643 "Guidance for Effective Use of Pylons for Lane Separation on Preferential Lanes and Freeway Ramps".

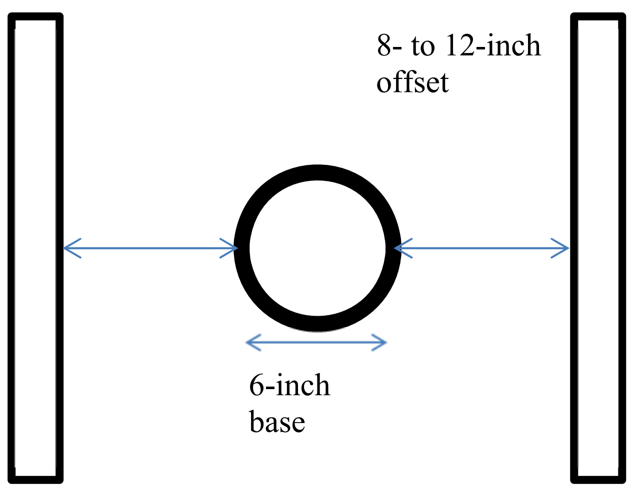


Figure 36. Increased Minimum Pylon Offset in Relation to Pavement Marking Edge Lines.

Mounting Preference

The agencies surveyed prefer to use direct pavement-mounted pylons on higher-speed facilities as shown in Figure 37. TxDOT prefers to use curbs in urban areas with lower speeds as shown in Figure 38. TxDOT staff indicated that they felt the curbs added more of a deterrent at lower speeds.

Figure 37. Pavement-Mounted Pylon.

Figure 38. 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 use contrast is that motorists have difficulty seeing the pylons at the entrance and exit locations, or that the pylons are not conspicuous enough where other traffic control devices are present. These agencies reported no reduction in hit rate after a 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 39.

In addition to the contrast marking concept, pylon placement was also considered as part of the experimental design. Currently, the standard pattern is a single-file line. Figure 40 shows some alternative configurations that could be used to increase the target value of the pylon configuration. An even (side-by-side) or staggered pattern could double the target value (see Figure 40). 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.

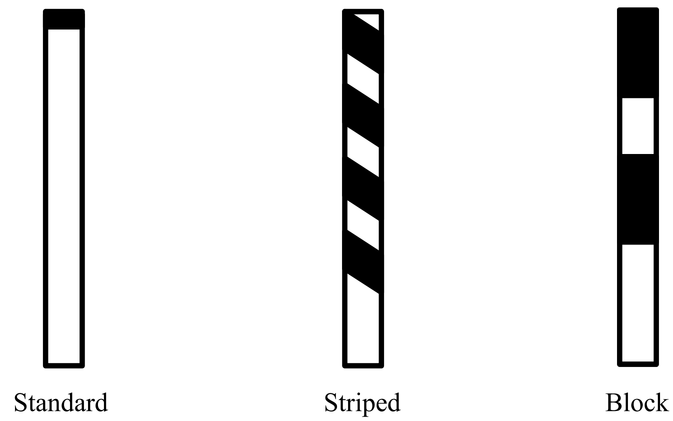


Figure 39. Potential Pylon Contrast Marking Patterns.

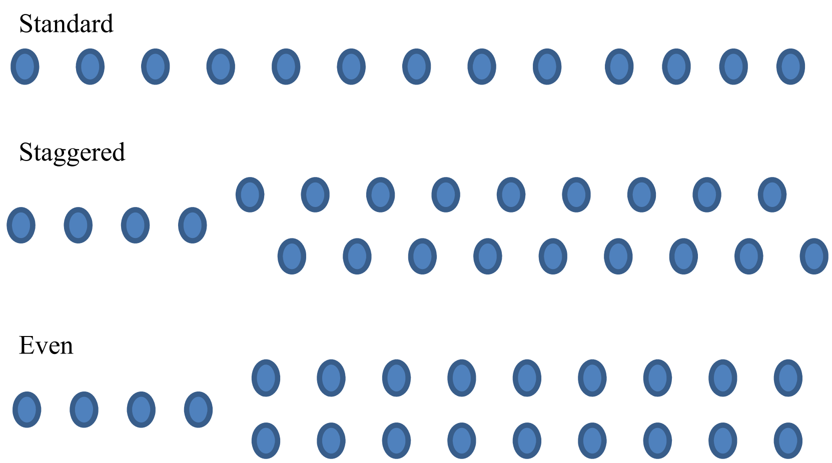


Figure 40. Potential Pylon Patterns.

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 possible 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 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 pylon hits.
- Contrast markings were perceived to be a solution for entrance and exit location pylon hits. However, the agencies observed no reduction.
- 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-the-road maintenance items such as mowing, sign repair, and sign replacement.
- The public has an expectation that tolled facilities, including managed lanes, have a higher standard with regard to appearance, maintenance, and operations (*14*).
- A buffer width spacing of as small as 2 to 3 feet, which translates to 8 to 12 inches from the pylon to the 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. TxDOT 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.
- 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 motorists to make appropriate decisions. The use of pylons can reinforce the areas in which decisions can be made but are not in themselves a replacement for effective 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 used to reinforce the lane assignment at entrance and exit locations, especially in areas where horizontal curvature can distort the lane/sign relationship.

CHAPTER 7. TOLLING AND PRICING

The Katy Freeway (both the general-purpose lanes and the managed lanes) is equipped with a substantial number of traffic sensors and therefore can yield an impressive, sometimes overwhelming amount of information on the usage of the freeway. Researchers took advantage of these data to conduct a comprehensive analysis of managed lane use. They examined the public's use of the managed lane facility in terms of both the number and percentage of Katy Freeway trips taken on the facility, and the conditions contributing to managed lane use. They also looked at the revenues from managed lanes and travel time savings.

This chapter details the data available, briefly outlines the steps taken to analyze the data, and gives the results of the analysis.

DATA SOURCES

The toll rates on the Katy Freeway Managed Lanes vary by time of day, as noted in Figure 41. There is no toll for HOVs and motorcycles for many hours of the day (5:00 to 11:00 AM and 2:00 to 8:00 PM). To avoid the toll during these hours, HOVs and motorcycles must travel on the inside lane of the managed lanes. The KML has several entry and exit points, and these locations impact the distance traveled on the managed lanes. The entry and exit locations are:

- SH 6.
- Addicks Park and Ride Lot.
- Between Dairy Ashford and Kirkwood.
- Between Gessner and Bunker Hill.
- Between Chimney Rock and Antoine.
- Between Antoine and Silber.
- East of Loop 610.

Numerous datasets contain information on travel on the Katy Freeway. A brief outline of the contents of each is included in Table 15. The locations of the sensors for the AVI and Wavetronix datasets mentioned in Table 15 are shown in Figure 42.

Data from all days for the year 2011 were collected for all datasets. For analysis purposes, only non-holiday weekdays were examined. The data were then examined for errors. Most of the data were in good shape with the exception of the TxDOT Wavetronix© sensors. Many of the TxDOT Wavetronix sensors had serious errors in at least some of the lanes. Therefore, researchers used AVI data for all travel times and travel time variability. They selected the EB Wavetronix sensor at Dairy Ashford (number 1410) and the WB Wavetronix sensor at Kirkwood (number 1454) to represent the general-purpose lane volumes. These sensors produced what appeared to be consistent and reasonably good results and were near the midpoint of the KML. However, as outlined in the following section, the volumes that these sensors recorded seemed too low. One other data source had errors. The EB Wilcrest volumes collected as part of the *I-10HOVLnsTrans* dataset from HCTRA were incorrect (reading 0 for much of the year).

Next, the transponder IDs were converted to random numbers. For example, transponder ID 1234 may be converted to 4732 for every instance that ID 1234 appears in the multiple datasets (*AVI: Valid Matches* from TxDOT and *TransKatyMangdLns* from HCTRA). This does not change any of the analysis or the results but was done as a safety precaution. In this way anyone who accessed this dataset could not link it to the actual TxTag, HCTRA, or DNT account.

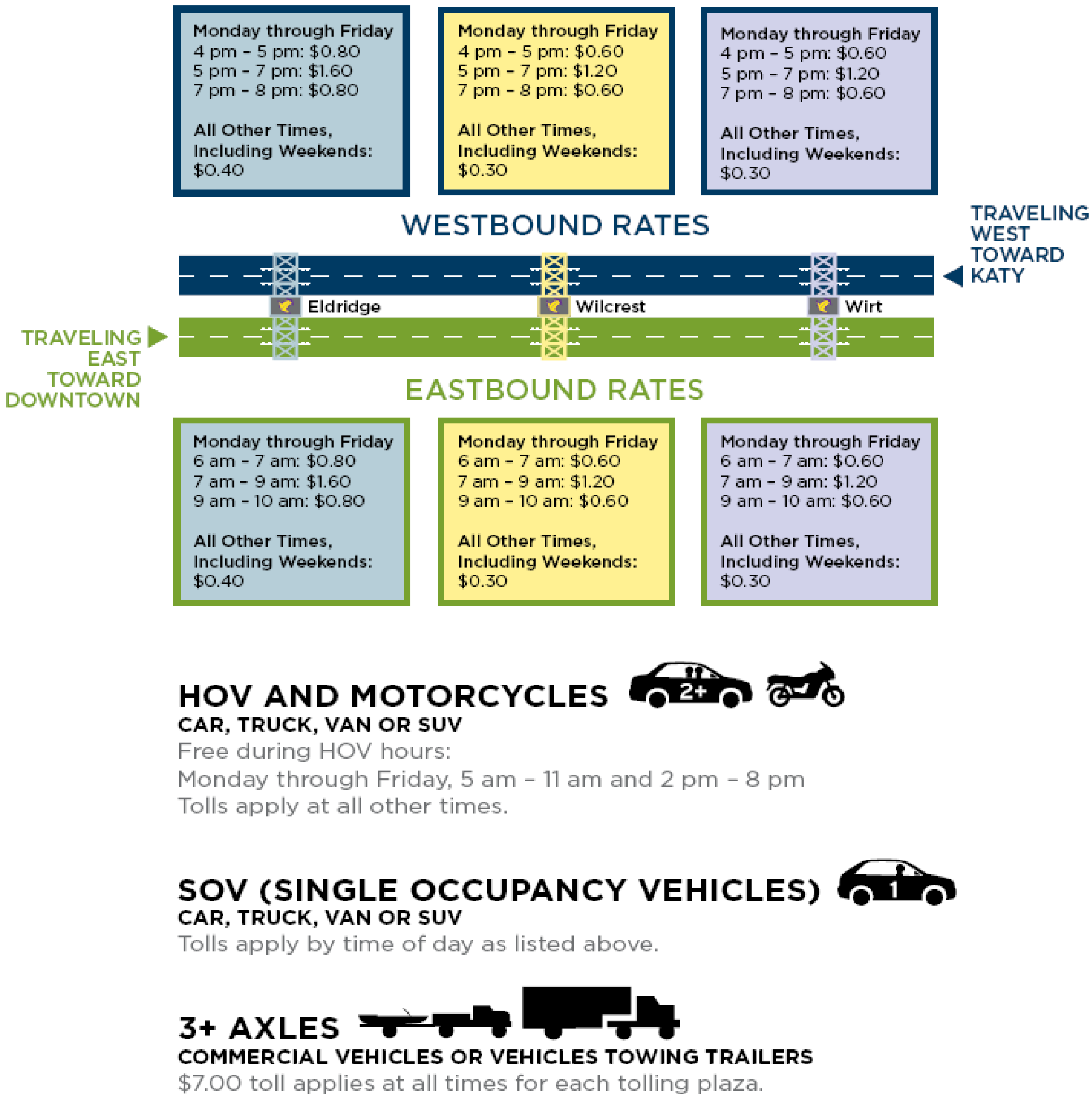


Figure 41. Toll Rates on the KML (https://www.hctra.org/katymanagedlanes/index.html).

Table 15. Datasets Used in the Analysis of Traffic on the Katy Freeway.

Name	Description	Data	Notes
AVI: Valid Matches	All transponder (tag) IDs that were observed at sequential AVI sites (within reasonable time parameters)	TAGID, AVI Sensor 1, AVI Sensor 2, Time at Sensor 1, Time at Sensor 2, # seconds difference, equivalent speed (mph)	Over 1 million records per day for all of Houston. Approximately 170,000 records per day on Katy Freeway.
AVI: Match Summary	Average travel speeds between any two sequential AVI sensors aggregated into 15-minute periods	Date, Time, AVI Sensor 1, AVI Sensor 2, Time at Sensor 1, Time between sensors (seconds), equivalent speed (mph), # vehicles	Over 30,000 records per day for all of Houston. Summarizes the "Valid Matches" dataset.
Wavetronix: 30-Second Summaries	Instantaneous speeds and volumes at a sensor, aggregated into 30-second intervals	Wavetronix Sensor, Date, Time, Lane, Volume, Speed, Occupancy, Small, Medium, Large	Approximately 50,000 records per day on Katy Freeway alone
TransKatyMangdLns	All transponder-based tolled vehicles on the KML	Date, Time, TAGID, Location, Lane ID, Plaza ID, Disposition, Reason Code, License Plate	Over 150,000 records per file, which contains one week of data
V_tolsKatyMangdLns	All video-based tolled vehicles on the KML (have an account but transponder failed)	Date, Time, unknown, Location, Lane ID, Plaza ID, Disposition, Reason Code, License Plate Number	Over 80,000 records per file, which represent one month of data. Essentially the same as *TransKatyMangdLns.*
I-10HOVLnsTrans	The 15-minute total number of vehicles observed on the KML	Date, Time, 15-minute volumes for KTY EB @ Eldridge, KTY EB @ Wilcrest, KTY EB @ Wirt, KTY WB @ Wirt, KTY WB @ Wilcrest, KTY WB @ Eldridge	During toll hours these are tolled vehicles. During HOV hours these vehicles travel for free.

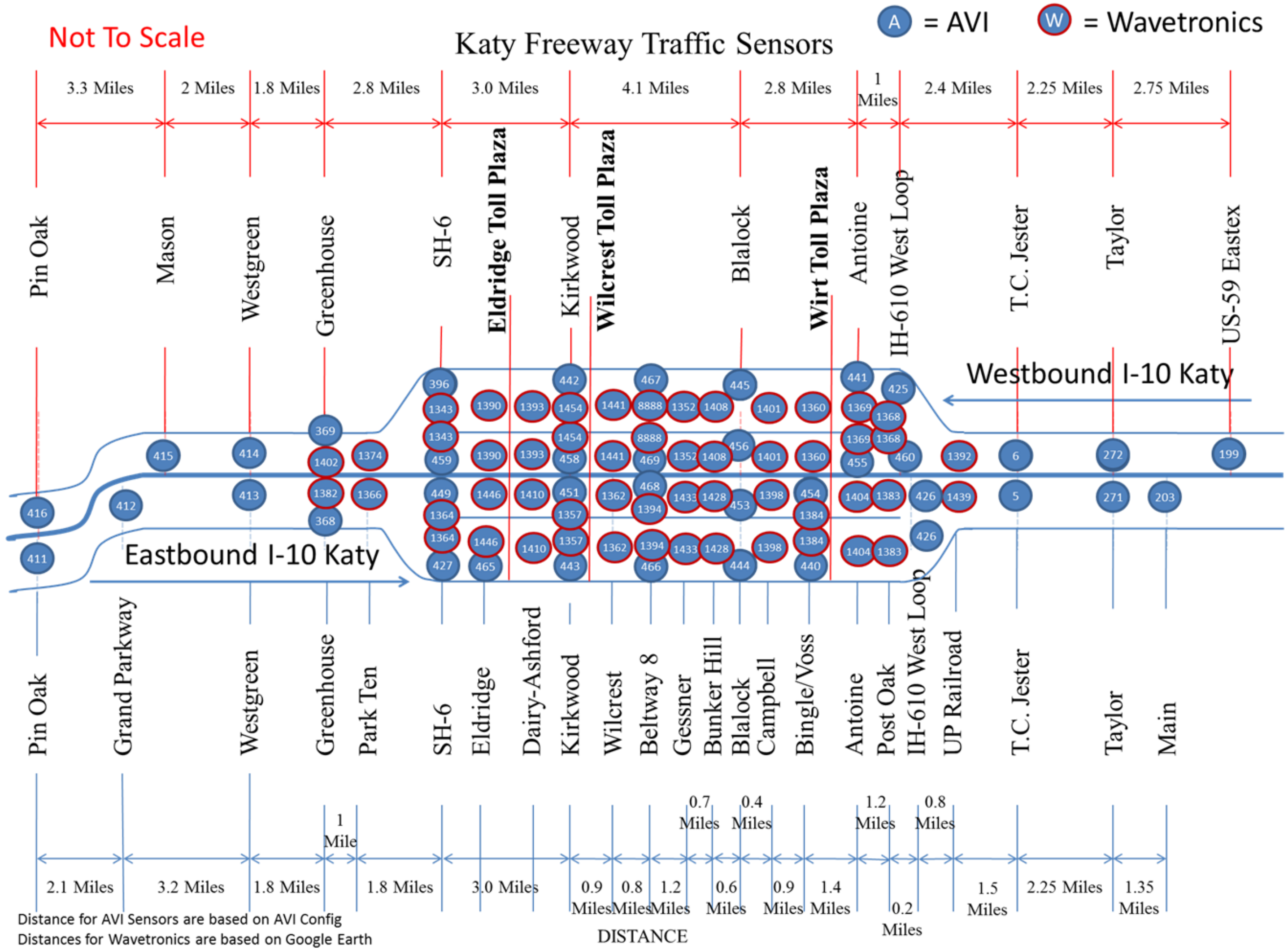


Figure 42. Sensor Locations.

MANAGED LANE TRAFFIC VOLUMES (HCTRA SENSORS)

Traffic volume data for the year 2011 on the KML were obtained from two sources. For HOV volumes (all untolled traffic), HCTRA Wavetronix sensors were used (*I-10HOVLnsTrans*) since many of these vehicles were not equipped with a transponder. The Wavetronix sensors were located on the KML near the cross streets of Eldridge, Wilcrest, and Wirt toll plazas. For toll-paying vehicles, the volumes were obtained from the HCTRA tolling database (*TransKatyMangdLns* and *V_tolsKatyMangdLns*). Speed data were obtained from the Houston Regional Traffic Data Generator that TTI maintained and is based on AVI data in the dataset *AVI:Match Summary*.

The average EB volume, including the traffic in the HOV and toll lanes, and average EB speed for every 15-minute period are presented in Figure 43. The volume includes all non-holiday weekdays for all of 2011. The EB traffic volume peaked from 6:30 to 7:30 AM, and the average speed decreased to approximately 35 mph on the GPLs and down to 52 mph on the managed lanes. During the afternoon peak period, from approximately 4:00 to 7:00 PM, a small number of EB travelers were on the managed lanes, peaking at approximately 280 in the 15-minute period from 5:15 to 5:30 PM. During the rest of the day, EB volumes on the managed lanes were very small. Speeds in the GPLs were about 20 mph slower than in the managed lanes in the morning peak hour, and 5 mph slower in the off-peak hours (Figure 43). The volumes at Wilcrest were considerably lower than at the other two locations. In examining the raw data, researchers found that the Wilcrest station stopped collecting volumes early in the year, so these values were not included in Figure 43.

The non-holiday weekday average WB volume, including the traffic in the HOV and toll lanes, and average WB speed for every 15-minute period are presented in Figure 44. The WB traffic volume peaked from 3:30 to 6:30 PM, and, similar to the AM peak, the average speed decreased into the high 20s mph on the GPLs and low 50s mph on the managed lanes. During the rest of the day, WB volumes on the managed lanes were very small. Speeds in the GPLs were more than 20 mph slower than in the managed lanes in the afternoon peak hour, and 5 mph slower in the off-peak hours (Figure 44).

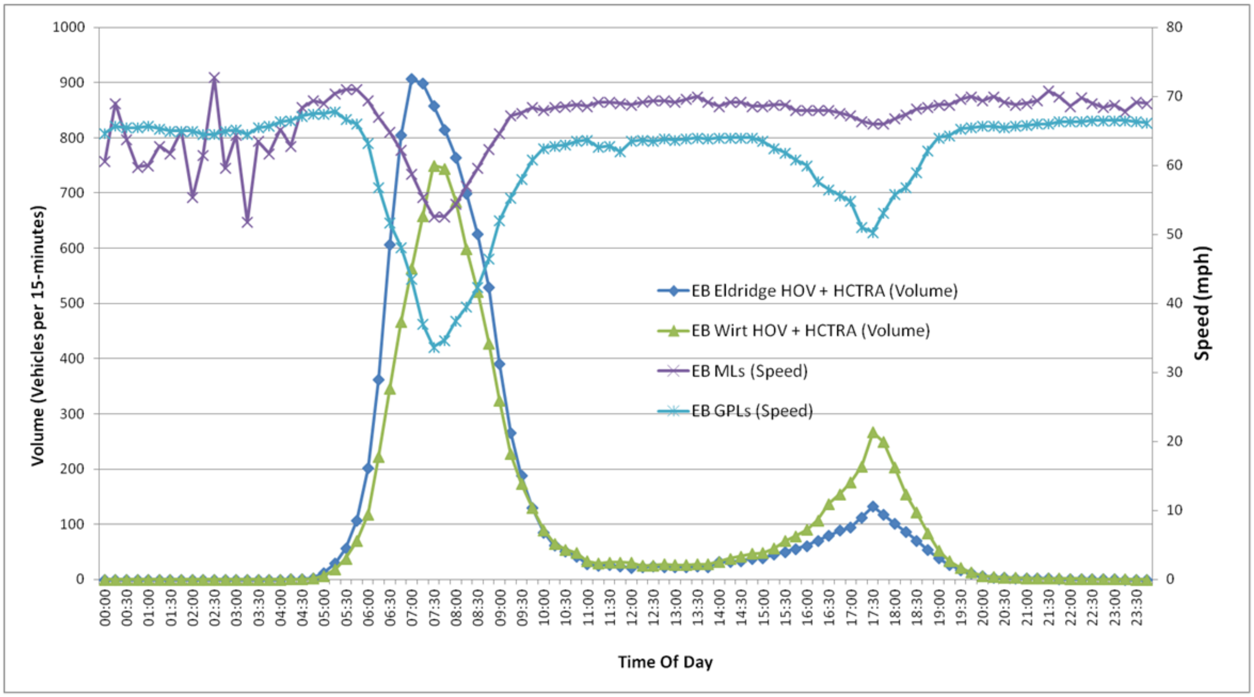


Figure 43. Average EB Managed Lane Volume and Speed on the Katy Freeway (All Non-holiday Weekdays in 2011).

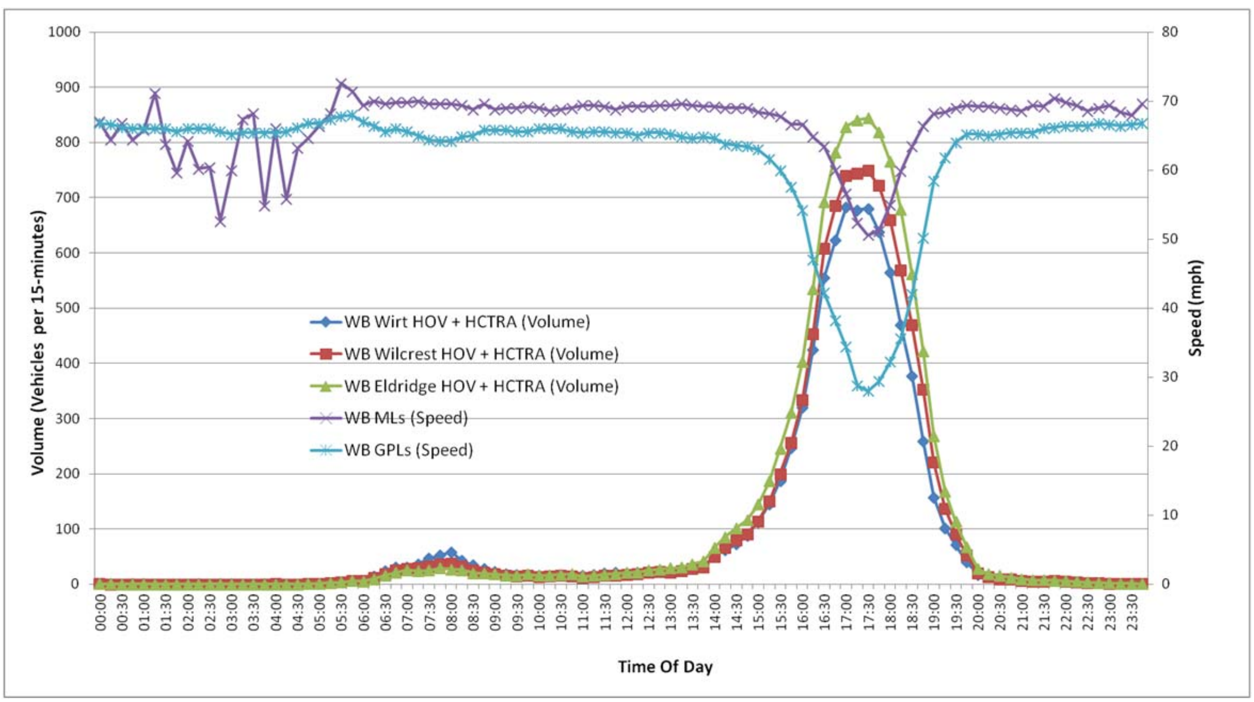


Figure 44. Average WB Managed Lane Volume and Speed on the Katy Freeway (All Non-holiday Weekdays in 2011).

GPL and Managed Lane Traffic Volumes (TxDOT Sensors)

For comparison purposes, researchers examined the volumes obtained using TxDOT Wavetronix sensors at locations very close to the toll plazas where HCTRA collected the data that were used in the analysis. The speeds are the same as those analyzed in the previous section. Figure 45 includes the non-holiday weekday average EB volume (GPLs, managed lanes, and total) and speed by 15-minute periods in 2011 at the Dairy Ashford (Wavetronix Sensor 1410) sensor. Diary-Ashford is located between Eldridge and Wilcrest and thus would likely have managed-lane volumes similar to those recorded at the Eldridge and Wilcrest tolling areas (refer to Figure 42).

As shown in Figure 45, the EB traffic managed lane volume peaked from 6:30 to 8:00 AM, and the average 15-minute EB volume in the managed lanes at Dairy Ashford peaked at just fewer than 600 vehicles. This number is much lower than the average 15-minute EB volume in the managed lanes at Eldridge recorded by HCTRA sensors—about 900 vehicles per hour (Figure 43). This may suggest that approximately 300 more vehicles left the managed lanes than vehicles entering the managed lanes at some points between Eldridge and Dairy Ashford. Or, more likely, the TxDOT Wavetronix sensor at Dairy Ashford missed some vehicles.

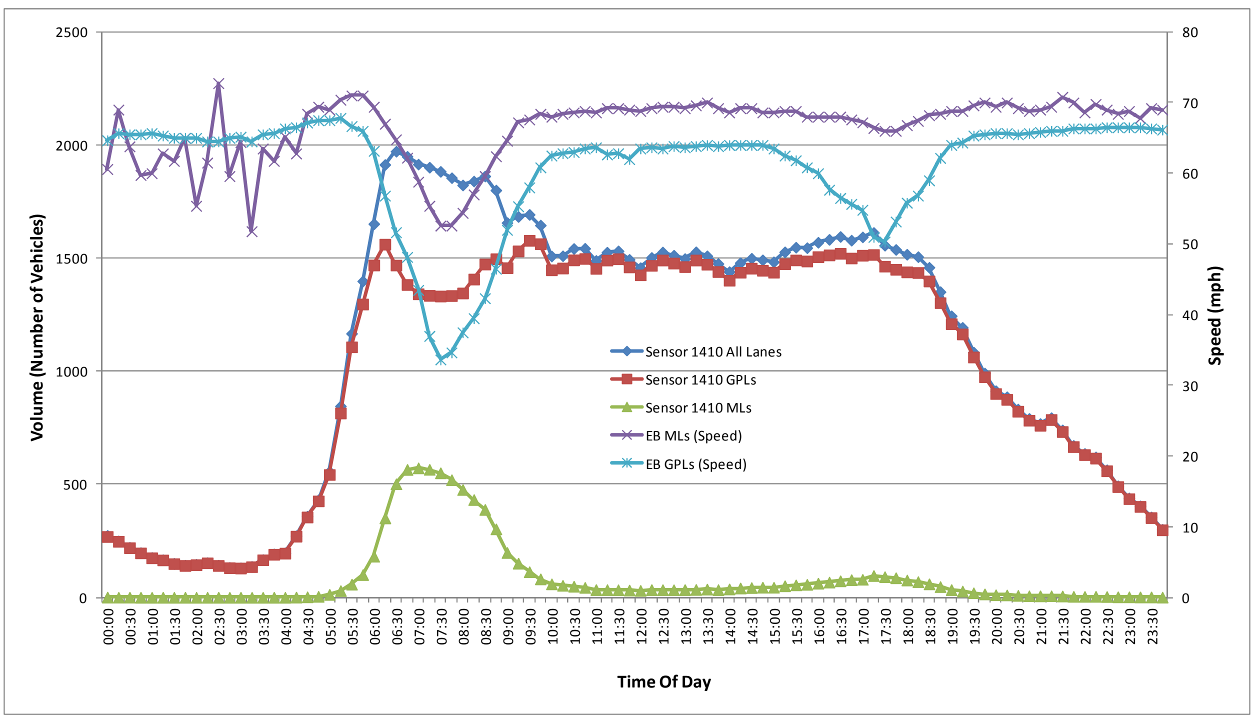


Figure 45. Average Volume for Wavetronix Sensor 1410 EB at Dairy Ashford on the Katy Freeway (All Non-holiday Weekdays in 2011).

Similarly, Figure 46 includes the non-holiday weekday average WB volume (GPLs, managed lanes, and total) and speed by 15-minute periods in 2011 at the Kirkwood (Wavetronix Sensor 1454) sensor. Kirkwood is located between Eldridge and Wilcrest and thus would likely have managed lane volumes similar to those recorded by HCTRA at the Eldridge and Wilcrest tolling areas (refer to Figure 44).

The WB traffic volume in the managed lanes peaked from 4:30 to 6:00 PM, and the average 15-minute WB volume in the managed lanes at Kirkwood peaked at about 450 vehicles per hour. The average 15-minute WB volume in the managed lanes at Eldridge and Wilcrest peaked at about 850 and 750 vehicles (Figure 44), respectively. This may imply that the TxDOT Wavetronix sensor in Kirkwood (Wavetronix Sensor 1454) is also missing some vehicles.

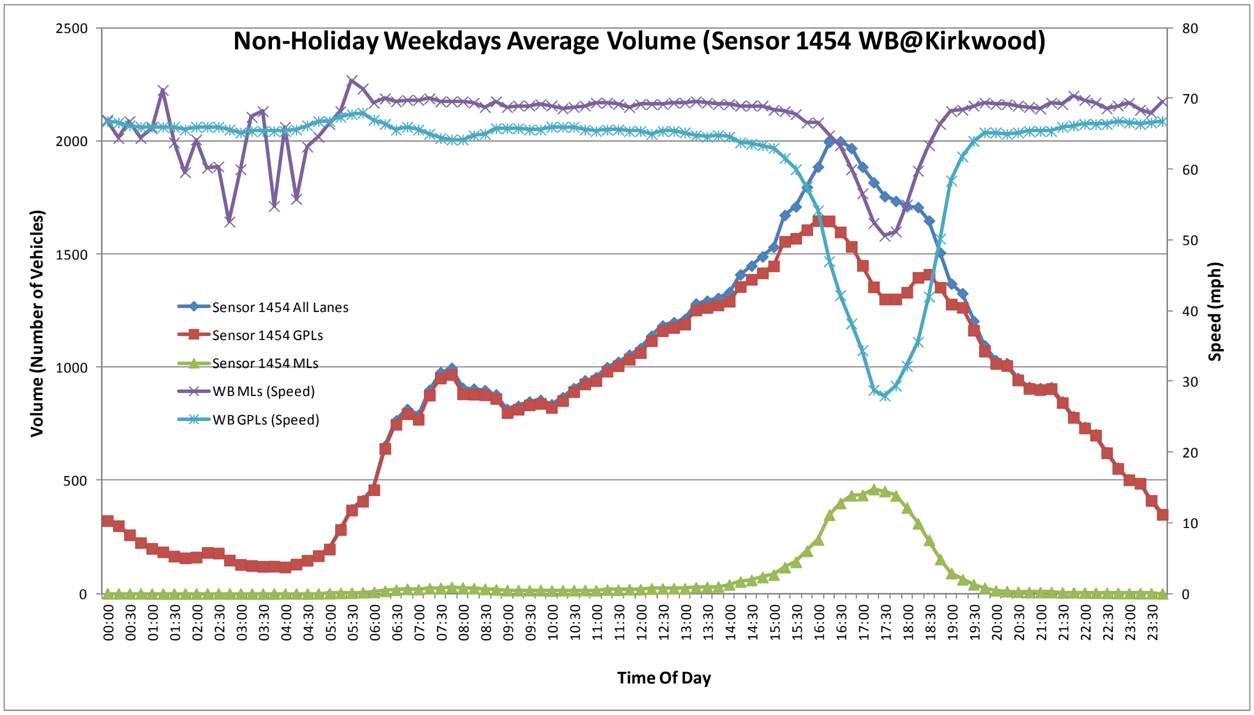


Figure 46. Average Volume for Wavetronix Sensor 1454 at Kirkwood on the Katy Freeway (All Non-holiday Weekdays in 2011).

Based on these analyses, it is likely that the TxDOT Wavetronix sensors that appeared to be providing the most reasonable volume data (1410 and 1454) were still missing a significant percentage of vehicles. Based on this information, TxDOT worked with its contractor to recalibrate the Wavetronix sensors in 2012. However, for this report, researchers relied on data from HCTRA for managed lane volumes and used transponder reads for volumes of transponder-equipped vehicles on the GPLs. Researchers did not attempt to use the TxDOT Wavetronix recorded volumes to estimate volumes on the GPLs. Therefore, Figure 43 and Figure 44 provide the best estimates of managed lane volumes.

Frequency of Katy Freeway Use

The vast majority of travelers who use the Katy Freeway (GPLs or managed lanes) and have a transponder are identified by the AVI sensors along the freeway (see Figure 42). Almost all of these transponders are sticker tags and stick to the windshield. Therefore, it is highly unlikely that travelers would remove their tag for specific trips. (However, technology does exist where travelers can shield their tag from being read, but this is again unlikely in this context. It is used on HOT lanes where the traveler must cover the transponder in order to not be charged). Also, the TxDOT AVI system for the managed lanes and GPLs is not perfect and does miss some vehicles. It was designed to gather enough data to provide accurate travel times, and it easily accomplishes this goal. But the TxDOT AVI system was not developed to capture all vehicles. Therefore, not all trips on the GPLs are accounted for in the following analysis. Conversely, managed lane trips were also recorded by HCTRA's AVI system, which does capture the vast majority of managed lane trips because it was designed for toll collection. The following analyses use the HCTRA data for the managed lanes.

All transponders that were identified as traveling between any pair of sensors on any lane of the Katy Freeway during all non-holiday weekdays in 2011 were used for this analysis. These data come from combining the datasets: *AVI: Valid Matches*, *TransKatyMangdLns*, and *V_tolsKatyMangdLns*. This totaled over 35 million trips, which is more than enough to provide reasonable results, but is not all trips. The frequency of how often a given traveler was observed on any lanes of the Katy Freeway is shown in Figure 47. As expected, there are many travelers who only use the Katy Freeway occasionally, while there are over 100,000 that use it quite regularly.

Based on the results shown in Figure 48, it is clear that a select few travelers use the managed lanes quite often, while many others use the managed lanes very rarely or not at all. The total trips made by users on the general-purpose lanes are significantly larger (Figure 49). The paid usage of the managed lanes is examined in Figure 50 and was calculated as shown in Equation 1 below. As expected, many (over 72 percent) of the transponder-equipped vehicles never paid to use the managed lanes. Another 21 percent used it for 2 percent to 60 percent of their travel. Then just over 3 percent of travelers only used the managed lanes when they traveled on the Katy Freeway. Although this is only 3 percent of the transponder-equipped vehicles, it is over 49,000 vehicles and was examined further.

Tollway lane users were broken into four categories for further analysis:

- Those whose only trips on the Katy Freeway were in the tollway lane (exclusive).
- Those whose trips in the tollway lane comprised between 50 percent and 99 percent of their Katy Freeway travel (frequent).
- Those whose trips in the tollway lane comprised between 5 percent and 50 percent of their Katy Freeway travel (occasional).
- Those whose trips in the tollway lane comprised between 0.01 percent and 5 percent of their Katy Freeway travel (rare).

$$Percent\ of\ Paid\ ML\ Trips = \frac{\#\ Paid\ Trips\ on\ MLs}{(\#Paid\ Trips\ on\ MLs + \#\ Free\ Trips\ on\ MLs + \#\ Trips\ on\ GPLs)}$$

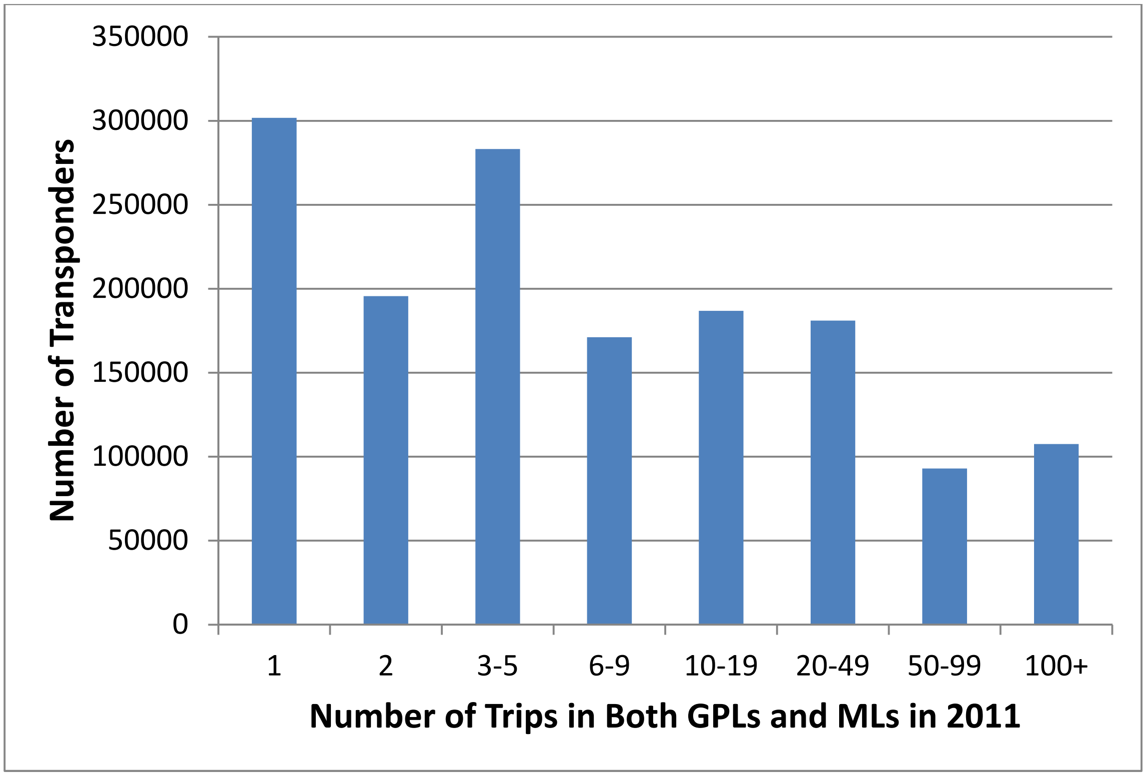


Figure 47. Number of Vehicle Trips on the GPLs and Managed Lanes.

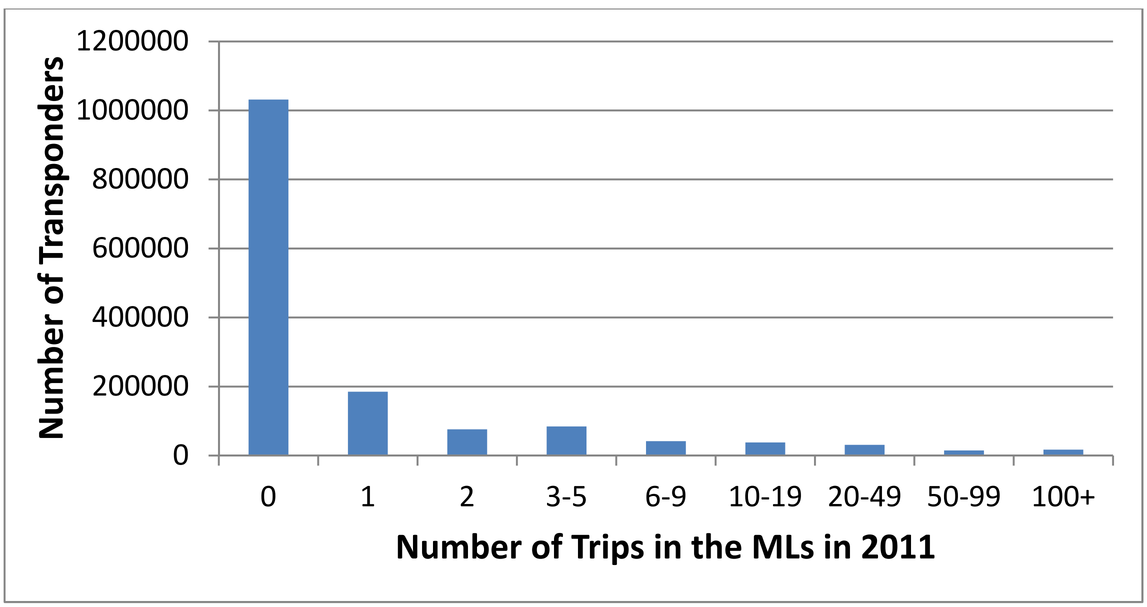


Figure 48. Number of Vehicle Trips on the Managed Lanes.

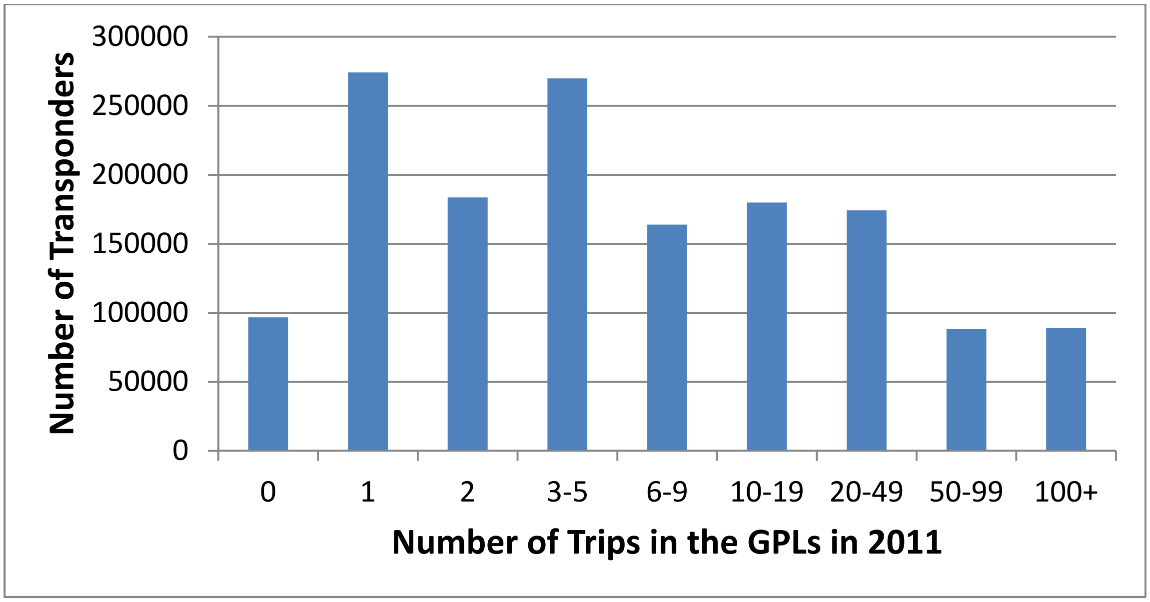


Figure 49. Number of Vehicle Trips on the GPLs.

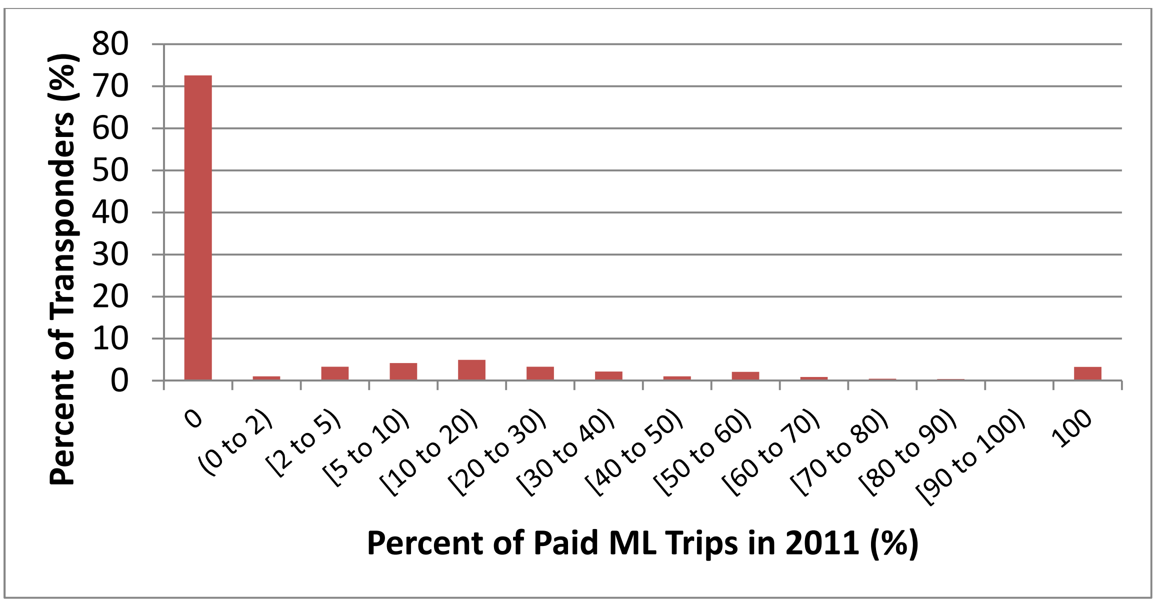


Figure 50. Percentage of Paid Trips on the Managed Lanes.

The percentage of trips taken by day of week and time of day were significantly different ($p < 0.05$) for the members of these four groups (see Table 16). However, there were no patterns to these differences. One of the few clear differences between the four groups was that the frequent users were more often traveling during a weekday at peak times, likely commuting. In fact, 24 percent of the time they were traveling during the peak toll hours (7:00 to 9:00 AM in the EB direction and 5:00 to 7:00 PM in the WB direction). Therefore, the majority of groups were not traveling during the peak period and were looking for something other than travel time savings. In the survey of travelers, respondents were asked their reasons for using the managed lanes. Most responded with answers pertaining to saving time or traveling for free (as a carpool).

Since shoulder-period and off-peak-period travelers likely saved little time and were paying to use the managed lanes, these answers would not be their reason for using the lane. The next most frequently cited reasons were that the managed lanes were less stressful than the GPLs, the managed lanes feel safer than the GPLs, and there are no trucks on the managed lanes. These travelers make up a loyal tollway lane group that values these characteristics of the lanes.

Table 16. Comparison of Paying Tollway Users.

	Group			
	Exclusive	**Frequent**	**Occasional**	**Rare**
Number of Transponders	49,738	61,447	239,251	66,548
Percentage of Transponders	12	15	57	16
Number of Trips	144,862	3,072,038	15,320,000	7,285,342
Percentage of Trips	1	12	59	28
Day of Week*				
Monday	14	17	15	15
Tuesday	17	19	17	16
Wednesday	18	19	17	16
Thursday	19	19	17	16
Friday	19	17	17	16
Saturday	7	5	10	12
Sunday	5	3	7	9
Time of Day*				
Peak (7–9 AM EB and 5–7 PM WB)	17	24	13	8
Shoulder (6–7 AM and 9–10 AM EB plus 4–5 PM and 7–8 PM WB)	7	13	10	9
Off-Peak (All Other Times)	76	63	76	83

* Significant difference ($p < 0.05$) between the groups.

Analysis of Katy Tollway Use

Due to the hundreds of thousands of travelers who use the Katy Freeway, it was impossible to examine all records of all the travelers on the road. Therefore, only a random sample of all transponder holders was examined. It was necessary to use only transponder owners since there was no way to identify travelers without transponders in the GPLs. The three datasets that provide transponder IDs are *AVI: Valid Matches*, *TransKatyMangdLns,* and *V_tolsKatyMangdLns*.

The month of September 2011 was selected for generating the sample for this study. A trip segment was identified when a transponder ID was detected at a sensor and then subsequently detected at the next downstream sensor. An entire trip was generated by chaining together all the appropriate trip segments for that ID. After generating the September 2011 trips, there were still far too many to reasonably analyze, and the dataset was further reduced by using only the morning (midnight to noon) EB trips greater than 4 miles in length. Requiring a 4-mile length helped eliminate the many very short trips that were created due to the AVI readers missing a transponder ID at one of the readers along that vehicle's trip. Due to how the dataset was created, transponders identified at sensor 368 (Greenhouse) were not linked to any of the sensors on the managed lanes, specifically number 369 at SH 6 (refer to Figure 42). Therefore, all trips with a start sensor upstream of sensor 368 (upstream of the start of the managed lanes) were not considered. Also, only frequent users of the freeway were considered in the study, and all those travelers who had less than 20 trips in the month of September 2011 were eliminated. Although this did reduce the dataset considerably, there were still over 46,500 trips by 832 different users in the dataset analyzed. Most trips, 94 percent, were on the GPLs with 6 percent of trips on the managed lanes.

Using these trips, researchers create a dataset that could be imported into NLogit for utility modeling. The dataset had all of the data needed for developing utility equations of mode (in this case, lane) choice. For each trip, the traveler made the choice of driving on the GPLs, toll lane, or HOV lane. Therefore, for each trip observed, two additional, corresponding trips were generated for the two lanes that were not chosen. For instance, if a trip was observed on the toll lane, corresponding trips on the HOV and GPL were generated. The actual (toll-lane) trip recorded the exact travel time of that traveler's trip. The corresponding trips (HOV and GPL) were the same distance but had the average travel speed characteristics of the appropriate other lanes for that five-minute time period. The traveler's experience on his or her previous trip was used as the traveler's perception of travel time reliability. If the average speed of the previous trip was less than 20 mph on the GPLs or less than 30 mph on the managed lanes (toll lane or HOV lane), then that was identified as a bad last trip on the lane used for that last trip. This may help identify travelers who switch lanes based on their previous trip. Additionally, the toll rate on the toll lane and, if applicable, the HOV lane (see Figure 41) was assigned to the trips. Finally, two other dummy variables were included in the dataset: (1) if a major incident occurred upstream of the trip or (2) if there was more than 0.4 inches of precipitation during that hour of the day.

The coefficients of the utility equations were then estimated. The dummy variables and the bad trip variable were not significant for this particular group of travelers and were not included in these models. The results were as follows:

$$U_{GPL} = \beta_{TT} TravelTime_{GPL} + \beta_{TTR} TravelTimeReliability_{GPL}$$
$$U_{HOVL} = \beta_{HOVL} + \beta_{TollHOVL} Toll_{HOVL} + \beta_{TT} TravelTime_{HOVL} + \beta_{TTR} TravelTimeReliability_{HOVL}$$
$$U_{TL} = \beta_{TL} + \beta_{TollTL} Toll_{TL} + \beta_{TT} TravelTime_{TL} + \beta_{TTR} TravelTimeReliability_{TL}$$

Where:

GPL = general-purpose lane.

TL = toll lane.

HOVL = high-occupancy vehicle lane.

Toll = toll, as defined in Figure 41.

TT = travel time. This is the exact travel time for the trip the vehicle took and is the five-minute average travel time for the lane that the vehicle did not choose.

TTR = travel time reliability. This is the standard deviation of the mean travel time. However, the true standard deviation of travel times over a series of sensors could not be calculated because for many five-minute time segments, there were too few vehicles that traveled the entire stretch of roadway to estimate the true covariance and therefore the actual standard deviation. To account for this, researchers examined multiple time periods that did have sufficient data to compare the covariance of travel times of vehicles that made the whole trip to the covariance of all vehicles that only made part(s) of the trip. The relationship found was:

$$True\ Standard\ Deviation = 0.8 \times Standard\ Deviation\ of\ all\ Vehicles + 0.907$$

The resulting equations, with the estimated coefficients, were:

$$\begin{aligned}
U_{GPL} &= -0.006 TravelTime_{GPL} + 0.023 TravelTimeReliability_{GPL} \\
U_{HOVL} &= -4.39 + 1.32 Toll_{HOVL} - 0.006 TravelTime_{HOVL} + 0.023 TravelTimeReliability_{HOVL} \\
U_{TL} &= -3.49 + 1.32 Toll_{TL} - 0.006 TravelTime_{TL} + 0.023 TravelTimeReliability_{TL}
\end{aligned}$$

Unfortunately, both the toll and the reliability coefficients were of the wrong sign. Higher tolls and higher variability should lead to lower utility (and thus have a negative sign). This may have been due to the increased use of the tollway lane when the toll price was higher. Peak demand occurs during periods of the highest toll rates. Due to these incorrect signs, it was not possible to calculate a value of time from the utility equations. However, the next section of this report examines the actual use and tolls paid on the managed lanes, and estimates a value of time from those data.

Travel Time Savings of the Tollway

This section examines the amount of travel time saved by vehicles using the tollway. The savings are based on the travel time difference between the tollway lanes and the GPLs. Additionally, this analysis only examines those travelers in the tolled lane and does not include the travelers in the HOV lane. This provides the amount of time saved for travelers as if the tollway had not been built and the Katy Freeway HOV lane remained a single lane.

This analysis also assumes that the vehicles using the toll lane could enter the GPLs and not impact the speed of the GPLs. If the tollway was not constructed, then many of these vehicles would use the GPLs, reducing the travel speed of the GPLs. Some of the vehicles would use other routes, and some might not make the trip. Since researchers cannot estimate how travel times would be impacted by the lack of toll lane, they used a conservative approach that assumed the GPLs would function as they do now, with the toll lane built.

As mentioned previously, the volume of vehicles that TxDOT's AVI system and Wavetronix system recorded on the toll lane is not as accurate as the volumes that HCTRA's AVI system had recorded. Therefore, volumes of vehicles on the toll lane were obtained from the datasets *TransKatyMangdLns* and *V_tolsKatyMangdLns* that HCTRA supplied. Travel times were obtained from TxDOT's AVI system (dataset *AVI: Match Summary*) since it provided accurate travel times on the lanes. (Even though TxDOT's AVI system missed reading some tagged vehicles on the lanes, it did provide accurate travel times that for those vehicles it did read. Therefore, the TxDOT AVI system could provide excellent travel times even though the volume count was low).

HCTRA's AVI system recorded the number of vehicles with transponders in the toll lane (which should be nearly all vehicles) at the three toll plaza locations (Eldridge, Wilcrest, and Wirt). Since researchers only knew when the vehicles were at these locations, they needed to assume the length of travel of the vehicles on the toll lane and compare that to a similar length of travel on the GPLs. The following sensors were used to calculate the travel time savings (TTS) (see Figure 42 for locations of the sensor numbers):

- TTS (EB) for the Eldridge toll plaza: the TT on the GPLs from 427 to 443 minus the TT on the managed lanes from 449 to 451.
- TTS (EB) for the Wilcrest toll plaza: the TT on the GPLs from 443 to 444 minus the TT on the managed lanes from 451 to 453.
- TTS (EB) for the Wirt toll plaza: the TT on the GPLs from 444 to 426 minus the TT on the managed lanes from 453 to 426.
- TTS (WB) for the Wirt toll plaza: the TT on the GPLs from 425 to 445 minus the TT on the managed lanes from 460 to 456.
- TTS (WB) for the Wilcrest toll plaza: the TT on the GPLs from 445 to 442 minus the TT on the managed lanes from 456 to 458.
- TTS (WB) for the Eldridge toll plaza: the TT on the GPLs from 442 to 396 minus the TT on the KML from 458 to 459.

Using the above assumptions, there were 8.29 million transactions saving an average of 117 seconds per transaction. WB travelers saved more time on average than EB travelers—151 seconds per transaction versus 85 seconds. The total hours saved were 270,393 hours. Using TxDOT's value of travel time savings of $20.99 per passenger car hour, the value of time saved in the toll lane in 2011 was $5,675,547. This is a conservative estimate of the true value of time saved due to the tollway since:

- This estimate uses the standard value of travel time savings, $20.99 per hour. Research has shown that travelers in managed lanes frequently use these lanes only when they are rushed for time and value their time greater than average.
- This estimate does not take into account the travel time savings that may occur for HOVs traveling in the off-peak direction. Although this is a small amount, there are

some times of day when the HOVs in the off-peak direction are saving travel time by having the HOV lane operational in both directions during the entire day.

- This estimate does not calculate how much slower GPL traffic would be if the tollway did not exist. The travel time savings are based on the travel speeds in the GPLs as they are now.
- This estimate does not take into account any value travelers place on the additional travel time reliability offered by the tollway lane. However, part of this additional value may be captured in the value of time.

Also, there is traffic on the tollway even when there are no travel time savings on the tollway. This is a very small proportion of traffic, but it does happen. In 2011, 1.1 percent of trips on the toll lanes were during times that the tollway lane was operating at a lower average speed than the GPLs.

Using the same set of data, it was possible to estimate the amount of revenue generated from tolls on the lanes (Table 17). Revenues from the toll lane and HOV lane combined exceeded $7 million in 2011. These are not exact figures because HCTRA works with any anomalies and violations through their back office procedures, and they are not reflected here. Also, the HOV lane Wavetronix sensor at Wilcrest was not operational in the EB direction for most of the year, leading to low traffic volumes recorded at this location. Almost 98 percent of the revenues were from the toll lane, and only 2 percent were from the HOV lane.

Table 17. Revenue Estimates.

Toll Plaza	Direction	Lane	Number of Vehicles	Toll	AverageToll
Eldridge	Eastbound	Toll	1,570,851	$1,848,922	$1.18
Eldridge	Eastbound	HOV	104,942	$41,977	$0.40
Eldridge	Westbound	Toll	1,539,697	$1,774,283	$1.15
Eldridge	Westbound	HOV	78,949	$31,580	$0.40
Wilcrest	Eastbound	Toll	1,239,319	$1,030,945	$0.83
Wilcrest	Eastbound	HOV	4,764	$1,429	$0.30
Wilcrest	Westbound	Toll	1,332,450	$591,573	$0.44
Wilcrest	Westbound	HOV	62,401	$18,720	$0.30
Wirt	Eastbound	Toll	1,421,301	$1,117,419	$0.79
Wirt	Eastbound	HOV	75,328	$22,598	$0.30
Wirt	Westbound	Toll	1,189,875	$519,804	$0.44
Wirt	Westbound	HOV	86,446	$25,934	$0.30
TOTAL			8,706,323	$7,025,185	$0.81

The fact that the revenue ($7,025,185) exceeded the estimated value of travel time savings ($5,675,547) indicates that the value of time used here ($20.99 per hour) greatly underestimates the value travelers are placing on the use of the tollway lanes. The amount of toll paid by the traveler divided by the travel time saved provides some indication of the travelers' value of time. This is a minimum since researchers do not know how much more toll they might have been willing to pay (see Figure 51).

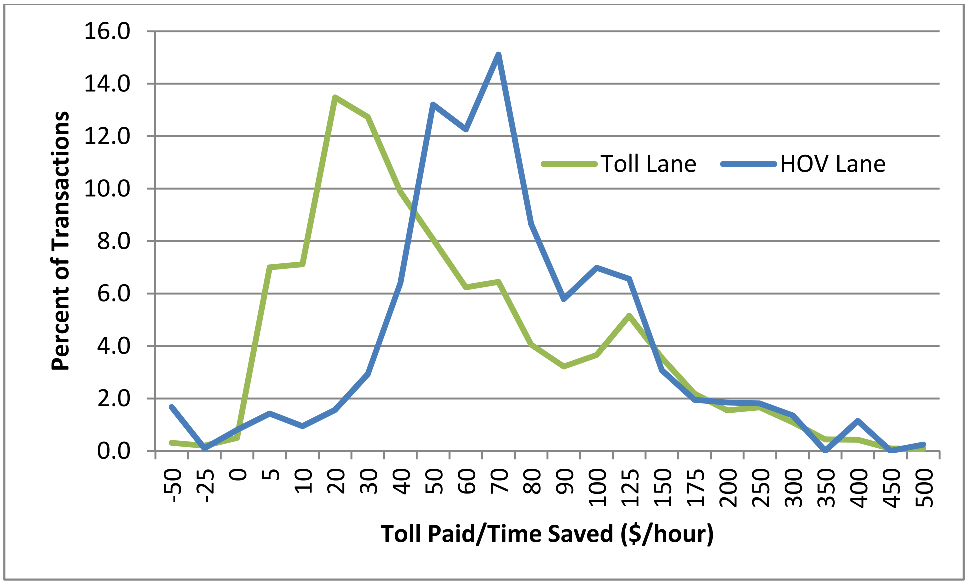


Figure 51. Distribution of Values of Time (Both Directions, Based on All Transactions in 2011 but Removing Those Less Than −$100 per Hour and More Than $500 per Hour).

The weighted mean values of time were $59.07 per hour for the SOV managed lane and $77.80 per hour for the HOV lane. It is not surprising that the value of time was higher for the HOV lane since travelers were paying to use this lane only in off-peak hours. Thus, although the toll was low, travel time savings were also very small. Using these values of time, rather than TxDOT's $20.99 per hour, yields a much higher benefit to travelers from the managed lanes. This calculation again only uses the single tolled lane in each direction (270,393 hours) multiplied by $59.07 per hour, which leads to a benefit of $15.97 million per year. This is only the benefit from travel time savings and ignores other benefits such as reduced emissions and reduced vehicle operating costs.

CHAPTER 8. ACCESS DESIGN

The construction of the Katy Freeway Managed Lanes provided a unique opportunity to meet the needs of motorists by providing a completely new set of access points to and from the managed lane facility, as compared to many similar facilities that are predominantly retrofit installations. The access points on the KML are intended to provide timely, useful access between the managed lanes and the I-10 general-purpose lanes, as well as origins and destinations beyond the freeway.

Researchers investigated the performance of these access points and whether the design of access to managed lanes is meeting the needs of motorists who use them. This chapter provides an overview of the access points on the KML, a discussion of the field data collected and how it was reduced and analyzed, and the research team's conclusions about how the access points perform based on the analysis.

CHARACTERISTICS OF KML ACCESS POINTS

Including the "diamond lane" (i.e., HOV-only) section of the facility, there are 15 access points in each direction of the KML between its western terminus east of Mason Road and its eastern terminus west of Washington Avenue/Westcott Street. A summary of each access point, describing the access design type, location, and number of managed lanes downstream, is shown in Table 18 and Table 19.

Table 18. KML EB Access Points.

Eastbound Access	Access Type	Location/Cross Street	Number of Managed Lanes
1	Lane Addition	E. of Mason (Western Terminus)	1
2	Lane Addition	Between Fry and Greenhouse	2
3	Lane Drop	Between Greenhouse and Barker-Cypress	1
4	Slip Ramp	Between Barker-Cypress and S. Creek	2
5	Lane Drop	Between S. Creek and Park 10	1
6	Lane Addition	Between Memorial Brook and SH 6 (change from HOV to HOT)	2
7	Direct-Connect Entrance/Exit	Addicks Park and Ride T-Ramp	2
8	Direct-Merge Exit	E. of Dairy Ashford	2
9	Direct-Merge Entrance	W. of Kirkwood	2
10	Direct-Merge Exit	Between Gessner and Bunker Hill	2
11	Direct-Merge Entrance	Between Bunker Hill and Echo Lane	2
12	Lane Drop	Between Wirt and Antoine	1
13	Direct-Connect Exit	Entrance to Post Oak Park and Ride	0
14	Direct-Connect Entrance	Exit from Post Oak Park and Ride	1
15	Lane Drop	W. of Westcott (Eastern Terminus)	0

Table 19. KML WB Access Points.

Westbound Access	Access Type	Location/Cross Street	Number of Managed Lanes
1	Lane Addition	W. of Westcott (Eastern Terminus)	1
2	Direct-Connect Exit	Entrance to Post Oak Park and Ride	0
3	Lane Addition	E. of I-610 (Shoulder Lane Terminus)	1
4	Direct-Connect Entrance	Exit from Post Oak Park and Ride	1
5	Lane Addition	Antoine (W. of Silber)	2
6	Direct-Merge Exit	Between Echo and Bunker Hill	2
7	Direct-Merge Entrance	Between Bunker Hill and Gessner	2
8	Direct-Merge Exit	W. of Kirkwood	2
9	Direct-Merge Entrance	E. of Dairy Ashford	2
10	Direct-Connect Entrance/Exit	Addicks Park and Ride T-Ramp	2
11	Lane Drop	Between Memorial Brook and SH 6 (change from HOT to HOV)	1
12	Direct-Merge Entrance	Broadfield	1
13	Lane Addition	Between Barker-Cypress and Greenhouse	2
14	Lane Drop	Between Greenhouse and Fry	1
15	Lane Drop	E. of Mason (Western Terminus)	0

Access design types are described in the following list (graphical examples are provided in Figure 52):

- Lane addition: a through travel lane is added to the managed lane facility. Drivers may continue traveling on the managed lane facility in this lane without being required to merge with other traffic.
- Lane drop: a through travel lane is removed from the managed lane facility. Drivers in this lane are required to leave the managed lane facility, and they must change lanes to remain in the facility.
- Slip ramp: a segment along the boundary between the managed lanes and GPLs that allows both entrance and exit maneuvers. It functions very similarly to a weaving section between an entrance-exit ramp pair for access between GPLs and the frontage road. It is typically denoted by a dotted white line and not used for access on barrier-separated facilities.
- Direct-merge entrance or exit: a ramp that merges directly into the managed lane facility (entrance) or the GPLs (exit), similar to the design of entrance and exit ramps between the GPLs and the frontage road.
- Direct-connect entrance or exit: a ramp that provides access to the managed lane facility directly from local streets or roadside facilities, such that traffic does not have

to travel in the GPLs. On this managed lane facility, direct-connect ramps provide access to and from park-and-ride facilities.

(a) Lane Addition

(b) Lane Drop

(c) Slip Ramp

(d) Direct Merge

(e) Direct Connect

(Image Credit: Google Earth™ Mapping Service)

Figure 52. Examples of Access Design Types.

The review of access points in this study focused on the portion of the corridor between the I-610 interchange (and the Post Oak Park and Ride Lot access) and the boundary between HOV/toll operations to HOV-only lanes. In terms of Table 18 and Table 19, the study corridor included EB access points 6 through 13 and WB access points 4 through 11.

FIELD DATA

To enable observation of, and creation of a permanent record of, the access operations on the KML, researchers chose video recording as the primary form of data to be collected for this task. Members of the research team in TTI's Houston office worked in conjunction with HCTRA and TranStar to arrange to use HCTRA's video camera system as the source of video footage. A selection of HCTRA's cameras was trained on various points of interest within the study corridor during predetermined dates and times, and the footage from those cameras was recorded on an external hard drive. In total, approximately 1965 hours of video data (approximately 1.1 terabytes of data files) were recorded during April and May 2012. A summary of the video footage recorded is shown in Table 20.

Sites were selected based on observations during visits to the study corridor during March and April, as well as feedback from the Project Monitoring Committee during the April visit and previous meetings. The focus of the project was on direct-merge sites, given that those are the ramps most commonly found within the study corridor. However, some resources were also directed to the access points at either end of the corridor and the direct-connect ramp at the Addicks Park and Ride Lot facility. In addition, a combination of views was recorded to evaluate cross-facility weaving in advance of the WB GPL exit at BW 8. The operations at each of these types of access points will be discussed in their own sections of this chapter.

Periodically, it was necessary for camera operators to reposition the cameras to observe a traffic incident and then return the camera to its previous position after the incident was resolved. These incident times are not noted in Table 20; however, the length of recording time, particularly for Camera #4103, 4112, and 4122, provided multiple days on which to observe typical access operations in the event that an incident prevented viewing on a particular day.

Table 20. Video Footage Recorded from HCTRA Camera System.

HCTRA Camera		Access Point Recorded	Begin Recording		End Recording	
Name (I-10 ML…)	No.		Date	Time	Date	Time
@ Silber	4103	WB Direct-Merge Entry W. of Silber (Looking West)	4/10/12	10:00 AM	4/18/12	10:00 AM
@ Bunker Hill WB Exit	4112	EB Direct-Merge Entry between Bunker Hill and Echo (Looking East)	4/10/12	10:00 AM	4/18/12	10:00 AM
@ Tully Rd.	4122	EB Direct-Merge Exit E. of Dairy Ashford (Looking West)	4/10/12	10:00 AM	4/18/12	10:00 AM
@ Dairy Ashford	4124	EB Direct-Merge Exit E. of Dairy Ashford (Looking East)	4/18/12	4:00 PM	4/19/12	2:30 PM
@ Gessner WB exit	4114	WB Direct-Merge Entrance between Gessner and Bunker Hill (Looking East)	4/18/12	10:00 AM	4/25/12	1:30 PM
@ Brogden	4108	EB and WB Managed Lanes (Looking East)	4/18/12	10:00 AM	4/25/12	1:30 PM
@ Gessner WB exit	4114	WB GPL Exit to BW 8 (Looking West)	4/25/12	1:40 PM	4/25/12	11:59 PM
@ Bunker Hill WB Exit	4112	WB Direct-Merge Exit between Echo and Bunker Hill (Looking East)	4/25/12	1:40 PM	4/25/12	11:59 PM
T-Ramp Entrance	4128	EB Direct-Merge Entrance from Addicks Park and Ride T-Ramp (Looking East)	4/25/12	1:40 PM	4/25/12	11:59 PM
West Entrance	4130	Beginning of EB Managed Lane/ HOT Facility (Looking West)	5/4/12	10:00 AM	5/5/12	12:30 PM
West Entrance	4130	Near End of WB Managed Lane/ HOT Facility (Looking East)	5/5/12	12:30 PM	5/11/12	12:00 PM
T-Ramp Entrance	4128	EB Direct-Merge Entrance from Addicks Park and Ride T-Ramp (Looking East)	5/11/12	12:00 PM	5/17/12	11:59 PM
@ Kirkwood EB Exit	4123	WB Direct-Merge Entrance E. of Dairy Ashford (Looking West)	5/11/12	6:30 PM	5/11/12	11:59 PM
@ Bunker Hill WB Exit	4112	EB Direct-Merge Entry between Bunker Hill and Echo (Facing East)	5/21/12	12:00 AM	5/22/12	11:59 PM
@ Tully Rd.	4122	WB Direct-Merge Entrance W. of Kirkwood (Looking East)	5/21/12	12:00 AM	5/22/12	11:59 PM
@ Brogden	4108	EB and WB Managed Lanes (Looking East)	5/21/12	12:00 AM	5/22/12	11:59 PM
@ Gessner WB exit	4114	WB Direct-Merge Entrance between Gessner and Bunker Hill (Looking East)	4/30/12	12:00 AM	4/30/12	12:45 PM
@ Bunker Hill WB Exit	4112	WB Direct-Merge Exit between Echo and Bunker Hill (Looking East)	4/30/12	12:00 AM	4/30/12	12:50 PM
T-Ramp Entrance	4128	EB Direct-Merge Entrance from Park and Ride T-Ramp (Looking East)	4/30/12	12:00 AM	5/2/12	8:00 AM
@ Gessner WB exit	4114	WB GPL Exit to BW 8 (Looking West)	4/30/12	12:45 PM	5/3/12	6:55 PM
@ Bunker Hill WB Exit	4112	ML between Echo and Piney Point (Looking East)	4/30/12	12:50 PM	5/3/12	6:55 PM
T-Ramp Entrance	4128	WB Managed Lanes (Looking West)	5/2/12	8:00 AM	5/3/12	6:55 PM

DIRECT-MERGE RAMP OPERATIONS

Site Descriptions

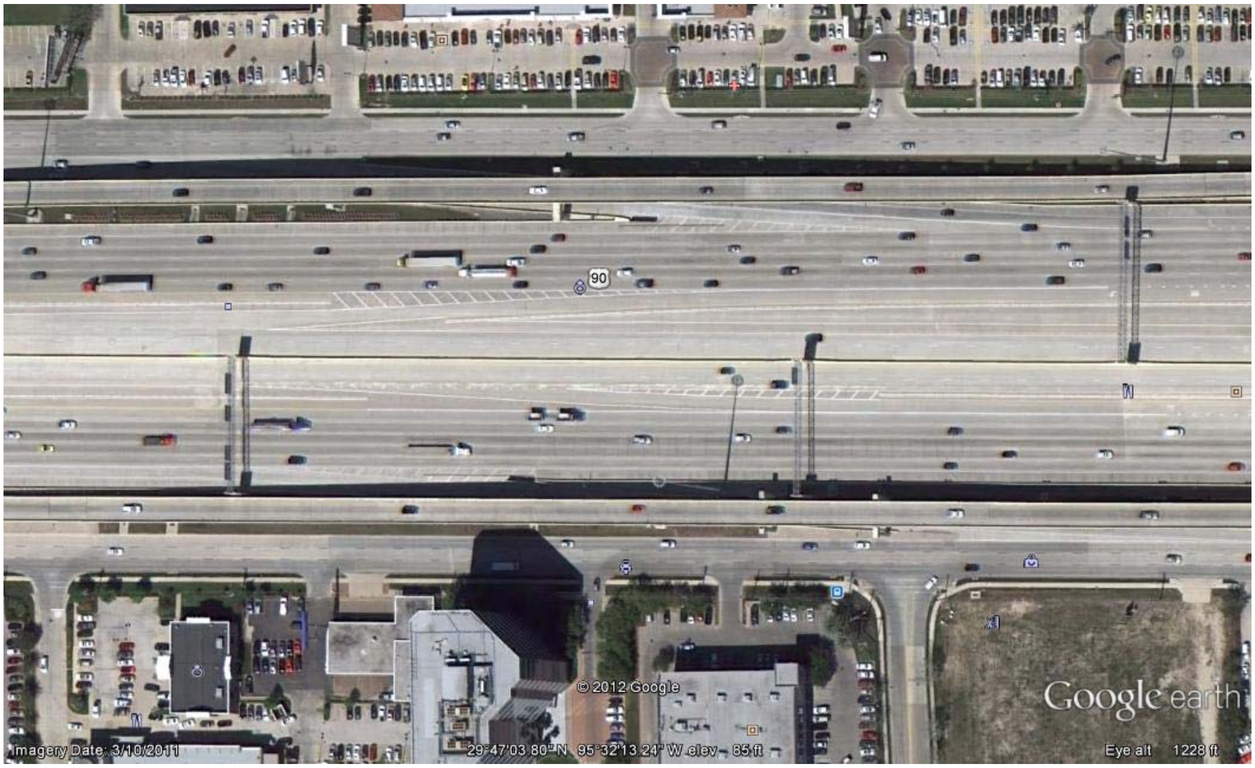
After reviewing the available recorded views and considering the optimal combination of study sites, researchers chose the following direct-merge ramp study sites for analysis:

- WB direct-merge entrance between Gessner and Bunker Hill (WB Access #7).
- EB direct-merge entrance from Addicks Park and Ride Lot T-ramp (EB Access #7).
- WB direct-merge entrance west of Silber (WB Access #5).
- WB direct-merge exit between Echo and Bunker Hill (WB Access #6).

These four sites provided the best available views to document access maneuvers while still providing both entrance and exit and both EB and WB. This set of study sites also includes the T-ramp.

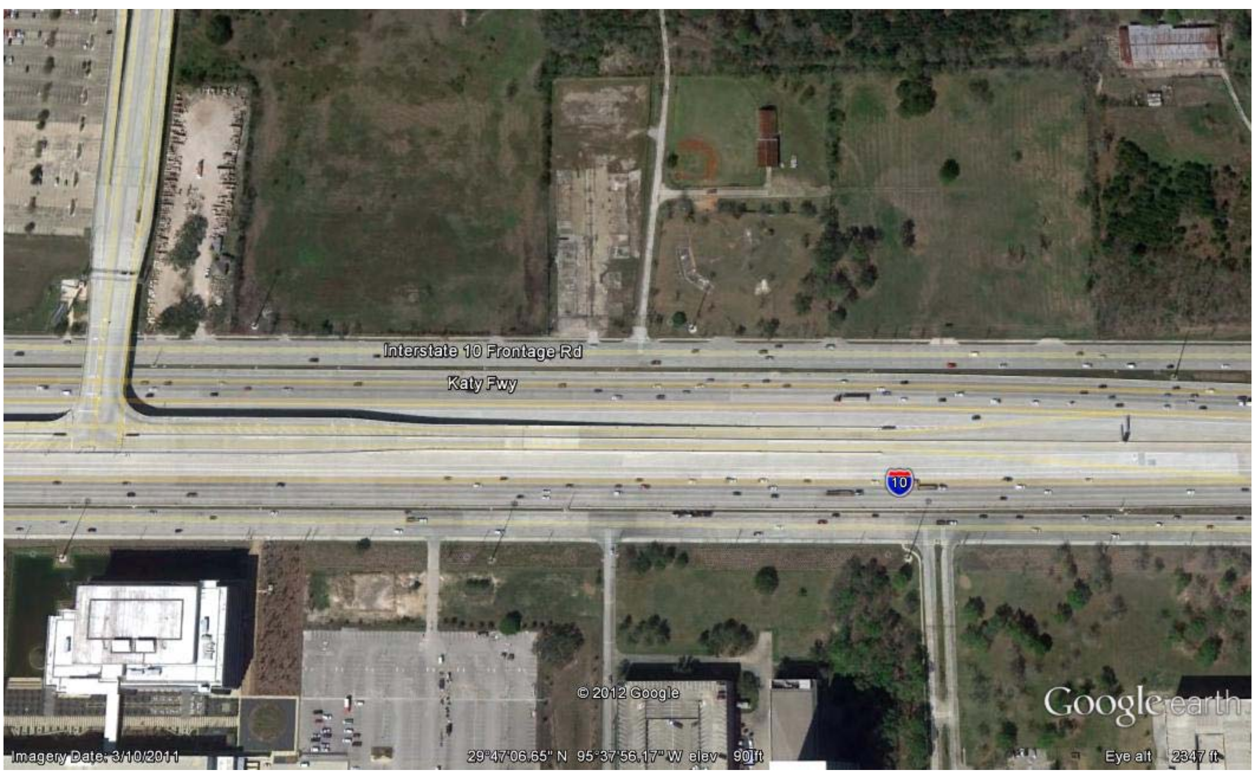
The WB entrance between Gessner and Bunker Hill, shown in Figure 53, has a design that is fairly typical of entrances in the study corridor. There is a lengthy (approximately 3800-foot) weaving area upstream where GPL vehicles can change lanes to enter the managed lanes and vehicles exiting the managed lanes can enter the GPLs. There are five through GPLs (plus one weaving lane) and two managed through lanes in the cross section. In addition, there is a buffer of approximately 30 feet between the left shoulder edge line of the weaving lane and the right shoulder edge line of the managed lane. As a result, drivers entering the managed lanes at this location actually have two maneuvers to make: changing lanes into the weaving lane and merging into managed lane traffic. The length of the entrance ramp proper is approximately 900 feet, plus a merging area, but drivers may enter the weaving lane much earlier, depending on where they decide to make the first lane-change maneuver.

The EB direct-merge entrance from the Addicks Park and Ride Lot T-ramp, shown in Figure 54, has a similar design where it meets the managed lanes but a unique design at its upstream end, which is a signalized T intersection. Thus, there is only one maneuver that drivers have to make at this access point, which is merging into the left managed lane. The fact that this ramp has a signalized intersection adds an influence on traffic operations, particularly during the peak period. The traffic signal creates platoons of vehicles entering the managed lanes. The driver at the head of the platoon may have more flexibility on where to enter the managed lane if there is a need to choose a gap in traffic, while drivers in the remainder of the platoon may be restricted in their choice of merge point. The ramp proper is approximately 2200 feet long, plus a merging area of approximately 1100 feet as the ramp tapers into the left managed lane. This length provides a great deal of storage space during the morning peak if needed. Because this ramp is a direct connection to the managed lanes, drivers do not need to travel through the GPLs.



(Image Credit: Google Earth™ Mapping Service)

Figure 53. WB Entrance between Gessner and Bunker Hill (WB Access #7).



(Image Credit: Google Earth™ Mapping Service)

Figure 54. EB Entrance from Addicks Park and Ride Lot T-Ramp (EB Access #7).

The WB entrance west of Silber, shown in Figure 55, is similar to WB Access #7, but the available length for drivers to make their initial lane-change maneuver is much shorter, approximately 580 feet. This is a taper ramp, not a weaving lane as found in WB Access #7. In addition, while the ramp proper is about 900 feet long, drivers do not have to merge into managed lane traffic at the end of the ramp because the lane continues as a through lane. Thus, while there are five GPLs in the cross section throughout this part of the corridor, there is only one managed lane and a 50-foot buffer at the upstream end of the ramp, but two managed lanes and a 33-foot buffer at the downstream end.

The WB exit between Echo and Bunker Hill, shown in Figure 56, is also fairly typical of exit points in the study corridor. A taper opening approximately 330 feet long is the first maneuver point for exiting drivers, where they can enter the ramp to the GPLs. The ramp proper is about 720 feet long, followed by the aforementioned 3800-foot weaving section that terminates at WB Access #7. The long weaving section provides ample opportunity for drivers exiting the managed lanes to merge into the five GPLs. The cross section here is similar to the other locations studied, but the buffer between GPLs and managed lanes is narrower, about 23 feet.

(Image Credit: Google Earth™ Mapping Service)

Figure 55. WB Entrance West of Silber (WB Access #5).

(Image Credit: Google Earth™ Mapping Service)

Figure 56. WB Exit between Echo and Bunker Hill (WB Access #6).

Data Reduction

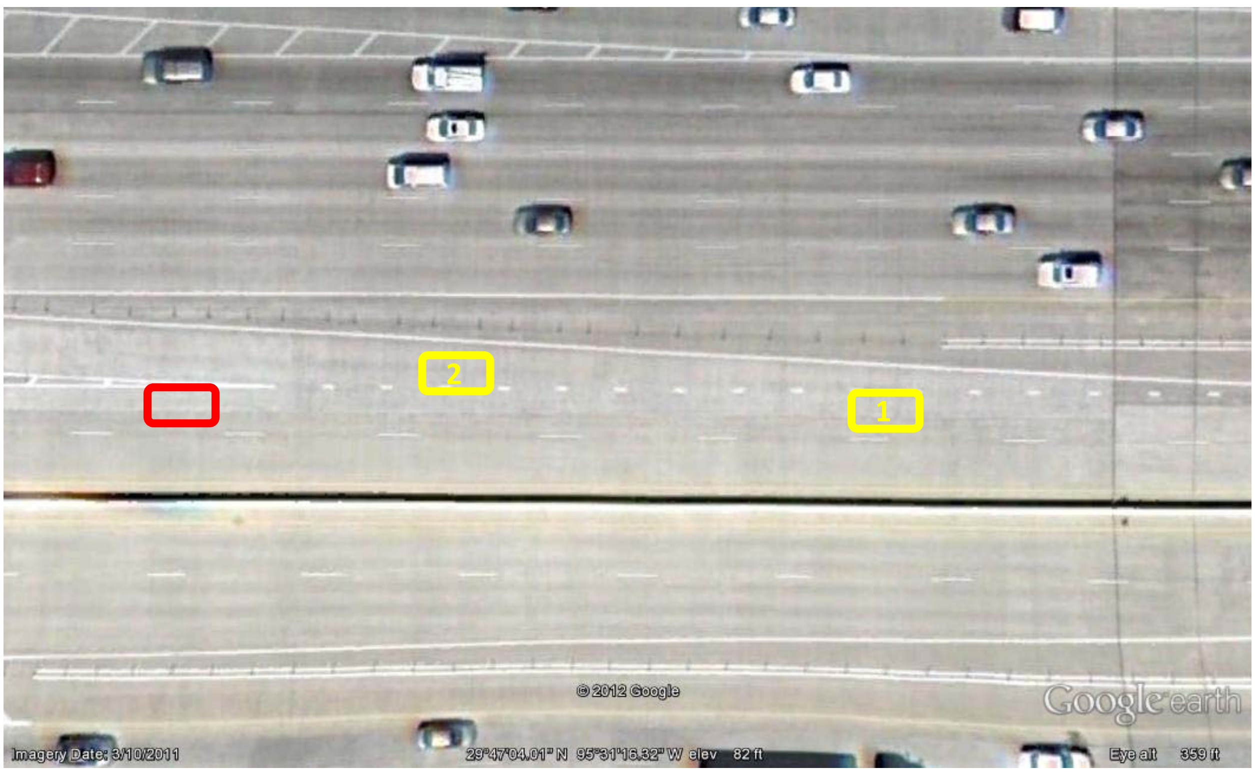
Researchers chose a peak period and a non-peak period in which to reduce and analyze data; both periods were two hours in duration. The study periods for each site are shown in Table 21.

Table 21. Study Periods for Direct-Merge Access Points.

Site	Peak Period				Non-peak Period			
	Begin		End		Begin		End	
WB 7	4/18/12	4:30 PM	4/18/12	6:30 PM	4/25/12	12:45 PM	4/25/12	1:20 PM
					4/30/12	11:20 AM	4/30/12	12:45 PM
EB 7	4/30/12	6:55 AM	4/30/12	8:55 AM	4/30/12	11:20 AM	4/30/12	1:35 PM
WB 5	4/11/12	4:45 PM	4/11/12	6:45 PM	4/11/12	11:20 AM	4/11/12	1:20 PM
WB 6	4/25/12	4:35 PM	4/25/12	6:35 PM	4/25/12	1:40 PM	4/25/12	3:40 PM

NOTE: An incident occurred during the 4/25/12 review period, and the image was changed from its position on WB 7, so researchers selected the video recording from 4/30/12 to complete the two-hour period from 11:20 AM to 1:20 PM.

Researchers obtained multiple units of data from the HCTRA video, divided mainly into traffic volume counts and maneuver characteristics. The research team conducted 15-minute volume counts of vehicles in the managed lanes and in the left GPL to determine the general exposure level of vehicles conducting access maneuvers. After completing traffic counts, researchers reviewed the video to document the details of each access maneuver during the study period. Using a method similar to that used in TxDOT Project 0-5547 (*17*), researchers documented the beginning and ending time of each lane change, noted by the time at which the vehicle's left and right tires crossed the lane line. For example, in the hypothetical lane change shown in Figure 57, the yellow vehicle exiting the managed lanes begins the lane change when the right tires cross the dotted lane line at Position 1 and completes the lane change when the left tires cross the dotted line at Position 2. The precise time of both of these events, as noted by the time-stamp embedded in the video, is recorded in a spreadsheet, along with the position of the vehicle. The vehicle position is categorized as "normal," "early," or "late." The hypothetical vehicle in Figure 57 is "normal" for both events because the event occurs within the area of the dotted lane line. If a vehicle crosses a solid line to make a lane change, the vehicle is categorized as "late," such as the red vehicle in Figure 57, which begins the lane change downstream of the dotted line, or "early" if the lane change is upstream of the dotted line.



(Image Credit: Google Earth™ Mapping Service)

Figure 57. Example of Lane Change in Access Maneuver.

For an exit maneuver such as the one portrayed in Figure 57, this is the initial movement to enter the ramp. The final movement, when the vehicle merges into the GPLs, is documented the same way. The result is a row of data in a spreadsheet that looks similar to that shown in Table 22. The time was actually recorded to the thousandth of a second by the video time-stamp, but it is displayed in whole seconds for legibility. For an entrance maneuver, the initial movement would be the lane change from the GPL to the ramp, and the final movement would be from the ramp to the managed lane, but each line of data is displayed similar to that in Table 22.

Table 22. Example of Spreadsheet Data for Exit Maneuver.

Maneuver	Date	Type	Initial Movement				Final Movement			
			Begin		End		Begin		End	
			Time	Position	Time	Position	Time	Position	Time	Position
34	4/11	Exit	16:45:02	Normal	16:45:03	Normal	16:45:09	Normal	16:45:10	Normal

After observing and documenting the maneuvers during the study period, researchers calculated the duration or elapsed time of each initial movement and final movement, as well as the elapsed time of the overall maneuver from the beginning of the initial movement to the end of the final movement. These times were compared to determine typical driving patterns for normal, early, and late vehicles in both peak and non-peak traffic conditions.

Number of Observations

Initially, researchers had planned to document every access maneuver observed during each study period. For the non-peak periods, this was a straightforward task; for the peak periods, however, it became apparent that the number of maneuvers far exceeded the minimum number needed to obtain a representative sample of maneuvers during the period. In attempting to reduce the peak-period data for EB Access #7, for example, researchers observed 250 maneuvers in just under 20 minutes of video. While documenting every maneuver provides the most complete evaluation of conditions, the addition of hundreds, or even thousands, of maneuvers does not necessarily provide additional insight or information into the conditions at the site. With that in mind, researchers decided to limit the number of documented observations to 100 for periods with high maneuver volumes; researchers reviewed maneuvers in smaller periods of time distributed throughout the two-hour study period to better ensure the collection of a representative sample. In addition, in the non-peak period for EB Access #7, access volumes were low enough that researchers reviewed additional video to obtain a minimum of 40 maneuvers. The total number of observations for these four sites was 801 maneuvers. The number of maneuvers observed at each site, as well as an extrapolated number of maneuvers for the entire period where applicable, is shown in Table 23.

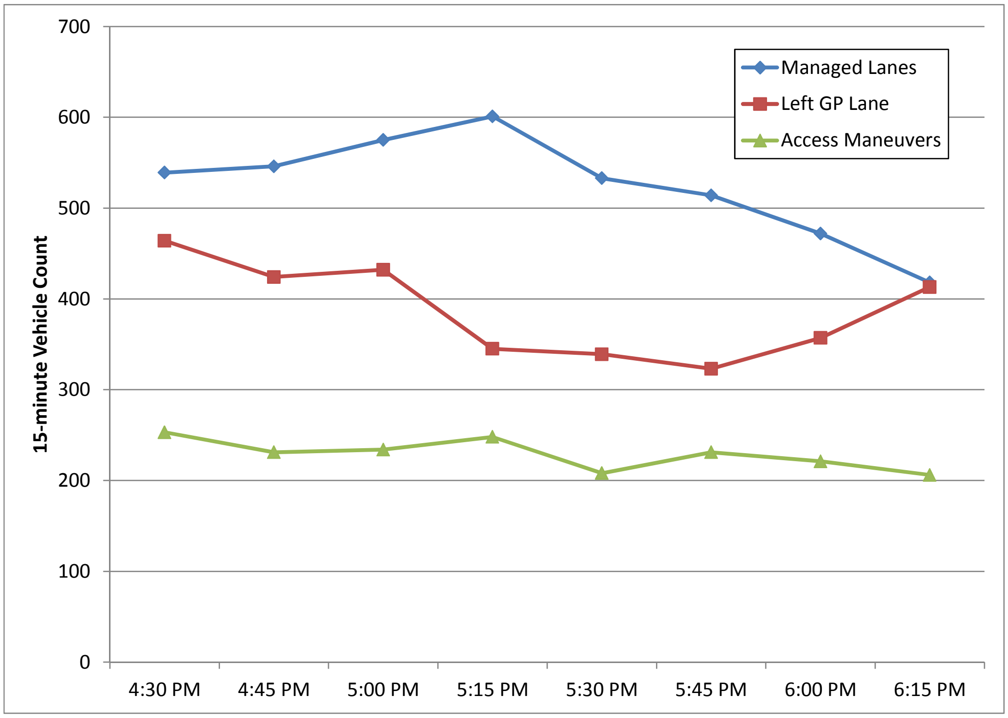
Table 23. Number of Observed Access Maneuvers.

Site	Peak			Non-peak		
	Observed Maneuvers	Time	Extrapolated Count*	Observed Maneuvers	Time	Extrapolated Count*
WB 7	100	0:06	2000	52	2:00	--
EB 7	250	0:20	1500	40	2:10	--
WB 5	100	0:06	2000	59	2:00	--
WB 6	100	0:36	333	100	1:28	136

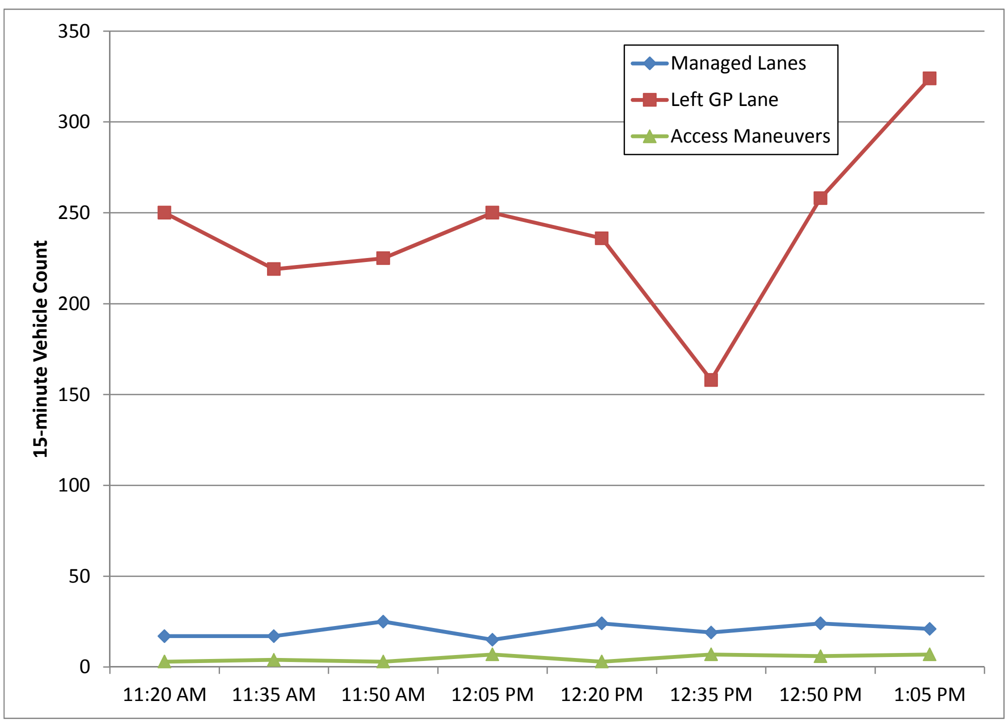
* The number of observations that are estimated to take place during the entire two-hour period if maneuvers occur with the same frequency as in the documented observations, where 100 observations were recorded in less than two hours.

Traffic Volume Counts

As mentioned previously, the research team counted the number of vehicles in the managed lanes and in the left GPL adjacent to each access point for each study period. Counts were conducted in 15-minute increments that for the two managed lanes, ranged from as low as 15 for non-peak periods to as high as 781 for peak periods; and for the left GPL, ranged from a non-peak-period low of 154 to a peak-period high of 561. The counts for each site are shown graphically in Figure 58 through Figure 61.

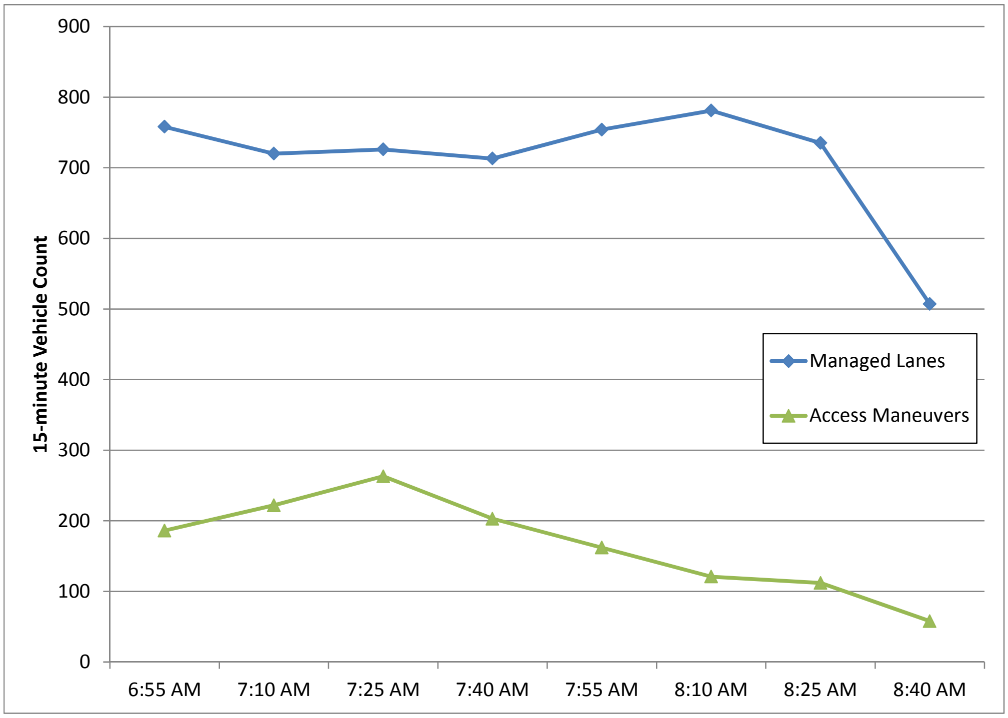


(a) Peak

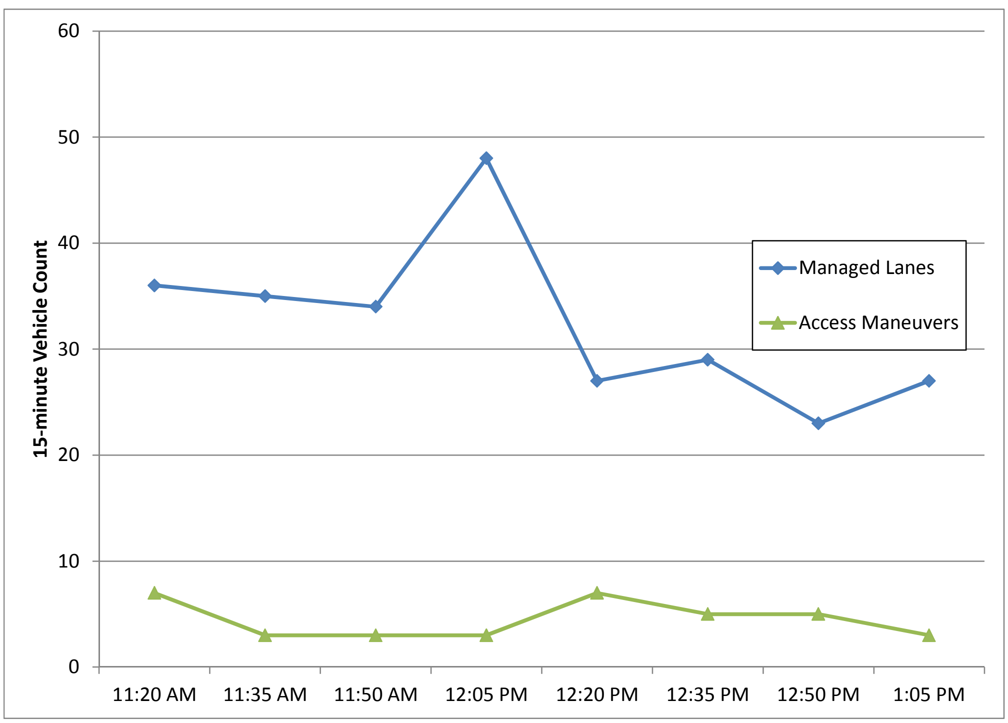


(b) Non-peak

Figure 58. 15-Minute Volume Counts for WB Access #7.

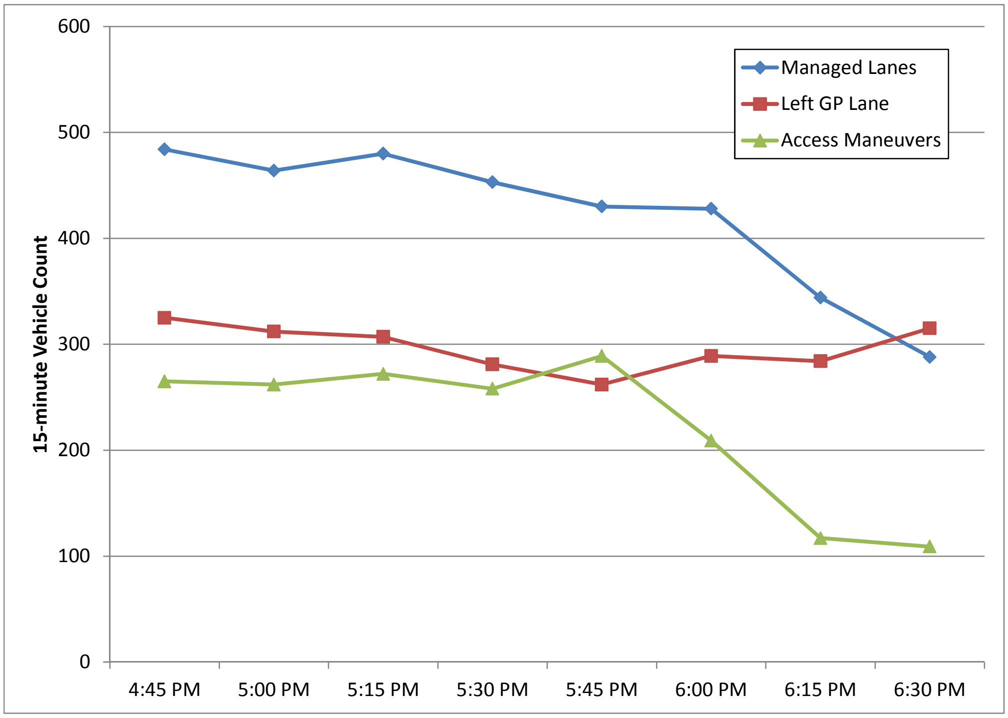


(a) Peak

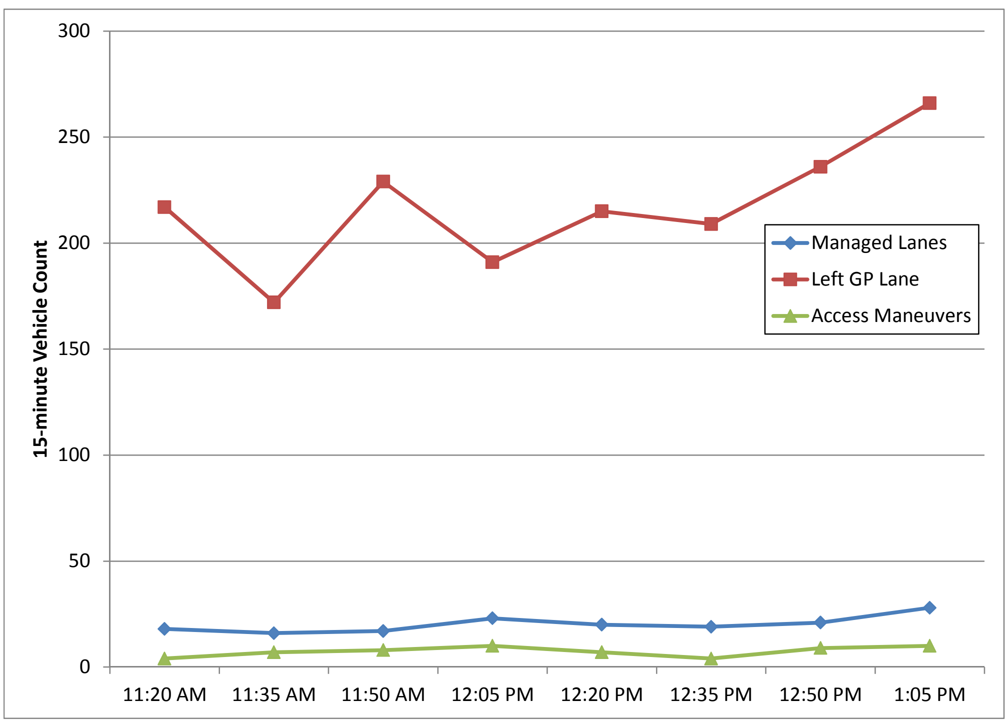


(b) Non-peak

Figure 59. 15-Minute Volume Counts for EB Access #7.

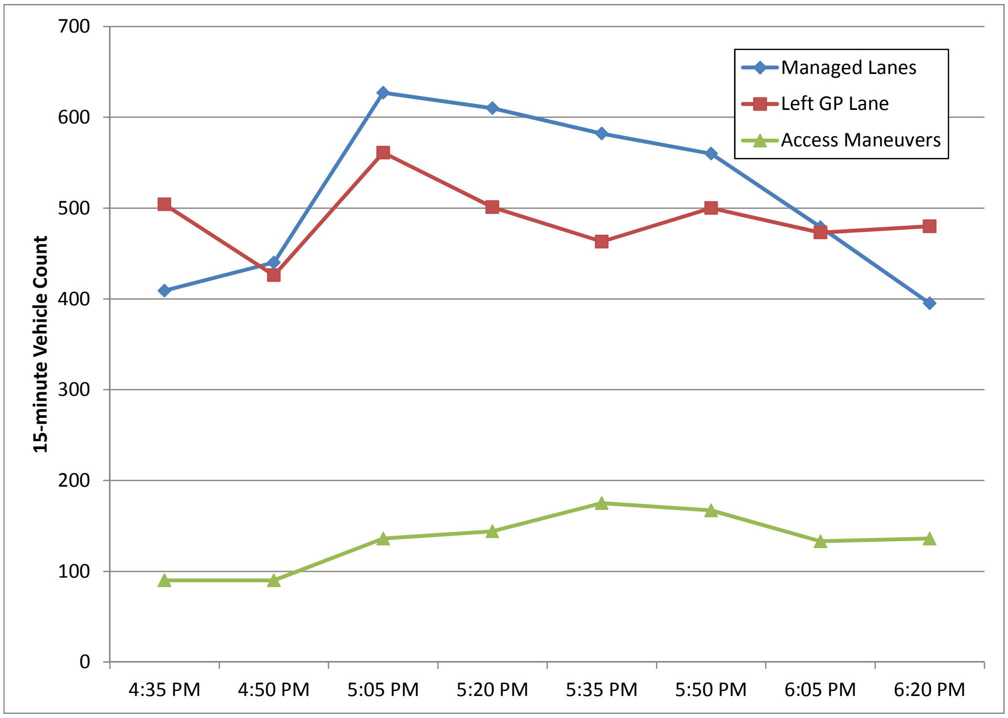


(a) Peak

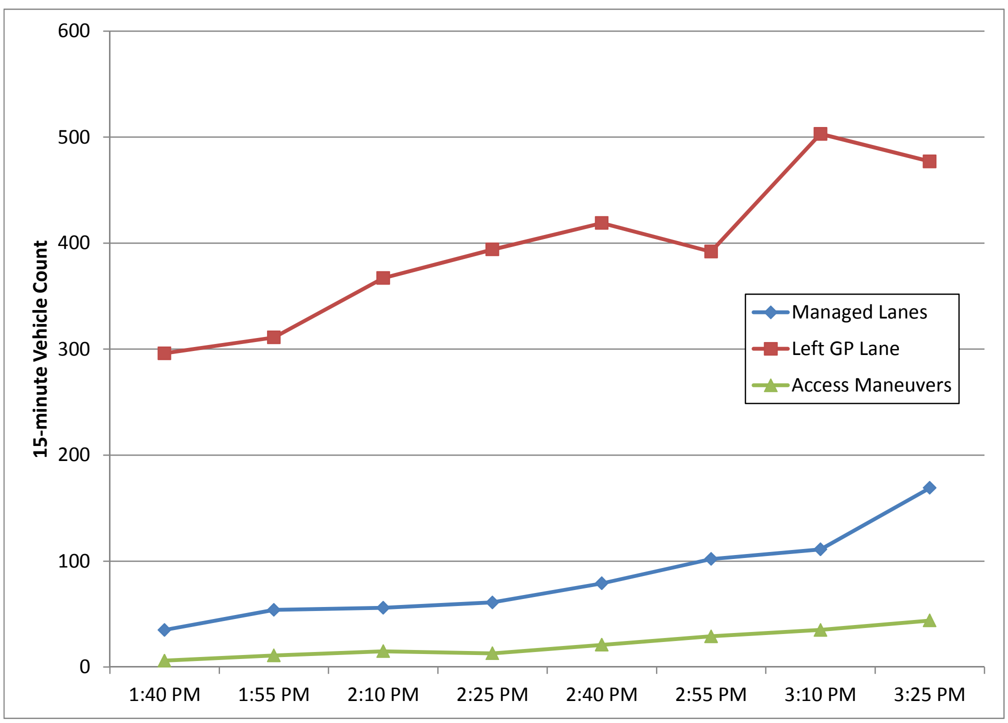


(b) Non-peak

Figure 60. 15-Minute Volume Counts for WB Access #5.



(a) Peak



(b) Non-peak

Figure 61. 15-Minute Volume Counts for WB Access #6.

The counts from the left GPL for EB Access #7 are not shown because the traffic entering the managed lane at that location did not interact with traffic in the GPLs. At each site, there is a noticeable, and expected, difference between peak and non-peak period counts for all the lanes reviewed. It was not uncommon for the volumes in the two managed lanes to be higher than the left GPL during peak periods, and access maneuvers during peak periods were one to two orders of magnitude greater than during non-peak periods. These factors help to describe the increased demand on the managed lanes and the increased exposure to potential conflicts by vehicles accessing the managed lanes. During periods of lower volume, the fewer drivers who use the managed lanes have greater flexibility when entering or exiting the facility because available gaps in traffic are much larger and prevailing speeds are much closer to free-flow conditions. During periods of higher volume, drivers are often forced to choose an appropriate gap in traffic, which may be at constrained speeds, and they may enter that gap "early" or "late" if they feel it is necessary to complete the access maneuver.

Distribution of Elapsed Times by Study Period

The amount of time a driver uses to complete a lane change is an indication of how readily the driver can change lanes at his or her discretion. Shorter lane changes typically indicate that a driver can enter the destination lane at will, while longer lane changes suggest that a driver has to adjust to accommodate a specific gap in traffic, either over a longer distance or at slower speeds (or both). Similarly, the elapsed time between the beginning of the initial movement and the end of the final movement is an indicator of whether the design of the ramp facilitates free-flowing access for drivers or whether there is an impediment to access. In many cases, longer elapsed times are affected by increased traffic volumes in peak periods, where available gaps in traffic are scarcer and traffic moves at lower prevailing speeds. Shorter elapsed times, on the other hand, reflect the least amount of time a vehicle would take to travel through the access point, affected only by access design.

Because the design of the KML includes a considerable buffer area adjacent to the GPLs, access requires two lane changes, and elapsed times are longer than if the access used a slip ramp design (see Figure 52), so some geometric delay is introduced, regardless of the prevailing traffic conditions. An access maneuver on a slip ramp (i.e., one lane change) typically takes place in two seconds or less under free-flow conditions, while a typical free-flow maneuver on a KML direct-merge ramp could be closer to 15 seconds in duration. The additional 13 seconds of travel time is the geometric delay that is a result of the design that requires two lane changes and travel time on a ramp. While delay is often thought of as a negative, the geometric delay in this case is not necessarily so because it is due to the wide buffer between GPLs and managed lanes that many other facilities do not provide. This buffer helps to separate the GPL and managed lane traffic streams, which is intended to improve operations and safety. Therefore, for this study, the concept of geometric delay simply helps to establish the baseline of the expected duration of an access maneuver.

Elapsed times for maneuvers at the four direct-merge sites are shown in Table 24 for peak periods and in Table 25 for non-peak periods. Some times were not calculated because the available viewing angle could not capture the entirety of the access maneuver. For example, at EB Access #7, the available viewing angle did not include the signalized T intersection at the beginning of the entrance ramp, so the elapsed time of initial maneuvers could not be calculated. However, given that the signal controlled the access and not the decisions of drivers in response to prevailing traffic, this elapsed time is not directly comparable to that of other initial maneuvers. Similarly, at WB Access #5, the available camera angle provided an obstructed view of the downstream end of the access ramp; however, because this access point adds a lane to the managed lane facility, it is not necessary for entering vehicles to merge and does not compare directly with the other sites in that regard.

Table 24. Elapsed Times for Peak-Period Access Maneuvers on Direct-Merge Ramps.

Site	Average	Standard Deviation	Median	Minimum	Maximum
Initial Maneuvers (Seconds)					
WB 7	2.0	0.9	1.8	0.8	4.3
EB 7	N/A	N/A	N/A	N/A	N/A
WB 5	1.8	0.7	1.7	0.3	4.3
WB 6	2.2	0.6	2.0	0.7	4.0
Final Maneuvers (Seconds)					
WB 7	2.0	0.9	1.9	0.1	6.3
EB 7	3.6	2.5	2.9	0.5	20.8
WB 5	N/A	N/A	N/A	N/A	N/A
WB 6	2.7	0.9	2.5	1.3	6.7
Overall Maneuvers (Seconds)					
WB 7	21.0	5.1	21.0	14.5	29.9
EB 7	N/A	N/A	N/A	N/A	N/A
WB 5	11.3	1.5	11.1	8.1	15.6
WB 6	14.5	0.3	14.3	7.6	22.3

N/A = not available.

Table 25. Elapsed Times for Non-peak-Period Access Maneuvers on Direct-Merge Ramps.

Site	Average	Standard Deviation	Median	Minimum	Maximum
Initial Maneuvers (Seconds)					
WB 7	1.8	0.7	1.9	0.8	2.9
EB 7	N/A	N/A	N/A	N/A	N/A
WB 5	2.0	0.9	2.0	0.1	4.7
WB 6	2.2	0.5	2.1	1.2	3.9
Final Maneuvers (Seconds)					
WB 7	2.2	0.6	2.1	1.1	3.7
EB 7	2.0	0.8	1.9	0.7	4.3
WB 5	N/A	N/A	N/A	N/A	N/A
WB 6	3.0	0.9	2.8	1.6	7.2
Overall Maneuvers (Seconds)					
WB 7	15.0	2.9	15.1	10.7	19.9
EB 7	N/A	N/A	N/A	N/A	N/A
WB 5	10.2	1.5	10.1	6.9	14.2
WB 6	14.8	3.5	14.5	8.4	24.2

N/A = not available.

Table 24 shows that single-lane-change maneuvers (e.g., initial and final maneuvers) commonly took between one and three seconds during peak periods, while overall elapsed time for a complete maneuver (i.e., from the beginning of the initial maneuver to the end of the final maneuver) was typically between 10 and 25 seconds. The elapsed time for initial maneuvers was typically shorter than that for final maneuvers, which is not unexpected, because drivers completing the final maneuver need to identify a gap in traffic and merge, while the initial movement is merely a process of entering the access ramp from the adjacent lane. The magnitude of the final maneuver is most obviously demonstrated in the data from EB Access #7, where drivers released from the traffic signal in platoons merged with drivers in the managed lanes. Under the most congested traffic conditions, the stop-and-go operations required drivers to meticulously select a gap in traffic (or accept a gap deliberately created by an accommodating adjacent driver). The slower speeds and lengthier distances result in higher values in average, standard deviation, median, and maximum elapsed times than the other sites. Minimum times less than 0.5 second are those of motorcycles, which have only one axle to cross the lane line in the protocol used for this study.

The data in Table 25 indicate that elapsed times for initial maneuvers in non-peak periods are not substantially different from those in peak periods. This is expected because the process of completing such a maneuver is not particularly dependent on traffic conditions. A GPL or managed lane may be congested in peak periods, but the access ramp typically is not, so a driver making an initial maneuver only needs to change lanes and enter the ramp. The largest difference between peak and non-peak final maneuvers was for EB Access #7, where the peak-period conditions were most congested and the platooning effect of the traffic signal also affected operations. Final maneuvers at WB Access #7 were somewhat shorter in duration, but they were not particularly different at WB Access #6. This may be due to drivers actively looking for their opportunity to merge while on the access ramp so that when they approach the adjacent gap, the actual lane-change maneuver is not especially time-consuming. Indeed, the elapsed times for the initial and final movements are most similar in non-peak periods, when finding an appropriate gap would be the easiest.

This compares well with the observation that the overall duration of the access maneuver is typically at least as long in the peak period as in the non-peak period, if not longer. The extra time spent searching for an appropriate gap, along with the effects of congestion on running speed, could easily add one or more seconds to the elapsed time of an entire access maneuver. The peak and non-peak times are very similar at WB Access #6, but the other sites have peak/non-peak differences of at least one full second for average, median, minimum, and maximum times. That being said, the observed elapsed times do not suggest any particular problem or issue with the design of the ramps. Rather, the indication is that the design of the ramps is able to accommodate volumes of traffic much larger than are found in the typical non-peak period with minimal effect on operations.

Distribution of Elapsed Times by Ramp Position

Another way to consider the elapsed time of vehicles accessing the managed lanes is from the perspective of ramp position. Researchers considered vehicles to be in one of three positions relative to the access ramp (e.g., "early," "normal," or "late"), and Figure 57 illustrates examples of "normal" and "late" vehicles. A vehicle with an "early" or "late" ramp position suggests the possibility that something about the ramp design and/or the traffic conditions may have affected the driver's decisions during the access maneuver. Some examples include:

- A "late" position in the final maneuver suggests the driver may have believed that there was not an appropriate gap in traffic to merge within the dotted line area of the ramp.
- A "late" position in the initial maneuver suggests the driver may not have noticed that the ramp was approaching or may have been traveling too fast to enter the ramp on the dotted line.
- An "early" position may be an indication that the driver thinks that he or she will need all available roadway length to complete the desired maneuver and uses the space upstream of the dotted line to provide additional length. This is especially true for cross-facility weaving operations, which will be discussed in a subsequent section.

Table 26 and Table 27 show the ramp positions of all the vehicles using the access ramps in this study. Vehicles in the tables are categorized as "normal" if all starting and ending positions were normal; otherwise, the vehicle is counted in each category that applies. Therefore, vehicles may be counted more than once (e.g., a vehicle that started late and ended late). The tables show that the vast majority of weaving maneuvers in this study were normally positioned when entering or exiting the ramp. This indicates that the design of the ramps is sufficient for typical operating conditions; however, a closer look at the elapsed times of maneuvers can provide additional insight on drivers who were early or late in their access to or from the managed lanes.

Table 26. Ramp Position of Peak-Period Access Maneuvers on Direct-Merge Ramps.

Site	Total Maneuvers	Normal	Start Early	End Early	Start Late	End Late
Initial Maneuvers						
WB 7	100	96	0	0	3	3
EB 7	250	250	0	0	0	0
WB 5	100	77	22	2	0	1
WB 6	100	97	1	0	0	2
Final Maneuvers						
WB 7	100	96	0	0	1	4
EB 7	250	204	6	6	33	40
WB 5	100	100	0	0	0	0
WB 6	100	64	36	10	0	0
Overall Maneuvers						
WB 7	100	92	0	0	4	7
EB 7	250	204	6	6	33	40
WB 5	100	77	22	2	0	1
WB 6	100	63	36	10	0	2

Table 27. Ramp Position of Non-peak-Period Access Maneuvers on Direct-Merge Ramps.

Site	Total Maneuvers	Normal	Start Early	End Early	Start Late	End Late
Initial Maneuvers						
WB 7	53	46	0	0	6	7
EB 7	40	40	0	0	0	0
WB 5	59	51	4	1	0	3
WB 6	100	94	6	1	0	0
Final Maneuvers						
WB 7	53	49	0	0	0	4
EB 7	40	39	0	0	0	1
WB 5	59	59	0	0	0	0
WB 6	100	79	21	3	0	0
Overall Maneuvers						
WB 7	53	43	0	0	6	10
EB 7	40	39	0	0	0	1
WB 5	59	51	4	1	0	3
WB 6	100	73	27	4	0	0

Figure 62 through Figure 65 show selected elapsed time distributions by time of day, in peak and non-peak periods. While the number of early and late maneuvers was low, some potential patterns can be identified. For example, vehicles that started their initial maneuvers late or completed their final maneuvers early tended to have shorter elapsed times in both peak and non-peak periods, as shown in Figure 62. This makes sense because vehicles that make their initial lane change late would normally take less time to complete the maneuver, all other things being equal. Indeed, the vehicles that were initially late and the vehicles that finished early generally tended to be "normal" on their other lane changes, thereby traveling a shorter distance than those vehicles that were categorized as "normal" for both maneuvers. Likewise, vehicles that started early or end late tended to have longer elapsed times, as shown in Figure 63.

In most cases, elapsed times did not appear related to time of day, suggesting that within a given period, traffic conditions did not change substantially enough to affect access maneuvers. There was a potential time-of-day trend at WB Access #5 for initial maneuvers during the peak period. For the vehicles observed, the elapsed times were somewhat longer as the time of day grew later; however, it is unclear whether this trend would continue throughout a longer time period or whether it is merely a temporary fluctuation.

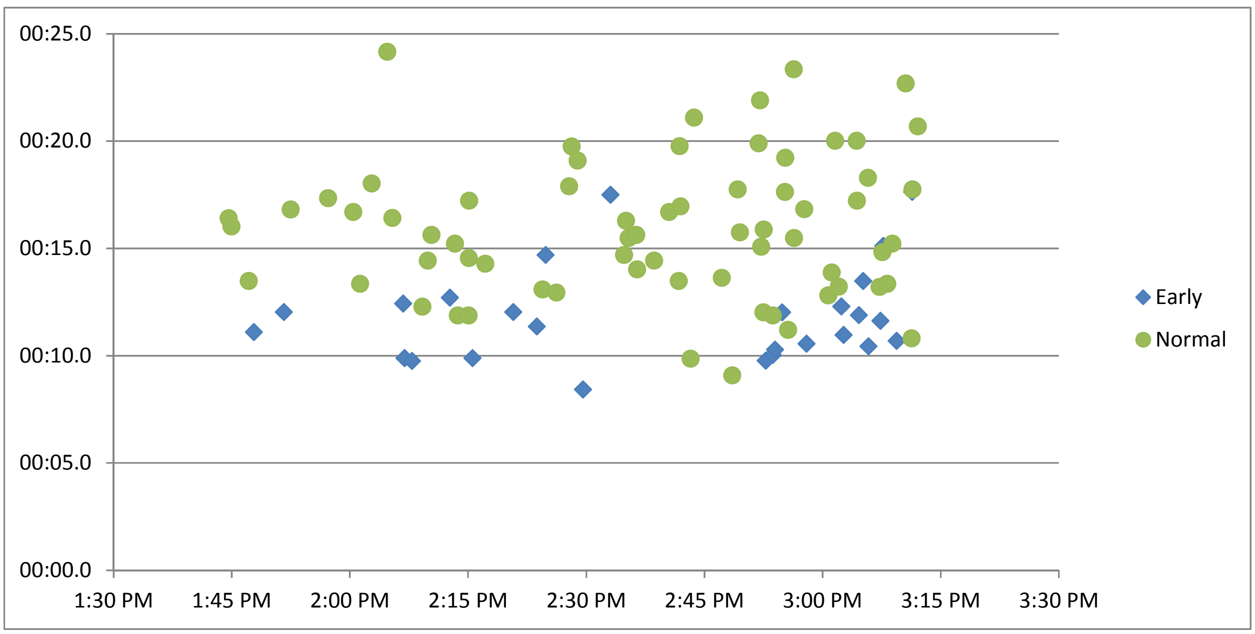


Figure 62. Overall Elapsed Times for Non-peak Maneuvers at WB Access #6.

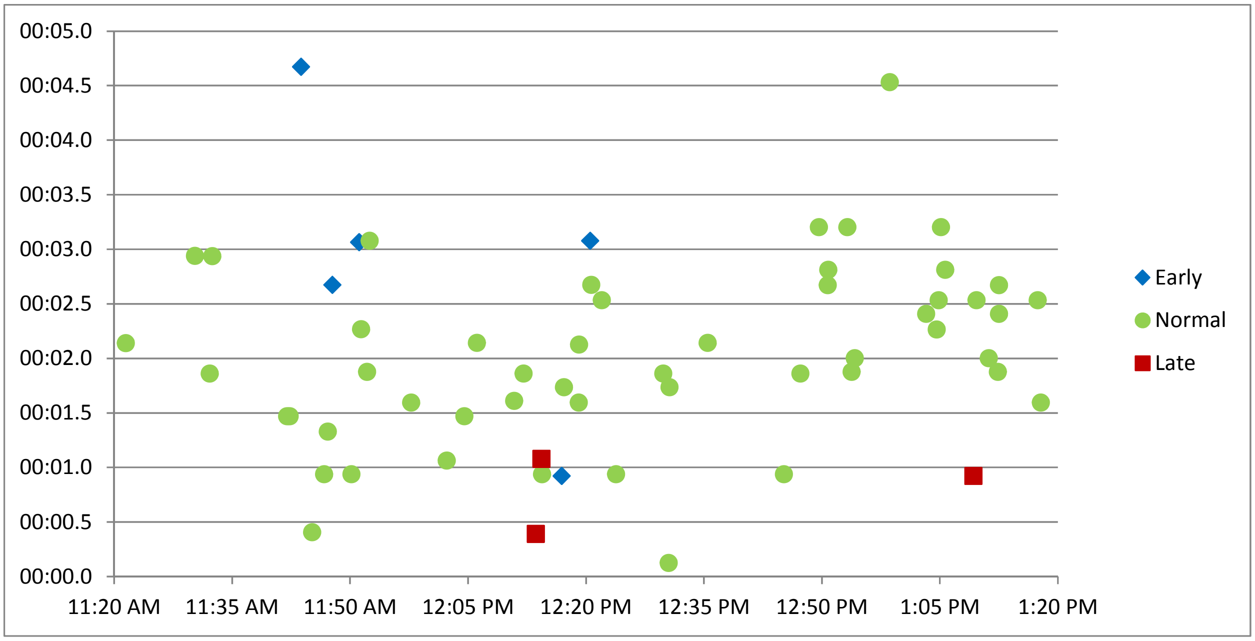


Figure 63. Initial Elapsed Times for Non-peak Maneuvers at WB Access #5.

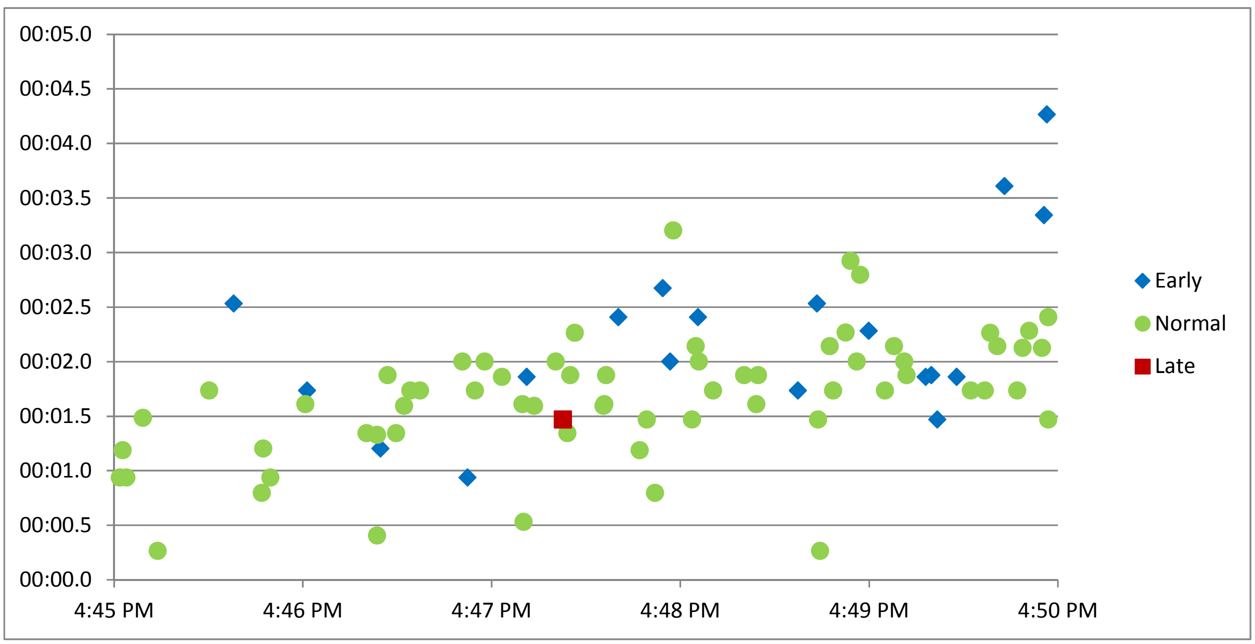


Figure 64. Initial Elapsed Times for Peak Maneuvers at WB Access #5.

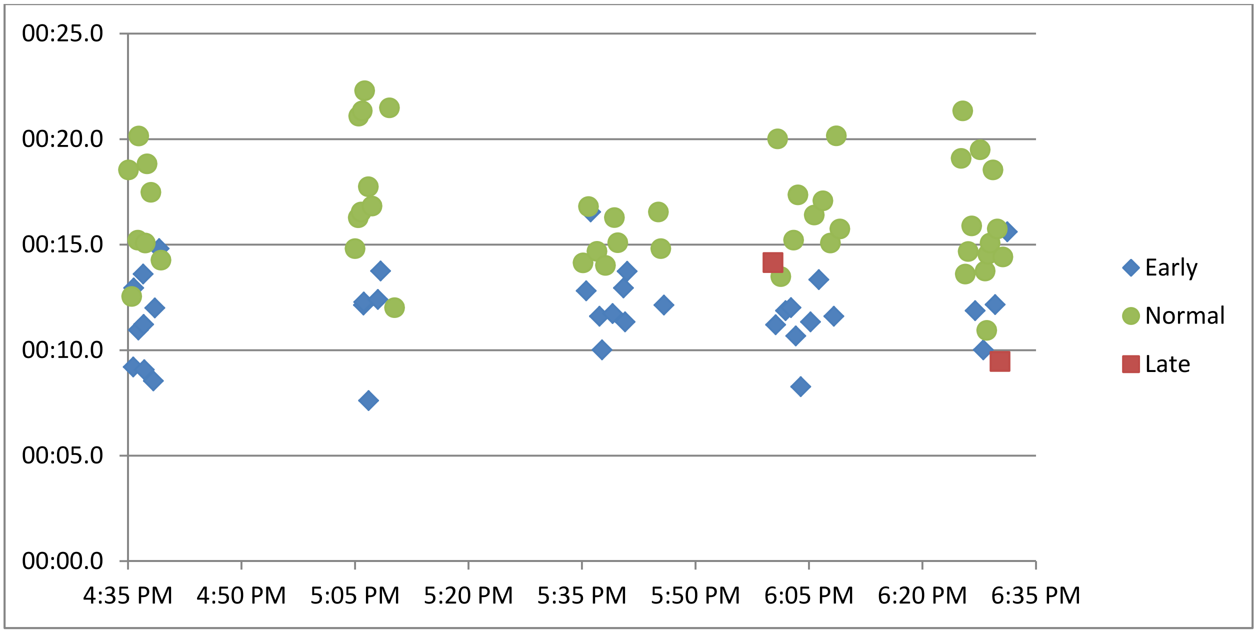


Figure 65. Overall Elapsed Times for Peak Maneuvers at WB Access #6.

The proportion of early and late maneuvers tended to increase in peak periods, compared to non-peak periods. Figure 65 shows the distribution of overall elapsed times in the peak period at WB Access #6. This can be compared to the non-peak period in Figure 62, which, though it had a number of early vehicles, did not have as many as the peak period. Two factors provide possible explanations for this discrepancy:

- The increased traffic volumes in the peak period served to encourage drivers to accept a sufficient gap in traffic while merging, regardless of whether they were crossing a dotted line or a solid line. This explanation is potentially applicable to all study sites.
- The proximity of the managed lanes access to an adjacent GPL exit to the frontage road or crossing highway encourages drivers to enter the GPLs as early as possible to provide the most available distance to complete the subsequent four or five lane changes necessary to use the GPL exit from the freeway. Combined with the increased traffic volumes on the GPLs and managed lanes and the potentially higher demand for managed lane drivers to attempt to exit the freeway during the peak period, the effect would be to further increase the frequency of early maneuvers. This explanation is specifically applicable to WB Access #6 and will be discussed in greater detail in the next section on cross-facility weaving.

CROSS-FACILITY WEAVING OPERATIONS

Site Description

Researchers reviewed one cross-facility weaving area. Cross-facility weaving occurs when a driver in the managed lanes travels across the GPLs to exit the freeway or when a driver entering the freeway crosses the GPLs to enter the managed lanes. This typically involves multiple lane changes over a short distance and should be a consideration when designing managed lane access points so that drivers are not commonly attempting to complete a cross-facility weaving maneuver in a distance that is not long enough, particularly in the increased volumes present during typical peak periods.

Previous studies (*17*, *18*, *19*, *20*, *21*) have suggested that cross-facility weaving areas should provide between 400 and 1000 feet per lane change, depending on anticipated traffic volumes and other conditions. For many managed lane facilities that are retrofit installations, these distances are not provided because accommodating every key access point is not feasible or because a particular cross-facility weaving area was not anticipated to be heavily traveled when the facility was designed or built. The generous GPL cross section and completely new managed lanes facility that resulted from the reconstruction of the Katy Freeway, however, provides the opportunity to better accommodate cross-facility weaving.

This cross-facility weaving area begins with WB Access #6, the WB exit that starts at the overpass above Echo Lane, and it ends with the exit to the Sam Houston Tollway (see Figure 66). The 3800-foot weaving section between WB Access #6 and WB Access #7 provides ample opportunity for drivers exiting the managed lanes to merge into the GPLs, but the short length of the ramp proper also maximizes the length available for drivers to make the six (or seven) necessary lane changes to exit at the tollway.

There is a distance of approximately 7200 feet between the end of the access ramp at WB Access #6 and the beginning of the access ramp at the Sam Houston Tollway exit. In addition, there is approximately 800 feet of “early” distance on the ramp at WB Access #6 and 600 feet of “late” distance at the Sam Houston Tollway exit. Combined, that provides up to 8600 feet in which to make a minimum of six lane changes. Both the “normal” distance of 7200 feet and the maximized distance of 8600 feet are within previously recommended guidelines for six lane changes in cross-facility weaving areas, with 1200 feet and 1433 feet per lane change, respectively. Given that the Sam Houston Tollway exit is a two-lane exit, some drivers may desire to make an additional lane change prior to exiting the freeway, but even including the seventh lane change, the 7200-foot distance provides over 1000 feet of length per lane change, which is also in agreement with recommended guidelines.

(a) Beginning of Cross-Facility Weaving Area at WB Access #6

(b) End of Cross-Facility Weaving Area at Exit to Sam Houston Tollway

(Image Credit: Google Earth™ Mapping Service)

Figure 66. Extents of Cross-Facility Weaving Area.

Data Reduction

With the site characteristics defined, researchers sought to determine whether those distances were, in fact, sufficient to complete the cross-facility weaving maneuver between WB Access #6 and the Sam Houston Tollway. They reviewed access maneuvers during both peak and non-peak conditions. Because WB Access #6 was chosen as a study site for review of direct-merge ramps, it was also used to provide the data for the review of cross-facility weaving. Therefore, the periods of time considered were the same as those for WB Access #6 shown in Table 21.

The data reduction process was also very similar to that previously described for direct-merge ramps. The key difference was the addition of a third ramp maneuver. While direct-merge ramp access required two maneuvers at either end of the access ramp, cross-facility weaving required a final maneuver to enter the exit ramp at the Sam Houston Tollway. As a result, the reduced spreadsheet data were similar to those shown in Table 22, but the spreadsheet included data for three maneuvers (initial, second, and final) instead of just two.

Using the study period already defined for WB Access #6, researchers reviewed not only the recorded video for that location and time, but also the concurrent recorded video for the GPL exit to the Sam Houston Tollway (Camera #4114 in Table 20). Using the exit maneuvers already recorded for WB Access #6, researchers then reviewed the video from Camera #4114 (see Figure 67) to identify vehicles exiting the freeway that had previously exited the managed lanes. This allowed researchers to document the cross-facility weaving maneuvers that occurred during the study period, including the ramp locations and elapsed times of each maneuver.

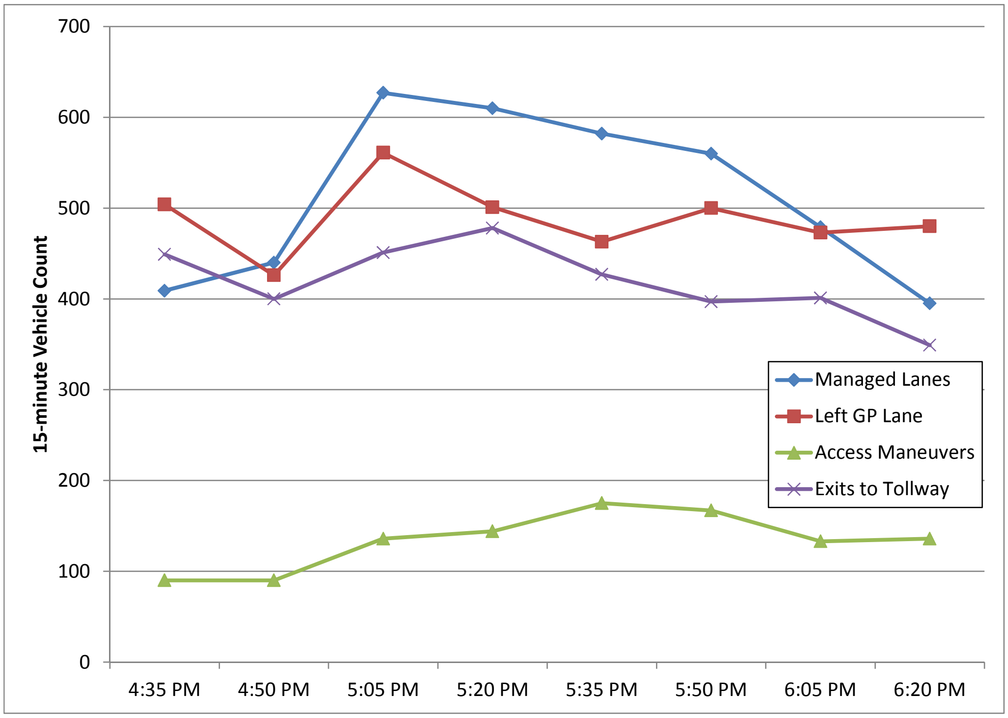
Number of Observations

Of the 100 observed vehicles exiting the managed lanes at WB Access #6 in the non-peak study period, researchers identified 19 vehicles that exited the GPLs at the Sam Houston Tollway exit. Similarly, researchers observed 18 vehicles in the peak period that exited the GPLs at the Sam Houston Tollway out of the 100 vehicles that were observed at WB Access #6. Thus, 18.5 percent of the vehicles observed using the managed lanes exit at WB Access #6 completed a cross-facility weaving maneuver to enter the Sam Houston Tollway. Also, a small proportion of the vehicles from WB Access #6 did not appear within the field of view of Camera #4114, suggesting that those drivers may have completed a shorter cross-facility weaving maneuver to exit the freeway at Gessner. Remaining vehicles from WB Access #6 were in the GPLs when they appeared on Camera #4114 and continued WB on the Katy Freeway, and there was no indication that any of them had failed in an attempt to exit at the Sam Houston Tollway.

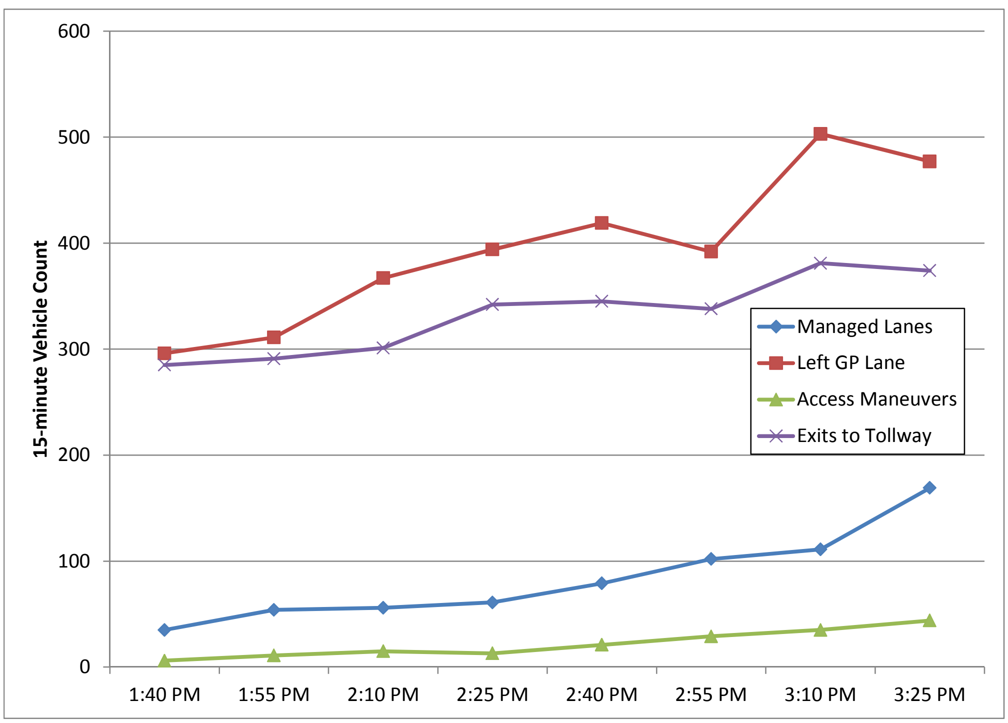
Figure 67. Screenshot of Video Recording at Sam Houston Tollway Exit.

Traffic Volume Counts

As with the direct-merge sites, the research team counted the number of vehicles using the exit ramp from the Katy Freeway to the Sam Houston Tollway. The 15-minute counts at the exit ramp are plotted with the counts from WB Access #6 in Figure 68. As with the volume counts at the managed lanes access point, the number of vehicles exiting to the Sam Houston Tollway increased in the peak period, as compared to the non-peak period. Thus, while the number of cross-facility weaving vehicles was not a sizeable proportion of all exiting vehicles, the fact that the share of vehicles at WB Access #6 that exited to the Sam Houston Tollway remained constant is noteworthy.



(a) Peak



(b) Non-peak

Figure 68. 15-Minute Volume Counts for Cross-Facility Weaving Area.

Distribution of Elapsed Times by Study Period

Elapsed times for cross-facility weaving maneuvers are shown in Table 28. The speed-change lane and weaving area between the Gessner entrance and the Sam Houston Tollway exit is approximately 865 feet. The view from Camera #4114 was only able to show the last 190 feet of that 865-foot lane while still providing a reasonably clear view of the actual exit ramp (see Figure 67). Because the camera was not able to include the entire length of the speed-change lane, all but three cross-facility weaving vehicles had already completed their lane changes by the time they appeared within the camera's field of view. In fact, 17 of the 18 peak-period vehicles had already arrived in their final lane choice prior to entering the field of view; therefore, the standard deviation for peak-period final maneuvers could not be calculated for a single vehicle, and the remaining values (average, median, minimum, and maximum) are all equal at 1.7 seconds.

Table 28. Elapsed Times for Cross-Facility Weaving Maneuvers.

Study Period	Average	Standard Deviation	Median	Minimum	Maximum
Initial Maneuvers (Seconds)					
Peak	2.1	0.4	2.0	1.6	2.9
Non-peak	2.3	0.5	2.3	1.6	3.7
Second Maneuvers (Seconds)					
Peak	2.8	0.7	2.7	1.7	4.3
Non-peak	2.8	1.3	2.3	1.6	7.2
Final Maneuvers (Seconds)					
Peak	1.7	--	1.7	1.7	1.7
Non-peak	2.0	0.6	2.0	1.6	2.4
Overall Maneuvers (Minutes:Seconds)					
Peak	2:04.2	0:25.5	1:58.4	1:28.6	2:51.1
Non-peak	1:20.8	0:10.8	1:23.2	1:02.7	1:47.1

-- = Not calculated (based on a single observation).

Elapsed times for single-lane-change maneuvers were fairly consistent with those at the direct-merge sites, and, as a subset of the WB Access #6 observations, the initial and second maneuvers shown in Table 28 are nearly identical. Because of the additional distance traveled between the two ramps, the overall elapsed times are much longer than for direct-merge sites, with typical times around 2.0 minutes for peak-period maneuvers and 1.4 minutes for non-peak-period maneuvers. The additional elapsed time in the peak period is reasonable when accounting for the additional volume and slower speeds encountered during that time. Considering that peak-period drivers are traveling as much as 8600 feet in those two minutes, the result is an average speed of 48.9 mph over that distance; the corresponding speed in non-peak conditions is 69.8 mph. In reality, average speeds are somewhat higher because most observed weaving vehicles completed their lane changes in distances of less than 7800 feet (8600 feet minus 600 feet of "late" distance and 190 feet of viewing distance).

The fact that 34 of the 37 cross-facility weaving vehicles completed their lane changes prior to entering the second camera's field of view, combined with the moderate to high speeds at which maneuvers are being completed, indicates that there is ample length for drivers to complete such maneuvers from WB Access #6. This also lends credence to the possibility that the vehicles not appearing on Camera #4114 exited at Gessner after completing a shorter cross-facility weaving maneuver. Furthermore, the lack of evidence of any aborted or failed cross-facility weaving maneuvers in either the peak or non-peak periods also supports the premise that the distance between WB Access #6 and the GPL exit to the Sam Houston Tollway is sufficient to accommodate such maneuvers.

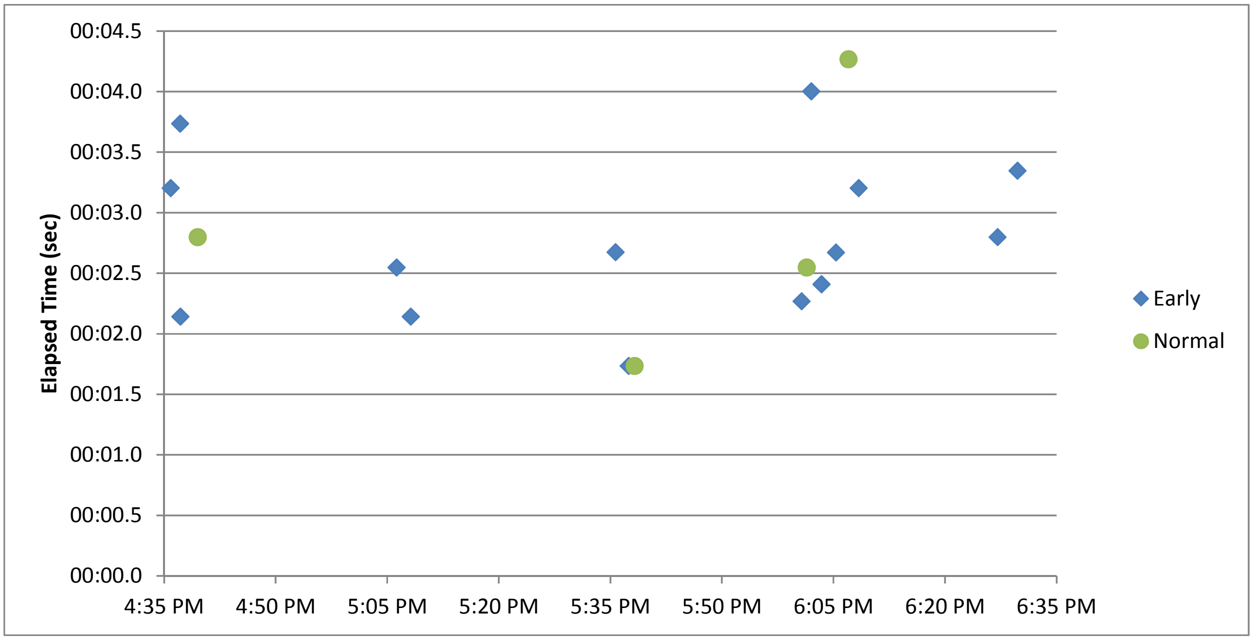
Distribution of Elapsed Times by Ramp Position

Even though weaving vehicles almost always completed their maneuvers in 7800 feet or less, there is still a question as to whether drivers believed that they had sufficient distance to complete their maneuvers. An examination of the ramp positions at which drivers began and ended their weaving maneuvers helps to answer this question.

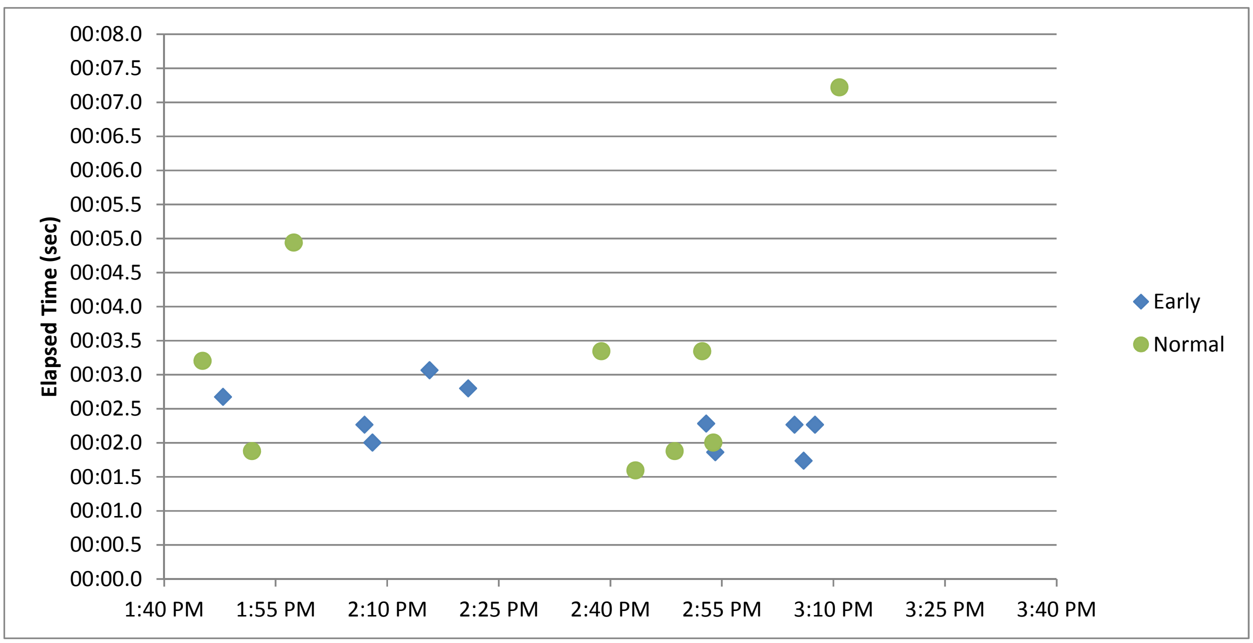
Initial and Second Maneuvers

In both the peak and non-peak periods, only one vehicle had an initial maneuver that was not classified as "normal"; each period had a vehicle that began its initial maneuver early. For the second maneuver, however, over half of the observed vehicles (14 of 18 in the peak period and 10 of 19 in the non-peak period) were classified as "early." The distribution of elapsed times for these second maneuvers is shown in Figure 69. The high proportion of early vehicles, particularly in the peak period, indicates that weaving drivers are motivated to use all available distance between the two ramps to increase the likelihood that their weaving maneuver will be successful. Only one of these early vehicles was classified as "late" at the Sam Houston Tollway exit ramp, but even though their position at the exit ramp suggests that almost all of these early vehicles had sufficient distance to complete their maneuvers, these drivers chose to cross the solid line at WB Access #6 and enter the left GPL early.

Figure 69 shows that the early maneuvers did not display a pattern of shorter or longer elapsed times than normal maneuvers, and they were distributed throughout the study period. In general, elapsed times remained relatively constant throughout the peak period between 1.5 and 4.5 seconds, and, except for two elapsed times of 5 seconds or more, the times in the non-peak period fell within a similar range.



(a) Peak



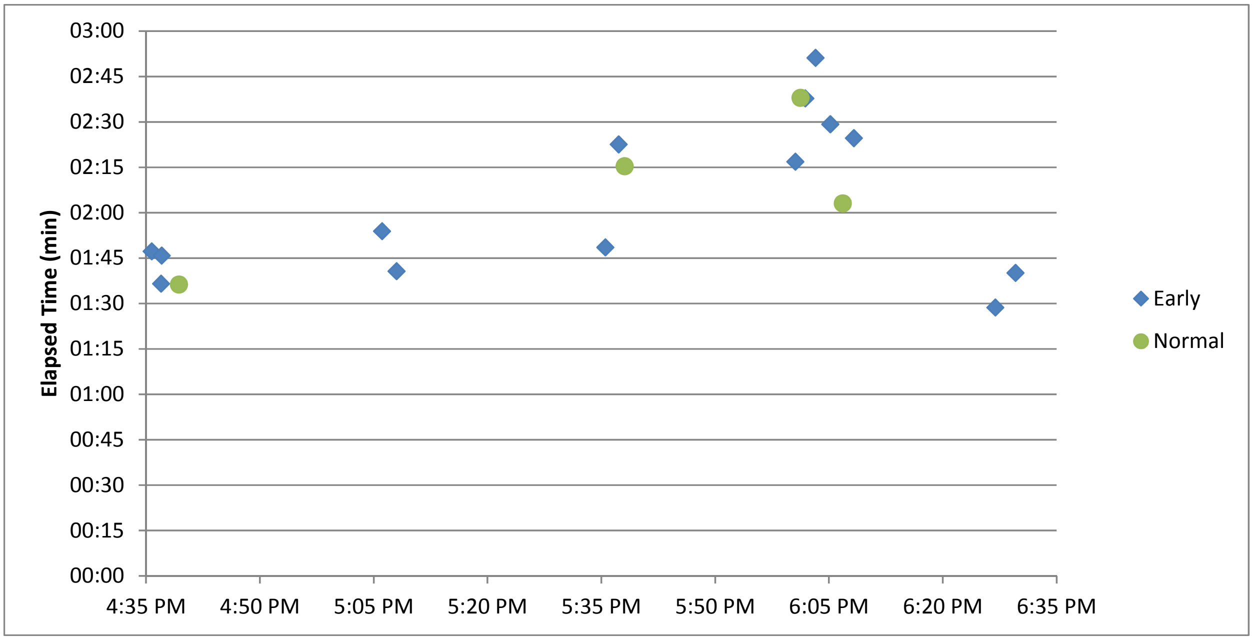
(b) Non-peak

Figure 69. Distribution of Elapsed Times for Second Maneuvers of Cross-Weaving Vehicles.

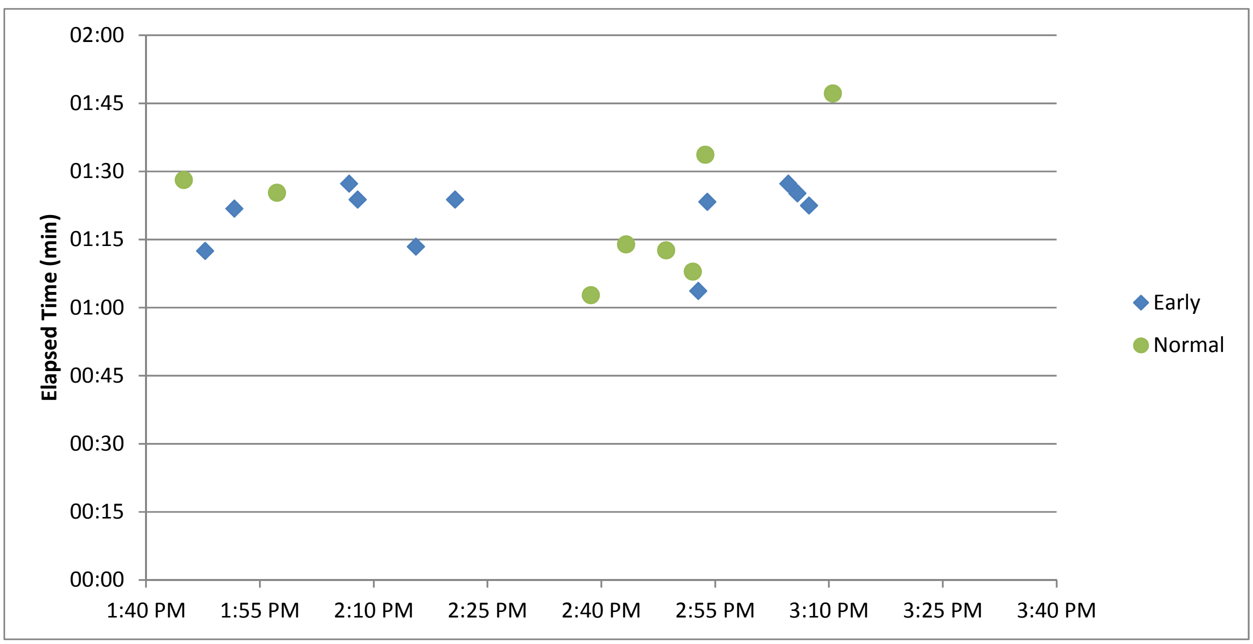
Final and Overall Maneuvers

Because such a large share of weaving vehicles (34 of 37) completed all of their lane changes prior to entering the field of view in Camera #4114, there is little elapsed time data to display in a table or graph. However, all 34 of these vehicles can be categorized as performing their final maneuvers as either “normal” or “early.” Given that “early” lane changes at the Sam Houston Tollway exit would involve crossing the painted gore into the entrance ramp from Gessner, it is likely that most, if not all, of those vehicles could be placed in the “normal” category. Regardless, the number of “normal” and “early” vehicles at the final maneuver is not as informative as the number of “late” vehicles, of which there was only one in each time period. In both cases, the “late” vehicles executed their final maneuver to enter the right lane of the two-lane exit, so even those two vehicles had completed the minimum six lane changes necessary to exit the freeway within the “normal” distance.

With that in mind, the most useful descriptor for most observed vehicles is the ramp position of the second maneuver. Figure 70 shows the distribution of overall elapsed times for cross-facility weaving vehicles, based on the ramp position of the second maneuver. Again, there is no noticeable difference between elapsed times of “early” vehicles and those of “normal” vehicles. Early vehicles are distributed across the range of elapsed times and throughout both study periods. There does appear to be a spike in elapsed times in the peak period around 6:00 PM, as compared to the rest of the study period. However, entering the GPLs early does not seem to provide an advantage in terms of reduced elapsed time (or corresponding distance) to make the maneuver. In either time period, regardless of where drivers entered the GPLs, the data indicate that completing the cross-facility weaving maneuver was readily accomplished within the distance provided.



(a) Peak



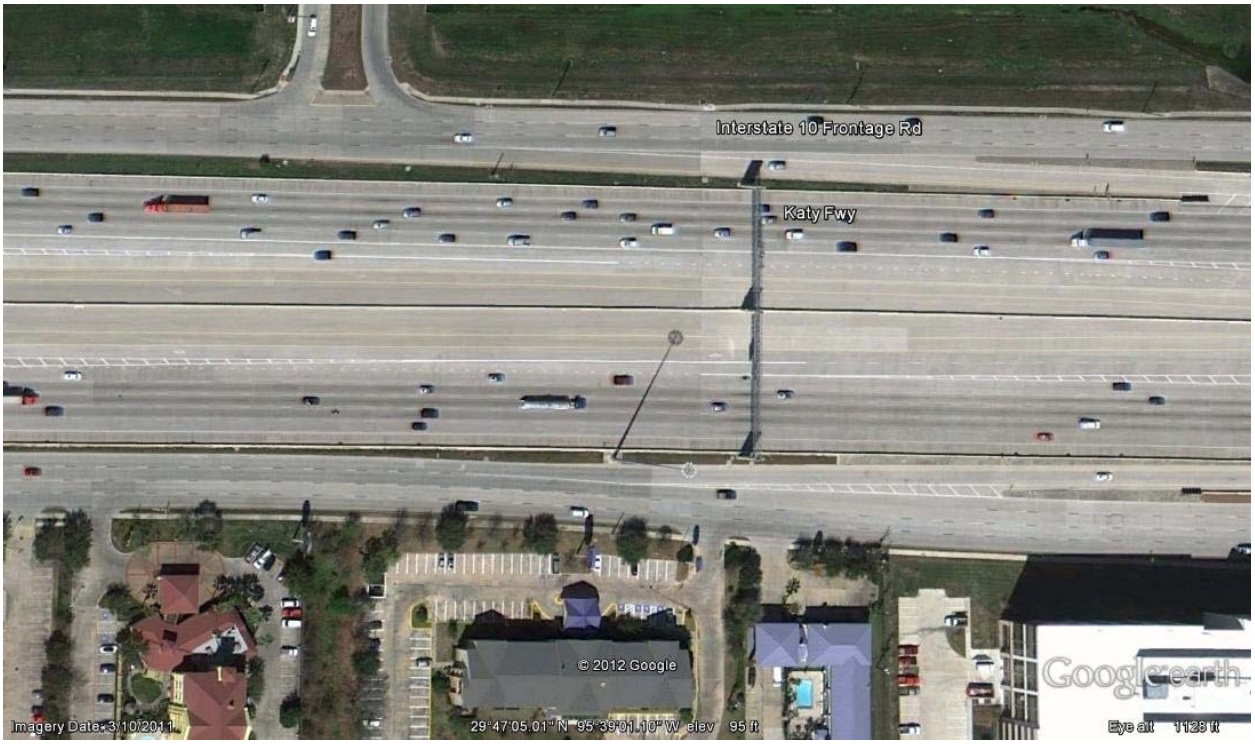
(b) Non-peak

Figure 70. Distribution of Overall Elapsed Times for Cross-Weaving Vehicles.

"FUNNEL" OPERATIONS

Site Description

In addition to the study sites already discussed, the Project Monitoring Committee indicated a desire to study the entrance to the managed lanes from the diamond lane section on the western end of the facility. This access point is commonly known as the "Funnel" and is listed as EB Access #6 in Table 18. An aerial view of the location is shown in Figure 71. The length of the lane addition taper in advance of this direct-merge ramp from the left GPL (defined by the dotted line pavement marking) is approximately 660 feet, while the ramp proper (defined by the solid lines on either side of the ramp) is only about 100 feet. The ramp continues as its own through lane, adding a second lane to the managed lane facility, so entering vehicles are not required to merge.



(Image Credit: Google Earth™ Mapping Service)

Figure 71. EB Entrance at the Diamond Lane Boundary (EB Access #6).

Data Reduction

Researchers used the same video data reduction procedure as described previously, reviewing video from Camera #4130 in Table 20. A screenshot of the camera image is shown in Figure 72. Because no merging into the managed lane was necessary, and because the location of the camera prohibited viewing the entire length shown in Figure 71 within a single field of view, researchers focused efforts on the vehicles entering the managed lanes from the GPLs.

Figure 72. Screenshot of Video Recording at "Funnel" Entrance.

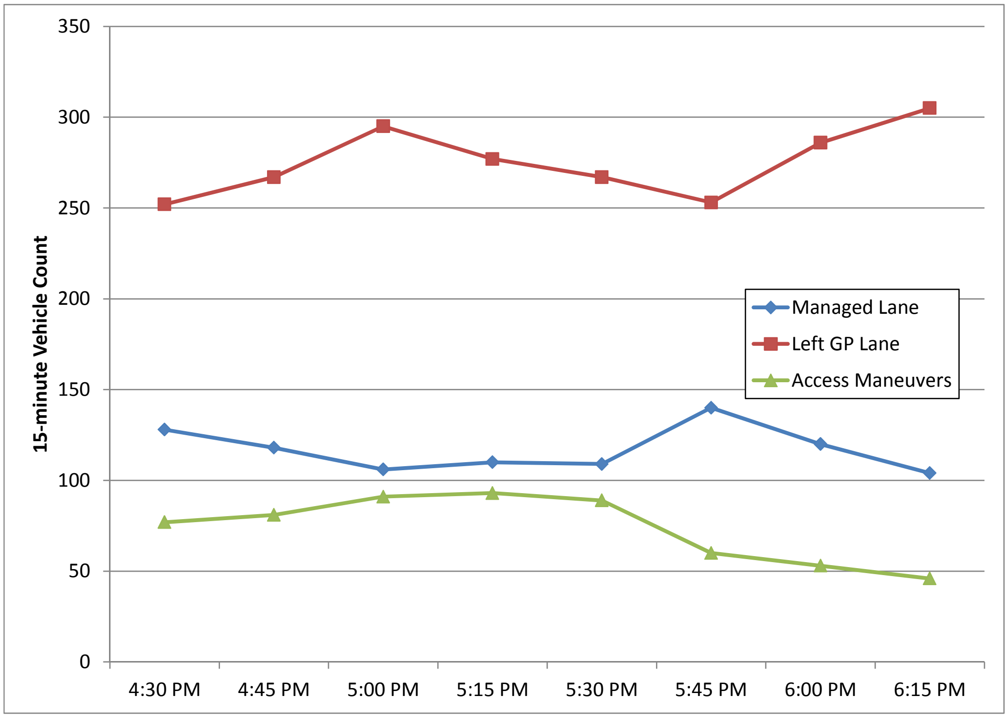
Number of Observations

As with the previously discussed study sites, researchers reviewed video in peak and non-peak periods. Study periods were on May 4, 2012, from 12:00 to 2:00 PM (non-peak) and 4:30 to 6:30 PM (peak). The total number of documented maneuvers at this site was 232. Researchers observed 132 maneuvers in the non-peak period; in the peak period, they counted 590 maneuvers and documented a sample of 100 of those maneuvers.

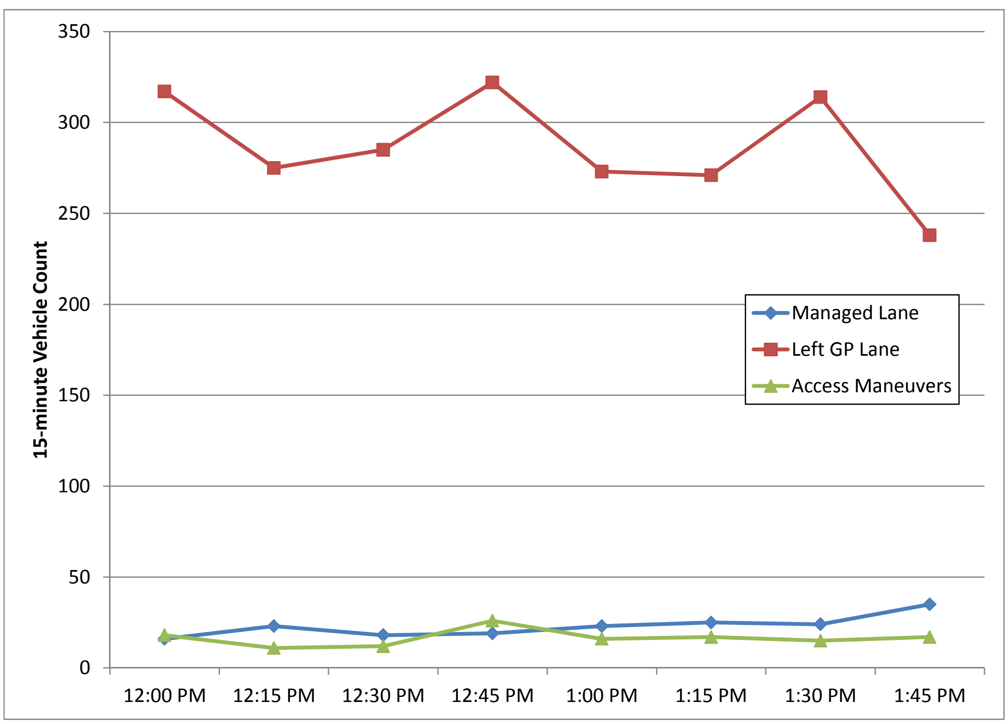
Traffic Volume Counts

Members of the research team counted the number of vehicles in the diamond lane and in the left GPL for each study period, as well as the number of access maneuvers. Counts were conducted in 15-minute increments. The counts for each site are shown graphically in Figure 73.

Volumes in the left GPL remained fairly constant throughout both periods, typically between 250 and 300 every 15 minutes; however, the number of peak-period vehicles in the diamond lane and the number of access maneuvers increased approximately fivefold compared to the non-peak period.



(a) Peak



(b) Non-peak

Figure 73. 15-Minute Volume Counts for EB Access #6.

Distribution of Elapsed Times

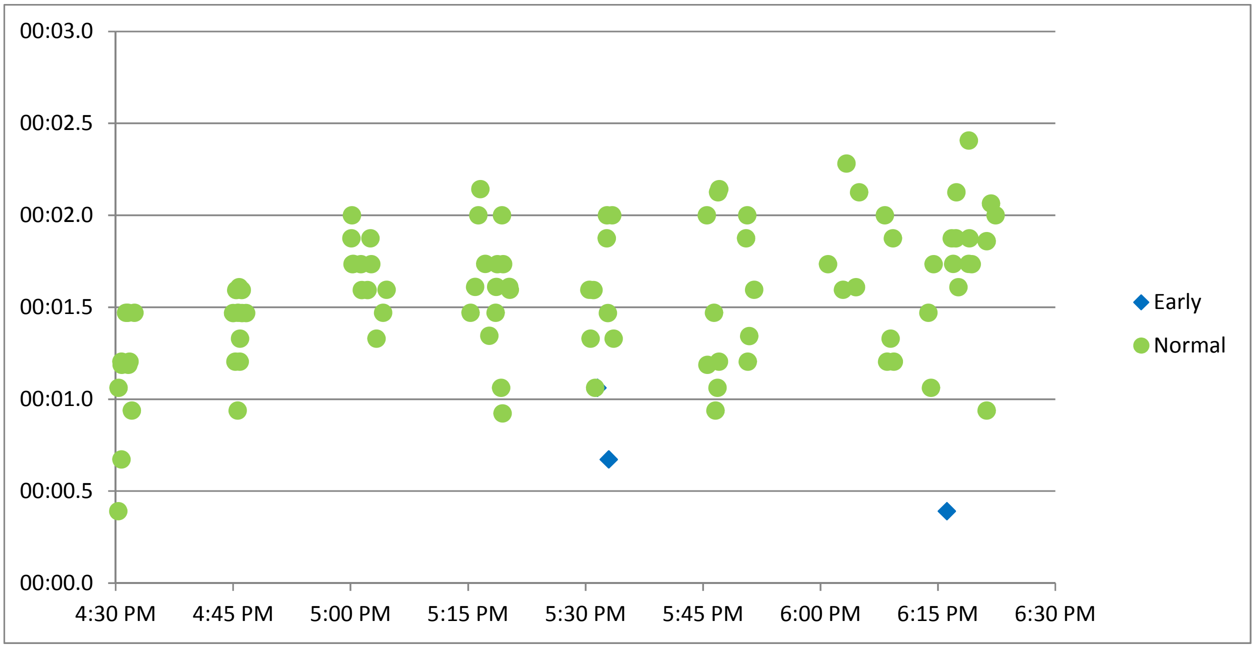
Because no merging was necessary at EB Access #6, the reviewed maneuvers included only the initial lane change. The key statistics for elapsed times for those maneuvers are shown in Table 29. These elapsed times are similar to those of initial maneuvers at the other study sites, though somewhat shorter.

Table 29. Elapsed Times for Entry Maneuvers at EB Access #6.

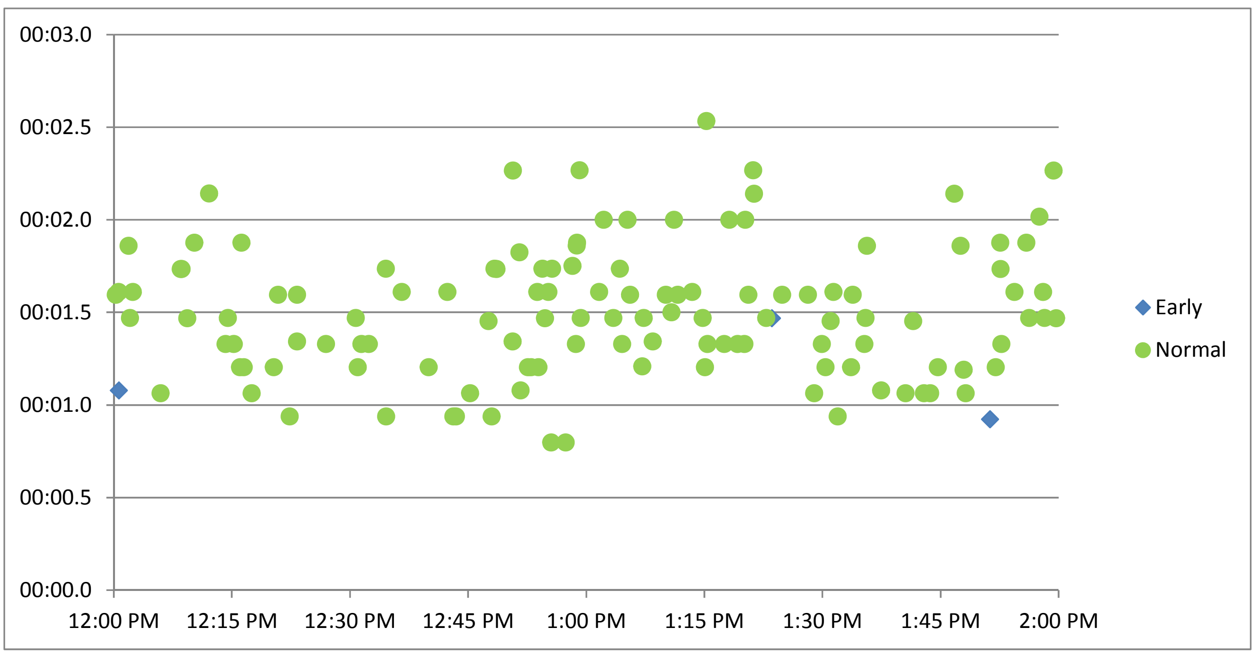
Study Period	Average	Standard Deviation	Median	Minimum	Maximum
Initial Maneuvers (Seconds)					
Peak	1.6	0.4	1.6	0.4	2.7
Non-peak	1.5	0.4	1.5	0.8	2.5

Only three vehicles in each period were observed to begin maneuvers early. The remaining vehicles were classified as “normal.” The distribution of the elapsed times by ramp position and time of day is shown in Figure 74. The early maneuvers were all among the shortest elapsed times in both time periods, but there were “normal” maneuvers with similar times. The elapsed times remained fairly consistent during the non-peak period, but there appears to be a possible trend of gradually increasing elapsed time during the peak period. The reason for this trend is unclear, given that the adjacent volumes that might affect access do not vary. However, the difference in elapsed times between 4:30 and 6:30 PM is generally within 0.5 second, so if the trend is in fact real, its actual effect is not significant on a practical basis.

In summary, traffic operations at EB Access #6 are generally unremarkable. Given the consistent volumes and elapsed times, combined with a nearly 100 percent “normal” rate of ramp position, the data indicate that the design of this access point is sufficient to accommodate the expected demand.



(a) Peak



(b) Non-peak

Figure 74. Distribution of Elapsed Times for Maneuvers at EB Access #6.

CONCLUSIONS

Researchers reviewed 1033 managed lane access maneuvers from 20 hours of peak and non-peak study periods on the KML. Of those 1033 maneuvers, 801 took place on four direct-merge access ramps along the managed lane facility, and 232 were at the western entrance to the managed lanes at the end of the diamond lane section. Researchers also reviewed 37 cross-facility weaving maneuvers that were a subset of the maneuvers at the managed lane exit ramp at Echo Lane.

Researchers analyzed the characteristics of these maneuvers to draw conclusions about the operational performance of the access points of the KML, considering traffic volumes in the managed lanes and GPLs, elapsed time to complete the maneuvers, position of vehicles within the access ramps, and peak versus non-peak comparative performance. In general, the data indicate that design of the access points studied is sufficient to accommodate the expected demand of drivers entering and exiting the managed lanes throughout the facility. The data also indicate that the placement of the managed lane exit at Echo Lane is appropriate to accommodate drivers desiring to exit the Katy Freeway at the Sam Houston Tollway.

Specifically, researchers have observed and concluded the following:

- Direct-merge ramps:
  - The design of the access points is sufficient to accommodate the expected demand at the sites studied. It was not uncommon for the volumes in the two managed lanes to be higher than the left GPL during peak periods, and access maneuvers during peak periods were one to two orders of magnitude greater than during non-peak periods. Despite the increased volumes, there was no indication that operations were affected beyond the expected changes in operating speed that normally appear in congested conditions.
  - The design of the access points includes the buffer between the GPLs and managed lanes, which means that completing an access maneuver on the KML takes more time than a simple lane change at a slip lane, but the increased time does not negatively affect access operations. Single lane changes typically required between 1 and 3 seconds, while entire access maneuvers were generally completed within 10 to 25 seconds.
  - Access maneuvers to the managed lanes from the Addicks Park and Ride Lot T-ramp were the most sensitive to peak-period traffic, due in part to the fact that traffic enters the ramp in platoons as it is released from the traffic signal at the park-and-ride facility.
  - Overall, the observed elapsed times do not suggest any particular problem or issue with the design of the ramps. Rather, the indication is that the design of the ramps is able to accommodate volumes of traffic much larger than are found in the typical non-peak period with minimal effect on operations.
  - Most vehicles entered and exited the access points within the dotted line markings, categorized as "normal" within this study. There were some vehicles that began their maneuvers early or late, and the proportion of early and late maneuvers tended to increase in peak periods, compared to non-peak periods.
- Cross-facility weaving:
  - There is a distance of approximately 7200 feet between the managed lane exit at Echo Lane and the Katy Freeway exit to the Sam Houston Tollway, plus an

additional 1400 feet that drivers who begin early and end late could use. Traveling from one access point to the other requires a minimum of six lane changes and a maximum of seven. However, seven lane changes in 7200 feet provide over 1000 feet of length per lane change, which is in agreement with recommended guidelines.
    - Of the 200 vehicles observed using the managed lanes exit at Echo Lane, 19 percent of the non-peak-period vehicles and 18 percent of the peak-period vehicles completed a cross-facility weaving maneuver to exit the freeway at the Sam Houston Tollway.
    - All but three of the cross-facility weaving vehicles (one in the peak period and two in the non-peak period) completed all of their lane changes in less than 7800 feet. Only one vehicle in each period entered the Sam Houston Tollway ramp "late," and both of those vehicles were making the optional seventh lane change.
    - Elapsed times for single-lane-change maneuvers were fairly consistent with those at the direct-merge sites. Because of the additional distance traveled between the two ramps, the overall elapsed times are much longer than for direct-merge sites, with typical times around 2.0 minutes for peak-period maneuvers and 1.4 minutes for non-peak-period maneuvers.
    - There were no aborted or failed cross-facility weaving maneuvers in either the peak or non-peak periods.
    - A high proportion of weaving vehicles entered the GPLs "early" from the managed lanes exit, particularly in the peak period. However, the distribution of elapsed times and position of final maneuvers was not particularly different from vehicles that exited within "normal" distance.
    - The high rate of weaving vehicles completing their lane changes within "normal" distance, combined with the moderate to high speeds at which maneuvers are being completed, indicates that the distance between the managed lanes exit at Echo Lane and the GPL exit to the Sam Houston Tollway is sufficient to accommodate cross-facility weaving maneuvers.
- "Funnel" operations:
    - The entrance to the managed lanes facility at the boundary of the diamond lane section adds a through lane to the existing lane. Consequently, the entrance ramp proper is very short, and no merging is necessary for vehicles entering from the GPLs.
    - Volumes in the left GPL remained fairly constant throughout both peak and non-peak periods, typically between 250 and 300 every 15 minutes. However, the number of peak-period vehicles in the diamond lane and the number of access maneuvers increased approximately fivefold compared to the non-peak period.

- Because no merging was necessary, the reviewed maneuvers included only the initial lane change. Those elapsed times are similar to those of initial maneuvers at the other study sites, though somewhat shorter.
- Only three vehicles in each period were observed to begin their maneuvers early; the remaining vehicles were classified as "normal." The early maneuvers were all among the shortest elapsed times in both time periods, but there were "normal" maneuvers with similar times.
- Traffic operations at the "Funnel" during the study period were generally unremarkable. Given the consistent volumes and elapsed times, combined with a nearly 100 percent "normal" rate of ramp position, the data indicate that the design of this access point is sufficient to accommodate the expected demand.

CHAPTER 9. LANE SEPARATION

This chapter describes the trade-offs between different types of traffic control devices used for lane separation. There are three main types of lane separation:

- Pavement marking buffer.
- Pylons.
- Barriers.

There are also several variations on these, and various types of lane separation methods have been used on different HOV/HOT lanes across the country. When determining which type to deploy, designers need to consider cost of construction, operations flexibility, enforcement impacts, safety impacts, and maintenance.

This chapter focuses on barrier versus pylon separation types since the partner agencies felt a toll facility required some kind of physical separation. This chapter leverages results from TxDOT Project 0-6643, Guidance for Effective Use of Pylons for Lane Separation on Preferential Lanes and Freeway Ramps, in which an analysis of concrete barriers versus pylons was conducted.

Many managed lane facilities being implemented are retrofit into existing facilities and have restricted right-of-way (ROW). Some barrier options may not be possible on these retrofit projects; however, on the Katy Freeway most sections were built to have ideal conditions for optimal separation between concurrent-flow lanes. The lane separation concept typically relates to separating a preferential lane such as HOV, HOT, or managed lanes from the general-purpose lanes. The preferential lanes typically offer the user a travel time or congestion relief benefit, and have some kind of restriction (based on occupancy) or added fee (in the form of a toll) for their use.

BUFFER SEPARATION

Buffer-separated facilities are those separated by some lateral distance using pavement markings. The lateral distance and markings provide the driver with visible cues indicating that the markings should not be crossed. A double white line may typically be used to indicate a regulatory condition that may carry a legal fine, regardless of the lane requirements. Additional elements that can be used in buffer applications include raised retroreflective pavement markings, profile markings, cross hatching (transverse), or other marking configurations. Figure 75 shows an example of a buffer-separated facility.

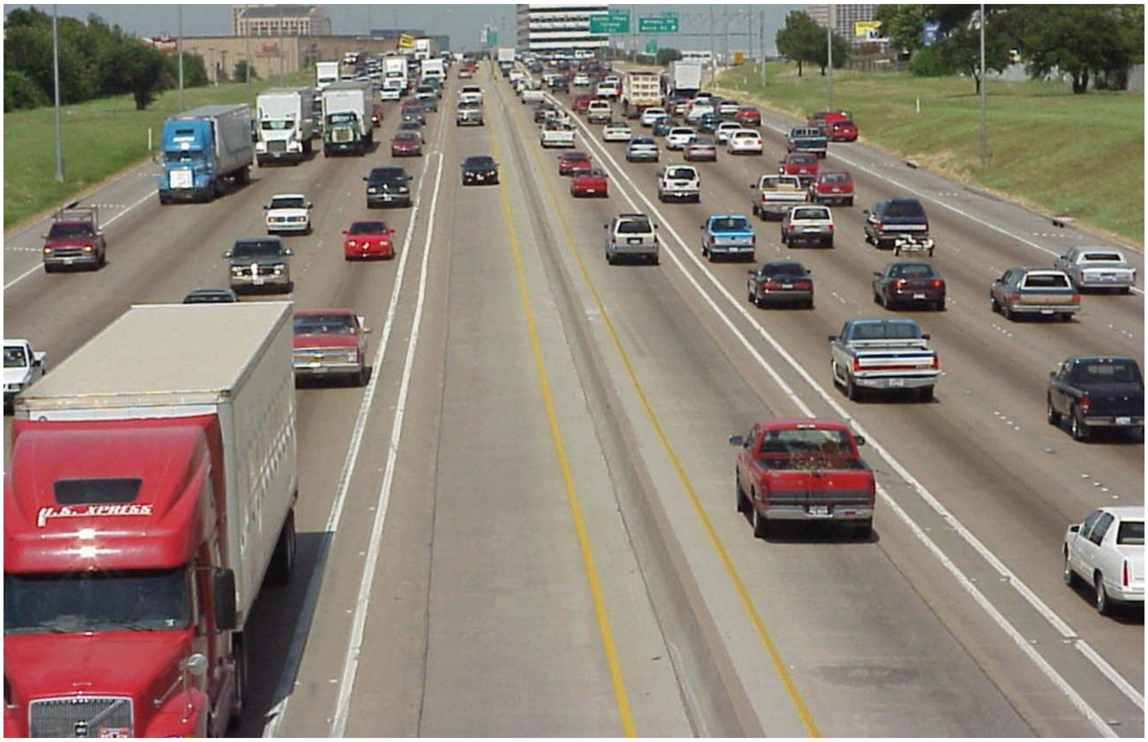


Figure 75. Example of Buffer-Separated HOV Lane Facility.

PYLON SEPARATION

Pylons are used to enhance, or emphasize and thus aid in, compliance of pavement marking buffers. Pylons are widely used on preferential lanes to aid in compliance of the double line, which indicates *do not cross*. The term "flexible pylon" or "pylon" refers to the plastic vertical posts that are mounted on bases and/or curbs with a hinge mechanism. Many terms are used for pylons:

- 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 delineator.

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 76a), the pylon posts are fixed to a raised plastic curb.
- In a surface-mounted pylon (shown in Figure 76b and Figure 76c), the pylon posts are either glued and/or screwed directly to the pavement or to the concrete surface using a pylon base.
- Embedded pylons (Figure 76d) 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 pylons are closely spaced, they provide a "picket fence" visual effect. The use of curbs, upon which to affix the pylons, may discourage more drivers from crossing the pylons as compared to pavement-mounted pylons although this has not been scientifically evaluated. However, curb-mounted pylons may, in some conditions, impede drainage capacity when closely spaced. When curb-mounted pylons are used, drainage requirements at the specific site may influence the minimum spacing between the curb sections. Some of the newer curb designs make provision for drainage using a lateral channel to allow water to pass under the curb. However, curbs may collect debris against (and between) them, which can present both maintenance and drainage issues. Ice buildup can also be a problem with some curb designs.

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

Figure 76. Examples of Pylons and Mounting Styles.

Pylon Color

White, yellow, and orange pylon posts are typically used for lane separation and channelization applications on roadways. The 2009 *Manual on Uniform Traffic Control Devices*

(MUTCD) specifies that channelizing devices used outside of a work zone shall be orange or of the same color as the pavement marking being supplemented or replaced (*22*). Section 3H.01 of the MUTCD also states that when channelizing devices are used outside of 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 device separates traffic flow in the opposite direction (*22*).

Contrasting colors can also increase the visibility of pylons. Although no guidelines are available on the use of contrasting colors for channelizing devices, Chapter 3A of the MUTCD provides some guidance with respect to the use of black pavement marking with other color marking to enhance the visibility of the markings:

> 08 Black may be used in combination with the colors mentioned in the first sentence of Paragraph 1 where a light-colored pavement does not provide sufficient contrast with the markings.
> Support:
> 09 When used in combination with other colors, black is not considered a marking color, but only a contrast-enhancing system for the markings (*22*).

Pylon Height

Surface-mounted pylons with heights of 36 inches, 42 inches, and 48 inches are more commonly being used on high-speed facilities for lane separation. Section 6F.65 of the 2009 MUTCD *(22)* specifies that tubular markers shall not be less than 18 inches high and 2 inches wide when facing road users. When tubular markers are used on freeways or other high-speed highways, the height of the tubular markers shall not be less than 28 inches. However, pylons are available on the market in various heights from 19 inches to 72 inches. Based on the type of mounting system used, the overall installation height can be slightly higher than the height of the pylon post itself.

Surveys and interviews indicate that shorter pylons are more durable than taller pylons. Taller pylons when hit can “wrap” around a bumper, causing them to cling to the hood upon impact. This condition puts high stresses on the pylon and delineator base and can result in ripping the delineator from the base or shearing the pylon from the base.

Definition of Terminology

Several terms are used to describe the pylons and their relation to each other and to the adjacent travel lanes. The definitions are described below and illustrated in Figure 77 and Figure 78.

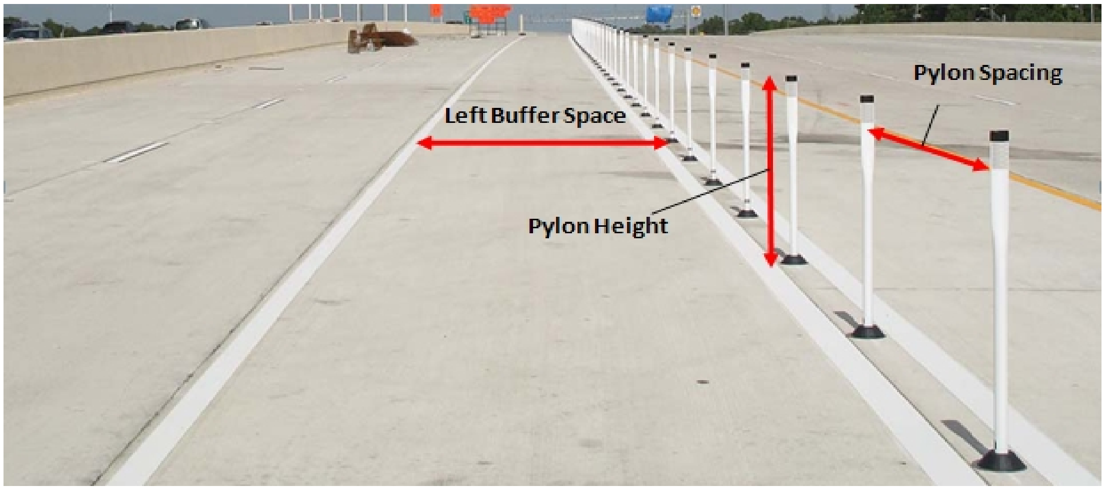


Figure 77. Definitions of Terminology.

Figure 78. Definition of Curb Spacing.

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 Spacing

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

Buffer Width (Right or Left)

Buffer width is the offset distance between the center of the edge line of the GPL and the center of the edge line of the preferential 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.

Curb Spacing

Curb spacing is the longitudinal gap between the adjacent curbs; it is usually determined by drainage considerations. In cases where the curbs are interlocked longitudinally, there is no distance between curb sections. Curb spacing is usually measured from the front of the curb to the front of the next curb.

Curb Height

Curb height is measured from the pavement surface to the top of the curb (or topmost 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.

Running Length

Running length is the longitudinal length of the pylon deployment along the roadway.

Pylon Visibility

Pylon visibility consists of four components: color, target value, contrast, and retroreflectivity. Pylons used for roadway delineation are typically white, yellow, or orange in color. A contrasting color (typically black) is also often used similar to a chevron. The 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 enhanced nighttime visibility of pylons, and is usually achieved by wrapping the pylon post with retroreflective sheeting.

BARRIER SEPARATION

Longitudinal barriers are intended to prevent vehicle encroachment, protect an immovable object, or separate two facilities in close proximity. Some uses for barriers are to prevent encroachment down steep slopes or into buildings, bridges, pedestrian facilities, or other facilities. There are many types of longitudinal barriers, the most common being:

- Cast-in-place concrete barrier.
- Portable concrete barrier.
- Guardrail—typically not reusable.
- Cable barrier—not durable and needs to be repaired or replaced after each hit.

Barriers located in urban areas can experience higher hit rates based on traffic volume, constrained geometrics, and other factors. For these reasons, reusable barriers (safety shape concrete barriers) are typically used in urban areas. In addition to the reduced long-term maintenance cost of concrete barriers, barriers consist of shapes that are designed to redirect vehicles and prevent encroachment. Longitudinal barriers, specifically concrete barriers, have the following benefits:

- Saving lives.
- Eliminating or reducing crossover incidents.
- Redirecting errant vehicles.
- Improving trip reliability.
- Reducing congestion.
- Offering long service life.

Concrete traffic barriers can have several safety shapes depending on purpose, use, or vehicle type. CTBs typically are permanent (poured/cast in place) or portable (pre-cast). Permanent barriers have very low maintenance requirements and typically perform well in crash conditions. However, if damage does occur, it can be costly to repair. Portable CTBs typically come in a 30-foot section and are bolted together to form a continuous wall. Periodic maintenance involves realigning the barrier due to vehicle strikes. Realignment maintenance may not be needed after each impact but may be done on a periodic (annual or longer) basis depending on frequency, severity, and geographic location of the crashes.

TRADE-OFFS—BARRIERS VERSUS PYLONS

Table 30 shows various design/operational, incident management, and maintenance trade-offs or considerations for CTBs versus pylons. The comparison is based on portable CTBs although most of these comparisons would be applicable to a comparison between pylons and cast-in-place traffic barriers. Table 30 provides a summary of the comparison; a more detailed description is provided below.

Design and Operational Considerations

The many differences between pylons and barriers can affect design and operations. Designers and operators need to carefully consider these trade-offs early in the project development process because some elements are very difficult and costly to change later and may have an impact on how the facility operates.

Table 30. Trade-Offs between Concrete Barriers and Pylons.

Feature	Barriers	Pylons
Design/Operational Considerations		
ROW/Buffer Width	4-foot minimum	1.5-foot minimum (maintenance is exponential)
End Treatment	Requires crash attenuator	None required but higher maintenance at entrance
Sight Distance	Perceived limitation	Perceived improvement—no walls to present obstruction
Encroachment	None	High potential
Congestion	Managed lane not affected by GPL congestion	Managed lane affected by GPL 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, and other 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 per linear foot	Low—$3 per linear foot
Crash Protection	Redirect traffic	None
Incident Management		
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—cannot get traffic into or out of managed lane	Very accessible—can get traffic into and out of managed lane
Maintenance		
Lane Closure Cost	Typically annually and may not be required	Higher cost—dependent on buffer width/frequency
Worker Safety	High—limited maintenance and protected by CTB	Low—higher need for maintenance and 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

ROW/Buffer Width

ROW, in the context of this discussion, is the amount of space required for the type of barrier separation provided, which can also be referred to as buffer width. Buffer width refers to the lateral space between the pylon and the moving lanes of traffic. TxDOT 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 foot. However, the maintenance cost increases dramatically as a function of buffer width (see Figure 79). With less than 2 feet of buffer space, pylon replacement can range from 120 percent per year to 300 percent per year. CTBs require about 4 feet of ROW as shown in Figure 80. ROW can be one of the largest cost items in an urban area roadway project. With respect to buffer provision, there is a trade-off between space and cost. Additional space can reduce the pylon replacement rate, increase the space available for incident management, and have some impact on capacity.

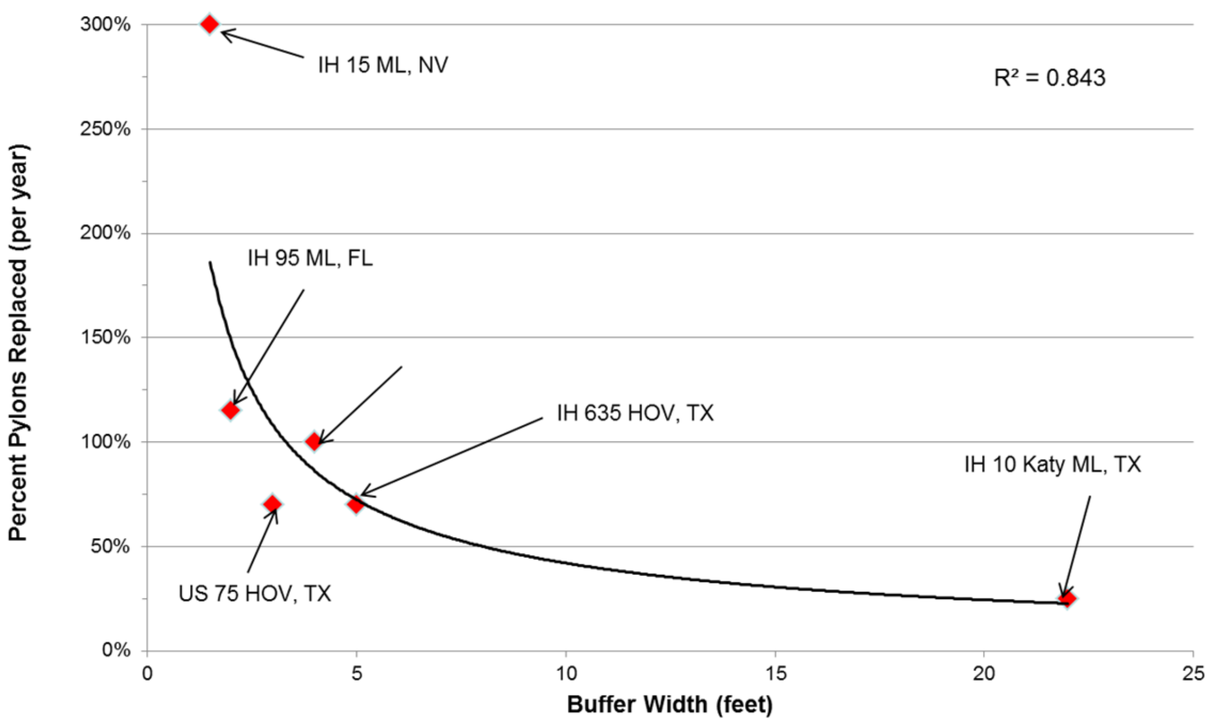


Figure 79. Buffer Width versus Pylon Replacement per Year.

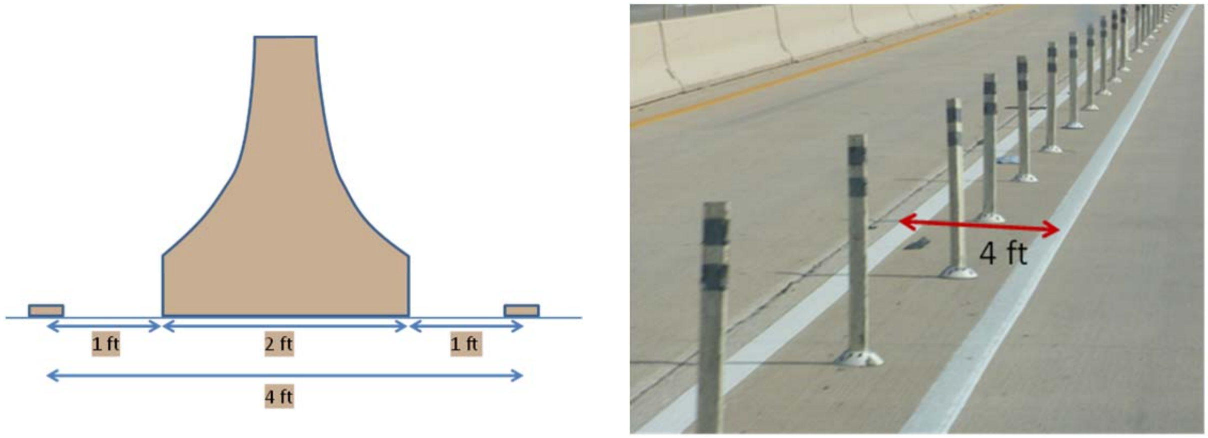


Figure 80. Space Requirements for CTBs and Pylons.

End Treatment

Pylons are crash worthy 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-foot 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 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

The crash protection afforded by concrete barrier placement can have different components, mainly regarding the amount of encroachment or redirection provided. These terms have the following definitions:

- Encroachment is the ability to keep errant vehicles from entering or leaving the lane.
- Redirection is the ability to redirect or keep a vehicle in the lane from which it came and traveling in 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, the barrier may not move at all, but if it does move, it is typically less than 1 foot. 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 lines. 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, CTBs prevent the movement.

Enforcement and Ease of Enforcement

Enforcement may be more of a factor on some facilities than on others, but several factors related to enforcement 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:

- The 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, CTBs provide positive separation with little chance of evading enforcement.

Incident Management

Incident Response

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 because they allow emergency responders to cross the buffer and access both the managed lanes and GPLs. In contrast, the use of CTBs restricts the ability of incident personnel to directly respond to an incident in the GPLs by using the travel time efficiency of the managed lanes (and vice versa). The use of CTBs could also require the incident responders to wait in traffic or travel against traffic in the managed lane to get to an incident or remove a disabled vehicle. In the event of a major crash on a managed lane or GPL, a pylon deployment enables transportation management personnel to directly maneuver a response vehicle across the pylons, into (or out of) the managed lane, 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 shoulder width adjacent to the travel lanes provides such refuge. Removing the vehicle from the travel lanes reduces the backup of other motorists, thus reducing the potential for secondary crashes and enhancing the safety of the stranded vehicle.

Congestion

When GPLs are congested and the managed lane is separated by a narrow buffer, there can be a resulting slowdown in the managed lane. The slowdown in the managed lane 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 81 illustrates the maneuver described above. The use of a CTB prevents motorists from making a cross-facility weave, so the speed in the managed lane is typically not affected by GPL incidents.

Figure 81. Example of GPL Cross-Facility Weave to Managed Lane (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 $5000 per lane mile per day. With narrow buffer widths, a lane closure could be required on both the managed lane and GPL 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

Because the maintenance intervals associated with CTBs are fewer, there is a resulting limited worker exposure when CTBs are 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 an off-peak time (nights and weekends). Repairing pylons on a narrow cross section, or narrow buffer, can require a lane closure on both the managed lane and GPL, leading to more worker exposure. Even if there is a modest amount of shoulder, the exposure rate for maintenance workers is higher since workers are conducting the maintenance more frequently. In addition, pylon maintenance is directly related to buffer width (as seen in TxDOT Project 0-6643); the larger the buffer width, the less frequently the pylons get hit, and the less workers are exposed to traffic. The cost of repairing or replacing the CTB after a crash is typically handled during the annual realignment, so there is little way to determine the crash cost maintenance. Pylons will not stop vehicles and need to be inspected, repaired, and/or replaced after each task. This is typically done as part of the weekly maintenance.

Life-Cycle Cost: Pylons versus CTBs

This section describes the cost comparison between pylons and CTBs. There is a trade-off between initial (or capital) cost compared with the maintenance cost of each application. Portable CTBs may have a higher capital outlay but a lower periodic maintenance cost. The following are the assumptions of the cost analysis:

- CTB assumptions:
  - $30 per linear foot to furnish and install (capital cost for portable CTB).
  - 20-year life (30- to 50-year life possible).
  - $5.77 per linear foot for barrier realignment.
  - $8,700 per crash attenuator.
  - One attenuator per 2 miles.
  - $3,500 to reset attenuator.
  - Reset attenuators 10 percent per year.
  - KML assumed to require 11 crash attenuators.
- Pylon assumptions:
  - 10-foot pylon spacing.
  - $30 per pylon to furnish and install.
  - 2-, 4-, 8-, and 20-foot buffer width assumed for the per-mile and 20-foot buffer on Katy Freeway for 12 miles.
  - Percent pylon replacement per year: 120 percent for 2-foot buffer width, 70 percent for 4-foot buffer width, 50 percent for 8-foot buffer width, and 20 percent for 20-foot buffer width on Katy Freeway.
  - 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).
- Pylon 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 the per-mile cost of treatment. Table 31 through Table 34 examine the relationship between buffer width and the resulting increase in maintenance cost. The cost for each treatment type that was calculated for the KML is presented in Table 35. The 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 the KML or the 20-foot buffer spacing since a lane closure is not typically necessary. The per-mile comparisons with a buffer less than 8 feet assumed that the entire lane would need to be closed both on the KLM and the GPLs.

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

Table 31. CTB versus Pylon Per-Mile Cost Comparison for 2-Foot Buffer Width.

Options	$/Lf*	Per-Mile Install Cost	Maintenance (Percent)**	Maintenance (Dollars)	Total	Percent CTB
Portable CTB	$30	$163,000	50	$302,600	$465,300	100
Pylon (7-Year Life	$3	$15,800	120	$251,500	$267,400	57
Pylon (20-Year Life)	$3	$15,800	120	$491,400	$507,300	109

* Lf = linear foot. $30/pylon/10 feet.

** Based on buffer width curve.

Table 32. CTB versus Pylon Per-Mile Cost Comparison for 4-Foot Buffer Width.

Options	$/Lf*	Per-Mile Install Cost	Maintenance (Percent)**	Maintenance (Dollars)	Total	Percent CTB
Portable CTB	$30	$163,000	50	$302,600	$465,300	100
Pylon (7-Year Life	$3	$15,800	70	$197,700	$213,500	46
Pylon (20-Year Life)	$3	$15,800	70	$337,600	$353,500	76

* $30/pylon/10 feet.

** Based on buffer width curve.

Table 33. CTB versus Pylon Per-Mile Cost Comparison for 8-Foot Buffer Width.

Options	$/Lf*	Per-Mile Install Cost	Maintenance (Percent)**	Maintenance (Dollars)	Total	Percent CTB
Portable CTB	$30	$163,000	50	$302,600	$465,300	100
Pylon (7-Year Life	$3	$15,800	50	$176,200	$192,000	41
Pylon (20-Year Life)	$3	$15,800	50	$276,100	$292,000	63

* $30/pylon/10 feet.

** Based on buffer width curve.

Table 34. CTB versus Pylon Per-Mile Cost Comparison for 20-Foot Buffer Width.

Options	$/Lf*	Per-Mile Install Cost	Maintenance (Percent)**	Maintenance (Dollars)	Total	Percent CTB
Portable CTB	$30	$163,000	50	$302,600	$465,300	100
Pylon (7-Year Life	$3	$15,800	20	$21,500	$37,400	8
Pylon (20-Year Life)	$3	$15,800	20	$61,500	$77,400	17

* $30/pylon/10 feet.

** Based on buffer width curve.

Table 35. CTB versus Pylon Katy Freeway Cost Comparison for 20-Foot Buffer Width.

Options	$/Lf*	Install Cost	Maintenance (Percent)**	Maintenance (Dollars)	Total	Percent CTB
Portable CTB	$30	$3,906,00	50	$7,261,887	$11,167,887	100
Pylon (7-Year Life	$3	$380,200	20	$516,700	$896,900	8
Pylon (20-Year Life)	$3	$380,200	20	$1,476,300	$1,856,500	17

* $30/pylon/10 feet.

** TxDOT.

As shown in Table 32 through Table 34, 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 life longer than 20 years, which in reality could change the numbers to favor CTBs over a longer assumed life.

A 4-foot area is required for a CTB, so the 2-foot comparison is not valid but used for illustration. The 20-foot 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 deployment of pylons versus deployment of CTBs. This information can be used to assist designers when making decisions related to the use pylons or CTBs. Some key factors to consider are:

- ROW (buffer space) and associated maintenance are two of the largest life-cycle deployment costs and can greatly influence the analysis and decision of which treatment to choose.
- ROW and maintenance are directly related. See Figure 79, which shows the correlation between buffer space and maintenance replacement; however, this figure does not directly report costs.
- Many other trade-offs regarding pylons versus CTBs 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. The designer will need to evaluate the specific project to determine the benefits and costs of the proposed treatments.

CHAPTER 10. OPERATIONAL POLICY

The Katy Freeway Managed Lanes are the most recent iteration in a history of HOV and tolling operations in the I-10 Katy Freeway corridor. This chapter documents the evolution of the HOV and tolling policies on the Katy Freeway over the years to provide information on the decision-making process and to offer guidance for future projects in the state. This chapter includes:

- Katy Freeway's history before managed lanes.
- KML policy evolution (HOV and tolling).
- Potential future tolling and HOV policies.

HISTORY BEFORE MANAGED LANES

HOV lanes on the I-10 freeway in Katy, Texas, first opened in 1984, providing expedited access to buses and vanpools only. As demand and congestion in the corridor increased, pressure to increase the usage of the HOV lane resulted in a policy that gradually granted access to more vehicles. In 1984 (following the initial policy), HOV-4+ vehicles were granted access. By 1987, access had been granted to HOV-3+ and then HOV-2+.

In 1988, congestion on the HOV lane led METRO to increase the requirement to HOV-3+ during the peak hours from 6:45 to 8:15 AM. This adjustment resulted in a decrease in both vehicle and person volumes of 62 and 33 percent, respectively (*23*). In 1990, METRO adjusted the morning peak hours from 6:45 to 8:00 AM. In 1991, METRO added the HOV-3+ requirement during the evening peak periods from 5:00 to 6:00 PM.

In 1998, METRO created a program called QuickRide, which permitted HOV-2 to use the HOV lane during peak periods for a fee of $2 per trip. Participating vehicles were required to register with METRO. The program aimed to increase person throughput on the corridor, manage HOV lane demand, and alleviate general-purpose lane congestion.

POLICY EVOLUTION

Policy evolution has occurred through a series of gradual progressions, and each change is displayed through a series of documents. The gradual policy progression consists of studies, negotiations, and agreements that attempt to maximize the performance of the corridor while minimizing costs. The stakeholders in the process occasionally had differing strategies and ideas of how to best accomplish this goal. The evolution consists of the following progression:

- 1997: a major investment study commissioned by TxDOT.
- 2002: a memorandum of understanding (MOU) for operations including TxDOT, Harris County, and METRO.
- March 2003: a tri-party agreement including TxDOT, Harris County, and FHWA.
- May 2003: a traffic and revenue (T&R) study.

- 2007: an evaluation of pricing options.
- 2007: Harris County Commissioners Court meetings.

Figure 82 illustrates the evolution of the HOV and tolling policies over time. The impacts of these strategies and ideas on HOVs and tolling are further discussed in the next subsections.

HOV Policy Evolution

Major Investment Study (MIS)—1997

The MIS, performed by Parsons Brinkerhoff on behalf of TxDOT in 1997, analyzed the I-10 Katy Freeway corridor with the intent of:

- "Identifying the mobility needs of the communities being served by the I-10 Katy Corridor.
- Determining the future transportation needs for the corridor.
- Evaluating a wide range of strategic investments and travel modes to meet the identified mobility needs.
- Assessing the environmental and community effects of the alternate investments.
- Recommending a Locally Preferred Alternative with input from the public and local involved agencies" (*24*).

The study found that the original HOV lane had several flaws (*24*). The reversible HOV lane had too few access points, and the lack of interconnection between HOV facilities reduced the attractiveness of the HOV system. The study found that the existing HOV system was unable to serve the increasing traffic levels, and congestion was diminishing its value.

The study used the Houston-Galveston Area Council (H-GAC) regional model to evaluate the demand for the future HOV facility in the year 2020. The study assumed that demand for the HOV lane was not limited by available capacity constraints or by the number of HOV lanes provided. The analysis found that using a single HOV lane for 2+ carpools would result in the facility being completely overburdened by 2020. Additionally, the use of a two-lane HOV or special-use lane with HOV-2+ classification would fill the facility to near capacity, resulting in congestion, low speeds, and a poor level of service. As a result, the MIS determined that an HOV-3+ classification "be required to maintain a one- or two-lane HOV facility operating at acceptable speeds and levels-of-service (53 mph and LOS C, respectively)" (*25*).

The MIS's final recommendation included the construction of two special-use lanes in either direction between I-610 and SH 6, and the addition of one SOV GPL in each direction.

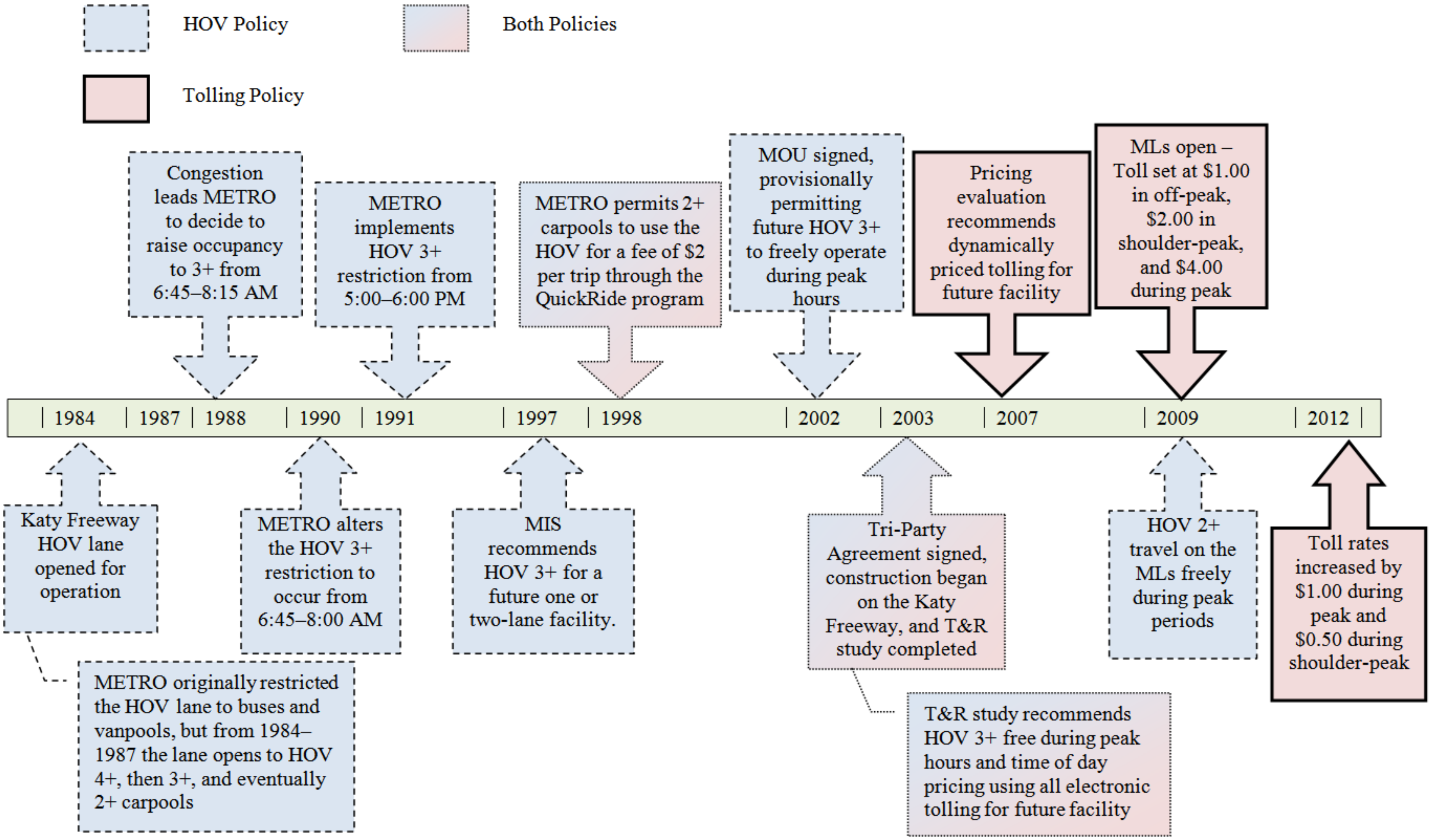


Figure 82. HOV and Tolling Policy Evolution Timeline.

Memorandum of Understanding (MOU)—2002

TxDOT, Harris County, and METRO signed an MOU in 2002 that laid out the intended operational plan for transit along the Katy Freeway (*26*). In this document, METRO reserved the right to provide light-rail transit service in the highway corridor. METRO would also be granted the right to freely operate 65 buses per hour in each direction 24 hours a day and seven days a week. HOV-3+ would be allowed to operate toll-free from 6:00 to 11:00 AM EB and from 2:00 to 8:00 PM WB, seven days a week.

Traffic and Revenue (T&R) Study—May 2003

TxDOT hired Wilbur Smith Associates to perform a T&R study in May 2003 (*27*). The study projected traffic and revenue rates for various construction alternatives on the Katy Freeway. The study assumed that the four managed lanes (two in each direction) would permit HOV-3+ and buses toll free in the AM and PM peak period (for the corresponding direction of traffic only). It also assumed that all vehicles (except buses) would be tolled at all other times.

Final HOV Policy

Upon opening, the HOV policies included:

- HOV-2+ vehicles and motorcycles can travel freely on the managed lanes during weekdays from 5:00 to 11:00 AM and from 2:00 to 8:00 PM. These vehicles must pay for their usage at all other times.
- HOVs are not required to carry a transponder but must pass through a declaration lane at tolling points.
- SOVs, hybrids, and small commercial vehicles can access the managed lanes but must pay toll.

Throughout much of the preceding process, the plan allowed HOV-3+ vehicles that registered with HCTRA to use the managed lanes freely during peak periods, but HOV-2 needed to pay. HCTRA changed this policy shortly before opening the managed lane facility (*28*). The change eliminated the need for registration and allowed HOV-2+ to use the facility freely. This change in policy resulted from negative public feedback during public meetings. The public generally advocated for HOV-2+ to be allowed to drive toll-free during peak periods without registering.

Tolling Policy Evolution

Major Investment Study—1997

The MIS considered tolling as a potential revenue source and as a means to cover operating expenses, influence behavior in relation to usage, and achieve equity or other social objectives. The study considered tolling in two of the alternatives as a means to "generate revenue, to offset a portion of the costs, and to help manage the freeway facility and reduce congestion” (*25*). The MIS estimated that the tolling option could generate approximately $19.2 million (updated for inflation to 2012 dollars). The tolling option considered using congestion pricing.

Memorandum of Understanding—2002

The MOU stated that all SOVs, HOV-2, and commercial vehicles (including trucks, non-METRO buses, and school buses) would pay tolls at all times (*26*).

Tri-party Agreement—March 2003

The tri-party agreement lays out the legal framework for the relationship between the three partner agencies: FHWA, TxDOT, and Harris County. In it, the agreement states that the “TOLL FACILITY is part of the PROGRAM” and that “All parties agree that the STATE has the exclusive authority to modify, alter, reconfigure, etc., the PROGRAM to the benefit and safety of the traveling public” (*29*).

While this statement does not describe the tolling policy, it does lay out the framework for altering that policy in the future.

Traffic and Revenue Study—May 2003

The 2003 T&R study recommended replacing the single HOV lane with four managed lanes. The pricing schedule would be set by time of day to maintain free flow. The tolls would be collected entirely in an electronic manner. This iteration recommended that trucks not be allowed to use the managed lanes. The recommended pricing structure is illustrated in Table 36 and Table 37.

Table 36. T&R Recommended EB Pricing Structure.

Eastbound	2007	2015	2022
AM Peak	$2.20	$5.45	$6.75
AM Shoulder	$2.15	$3.80	$5.45
Midday	$1.10	$2.15	$2.15
PM Shoulder	$1.10	$2.15	$2.15
PM Peak	$1.10	$1.65	$2.15

Table 37. T&R Recommended WB Pricing Structure.

Westbound	2007	2015	2022
AM Peak	$0.55	$1.10	$1.65
AM Shoulder	$0.55	$1.10	$1.65
Midday	$0.85	$0.85	$1.10
PM Shoulder	$1.65	$3.25	$4.90
PM Peak	$2.70	$4.35	$6.75

Pricing Evaluation—2007

The 2007 pricing evaluation, performed by Wilbur Smith Associates on behalf of TxDOT, recommended using dynamic pricing (*30*). The pricing would be recalculated on a regular basis (every five minutes) to adjust the price for demand. The pricing structure would have a base rate below which the toll rate could not drop. The price listed on the dynamic signs at a vehicle's entry point would remain the same for the vehicle throughout its trip on the corridor.

Price changes would be determined using an algorithm that relied on evaluating traffic conditions. If traffic conditions worsened, the algorithm would evaluate the specific conditions and set tolls at the rate determined to alleviate that specific level of congestion.

Final Tolling Policy

Before deciding on the final tolling policy, members of HCTRA visited several toll facilities across the country to evaluate their operations. HCTRA's visit to the SR 91 Express Lane facility in Orange County, California, was especially influential. This visit led HCTRA to use time-of-day pricing, stating that it should "opt for simplicity whenever possible" (*28*).

The tolling policy finally selected used time-of-day pricing, with differentiated pricing based on higher rates during peak periods. The price was set at $4 during peak periods, $2 during shoulder periods, and $1 during off-peak periods. These prices reflect the costs to travel throughout the entire tolled corridor.

The original pricing structure was in place from 2009 to September 7, 2012. On September 7, 2012, the prices during peak and shoulder-peak periods increased by $1.00 and $0.50, respectively. The price during off-peak periods did not change. The price change occurred concurrent to a citywide price increase, which affected several other toll facilities. The pricing change was implemented to "maintain free flowing traffic in the managed lanes" (*31*). Table 38 and Table 39 illustrate the old and new pricing.

Table 38. EB Old and New Rate Structure.

Eastbound AM	Old		New
Shoulder Peak	6:00–7:00	$2.00	$2.50
Peak	7:00–8:00	$4.00	$5.00
Peak	8:00–9:00	$4.00	$5.00
Shoulder Peak	9:00–10:00	$2.00	$2.50

Table 39. WB Old and New Rate Structure.

Westbound PM	Old		New	
Shoulder Peak	4:00–5:00	$2.00	3:00–4:00	$2.50
Peak	5:00–6:00	$4.00	4:00–5:00	$5.00
Peak	6:00–7:00	$4.00	5:00–6:00	$5.00
Shoulder Peak	7:00–8:00	$2.00	6:00–7:00	$2.50

CONCLUSIONS/POTENTIAL FUTURE TOLLING AND HOV POLICIES

The evolutionary changes in HOV and toll policy over the course of the project development process demonstrate the dynamic nature of technical and policy decision-making at a time when priced managed lanes were new to the region and relatively new to the industry. Modifications to the original plans for HOV discounts and variable pricing appear to have had no detrimental impact on operations or usage of the lane. The one area of impact could be in estimated versus actual revenues; however, we did not compare estimated and actual revenues under this study.

If congestion increases over time on the KML, HCTRA may consider several strategies to increase mobility on the corridor. One option is changing the tolling policy from a time-of-day toll (current system) to dynamic pricing. Dynamic pricing would use sensors on the roadway to detect how congested the roadway is, and change the price at regular intervals to charge the rate that corresponds with the traffic level. Dynamic pricing is mentioned as an option on the HCTRA website, and one of the interviewees mentioned it as an option as well (*32*). Additionally, dynamic pricing was discussed as an option in the 2007 pricing evaluation document (*30*).

One strategy that could be used would be simply increasing the pricing on the managed lanes. This would manage the demand on the roadway by reducing the number of motorists who would be willing to use the priced option on the road. HCTRA has already used this strategy (effective September 7, 2012) (*31*).

Another strategy would be to increase the occupancy requirements for HOVs to more than 2+. This would manage demand by reducing the number of vehicles eligible to freely use the facility. Placing the HOV requirement at 3+ was discussed throughout much of the process before opening, but it did not occur due to public resistance.

A final strategy would be to develop an automatic system that adjusts both tolling and HOV operations based on performance measures and benchmarks. A recent study recommended developing policy shifts that trigger once a certain threshold (based on performance measures) is reached (*33*). The shifts in policy could be alterations in the price of tolls or the types of vehicles that drive toll-free (e.g., requiring HOV-2 to pay a toll). Because these scenarios would be predetermined and preapproved, each policy change would not rest on the outcome of a referendum or policy discussion while the performance continues to degrade. The effect would be that once a facility reaches a certain level of congestion, a policy threshold is triggered and the next policy takes effect (e.g., higher tolls or increased HOV restriction).

CHAPTER 11. PUBLIC ATTITUDES AND PERCEPTIONS

This project examined public attitudes and perceptions by using two main instruments:

- A 2012 survey of Katy Freeway travelers.
- Interviews with individuals that were involved with or instrumental in the development of the Katy Freeway Managed Lanes and ongoing operations of the KML.

The survey examined respondents' most recent trip on the Katy Freeway, their typical travel on the Katy Freeway, their use or non-use of the managed lanes, their reasons for using or not using the managed lanes, and their socioeconomic characteristics. Additionally, respondents answered three stated preference questions regarding their use of the managed lanes.

The objective of the interviews was to identify best practices and highlight lessons learned that can be used to support successful implementation of managed lane projects across Texas. Interviewees included elected officials and current and former employees of TxDOT, METRO, HCTRA, and Harris County.

SURVEY

Survey Overview

The KML survey was designed to examine ways to improve traffic flow along the Katy Freeway (I-10), understand Houston road users' decision-making process (specifically with regard to managed lane usage), and evaluate the managed lanes with the purpose of supporting successful implementation of managed lanes across Texas.

The survey (www.katysurvey.org) was conducted from August 15, 2012, to September 19, 2012. Residents of Houston who use the Katy Freeway on a regular basis or have used it recently were encouraged to participate in the survey. The existence of the survey was advertised to the public through online and news media. The 2012 survey was created using Limesurvey, an open-source survey designing tool, which can be freely downloaded from www.limesurvey.org.

The 2012 survey consisted of four sections:

1. The first section introduced the Katy Freeway (I-10) and Katy Tollway lanes and asked the respondents if they ever used these. Then the respondents were asked about their most recent trip on the Katy Freeway. Questions included information about the purpose of the trip, if the respondents ever used the GPLs or the tollway lanes, the day of the week of the trip, when the trip began, where the respondents got on and off the Katy Freeway, the type of vehicle, the number of passengers in the vehicle, etc. (see Appendix A for the survey instrument).
2. In the second section, respondents were asked if they ever used the tollway lanes and, if so, the reasons for using these. If they had not used these lanes, the survey sought their reasons for not using the lanes. Then they were asked about the number of trips

they took on the Katy Freeway in a week, how many of those were on the tollway lanes, the average toll the respondent paid, and the travel time they saved.

3. In the third section, the respondents were presented with three stated preference (SP) questions. With each SP question pair, the respondent was asked to consider a realistic travel scenario on the Katy Freeway with four different modes of travel available.
4. The last section of the survey contained questions regarding the socio-demographic characteristics of the respondents, including ZIP code of origin and destination of their most recent trip, gender, age, ethnicity, level of education, and income.

Survey Details

Introduction to the New Managed Lanes

The KML survey begins with an introduction to the Katy Tollway, and each respondent is asked if he or she has traveled on either the Katy Freeway (I-10) or Katy Tollway lanes in the past six months (Figure 83).

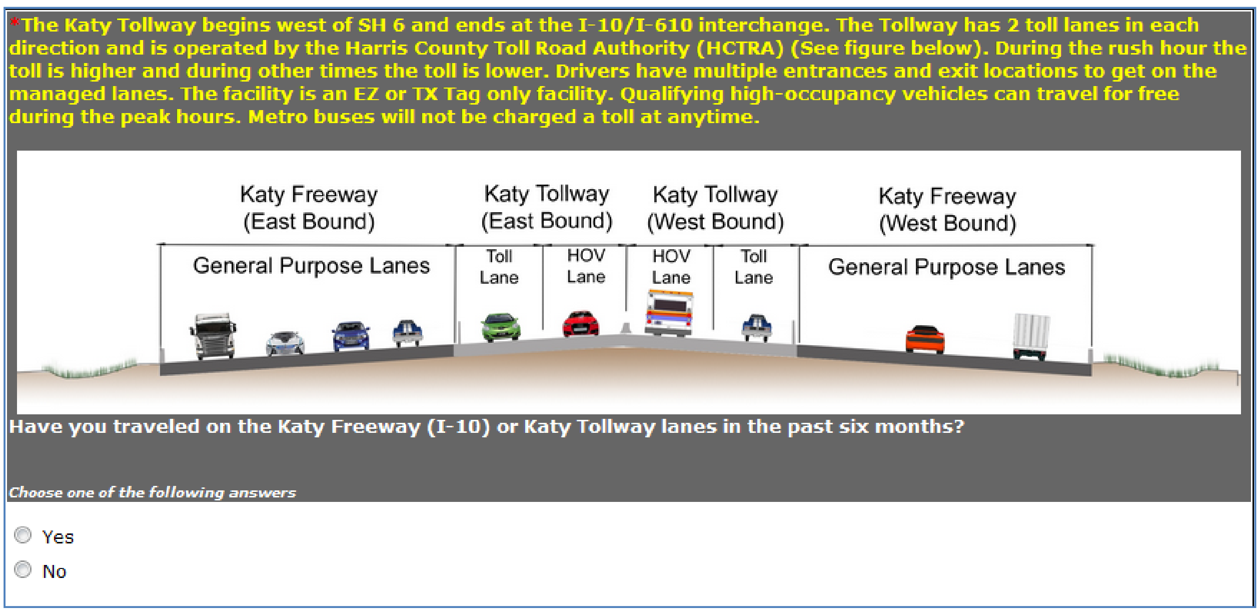


Figure 83. Introduction to the Katy Tollway.

Details of Respondent's Most Recent Trip

If the respondent did not have a recent trip on the Katy Freeway (I-10) in the past six months, then the survey was terminated with a "Thank you" page. If the respondent used the freeway or tollway in the past six months, then about half of the respondents were asked about their actual trip toward downtown Houston and the other half about their trip away from downtown. The respondent was then asked if that trip was on the GPLs or the tollway lanes. If the respondent indicated that the travel was on the GPLs, then the locations where he or she got on and off the freeway were determined. If the travel was on the tollway lanes, then the respondent was asked where he or she entered and exited the tollway lanes. The survey also sought answers from respondents regarding whether they ever changed the entry or exit locations along the Katy Freeway in order to access the tollway. The respondent was then asked several questions regarding his or her most recent Katy Freeway trip, such as day of the week and time of day of that trip, what type of vehicle used, etc. The complete survey questionnaire is attached in Appendix A of this report.

Respondents were then asked about their travel time on their last trip. The travel time is measured from the time they got in the vehicle to when they arrived at their destination. They were then asked if they ever used the Katy Tollway lanes. If they had, the survey sought their main reasons for using the tollway. If they had not, they had to cite their primary reasons for not using the tollway. Additionally, respondents' opinions on the levels of law enforcement were collected.

Respondents were also asked the number of trips they made on the GPLs of the Katy Freeway in the last work week (Monday through Friday), with each direction of travel counting as one trip. If the respondent indicated that he or she had used the tollway lanes, then the number of trips the respondent took during the last work week on the Katy Tollway lanes was requested.

Stated Preference Questions

A total of three SP questions were presented to each survey respondent in this section of the survey. In each question, the respondent was asked to consider a realistic travel scenario on the Katy Freeway with four different modes of travel available. Although in the survey the scenarios were hypothetical, travel scenarios were largely created based on the details of the respondent's most recent trip on Katy Freeway toward/away from downtown Houston, so it is highly likely that many respondents had faced a similar situation before on their actual trips. The modes included SOV, HOV, and varied based on time of day, travel time, travel time variability, and toll values. Modes in each SP question were:

- Drive alone on the general-purpose lanes (DA-GPL).
- Carpool on the general-purpose lanes (CP-GPL).
- Drive alone on the managed lanes[2] (DA-ML).
- Carpool on the managed lanes (CP-ML).

The SP questions were used to better understand how travelers choose between GPL and tollway lanes on the Katy Freeway. These questions were designed based on prospect theory (PT) principles because PT may improve on traditional methods, such as expected utility theory (EUT)

[2] The managed lanes in the survey questions were presented as tollway lanes to maintain consistency with the official name by the operating agency. This is because Katy Freeway travelers are familiar with tollway lanes instead of managed lanes.

and random utility maximization (RUM), in predicting the use of tollway lanes by Katy Freeway travelers.

EUT and RUM propose that people act rationally to maximize their utility/benefit from the decision that they have made, and the most well-known RUM-based discrete choice model is the multinomial logit (MNL) model. Despite the wide use of EUT and RUM, however, human decision making can deviate in many ways from assumptions inherent in EUT and RUM. Behavioral scientists have criticized violation of utility theories in descriptive models of individual choices. This has led to the development of unexpected utility theories, among which PT has been the most studied (*34*). Avineri and Prashker (*35*, *36*, *37*) indicated that their study results suggest that PT may be more appropriate in the prediction of route choice decision. PT posits that the most influencing element of a choice decision is the change of status against the status quo instead of the incentive to maximize the final utility as advocated in utility maximization theories. A PT value function is presented as gain or loss against the status quo. Therefore, the amount of change relative to the status quo (reference point) matters in decision making.

SP questions in this survey were designed specifically to test and compare predictive results of mode choice using four discrete choice models. One utility theory (UT)–based mixed logit (ML) model (named the deterministic UT model) assumed the travel time for a hypothetical trip was from a uniform distribution, while the PT-based ML model (named the deterministic PT model) differs from the deterministic UT model in the specification of the utility function, everything else being equal. The UT-based utility function assumes a linear relationship with attribute levels (travel time of a trip), while it is the difference of travel time relative to that of the most recent trip in the PT-based utility function. For example, in a UT-based model, the average travel time of 20 minutes with a range of 17 to 23 minutes of a hypothetical trip was assumed and presented to the respondent, while in a PT-based model, the difference in travel time (±3 minutes) was presented to the respondent. The PT-based model assumes that the differences in travel time ($20 - 17 = 3$ or $20 - 23 = -3$ minutes) relative to the most recent trip determine the value of the utility function, and consequently the probability of the mode chosen. By comparing the predictive results of the deterministic UT models and PT models (the two differ in the specification of the utility functions), it is possible to investigate if PT could improve on traditional UT methods.

The other UT-based ML model (named the probabilistic UT model) assumed that the travel time was generated from random probabilistic distribution. Likewise, the corresponding probabilistic PT-based ML model differs in the specification of utility function. Based on these four discrete choice models, SP questions were presented in four formats and were designed to accommodate the linear and nonlinear utility functions proposed from UT-based models and PT-based models, respectively. The travel time of a trip is by nature variant, and how likely a mode would be chosen partly depends on travelers' perceived reliability of that mode. For example, if the weather forecast indicated that there is 80 percent of chance of rain, then most people would think it is going to rain and would take an umbrella. In this case, the 80 percent was perceived as a certainty (100 percent). If it was forecast that there was only a 10 percent chance of rain, most people would not take an umbrella because they would not believe it is going to rain. Similarly, if a managed lane could offer a travel time with 80 percent reliability, travelers may consider it as 100 percent or close to reliable. SP questions in this format were specifically designed to investigate how managed lane users value probability/reliability of travel time. By incorporating a probability weighting function in the PT-based utility functions, two formats of UT-based and PT-based SP questions were developed. This resulted in four formats for the SP questions. Each respondent was given questions in only one of the four formats. Table 40 shows a sample question style and brief description of the four formats.

Table 40. SP Question Formats.

Format	Sample Question Style	Brief Description
1: Deterministic UT-based design	Average travel time = 20 but can be anywhere from 17 to 23 minutes.	• The travel time was assumed to be taken from a uniform distribution. • Traditional utility function as used in UT methods. • Travel on managed lanes was constrained to be faster than on GPLs.
2: Deterministic PT-based design	For the GPL modes, the travel time can be 3 minutes shorter or longer than your most recent trip. For the managed lane modes, the travel time can be 9 to 11 minutes shorter than your most recent trip.	• The travel time was assumed to be taken from a uniform distribution. • PT-proposed utility function using changes of status as attribute levels. • Travel on managed lanes was constrained to be faster than on GPLs. • The attribute levels of the utility function were presented as gain or loss relative to the reference point.
3: Probabilistic UT-based design	7 times out of 10, the trip takes 25 minutes; 3 times out of 10, the trip takes 18 minutes.	• The travel time was assumed to be taken from random probabilistic distribution. • Traditional utility function was used in UT methods. • Utility function incorporating probability weighting function. • Travel on managed lanes was constrained to be faster than on GPLs. • The attribute levels were assumed with probabilistic occurrence.
4: Probabilistic PT-based design	For the GPL modes, 8 times out of 10, the trip takes 3 minutes longer than your most recent trip; 2 times out of 10, the trip takes 13 minutes less than the most recent trip. For the managed lane modes, 9 times out of 10, the trip takes 19 minutes less than your most recent trip; 1 time out of 10, the trip takes 15 minutes less than the most recent trip.	• The travel time was assumed to be taken from a random probabilistic distribution. • PT-proposed utility function using changes of status as attribute levels. • Utility function incorporating probability weighting function. • Travel on managed lanes was constrained to be faster than on GPLs. • The attribute levels were presented as gain or loss relative to the reference point and assumed with probabilistic occurrence.

The four survey designs of the SP questions were developed to predict the travel demand on the use of managed lanes using two UT-based and two PT-based ML models. The UT-based models will use conventional utility function, while the PT-based models will incorporate

PT-proposed value functions and/or probability weighting functions in the utility functions. This allows for a check of the efficiency in estimating the parameters for the responses obtained from each survey design. From these models, the value of travel time savings and the value of travel time reliability will be estimated. Estimates (UT-based and PT-based) can then be compared with results from previous surveys conducted in 2008 and 2010. Route-choice decision prediction will also be compared to check the prediction accuracy of each model. How the attribute levels of each alternative were determined is discussed in the following sections.

Figure 84 presents a typical SP question in format 1 being asked in the survey. See Appendix A for other typical format SP questions.

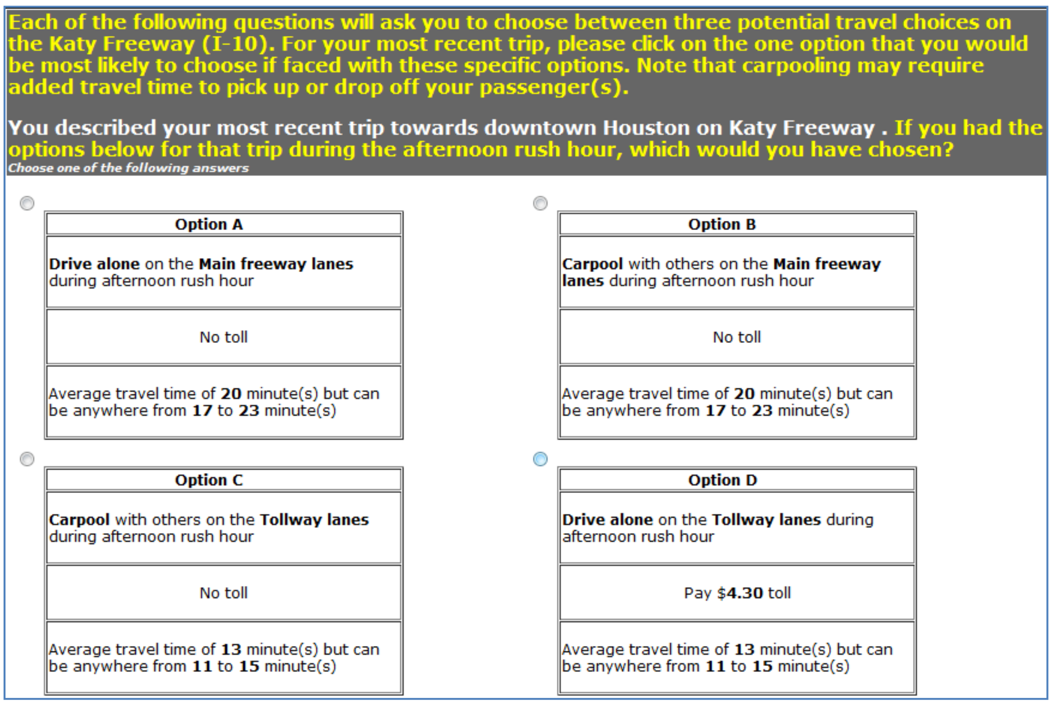


Figure 84. Typical Scenarios of Survey Design with Uniform Travel Time Distribution (Format 1).

In a typical SP question, the respondent was asked to choose the mode that best suited his or her travel preferences given a hypothetical set of trip characteristics. These characteristics were chosen primarily according to the respondent's answers to the questions pertaining to the respondent's most recent trip. The trip characteristics that were obtained in this manner include the trip time of day, the trip day of the week, travel time, and travel distance on the Katy Freeway/Tollway lanes of the most recent trip. These elements are used to build the text of the three SP questions. If a respondent did not answer any of the questions required to build the SP question text, the survey randomly selected various attributes in a reasonable range. For example, in the case of a missing time of day for the respondent's most recent trip, the peak period (either morning or afternoon) was randomly selected. If the user did not provide entry and exit location on the GPLs/tollway lanes such that a travel distance could not be estimated, the survey assigned a travel distance of 12 miles for a trip on the Katy Freeway. The initial toll values were based on the current tolls along the Katy Freeway but may vary considerably, depending on the survey design. Variation in tolls in SP questions would help identify the influence of the toll on mode choice. But to maintain reasonable scenarios, it is necessary to observe some constraints. First, the toll was set at $0 for CP-ML during peak periods, and the toll was always $0 for CP-GPL and DA-GPL. Second, for the faster and more reliable travel on the managed lanes, the travel time and travel time variability (the percentage variation of travel time from the average travel time) on the managed lanes was set lower than or equal to that of the GPLs.

The following sections discuss how the values of travel time, toll, and travel time variability were selected.

Time of Day. The actual toll rates for using the Katy Tollway lanes vary according to the time of day, so it was reasonable to adjust the toll values for the travel scenarios depending on the respondent's recent trip start time toward/away from downtown Houston. Time of day for the travel scenarios was determined according to Table 41. The time of day for the travel scenarios was determined based on the respondent's recent trip start time toward/away from downtown. In the cases where a respondent did not answer the start time of his or her recent trip, the time of day of the trip was then assigned to either the morning or evening peak period. If the respondent was previously asked about his or her trip toward downtown Houston, then the travel scenario was described as being during the morning peak period. The other scenarios were described as being during the evening peak hours if the trip was away from downtown. The toll values during off-peak hours are lower than during shoulder hours, which in turn are lower than the tolls during the peak hours. The actual toll rates are a little different from those provided in the hypothetical scenarios, and the HOVs are free during peak periods and pay the regular toll rates during off-peak periods.

Table 41. Time of Day Based on Trip Start Time.

Trip Start Time	Time of Day
12:00 AM to 6:00 AM	Off-peak hours
6:00 AM to 7:00 AM	Shoulder period
7:00 AM to 9:00 AM	Morning peak period
9:00 AM to 5:00 PM	Shoulder period
5:00 PM to 7:00 PM	Evening peak period
7:00 PM to 8:00 PM	Shoulder period
8:00 PM to 12:00 AM	Off-peak hours

Trip Distance. In the first part of the survey, the respondents were asked the points where they entered and exited the Katy Freeway. With this information, the traveler's trip distance on the Katy Freeway can be estimated. If there was no information obtained about the entrance and/or exit locations, then a trip distance of 12 miles on the managed lanes was assigned. To obtain a precise toll cost for the trip, it was also important to estimate the portion of the trip actually traveled on the managed lanes. In order to calculate the distance traveled on the managed lanes and GPLs, the Katy Freeway was then divided into two sections. Section one was defined as anywhere west of the managed lanes, and section two was the section that contained the managed lanes. Only the distance traveled on the managed lanes (section two) was considered when calculating the toll. In case of a managed lane distance less than 4 miles, it was increased by 4 miles to ensure that some difference in travel times between the managed lanes and GPLs would be generated. Some respondents' whole trip could potentially be on section one, where there are no managed lanes. In this case, a distance of 12 miles on the managed lanes was assigned to calculate a hypothetical toll value. Based on this estimated trip distance on managed lanes, the toll values are calculated using toll-per-mile values that are generated using different design strategies.

Calculation of Toll, Average Travel Time, and Maximum/Minimum Travel Time. In addition to trip distance (on section one and two) and time of day, it is necessary to incorporate average speeds, the toll per mile, and the travel time variability on each of the sections to calculate the toll, average travel time, and maximum and minimum travel times for each individual's trip. The average speed on section one was assumed to be 60 mph irrespective of the time of day because this section is far from downtown and often has free-flow speeds.

The following example illustrates how the toll, average travel time, and maximum and minimum travel time were estimated. Assume a respondent indicated that the travel distance on the Katy Freeway was 15 miles during peak hours, 5 miles on section one, and 10 miles on section two. The following values for the speed, toll rate, and travel time variability on section two (Table 42) will be used to illustrate this.

Table 42. Example Values for Speed, Toll Rate, and Travel Time Variability.

Modes	Average Speed (mph)	Travel Time Variability (Percent)	Toll (Cents/Mile)
DA-GPL	32.5	23	0
CP-GPL	32.5	23	0
DA-ML	52.5	14	33.33
CP-ML	52.5	14	0

Using these assumed values, the average travel time, toll, and maximum and minimum travel time for each mode can be calculated, and the example calculations are shown in Table 43.

Table 43. Example Calculation of Travel Time, Toll, and Maximum/Minimum Travel Time for Each Mode.

	DA-GPL and CP-GPL	DA-ML and CP-ML
Travel Time on Section One (Rounded to the Nearest Minute)	$(5/60) \times 60 = 5$	$(5/60) \times 60 = 5$
Travel Time on Section Two (Rounded to the Nearest Minute)	$(10/32.5) \times 60 = 18$	$(10/52.5) \times 60 = 11$
Total Travel Time (Minutes)	23	16
Toll	None	$(0.33 \times 10) = \$3.30$
Variability of Travel Time (Calculated Based on Travel Time on Section Two) (Minutes)	$(18 \times 0.23) = 4$	$(11 \times 0.14) = 2$
Maximum Travel Time (Minutes)	$23 + 4 = 27$	$16 + 2 = 18$
Minimum Travel Time (Minutes)	$23 - 4 = 19$	$16 - 2 = 14$

Additionally, two survey design strategies, the D_b-efficient design and adaptive random design, were used to generate the values of the toll per mile, average speed, and variability of travel time. Each respondent had an equal chance of receiving SP questions based on one of the two designs. Discussions of the D_b-efficient design, adaptive random design, and resulting generated attribute levels are provided in the following sections.

Attribute Levels Generated by the D_b-Efficient Design. Designs are D-efficient if the D-error of the asymptotic variance-covariance matrix of the parameter estimates of the discrete choice model is minimized. D_b-efficient, or Bayesian efficient, designs are found by minimizing the D_b-error. Priors of parameters were assumed from normal distributions with non-zero means. The mean values of priors for the attribute toll and speed were obtained from the discrete choice models estimated from the previous surveys conducted in 2008 and 2010, and from relevant literature for travel time variability. The mean and standard deviation of the priors used for obtaining the D_b-efficient design and the exact levels of attributes used for each mode at different times of day for the deterministic models (both UT and PT based) are shown in Table 44.

Three levels were assumed for each attribute in the deterministic models. For example, during the peak periods, the speeds on managed lanes could be 50/52.5/55 mph, while on GPLs they could be 30/32.5/35 mph. The speed differences between managed lanes and GPLs were constrained at around 20 mph in order to generate sufficient trade-offs between choosing managed lane modes and GPL modes. The 20-mph difference is a reasonable estimate based on speed analysis using TTI speed data (http://traffic.houstontranstar.org/hist/historydata.html).

Table 44. Mean, Standard Deviation of Attribute Priors, and Attribute Levels for Different Times of Day (Deterministic Models).

Attribute	Attribute Levels				Mean Value of Priors*	Standard Deviation of Priors
	Mode	Time of Day				
		Peak Hours	Shoulder Hours	Off-Peak Hours		
Toll (Cents/ Mile)	DA-GPL	0	0	0	−0.12	0.10^b
	CP-GPL	0	0	0		
	DA-ML	16.67, 33.33, 50	8.34, 16.67, 25	4.17, 8.34, 12.5		
	CP-ML	0	0	0		
Speed (mph)	DA-GPL & CP-GPL	30, 32.5, 35	30, 32.5, 35	42.5, 45, 47.5	−0.50	0.30
	DA-ML & CP-ML	50, 52.5, 55	50, 52.5, 55	57.5, 60, 62.5		
Travel Time Variability (Percent of Mean Travel Time)	DA-GPL & CP-GPL	14, 23, 33	14, 23, 33	5, 11, 18	−0.06	0.50
	DA-ML & CP-ML	10, 14, 18	10, 14, 18	4, 8, 12		

* Prior is the coefficient of travel time estimated from the previous survey.

The mean and standard deviation of the priors for the probabilistic models (both UT- and PT-based) are shown in Table 45.

The assumed toll values for the deterministic models were the same as for the probabilistic ones. Because the travel time and its variability in probabilistic models were presented as two probabilities in the utility function, one probability is defined as the best case, the other the worst. For example, during peak periods, the speeds on the managed lanes could be 50/60/65 mph in the best case and 45 mph in the worst case. On GPLs, the best case speed is 40 mph and the worst case, 20/25/30 mph. The speed values were selected for easy comparison to the speed values in the deterministic models, and to satisfy the constraint that the traffic flows faster on the managed lane than on the GPLs. The probability of each attribute level (say, the best case) could be 0/10/20/50/80/90/100 percent, and the probability of the worst case would be 100 minus the probability of the best case. The seven levels of probability make it possible to estimate the parameters of the probability weighting functions that PT proposed.

The D_b-efficient designs for this survey design strategy were generated using the N-Gene package (*38*). Codes used to generate D_b-efficient design in N-Gene are in Appendix B. The priors of UT- and PT-based MNL models (deterministic and probabilistic) were simulated using pseudo-random Monte Carlo simulation with 1000 independent draws from the prior distributions. The design for peak hours obtained from the software for the deterministic models and probabilistic models is shown in Table 46 and Table 47, respectively. The corresponding Bayesian designs for other times of day were obtained by replacing the attribute levels, as shown in Table 44 for deterministic models and Table 45 for probabilistic models. The design for the deterministic models has 15 rows divided into 5 blocks of 3 rows with a D_b-error of 0.1376, while design for the probabilistic models has 21 rows divided into 7 blocks of 3 rows with a D_b-error of 0.0363. Each respondent was randomly given a choice set from each block.

Table 45. Mean, Standard Deviation of Attribute Priors, and Attribute Levels for Different Times of Day (Probabilistic Models).

Attribute	Mode		Peak Hours Values	Peak Hours Probability	Shoulder Hours Values	Shoulder Hours Probability	Off-Peak Hours Values	Off-Peak Hours Probability	Mean Value of Priors	Standard Deviation of Priors
Toll (Cents/ Mile)	CP-ML		0	N/A	0	N/A	0	N/A	−0.12	0.10
	DA-ML		16.67, 33.33, 50	N/A	8.34, 16.67, 25	N/A	4.17, 8.34, 12.5	N/A		
	DA-GPL & CP-GPL		0	N/A	0	N/A	0	N/A		
Speed (mph)	CP-ML & DA-ML	Best case	55, 60, 65	0%, 10%, 20%, 50%, 80%, 90%, 100%	55, 60, 65	0%, 10%, 20%, 50%, 80%, 90%, 100%	60, 65, 70	0%, 10%, 20%, 50%, 80%, 90%, 100%	−0.50	0.3
		Worst case	45	$1-\text{probability}_{\text{Best Case}}$	45	$1-\text{probability}_{\text{Best Case}}$	55	$1-\text{probability}_{\text{Best Case}}$		
	DA-GPL & CP-GPL	Best case	40	$1-\text{probability}_{\text{Worst Case}}$	40	$1-\text{probability}_{\text{Worst Case}}$	50	$1-\text{probability}_{\text{Worst Case}}$		
		Worst case	20, 25, 30	0%, 10%, 20%, 50%, 80%, 90%, 100%	25, 30, 35	0%, 10%, 20%, 50%, 80%, 90%, 100%	35, 40, 45	0%, 10%, 20%, 50%, 80%, 90%, 100%		

Table 46. D_b-Efficient Design Generated for Deterministic Models Using N-Gene Software (for Peak Hours).

Mode	DA-ML			CP-ML		DA-GPL		CP-GPL		
Choice Situation	Speed (mph)	Toll (Cents/Mile)	Travel Time Variability (Percent)	Speed (mph)	Travel Time Variability (Percent)	Speed (mph)	Travel Time Variability (Percent)	Speed (mph)	Travel Time Variability (Percent)	Block
1	55	50	14	55	14	30	33	30	33	1
2	52.5	33.33	14	52.5	14	30	33	30	33	4
3	55	16.67	10	55	10	30	14	30	14	5
4	50	16.67	18	50	18	32.5	23	32.5	23	1
5	52.5	33.33	10	52.5	10	35	33	35	33	3
6	52.5	50	18	52.5	18	30	14	30	14	3
7	52.5	33.33	18	52.5	18	35	23	35	23	5
8	50	16.67	18	50	18	32.5	14	32.5	14	4
9	52.5	50	10	52.5	10	32.5	23	32.5	23	2
10	50	33.33	10	50	10	30	14	30	14	2
11	55	50	10	55	10	32.5	33	32.5	33	3
12	55	50	14	55	14	35	33	35	33	4
13	50	33.33	14	50	14	32.5	23	32.5	23	5
14	50	16.67	18	50	18	35	23	35	23	2
15	55	16.67	14	55	14	35	14	35	14	1

Table 47. D_b-Efficient Design Generated for Probabilistic Models Using N-Gene Software (for Peak Hours).

Mode	DA-ML	DA-ML & CP-ML				DA-GPL & CP-GPL				
Choice Situation	Toll (Cents/ Mile)	Speed of Best Case (mph)	Probability of Best Case (Percent)	Speed of Worst Case (mph)	Probability of Worst Case (Percent)	Speed of Best Case (mph)	Probability of Best Case (Percent)	Speed of Worst Case (mph)	Probability of Worst Case (Percent)	Block
1	16.67	60	20	45	80	30	20	40	80	1
2	50	65	0	45	100	25	50	40	50	4
3	50	60	90	45	10	20	80	40	20	7
4	50	65	100	45	0	20	50	40	50	2
5	50	65	0	45	100	20	90	40	10	3
6	16.67	55	10	45	90	25	90	40	10	5
7	16.67	60	90	45	10	25	10	40	90	6
8	16.67	55	10	45	90	30	100	40	0	7
9	33.33	60	80	45	20	20	100	40	0	5
10	16.67	55	80	45	20	25	10	40	90	2
11	50	65	100	45	0	20	80	40	20	1
12	16.67	55	20	45	80	25	0	40	100	4
13	50	55	20	45	80	30	100	40	0	2
14	16.67	55	50	45	50	30	80	40	20	1
15	50	60	50	45	50	30	90	40	10	7
16	33.33	60	80	45	20	20	0	40	100	6
17	33.33	65	10	45	90	30	10	40	90	5
18	33.33	65	0	45	100	30	20	40	80	3
19	33.33	65	50	45	50	25	0	40	100	6
20	33.33	55	90	45	10	25	20	40	80	4
21	33.33	60	1	45	99	20	50	40	50	3

Attribute Levels Generated by the Adaptive Random Design. The adaptive random attribute level generation method was used as the second type of design strategy. In this method, the levels of each attribute (toll per mile, average speed, and travel time variability) for the first SP question were generated randomly from a given range of values for each attribute. The attribute levels used for each attribute at different times of day are shown in Table 48. The adaptive random design strategy is given the name for its smart adjusting attribute level generation method: the toll levels in subsequent (second and third) choice sets were generated partially based on the response to the respondent's prior choices. The toll rates were increased by a random percentage anywhere between 30 and 90 if the respondent chose a toll option and decreased between 35 and 70 if the respondent chose a non-toll option for the previous SP question. In cases (very rare) where the travel time (calculated using randomly generated speed on the managed lane and GPL) for the GPL was found to be lower than that of the managed lanes (suggesting faster travel in the GPL than in the managed lanes), then the travel time of the managed lane was set to be the same as that of the GPL.

Table 48. Attribute Levels Used for Generating Random Attribute-Level Design.

Attribute	Attribute Levels			
		Time of Day		
	Mode	Peak Hours	Shoulder Hours	Off-Peak Hours
Toll (Cents/Mile)	CP-ML	0 + (0 to 10)	0 + (0 to 7)	0 + (0 to 5)
	DA-ML	5 + (0 to 28)	5 + (0 to 18)	5 + (0 to 14.6)
	CP-GPL	0	0	0
	DA-GPL	0	0	0
Speed (mph)	CP-ML	55 + (0 to 10)	55 + (0 to 10)	60 + (0 to 10)
	DA-ML	55 + (0 to 10)	55 + (0 to 10)	60 + (0 to 10)
	CP-GPL	20 + (0 to 15)	30 + (0 to 15)	40 + (0 to 15)
	DA-GPL	20 + (0 to 15)	30 + (0 to 15)	40 + (0 to 15)
Travel Time Variability (Percent of Mean Travel Time)	CP-ML	5 + (0 to 15)	5 + (0 to 15)	5 + (0 to 15)
	DA-ML	5 + (0 to 15)	5 + (0 to 15)	5 + (0 to 15)
	CP-GPL	25 + (0 to 25)	20 + (0 to 12.5)	15 + (0 to 8.6)
	DA-GPL	25 + (0 to 25)	20 + (0 to 12.5)	15 + (0 to 8.6)

Demographics of Respondents

Attributes of the respondents and their household may also influence choices that drivers make. In order to investigate the influence, if any, of the travelers' characteristics on the route choice decision making, the last section of the survey has standard questions about the socio-demographic characteristics of each respondent (see Appendix A).

Survey Administration

The survey was posted on a TTI server and was made available for public access through the www.katysurvey.org website. The data collection process started on August 15, 2012, and continued until September 19, 2012. Residents of Houston who use the Katy Freeway on a regular basis or have used it recently were encouraged to participate in the survey. Online and traditional media advertised the survey to the public. Some of the advertising was free of charge, and some was paid service. The website published the ads at different dates in order to have a constant flow of responses and also to have a rough idea of responses generated by each source.

The websites where the survey was advertised are:

- Houston TranStar (http://www.houstontranstar.org/) on August 15, 2012 (free).
- HCTRA (www.hctra.org) on August 16, 2012 (free).
- West Houston Association (http://www.westhouston.org/) on August 17, 2012 (free).
- Social media (free):
    - Targeted tweets to more than 50 targeted media and community groups and organizations through Twitter (https://twitter.com/), such as Fox News Traffic Anchor Michelle Merhar, who re-tweeted the survey to her many followers.
    - Tweets on August 20 and re-tweets on August 24, 2012, by the TxDOT Houston District.
- Facebook posts to more than 25 targeted media and city organization pages such as KHOU, KTRK, Fox Traffic, H-GAC, and TxDOT.
- Press release to targeted Houston media.
- *Houston Chronicle* (www.chron.com) on August 31, 2012 (paid).
- KUHF interview with Dr. Mark Burris on September 4, 2012 (http://app1.kuhf.org/articles/1346777349-Commuters-Asked-For-Input-On-Katy-Freeway-Managed-Lanes.html) (free).

Number of Responses

A total of 1067 surveys were completed. Efforts had the following results:

- The online ad resulted in 55 clicks through to the survey link, but fewer than nine completed the survey (see Table 49).
- Based on the data of survey respondents, social media pushes through the month of August and September (see Figure 85) garnered approximately 115 survey completions.
- A press release distributed to targeted Houston media produced a spike in data responses between the dates of August 21 and August 24, 2012, resulting in a large number of survey responses (see Figure 86).
- A print ad and an online ad, shown in Figure 87, were placed with the *Houston Chronicle*.

- A story produced by Houston Public Radio station KUHF posted on September 4, 2012, coupled with the *Chronicle* ad, produced another spike in data between September 4 and September 7. Some of this spike may be attributed to the ad placed in the *Chronicle* on August 31 because survey respondents may have read the ad between September 4 and September 7 upon returning home from the Labor Day holiday. A link to the September 4, 2012, KUHF story is posted at http://app1.kuhf.org/articles/1346777349-Commuters-Asked-For-Input-On-Katy-Freeway-Managed-Lanes.html.
- HCTRA and Houston TranStar posted a link to the survey on their respective websites. The link to the TranStar website was very effective (see Table 49), but no referrals came directly from the HCTRA website.

Table 49. Referral URLs for Completed Surveys.

URL	Number of Referrals
http://traffic.houstontranstar.org	420
None	388
Other	199
http://app1.kuhf.org/articles	33
http://instantnewskaty.com/	18
http://myemail.constantcontact.com	9

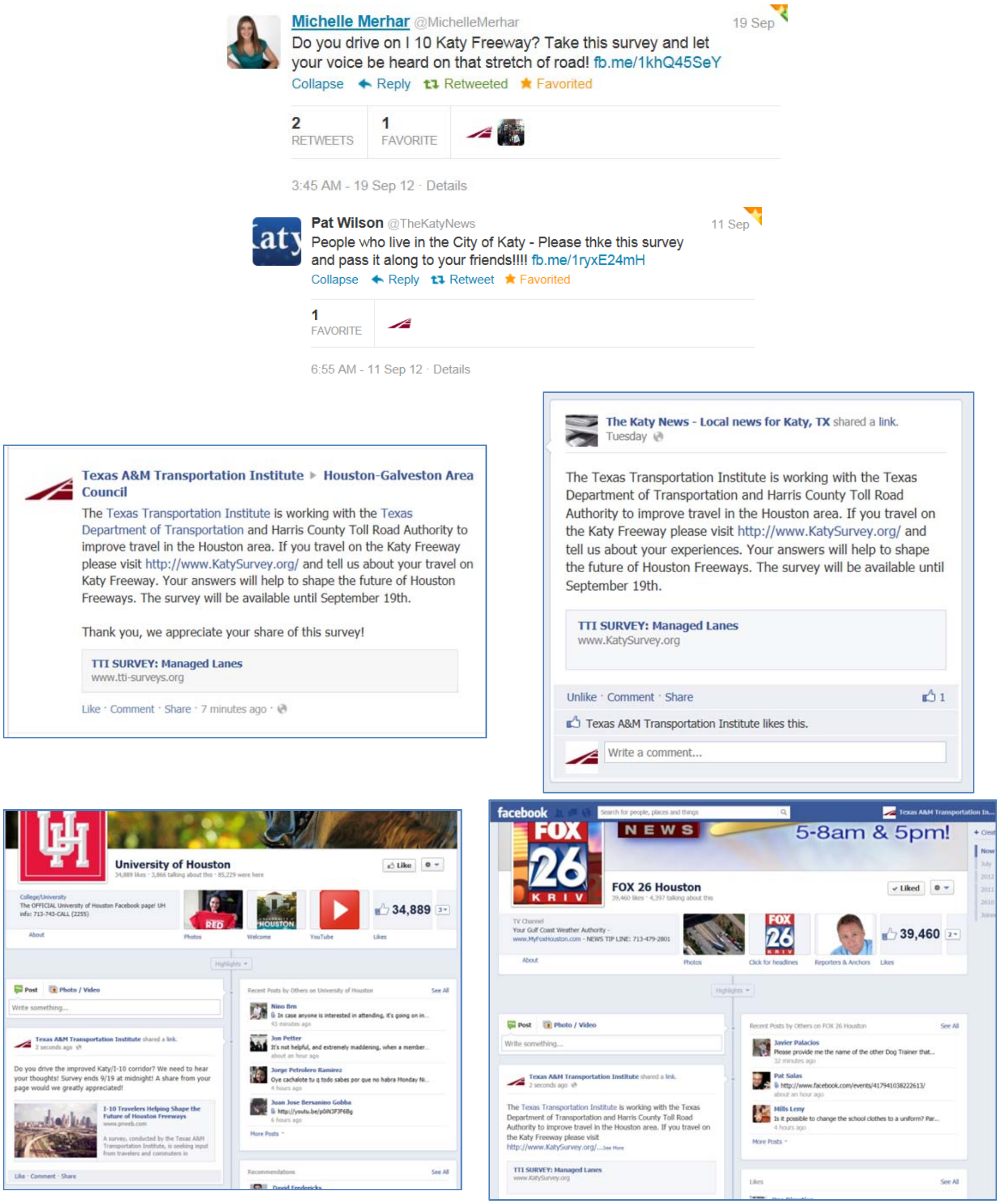


Figure 85. Samples of Social Media Posts.

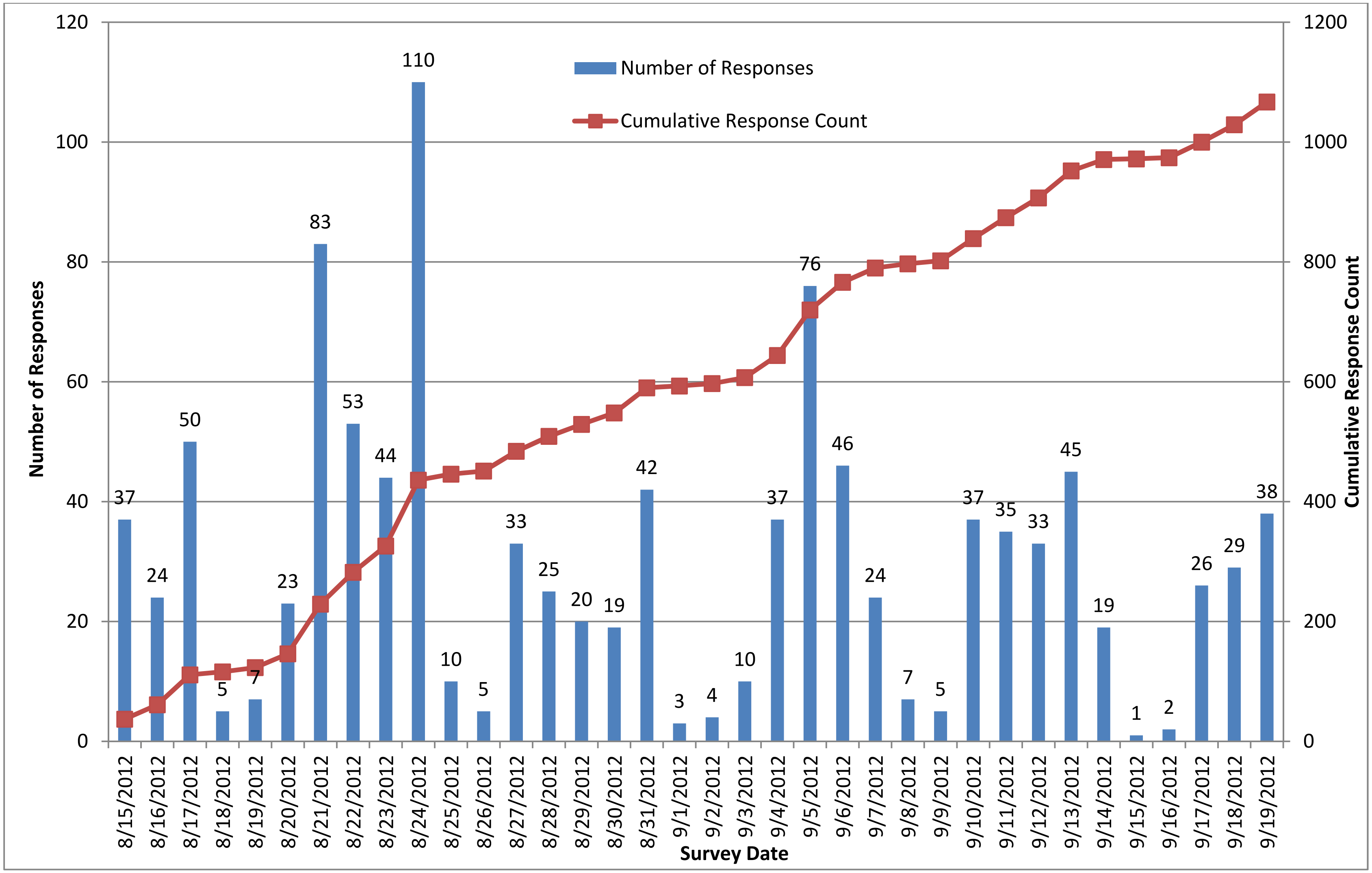


Figure 86. Response Rate by Date.

Figure 87. *Houston Chronicle* Online Ad and Print Ad.

Survey Results

The 2012 Internet-based travel survey of Katy Freeway travelers garnered 1067 completed responses. A very small number of these (40) were a mode other than passenger car/sports utility vehicle (SUV) or pickup. These were removed from analysis, leaving 1027 responses. The respondents' socioeconomic and commute characteristics were compared based on the survey design they received. Respondents were very similar across all design types, with only two significant ($p \leq 0.05$) differences, which were two of the reasons for using managed lanes (see Table 50). This indicates that travelers with similar characteristics and similar trips answered each group of questions, making it more likely that any differences in their choices of modes or values of time are due to the survey design and not due to having different types of travelers receive the different survey design types.

Next, traveler characteristics were examined based on their choice of mode in the SP questions. Each respondent could answer up to three SP questions, and therefore each respondent could have up to three entries, one for each SP question answered. In this analysis, any differences in characteristics based on mode selected could help identify characteristics useful in modeling mode choice. There were many significant ($p \leq 0.05$) differences in the characteristics of travelers based on mode chosen (see Table 51). The values with significant differences by mode chosen, as well as the variables that have the largest percentage difference by mode chosen, are the most likely to be significant variables in models of mode choice.

Many of these variables should be significantly different for each mode and are not appropriate for use in mode choice models. For example, the question "Ever used the Katy Tollway?" was answered "yes" by a higher percentage of respondents who selected a managed lane option in the SP questions. This result is as expected, but including such a variable in a mode choice model makes that model non-transferable to a location without managed lanes. Therefore, model development focused on traveler and trip characteristics that could be available on a freeway without managed lanes.

Travelers choosing to carpool on the GPLs were more likely to be on recreational/social/shopping/entertainment/personal errands trips and less likely to be commuting to or from work. This was somewhat surprising since the managed lanes were cheaper, and often free, for carpools. These respondents were over twice as likely (52 percent versus 20 percent) as commuters to be traveling in the off-peak period—and therefore not seeing nearly as much travel time savings from the managed lanes. Similarly, travelers who chose to carpool on the GPLs were much more likely to pay to park in Houston (30 percent versus 17 percent for other mode choices). This may again be due to recreational/social/shopping/entertainment/personal errands trips. These trips were more likely to have to pay for parking and were more likely to travel during the off-peak. However, time of day had little impact on whether the traveler paid to park because the difference from peak (17.0 percent paid to park) to off-peak (17.2 percent paid to park) was very small. Therefore, time of day would appear to be an unimportant variable to include in the models. This is despite the fact that toll rates and travel time savings vary in the SP questions by time of day. Therefore, this difference in the lanes should have already been accounted for.

Table 50. Traveler Characteristics by Survey Design Method.

Characteristic	Percent of Travelers								
	D-Efficient				Adaptive Random				Overall
	Deterministic		Probabilistic		Deterministic		Probabilistic		
	UT Design	PT Design	UT Design	PT Design	UT Design	PT Design	UT Design	PT Design	
Percent of each design type	12	14	13	13	13	12	10	13	100
Day of travel of most recent trip on the freeway									
Weekday	89	87	90	90	93	93	94	95	91
Weekend	11	13	10	10	7	8	6	5	9
Direction of travel									
Toward downtown	48	49	45	49	49	53	39	58	49
Away from downtown	52	51	55	51	51	47	61	42	51
Use of GPLs/managed lanes (based on travel direction)									
GPLs (toward downtown)	31	31	29	29	30	32	18	31	29
GPLs (away from downtown)	32	34	26	28	25	29	36	21	29
Managed lanes (toward downtown)	18	17	14	21	18	22	21	27	20
Managed lanes (away from downtown)	19	18	32	22	26	17	25	22	22
Trip purpose									
Commuting to or from my place of work	54	49	54	55	60	58	60	65	57
Recreational/social/shopping/entertainment/ personal errands	21	22	20	21	21	23	19	15	20
Work related (other than to or from home to work)	18	24	20	23	17	17	17	13	19
To attend class at school or educational institute	3	1	1	0	1	1	2	3	1
Other	4	2	3	1	1	0	1	2	2
Vehicle type									
Passenger car/SUV/pickup	13	13	13	13	13	12	10	13	100
Driver or passenger									
Driver	92	96	91	95	95	94	92	96	94
Passenger	8	4	7	4	5	6	8	3	6

Table 50. Traveler Characteristics by Survey Design Method (Continued).

Characteristic	Percent of Travelers								
	D-Efficient				Adaptive Random				Overall
	Deterministic		Probabilistic		Deterministic		Probabilistic		
	UT Design	PT Design	UT Design	PT Design	UT Design	PT Design	UT Design	PT Design	
Number of vehicle occupants									
1	69	72	76	72	70	70	73	80	73
2	22	18	18	16	22	20	18	14	19
3	5	6	5	5	4	4	6	1	4
4	2	3	1	6	1	2	1	3	2
5	2	1	0	1	3	4	2	1	2
Who did you travel with									
Co-worker/person in the same, or a nearby, office building	11	9	16	18	11	16	5	13	5
Neighbor	27	9	0	18	9	18	9	9	1
Adult family member	13	17	11	11	15	12	13	8	15
Another commuter in a casual carpool (also known as slugging)	33	17	17	0	17	17	0	0	1
Child	14	14	7	14	16	11	11	13	7
Other	6	13	6	31	0	25	13	6	2
Ever change entry or exit to have easier access to/from the managed lanes									
Yes	53	47	43	53	39	56	45	53	49
No	47	53	57	47	61	44	55	47	51
Number of changes of entry or exit to have easier access to/from the managed lanes									
0	0	4	5	0	0	0	5	0	1
1	60	65	50	57	36	61	35	52	53
2	28	17	27	37	41	26	50	33	32
3	12	13	18	7	23	13	10	15	14

Table 50. Traveler Characteristics by Survey Design Method (Continued).

Characteristic	Percent of Travelers								
	D-Efficient				Adaptive Random				Overall
	Deterministic		Probabilistic		Deterministic		Probabilistic		
	UT Design	PT Design	UT Design	PT Design	UT Design	PT Design	UT Design	PT Design	
Respondents indicated travel time of their most recent trip									
1 to 5 minutes	0	1	1	1	0	2	1	0	1
6 to 10 minutes	4	4	2	5	3	3	3	5	4
11 to 15 minutes	2	9	6	5	8	8	7	5	6
16 to 20 minutes	13	10	8	12	7	8	16	10	10
21 to 25 minutes	12	10	11	12	6	3	10	8	9
26 to 30 minutes	15	14	9	13	11	17	6	8	12
31 to 35 minutes	4	7	10	10	9	8	5	10	8
36 to 40 minutes	9	10	5	10	8	3	8	11	8
41 to 45 minutes	14	12	14	8	18	15	17	9	14
46 to 50 minutes	3	5	10	3	7	4	3	6	5
51 to 55 minutes	3	2	4	2	3	2	3	3	3
56 to 60 minutes	5	7	10	9	5	8	6	15	8
60+ minutes	16	8	11	11	15	18	17	9	13
Ever used the managed lanes									
Yes	77	75	63	79	74	73	66	74	73
No	23	25	38	21	26	27	34	26	27

Table 50. Traveler Characteristics by Survey Design Method (Continued).

Characteristic	Percent of Travelers								
	D-Efficient				Adaptive Random				Overall
	Deterministic		Probabilistic		Deterministic		Probabilistic		
	UT Design	PT Design	UT Design	PT Design	UT Design	PT Design	UT Design	PT Design	
Reasons for using the managed lanes (442 respondents)									
Access to/from the tollway lanes is convenient for my trips	10	23	10	13	8	13	10	13	12
Being able to use the lanes for free as a carpool*	19	17	12	14	10	14	5	9	26
Travel times on the tollway lanes are consistent and predictable	12	13	9	14	14	18	6	14	18
The tollway saves time*	14	18	10	15	10	13	9	11	64
During the peak hours, the tollway will not be congested	13	16	9	13	14	13	9	12	34
The tollway lanes are safer than the GPLs	18	13	12	12	13	16	4	13	17
The tollway lanes are less stressful than the GPLs	15	15	11	13	11	13	8	13	36
Trucks and large vehicles are not allowed on the tollway	18	13	7	10	16	20	5	11	14
Someone else pays my tolls	24	6	0	24	0	24	12	12	4
Other	8	5	18	8	23	10	10	18	9

Table 50. Traveler Characteristics by Survey Design Method (Continued).

Characteristic	Percent of Travelers								
	D-Efficient				Adaptive Random				Overall
	Deterministic		Probabilistic		Deterministic		Probabilistic		
	UT Design	PT Design	UT Design	PT Design	UT Design	PT Design	UT Design	PT Design	
Reasons for NOT using the managed lanes (165 respondents)									
Access to/from to the Katy Tollway lanes is not convenient for my trips	11	14	11	4	14	18	11	18	17
I have the flexibility to travel at less congested times	6	13	25	13	13	19	9	3	19
I do not feel safe traveling on the tollway lanes	0	25	25	0	25	0	25	0	2
The toll is too expensive for me	5	11	11	19	14	16	12	12	35
The tollway does not offer me enough time savings	13	16	15	9	9	11	13	15	33
I can easily use routes other than Katy Freeway, so I'll just avoid Katy Freeway if I think there is a lot of traffic	19	8	27	4	12	19	8	4	16
It is too complicated/confusing to use the tollway	4	4	25	13	21	8	17	8	15
I avoid toll roads whenever possible	16	9	14	9	11	11	16	14	27
I don't want to have a toll transponder in my vehicle	19	19	14	10	10	10	5	14	13
I don't have a credit card needed to set up a toll transponder account	0	25	0	0	25	0	25	25	2
I don't like that the toll changes based on the time of day	10	12	15	10	12	15	17	10	25
I don't have anyone to carpool with	15	21	18	6	12	9	9	12	21
Other	11	16	11	0	11	16	16	21	12

Table 50. Traveler Characteristics by Survey Design Method (Continued).

Characteristic	Percent of Travelers								
	D-Efficient				Adaptive Random				Overall
	Deterministic		Probabilistic		Deterministic		Probabilistic		
	UT Design	PT Design	UT Design	PT Design	UT Design	PT Design	UT Design	PT Design	
Law enforcement									
Providing too little enforcement on the Katy Tollway?	33	22	32	22	30	28	30	26	29
Providing too much enforcement on the Katy Tollway?	12	19	22	18	20	20	24	23	19
Providing the right level of enforcement on the Katy Tollway?	54	59	46	60	50	52	46	51	52
Number of trips on the GPLs in last week									
0	10	9	13	9	19	12	10	13	12
1	8	7	6	10	8	8	9	3	7
2	10	15	14	8	10	14	12	10	12
2.5	1	0	0	0	0	0	0	0	0
3 to 5	22	23	25	33	22	23	28	27	25
6 to 10	43	39	39	31	35	37	36	40	37
11 to 15	4	5	3	6	5	3	2	5	4
16 to 20	2	1	0	2	2	2	3	1	1
21 to 25	0	1	0	1	0	0	0	0	0
26 to 30	0	0	0	0	1	1	0	1	0
30+	0	0	1	0	0	0	0	0	0

Table 50. Traveler Characteristics by Survey Design Method (Continued).

Characteristic	Percent of Travelers								
	D-Efficient				Adaptive Random				Overall
	Deterministic		Probabilistic		Deterministic		Probabilistic		
	UT Design	PT Design	UT Design	PT Design	UT Design	PT Design	UT Design	PT Design	
Number of trips on the managed lanes in last week									
0	30	38	28	28	36	30	27	32	31
1	12	16	14	10	13	13	12	9	12
2	15	9	16	13	6	12	10	17	12
2.5	1	0	0	0	0	0	0	0	0
3 to 5	26	23	15	31	18	30	24	26	24
6 to 10	15	13	27	18	25	13	28	16	19
11 to 15	0	1	0	0	0	1	0	0	0
16 to 20	0	0	0	0	1	0	0	0	0
21 to 25	0	0	0	0	0	0	0	0	0
26 to 30	0	0	0	0	0	0	0	0	0
30+	0	0	0	0	0	0	0	0	0
Average toll paid per trip									
Less than $1.00	20	20	27	17	20	20	24	9	19
$1.00 to $1.99	21	26	19	23	7	20	15	20	19
$2.00 to $3.99	21	25	20	22	29	30	17	25	24
More than $4.00	16	9	19	16	22	13	27	19	17
Don't remember	21	20	16	21	22	16	17	27	20
Perceived travel time savings (from using the managed lanes)									
Less than 2 minutes	1	0	3	1	1	3	3	1	1
3 to 5 minutes	6	6	5	8	3	6	4	6	5
6 to 10 minutes	12	17	12	13	11	13	8	13	13
11 to 15 minutes	15	9	14	12	15	13	10	14	13
16 to 20 minutes	11	4	9	14	7	6	18	9	9
21 to 25 minutes	4	6	0	5	2	8	7	7	5
26 to 30 minutes	2	1	3	5	4	4	2	5	3
More than 30 minutes	3	1	2	1	4	3	1	1	2
Unsure	5	7	7	4	6	2	7	3	5

Table 50. Traveler Characteristics by Survey Design Method (Continued).

Characteristic	Percent of Travelers								
	D-Efficient				Adaptive Random				Overall
	Deterministic		Probabilistic		Deterministic		Probabilistic		
	UT Design	PT Design	UT Design	PT Design	UT Design	PT Design	UT Design	PT Design	
Pay for parking in Houston									
Yes	15	20	19	17	16	15	21	18	17
No	85	80	81	82	83	85	79	82	82
Parking cost per day ($)									
0	0	0	4	5	0	0	0	0	1
0.01 to 1.00	5	0	4	0	0	0	14	4	1
1.01 to 2.00	5	8	0	5	5	0	5	4	4
2.01 to 3.00	0	20	8	9	10	6	0	17	9
3.01 to 5.00	21	28	17	14	29	18	18	17	20
5.01 to 10.00	47	32	33	41	24	53	50	29	38
10.01 to 15.00	11	12	21	18	19	18	5	25	15
15.01 to 20.00	5	0	4	9	5	6	5	4	5
20.01 to 25.00	0	0	8	0	5	0	5	0	3
25.01 to 30.00	0	0	0	0	0	0	0	0	0
30+	5	0	0	0	5	0	0	0	1
Gender									
Male	61	64	58	53	54	58	60	60	58
Female	37	34	37	42	44	38	38	38	39
Age									
18 to 24	3	5	1	5	4	3	0	2	3
25 to 34	29	24	29	22	25	23	28	25	26
35 to 44	25	17	27	29	27	23	26	27	25
45 to 54	19	28	19	25	19	24	18	26	22
55 to 64	17	20	14	10	16	16	17	15	15
64 or older	3	5	5	4	5	6	5	3	4
Refused	2	1	1	2	1	4	3	1	2

Table 50. Traveler Characteristics by Survey Design Method (Continued).

Characteristic	Percent of Travelers								
	D-Efficient				Adaptive Random				Overall
	Deterministic		Probabilistic		Deterministic		Probabilistic		
	UT Design	PT Design	UT Design	PT Design	UT Design	PT Design	UT Design	PT Design	
Race/ethnicity									
White/Caucasian	72	78	75	71	79	73	69	78	74
Hispanic/Latino	8	9	5	5	8	8	6	8	7
African American	2	4	4	4	4	4	4	2	4
Asian American	4	2	7	5	0	3	9	4	4
Native American	2	0	1	0	0	0	1	1	0
Refused	11	5	4	11	7	11	11	5	8
Highest level of education									
Less than high school	0	1	0	1	1	1	0	0	0
High school graduate	4	3	2	7	1	2	5	3	3
Some college or vocational school	20	20	16	15	17	24	27	18	19
College graduate	44	41	50	50	50	46	35	41	45
Postgraduate degree	25	31	24	21	24	25	27	32	26
Refused	5	1	4	3	4	2	5	4	3
Income									
Less than $10,000	2	1	0	2	1	0	0	2	1
$10,000 to $14,999	2	0	1	2	1	0	0	1	1
$15,000 to $24,999	0	1	1	1	1	1	0	1	1
$25,000 to $34,999	4	4	2	1	2	0	4	1	2
$35,000 to $49,999	6	5	5	6	4	7	5	5	5
$50,000 to $74,999	11	14	14	12	11	13	14	15	13
$75,000 to $99,999	11	17	16	22	15	17	10	16	16
$100,000 to $199,999	37	35	31	32	41	39	44	32	36
$200,000 or more	10	14	14	9	11	13	10	9	11

* = Significant (p <0.05) differences between respondents by survey design type.
A = These sum to more than 100% as respondents could select multiple answers to this question.
B = Due to a mistake in the question skip pattern of the survey, respondents who used MLs on their current trip were not asked their reasons for using the lanes.
C = Due to a mistake in the question skip pattern of the survey, respondents who used MLs on their current trip were the only group asked this question.

Table 51. Traveler Data by Mode Choice (Online Survey).

Characteristic Mode	Percent of Travelers Choosing Mode				All
	DA-GPL A	CP-GPL B	DA-ML C	CP-ML D	
Day of travel of most recent trip on the freeway*					
Weekday	91	84	94	89	91
Weekend	9	16	6	11	9
Direction of travel*					
Toward downtown	49	51	46	53	49
Away from downtown	51	49	54	47	51
Use of GPLs/managed lanes (based on travel direction)*					
GPLs (toward downtown)	38	36	19	21	30
GPLs (away from downtown)	39	30	19	18	30
Managed lanes (toward downtown)	11	15	27	32	19
Managed lanes (away from downtown)	12	19	35	29	21
Trip purpose*					
Commuting to or from my place of work	59	40	55	60	58
Recreational/social/shopping/entertainment/ personal errands	20	39	18	23	21
Work related (other than to or from home to work)	19	18	24	11	19
To attend class at school or educational institute	1	2	2	2	1
Other	1	2	1	3	2
Vehicle type*					
Passenger car/SUV/pickup	53	3	26	18	100
Driver or passenger*					
Driver	96	80	97	88	95
Passenger	4	20	3	12	5
Number of vehicle occupants*					
1	82	33	82	41	73
2	12	49	14	40	19
3	3	3	2	12	4
4	2	9	2	3	2
5	1	6	1	5	2
Who did you travel with*					
Co-worker/person in the same, or a nearby, office building	12	25	22	25	5
Neighbor	4	4	8	3	1
Adult family member	67	61	51	51	15
Another commuter in a casual carpool (also known as slugging)	1	1	1	4	1
Child	31	28	21	27	7
Other	8	1	8	4	2

Table 51. Traveler Data by Mode Choice (Online Survey) (Continued).

Characteristic Mode	Percent of Travelers Choosing Mode				All
	DA-GPL A	CP-GPL B	DA-ML C	CP-ML D	
Ever change entry or exit to have easier access to/from the managed lanes*					
Yes	47	67	47	53	49
No	53	33	53	47	51
Number of changes of entry or exit to have easier access to/from the managed lanes*					
0	3	0	0	2	2
1	51	42	54	54	53
2	31	38	29	35	32
3	15	21	16	9	14
Respondents indicated travel time of their most recent trip*					
1 to 5 minutes	1	2	0	0	1
6 to 10 minutes	5	4	3	2	4
11 to 15 minutes	7	10	5	4	6
16 to 20 minutes	11	6	11	8	10
21 to 25 minutes	9	16	10	7	9
26 to 30 minutes	12	15	10	12	12
31 to 35 minutes	8	6	8	9	8
36 to 40 minutes	8	8	8	8	8
41 to 45 minutes	13	16	13	16	14
46 to 50 minutes	4	7	7	4	5
51 to 55 minutes	2	0	3	3	3
56 to 60 minutes	8	8	8	9	8
60+ minutes	12	4	14	16	13
Ever used the managed lanes*					
Yes	69	64	87	76	73
No	31	36	13	24	27
Reasons for using the managed lanes*					
Access to/from to the tollway lanes is convenient for my trips	13	5	18	5	12
Being able to use the lanes for free as a carpool	25	33	18	52	26
Travel times on the tollway lanes are consistent and predictable	17	18	28	14	18
The tollway saves time	69	50	78	64	64
During the peak hours, the tollway will not be congested	34	45	41	37	34
The tollway lanes are safer than the GPLs	17	13	23	21	17
The tollway lanes are less stressful than the GPLs	37	8	48	41	36
Trucks and large vehicles are not allowed on the tollway	12	10	23	18	14
Someone else pays my tolls	4	0	5	5	4
Other	11	13	4	12	9

Table 51. Traveler Data by Mode Choice (Online Survey) (Continued).

Characteristic Mode	Percent of Travelers Choosing Mode				All
	DA-GPL A	CP-GPL B	DA-ML C	CP-ML D	
Reasons for not using the managed lanes*					
Access to/from to the Katy Tollway lanes is not convenient for my trips	19	16	24	4	17
I have the flexibility to travel at less congested times	20	36	16	19	19
I do not feel safe traveling on the tollway lanes	3	4	0	0	2
The toll is too expensive for me	39	16	26	33	35
The tollway does not offer me enough time savings	38	28	29	21	33
I can easily use routes other than Katy Freeway, so I'll just avoid Katy Freeway if I think there is a lot of traffic	18	4	16	10	16
It is too complicated/confusing to use the tollway	12	16	13	40	15
I avoid toll roads whenever possible	33	32	18	6	27
I don't want to have a toll transponder in my vehicle	13	16	16	10	13
I don't have the credit card needed to set up a toll transponder account	3	0	3	0	2
I don't like that the toll changes based on the time of day	28	16	13	27	25
I don't have anyone to carpool with	23	8	13	27	21
Other	13	12	8	10	12
Law enforcement*					
Providing too little enforcement on the Katy Tollway?	24	30	25	48	29
Providing too much enforcement on the Katy Tollway?	22	11	22	12	19
Providing the right level of enforcement on the Katy Tollway?	54	59	54	41	52
Number of trips on the GPLs in last week*					
0	8	10	14	20	12
1	6	6	9	10	7
2	11	12	14	11	11
2.5	0	0	0	0	0
3 to 5	25	30	29	22	25
6 to 10	44	37	29	31	37
11 to 15	5	1	3	5	4
16 to 20	1	3	2	2	1
21 to 25	0	0	1	0	0
26 to 30	0	0	0	1	0
30+	0	0	0	0	0

Table 51. Traveler Data by Mode Choice (Online Survey) (Continued).

Characteristic Mode	Percent of Travelers Choosing Mode				All
	DA-GPL A	CP-GPL B	DA-ML C	CP-ML D	
Number of trips on the managed lanes in last week*					
0	40	33	22	24	31
1	12	14	13	12	12
2	12	12	14	10	12
2.5	0	0	0	0	0
3 to 5	24	14	29	22	24
6 to 10	11	27	22	32	20
11 to 15	0	0	0	1	0
16 to 20	0	0	0	0	0
21 to 25	0	0	0	0	0
26 to 30	0	0	0	0	0
30+	0	0	0	0	0
Average toll paid per trip*					
Less than $1.00	19	33	9	35	20
$1.00 to $1.99	25	25	16	13	20
$2.00 to $3.99	24	10	30	14	24
More than $4.00	16	8	20	17	17
Don’t remember	16	25	25	20	20
Perceived travel time savings (from using the managed lanes)*					
Less than 2 minutes	5	2	2	1	3
3 to 5 minutes	13	19	7	6	9
6 to 10 minutes	26	24	22	16	22
11 to 15 minutes	21	33	25	20	23
16 to 20 minutes	14	2	17	24	17
21 to 25 minutes	7	13	9	9	8
26 to 30 minutes	5	2	4	9	5
More than 30 minutes	2	6	5	4	4
Unsure	8	0	9	11	9
Pay for parking in Houston*					
Yes	17	30	18	14	17
No	83	70	82	86	83

Table 51. Traveler Data by Mode Choice (Online Survey) (Continued).

Characteristic Mode	Percent of Travelers Choosing Mode				All
	DA-GPL A	CP-GPL B	DA-ML C	CP-ML D	
Parking cost per day ($)*					
0	1	0	2	0	1
0.01 to 1.00	5	0	1	4	3
1.01 to 2.00	4	10	4	1	4
2.01 to 3.00	11	6	7	8	9
3.01 to 5.00	17	13	26	23	20
5.01 to 10.00	39	32	35	42	38
10.01 to 15.00	18	35	12	10	16
15.01 to 20.00	4	3	6	7	5
20.01 to 25.00	2	0	3	4	2
25.01 to 30.00	0	0	0	0	0
30+	0	0	4	0	1
Gender*					
Male	62	53	60	57	60
Female	38	47	40	43	40
Age*					
18 to 24	3	4	2	5	3
25 to 34	26	34	26	28	26
35 to 44	24	23	26	27	25
45 to 54	23	26	22	24	23
55 to 64	16	11	18	12	16
64 or older	6	3	5	1	5
Refused	2	0	1	2	2
Race/ethnicity*					
White/Caucasian	77	65	82	69	76
Hispanic/Latino	6	8	7	12	7
African American	4	6	2	5	4
Asian American	4	8	3	6	4
Native American	0	0	1	0	0
Refused	10	13	5	8	8
Highest level of education*					
Less than high school	0	0	0	1	1
High school graduate	4	7	2	3	3
Some college or vocational school	18	12	23	22	20
College graduate	47	40	49	40	46
Postgraduate degree	27	37	24	30	27
Refused	4	4	2	4	3

Table 51. Traveler Data by Mode Choice (Online Survey) (Continued).

Characteristic Mode	Percent of Travelers Choosing Mode				All
	DA-GPL A	CP-GPL B	DA-ML C	CP-ML D	
Income*					
Less than $10,000	1	2	1	2	1
$10,000 to $14,999	1	0	1	1	1
$15,000 to $24,999	1	1	0	1	1
$25,000 to $34,999	3	0	2	2	2
$35,000 to $49,999	6	16	5	6	6
$50,000 to $74,999	16	17	13	13	15
$75,000 to $99,999	18	20	18	19	18
$100,000 to $199,999	40	36	43	47	42
$200,000 or more	12	8	16	9	13

* = Significant (p <0.05) differences between respondents by mode chosen.
A = These sum to more than 100% as respondents could select multiple answers to this question.
B = Due to a mistake in the question skip pattern of the survey, respondents who used MLs on their current trip were not asked their reasons for using the lanes.
C = Due to a mistake in the question skip pattern of the survey, respondents who used MLs on their current trip were the only group asked this question.

Carpooling Behavior

The percentage of travelers who carpool and the frequency with which they carpool will have a significant impact on the use of the managed lanes—particularly the HOV lane, which is free to HOV travelers during most daylight hours. The survey asked respondents about their last trip and, if they were carpooling, gathered additional information on their carpooling behavior. The sample is relatively small—only 1027 respondents out of over 260,000 who use the Katy Freeway every day—and may not be representative of the entire Katy Freeway driving population. However, the results are similar to past surveys of Katy Freeway travelers, providing some assurance that the results are at least consistent.

To categorize travelers as carpoolers or SOVs, the question regarding the number of people in their vehicle on their most recent trip was used. Three respondents did not answer this question, leaving 1024 responses to examine. Of those 1024, 73 percent were SOVs, 18.6 percent were HOV-2s, and 8.4 percent were HOV-3+. This resulted in an average vehicle occupancy (AVO) of 1.41, which is reasonable when considering trips made over an entire day. During the peak period, the AVO was 1.36, somewhat higher than typical. During the shoulder and off-peak periods, the AVO was 1.44, fairly typical. Therefore, this sample may have a higher percentage of peak-period carpoolers than is typical. This was likely due to a fairly high percentage of the respondents who were using the managed lanes on their trip. Forty percent of all respondents and 36 percent of SOVs indicated that they had used the managed lanes for their last trip. This is a higher percentage than in the actual traffic stream because the percentage of managed lane users rarely exceeds one-third. Therefore, this sample is biased toward managed lane users.

Table 52 summarizes the questions asked of carpoolers, and their responses, and also includes a comparison of carpoolers and SOV travelers. In most aspects, carpoolers and SOVs were not significantly different ($p \leq 0.05$). One of the few differences was trip purpose, with more carpoolers conducting trips other than commuting. Surprisingly, the reasons for not using the managed lanes were not significantly different between carpoolers and SOVs. Both groups mentioned the expense as the most frequently cited reason for not using the lanes. Forty percent of carpoolers and 32 percent of SOVs cited this reason. This was surprising, considering the lanes are toll-free much of the time for carpools. Several possible explanations exist:

- Carpoolers who indicated this reason may have been traveling during times of the day when there was a toll. In examining the data, a similar percentage of carpoolers traveled in the off-peak (tolled times for HOVs), as SOVs did. When focusing on carpoolers who indicated the expense was their reason for not using the managed lanes, it was found that 44 percent traveled in the off-peak. This was not significantly different from the percentage of all carpoolers traveling in the off-peak. Therefore, time of day of travel was not the reason.
- Carpoolers may have misunderstood that they did not have to pay toll during off-peak periods. Although it was noted in the survey that carpools do not have to pay in the peak period, many may have thought this meant the traditional, short, peak-period time frames. In reality, it is most of the day (5:00 to 11:00 AM and 2:00 to 8:00 PM). This may be causing confusion for carpoolers in Houston.
- Carpoolers, like many people the researchers have surveyed, may generally dislike tolls and indicated this was their reason despite the fact they could travel toll-free most of the time.

One other item to note, as with other studies, is that approximately three-quarters of all carpools were with family members.

Table 52. Comparison of SOVs and Carpoolers.

Characteristic	**Percent of Travelers Driving as…**	
	SOV	**Carpool (HOV-2+)**
Trip purpose*		
Commuting to or from my place of work	66	32
Recreational/social/shopping/entertainment/personal errands	11	45
Work related (other than to or from home to work)	19	17
To attend class at school or educational institute	2	1
Other	1	4
Driver or passenger*		
Driver	100	79
Passenger	0	21

Table 52. Comparison of SOVs and Carpoolers (Continued).

Characteristic	Percent of Travelers Driving as…	
	SOV	Carpool (HOV-2+)
Who did you travel with		
Co-worker/person in the same, or a nearby, office building		17
Neighbor		3
Adult family member		49
Another commuter in a casual carpool (also known as slugging)		2
Child		24
Other		5
Amount of extra time required to form the carpool (minutes)		
0		55
1 to 5		16
6 to 10		10
11 to 20		9
21 to 30		6
Over 30		5
Ever used the managed lanes*		
Yes	80	55
No	20	45
Reasons for using the managed lanes[A,B]		
Access to/from to the tollway lanes is convenient for my trips	12	5
Being able to use the lanes for free as a carpool	24	17
Travel times on the tollway lanes are consistent and predictable	16	13
The tollway saves time	65	27
During the peak hours, the tollway will not be congested	31	22
The tollway lanes are safer than the GPLs	22	12
The tollway lanes are less stressful than the GPLs	35	20
Trucks and large vehicles are not allowed on the tollway	13	8
Someone else pays my tolls	4	2
Reasons for not using the managed lanes[A]		
Access to/from to the Katy Tollway lanes is not convenient for my trips	19	14
I have the flexibility to travel at less congested times	20	19
I do not feel safe traveling on the tollway lanes	1	5
The toll is too expensive for me	32	40
The tollway does not offer me enough time savings	32	34
I can easily use routes other than Katy Freeway, so I'll just avoid Katy Freeway if I think there is a lot of traffic	16	16
It is too complicated/confusing to use the tollway	11	21
I avoid toll roads whenever possible	27	24
I don't want to have a toll transponder in my vehicle	11	14
I don't have a credit card needed to set up a toll transponder account	1	3
I don't like that the toll changes based on the time of day	26	22
I don't have anyone to carpool with	28	7
Other	9	14

Table 52. Comparison of SOVs and Carpoolers (Continued).

Characteristic	Percent of Travelers Driving as…	
	SOV	Carpool (HOV-2+)
Law enforcement*		
Providing too little enforcement on the Katy Tollway?	25	34
Providing too much enforcement on the Katy Tollway?	21	17
Providing the right level of enforcement on the Katy Tollway?	54	49
Gender		
Male	61	58
Female	39	42
Age		
18 to 24	3	4
25 to 34	26	25
35 to 44	26	24
45 to 54	23	22
55 to 64	16	16
64 or older	4	6
Refused	2	3
Race/ethnicity		
White/Caucasian	77	71
Hispanic/Latino	6	12
African American	4	4
Asian American	4	5
Native American	1	0
Refused	8	8
Highest level of education		
Less than high school	1	1
High school graduate	3	6
Some college or vocational school	19	21
College graduate	46	43
Postgraduate degree	28	24
Refused	3	5
Income		
Less than $10,000	1	1
$10,000 to $14,999	1	1
$15,000 to $24,999	1	2
$25,000 to $34,999	3	3
$35,000 to $49,999	6	8
$50,000 to $74,999	15	15
$75,000 to $99,999	17	20
$100,000 to $199,999	43	38
$200,000 or more	13	12

* = Significant ($p < 0.05$) differences between carpoolers and SOVs.
A = Sum to more than 100 percent because respondents could select multiple answers to this question.
B = Due to a mistake in the question skip pattern of the survey, respondents who used managed lanes on their current trip were not asked their reasons for using the lanes.

Use and Impressions of the Managed Lanes

As discussed previously, the survey sample may be biased toward managed lane users, which is helpful to get more information on who is using these lanes. In Table 50 and Table 51, the overall use of managed lanes and the reasons for their use or non-use by all respondents is provided. Table 53 examines the respondents based on whether they:

- Used the managed lanes on their last Katy Freeway trip.
- Have ever used the managed lanes, just not on their last Katy Freeway trip.
- Have never used the KML.

Travelers who had never used the managed lanes were significantly more likely to be traveling on the weekend and less likely to be traveling for work or commute purposes. Based on this, one may expect these non-managed-lane users to be infrequent travelers of the Katy Freeway who are unfamiliar with the rules and benefits of the managed lanes. However, this group (never used the managed lanes) took an average of 5.5 trips per week on the Katy Freeway. This is similar to those who had used the managed lanes on their last trip (4.8 trips per week) and those who had used the managed lanes in the past (6.7 trips per week). They also took trips of similar length (37 minutes versus 37.6 minutes for respondents who used the managed lanes in the past and 41.5 minutes for respondents who used managed lanes on their most recent trip). Therefore, these non-managed-lanes users are frequent Katy Freeway travelers; they just use it more often on the weekend and for purposes other than commuting.

The main reasons for using the managed lanes was that the tollway saves time (cited by 64 percent of managed lane users), is less stressful (36 percent), and is not congested (34 percent). The main reasons for never using the managed lanes was that the toll was too expensive (35 percent of non-managed-lane users), the managed lanes do not offer enough travel time savings (34 percent), and they avoid tolls whenever possible (27 percent). Those that used the managed lanes for their last trip perceived an average travel time savings of 14.1 minutes, while those that have used it in the past perceived a time savings of 10.8 minutes. Although it is possible to save this much time on the managed lanes, more frequently the time savings is closer to the average of 3.6 minutes (214 seconds). Therefore, travelers are perceiving more travel time savings than they actual receive—a common occurrence on managed lanes.

Respondents who had used the managed lanes on their most recent trip were the least pleased with the amount of enforcement on the lanes. Interestingly, 32 percent wanted additional enforcement, while 22 percent wanted less enforcement.

Table 53. Traveler Data by Lane Used (Managed Lane versus GPL).

Characteristic	Percent of Travelers Who Had Used the KML			
	This Trip (n = 420)	In the Past (n = 443)	Never (n = 164)	All
Day of travel of most recent trip on the Katy Freeway*				
Weekday	95	91	81	91
Weekend	5	9	19	9
Direction of travel				
Toward downtown	47	51	51	49
Away from downtown	53	49	49	51
Time of day				
Peak	34	32	33	33
Shoulder	41	36	33	38
Off-peak	25	32	34	30
Trip purpose*				
Commuting to or from my place of work	62	59	40	57
Recreational/social/shopping/entertainment/personal errands	16	18	39	21
Work related (other than to or from home to work)	2	1	1	2
To attend class at school or educational institute	17	20	19	19
Other	3	1	1	1
Number of vehicle occupants*				
1	65	84	64	73
2	24	11	25	19
3	7	2	5	4
4	2	2	4	2
5	2	1	2	2
Who did you travel with				
Co-worker/person in the same, or a nearby, office building	21	15	10	17
Neighbor	5	2	1	3
Adult family member	44	52	55	49
Another commuter in a casual carpool (also known as slugging)	2	0	3	2
Child	23	27	22	24
Other	5	2	9	5
Ever change entry or exit to have easier access to/from the managed lanes*[C]				
Yes	49			
No	51			
Number of changes of entry or exit to have easier access to/from the managed lanes* [C]				
0	-			
1	53			
2	33			
3	14			

Table 53. Traveler Data by Lane Used (Managed Lane versus GPL) (Continued).

Characteristic	Percent of Travelers Who Had Used the KML			
	This Trip (n = 420)	In the Past (n = 443)	Never (n = 164)	All
Respondents indicated travel time of their most recent trip*				
1 to 5 minutes	0	0	2	1
6 to 10 minutes	2	3	6	3
11 to 15 minutes	4	6	11	6
16 to 20 minutes	8	10	14	9
21 to 25 minutes	8	9	8	8
26 to 30 minutes	10	12	10	11
31 to 35 minutes	7	8	6	7
36 to 40 minutes	9	7	6	8
41 to 45 minutes	14	11	11	12
46 to 50 minutes	6	4	2	5
51 to 55 minutes	4	2	1	3
56 to 60 minutes	8	8	6	8
60+ minutes	20	19	16	19
Reasons for using the managed lanes[A,B]				
Access to/from to the tollway lanes is convenient for my trips		12		
Being able to use the lanes for free as a carpool		26		
Travel times on the tollway lanes are consistent and predictable		18		
The tollway saves time		64		
During the peak hours, the tollway will not be congested		34		
The tollway lanes are safer than the GPLs		17		
The tollway lanes are less stressful than the GPLs		36		
Trucks and large vehicles are not allowed on the tollway		14		
Someone else pays my tolls		4		
Other		9		
Reasons for not using the managed lanes[A]				
Access to/from to the Katy Tollway lanes is not convenient for my trips			17	
I have the flexibility to travel at less congested times			20	
I do not feel safe traveling on the tollway lanes			2	
The toll is too expensive for me			35	
The tollway does not offer me enough time savings			34	
I can easily use routes other than Katy Freeway, so I'll just avoid Katy Freeway if I think there is a lot of traffic			16	
It is too complicated/confusing to use the tollway			15	
I avoid toll roads whenever possible			27	
I don't want to have a toll transponder in my vehicle			13	
I don't have a credit card needed to set up a toll transponder account			2	
I don't like that the toll changes based on the time of day			25	
I don't have anyone to carpool with			21	
Other			12	

Table 53. Traveler Data by Lane Used (Managed Lane versus GPL) (Continued).

Characteristic	Percent of Travelers Who Had Used the KML			
	This Trip (n = 420)	In the Past (n = 443)	Never (n = 164)	All
Law enforcement*				
Providing too little enforcement on the Katy Tollway?	32	25	27	28
Providing too much enforcement on the Katy Tollway?	22	17	21	20
Providing the right level of enforcement on the Katy Tollway?	46	58	52	52
Number of trips on the GPLs in last week*				
0	19	7	8	12
1	7	7	10	7
2	14	8	17	12
3 to 5	31	20	24	25
6 to 10	25	50	36	37
11 to 15	2	6	4	4
16 to 20	1	2	1	1
21 to 25	0	0	0	0
26 to 30	0	0	0	0
30+	0	0	0	0
Number of trips on the managed lanes in last week*				
0	11	50		31
1	11	14		12
2	11	14		12
3 to 5	32	17		24
6 to 10	35	4		19
11 to 15	0	0		0
16 to 20	0	0		0
21 to 25	0	0		0
26 to 30	0	0		0
30+	0	0		0
Average toll paid per trip				
Less than $1.00	21	17		20
$1.00 to $1.99	15	26		19
$2.00 to $3.99	24	23		24
More than $4.00	19	15		17
Don't remember	21	19		20
Perceived travel time savings (from using the managed lanes)*				
Less than 2 minutes	1	5		3
3 to 5 minutes	8	12		10
6 to 10 minutes	17	31		22
11 to 15 minutes	24	20		22
16 to 20 minutes	17	16		17
21 to 25 minutes	10	5		8
26 to 30 minutes	7	4		6
More than 30 minutes	5	0		4
Unsure	10	7		9

Table 53. Traveler Data by Lane Used (Managed Lane versus GPL) (Continued).

Characteristic	Percent of Travelers Who Had Used the KML: This Trip (n = 420)	In the Past (n = 443)	Never (n = 164)	All
Pay for parking in Houston				
Yes	18	16	22	18
No	82	84	78	82
Gender				
Male	58	60	64	60
Female	42	40	36	40
Age				
18 to 24	3	3	4	3
25 to 34	27	24	30	26
35 to 44	28	25	23	25
45 to 54	21	26	17	23
55 to 64	17	15	13	16
64 or older	3	5	10	5
Refused	1	2	3	2
Race/ethnicity*				
White/Caucasian	76	76	70	75
Hispanic/Latino	10	5	7	8
African American	3	4	5	4
Asian American	3	5	7	4
Native American	1	1	0	1
Refused	7	9	11	8
Highest level of education*				
Less than high school	1	1	0	1
High school graduate	3	3	7	4
Some college or vocational school	22	18	20	19
College graduate	50	45	33	45
Postgraduate degree	21	29	36	27
Refused	3	4	4	4
Income*				
Less than $10,000	0	1	4	1
$10,000 to $14,999	1	1	1	1
$15,000 to $24,999	1	1	2	1
$25,000 to $34,999	2	3	3	2
$35,000 to $49,999	5	7	8	6
$50,000 to $74,999	16	12	22	15
$75,000 to $99,999	18	19	16	18
$100,000 to $199,999	43	43	34	42
$200,000 or more	15	13	7	13

* = Significant ($p < 0.05$) differences between users and non-users of KMLs.

A = These sum to more than 100 percent because respondents could select multiple answers to this question.

B = Due to a mistake in the question skip pattern of the survey, respondents who used managed lanes on their current trip were not asked their reasons for using the lanes.

C Due to a mistake in the question skip pattern of the survey, respondents who used managed lanes on their current trip were the only group asked this question.

Lastly, this section examines the different demographic characteristics of these three groups of travelers to identify any potential equity issues with the use of the managed lanes. The equity issue concerning toll facilities often focuses on the users' ability to pay based on their income. The annual household income of non-managed-lane users (average of $102,743/year) was found to be significantly lower than that of the other two groups (average of $127,553/year) —although all groups were fairly well-off based on annual income. This is similar to results from other managed lanes where all income categories use the lane, but higher income travelers tend to use the lanes more. Also with respect to equity, the race of the travelers is often examined. In this case, a higher percentage of minorities have never used the managed lanes although, like with income, all races are using the lanes. Both of these issues may indicate an opportunity to attract more travelers to the lanes by reaching out to lower-income and minority groups.

Multinomial Logit Models of Mode Choice

In the previous section, the characteristics of the survey respondents were compared based on their chosen mode in the SP questions (Table 51).

The modes included SOV or HOV on managed lanes or GPLs, and varied based on time of day, travel time, travel time variability, and toll values. This analysis provides some indication as to how different characteristics/variables may affect decision making in mode choice. However, such one-dimensional analysis is constrained to incorporating only one variable at a time. In this section, using the SP data, the prediction and modeling of mode choice were developed using the MNL modeling technique. The MNL model can incorporate multiple factors to provide a better understanding of the influence of included variables. Based on previous studies for mode choice models with managed lanes, the models should include the travel time, travel time variability, and toll cost as explanatory variables.

To predict the mode choice and estimate the value of time and time variability, the MNL model developed here included travel time, travel time variability, and toll rate (see Table 54). This is the UT-based ML model assuming the travel time was from a uniform distribution for a hypothetical trip. The data used for this model were from SP questions presented in Format 1 (see Table 40 and Figure 84) developed for two survey design strategies (D_b-efficient and adaptive random). This resulted in a dataset including 793 observations from 265 respondents. The *toll rate*, *alternative specific constant* for modes *CP-GPL* and *CP-ML* parameters are statistically significant at 1 percent level. This model yields reasonable results with a log-likelihood (LL) ratio-test value of 9.94 (with critical $\chi^2_{(1)d.f.}$ = 3.841 at α = 0.05) with respect to a constant-only base model, and a value of travel time of $20.80 per hour and a low value of hour (see Table 54).

Table 54. Multinomial Logit Model for Respondents Presented with SP Question in Format 1.

Variable	Alternative(s)	Coefficient	Standard Error	Prob $\|z\|>Z^*$
Random Parameters in the Utility Functions				
ASC-CP-GPL	CP-GPL	-3.20^{***}	0.26	0.00
ASC-DA-ML	DA-ML	−0.39	0.28	0.17
ASC-CP-ML	CP-ML	-1.06^{***}	0.28	0.00
Travel Time (Minutes)	All	−0.05	0.04	0.17
Travel Time Variability (Minutes)	All	0.01	0.05	0.91
Toll Rate (Dollars)	DA-ML	-0.15^{***}	0.05	0.00
	Goodness-of-fit			
Log-Likelihood for Constants-Only Model	−894.93			
Log-Likelihood at Convergence	−889.96			
LL Ratio-Test (-2LL Function)	9.94			

* Significance at 10 percent level.
** Significance at 5 percent level.
*** Significance at 1 percent level.
LL *ratio-test* = $-2(LL_{BaseModel} - LL_{EstimatedModel})$.
ASC = alternative specific constant coefficient.

INTERVIEW RESULTS

To conduct a comprehensive evaluation of the KML, researchers interviewed individuals that were involved with or instrumental in the development of the KML and the ongoing operations of the KML. The objective in conducting these interviews was to identify best practices and highlight lessons learned that can be used in support of successful implementation of managed lanes projects across Texas. Nine interviews were conducted. Interviewees included:

- Current and former employees of TxDOT and METRO.
- Employees of HCTRA and Harris County.
- Elected officials.

Each interview lasted from one to two hours, and the majority of the interviews were conducted in person although some phone interviews were also conducted. To facilitate the interview process, an interview guide was developed. The sections of the interview included:

- Project development, including the tri-party agreement.
- Operational policy development.
- Toll policy development.
- Design.
- Maintenance.
- Operations.
- Enforcement.

The interviews are the best recollections of those who were interviewed. In some cases, information contradicted other information. The following represents a consensus from the interviews.

Project Development

The KML project was the culmination of several years of project development activities. These activities ranged from simply acknowledging that the existing facility at the time could not continue to serve the demand in the corridor, to discussions of a passenger rail corridor. Both TxDOT and METRO recognized that three to four lanes in each direction with a reversible HOV lane would not provide an acceptable level of service to a rapidly growing population nor enhance the economic competitiveness of the “energy corridor.”

The need to expand capacity in the corridor was acknowledged as early as the 1980s. At that time TxDOT operated the freeway, and METRO was responsible for the single, reversible HOV lane on the facility. The operations of the HOV lane had changed several times over the year in an attempt to maximize the use of the lane. In 1995, an MIS was conducted that identified several alternatives for expanding the freeway. The MIS identified the addition of special-use lanes as a viable alternative although the special use was not identified. The metropolitan planning organization (H-GAC) adopted the MIS in 1997, and work began on an environmental impact statement (EIS). Several options were considered including creating elevated sections, but this met with considerable resistance from the public. During this process, it became apparent that there were considerable ROW needs, which was also a public concern. The MIS also indicated that funding was not available to construct the project. At the time, METRO was negotiating to buy land from the Union Pacific railroad in hopes of making the corridor a high-capacity transit corridor that included adding a rail component. The operation of METRO and the probability of adding rail to its responsibilities was a contentious issue at the time. The public had recently rejected a proposal for a rail initiative by referendum. The lack of confidence in METRO may have contributed to the inability to conclude the purchase of the ROW. Instead, TxDOT was able to acquire the ROW with the help of state officials. This ROW acquisition helped refine some of the alternatives being considered. TxDOT continued with a design of adding four special-use lanes and two GPLs, one in each direction. The initial estimated cost was $900 million.

Most interviewees agreed that it took strong political will to get several of the local players to cooperate in the project development. In some instances, it was also necessary to convince members of the Texas Transportation Commission and the Texas Legislature to support the project. It was necessary to keep TxDOT administration apprised of the project in a more direct fashion than is typical in order to keep the project moving. The political influence seemed to aid in project acceleration. Because TxDOT still did not have adequate funding for the project, HCTRA stepped in to offer a $250 million contribution in exchange for operating the special-use lanes as a toll road. Because TxDOT had already decided to operate the four lanes as the special-use lanes, it was relatively easy for HCTRA to step in and help design the tolling infrastructure. However, METRO was still a partner agency and still responsible for operating the existing HOV lane. HCTRA had consultants conduct traffic and revenue feasibility studies to analyze under which scenarios the investment made financial sense.

These negotiations initiated what is known as the tri-party agreement. The agreement broadly defines the roles and responsibilities of the parties. TxDOT initiated the agreement, with HCTRA and FHWA as signatories. Eventually, an amendment was added that included METRO to the agreement. No template used in drafting the agreement, and the draft broadly defines the purpose of the agreement and the scope of the project. Subsequent agreements such as the operations and maintenance agreements describe in detail the specific procedures and protocols involved in operating and maintaining the entire corridor.

Several stakeholders were very influential in progressing and expediting the process of approving and constructing the KML project. They provided sufficient pressure to move the project throughout its various stages at an unprecedented rate. The stakeholders were also influential in the selection and elimination of some early design elements.

Design

The design of the managed lane was already under way when HCTRA got involved, so there was minimal discussion of ingress and egress points. TxDOT was originally responsible for "pavement and pylons," and HCTRA would take care of the tolling equipment and booths. Because there was very little guidance regarding managed lanes, many decisions were based on best judgment. HCTRA's consultant determined where tolling zones would be located based on its studies. There was a desire to maintain the existing level of access to the Katy Freeway due to potential public opposition if changes were made. Cost prohibitions limited some potential designs such as direct access from BW 8 into the managed lanes. Other exits were influenced by development in the corridor. There were no design exceptions required from FHWA, but new access points to the interstate required approval. The inside and outside shoulders are 12 feet wide to accommodate re-striping in the future. In retrospect, some of the shoulders could have been whittled away to better accommodate toll gantries, but at the time the location of the toll gantries was unknown.

The parties held considerable discussion about the separation from the main lanes. HCTRA's preference was to have concrete barrier separation. This was also the preference of the Harris County Constable's office that would be responsible for enforcement on the facility according to the operating agreements. This was seen as a safety issue and went so far as to involve state representatives. Other parties were concerned that having concrete barriers would create a "concrete canyon" and strenuously opposed this. Ultimately, the "candlestick pylons" were chosen with the provision that HCTRA would maintain them.

There was some "conflict" between TxDOT and METRO concerning the project design because METRO wanted to preserve the corridor as a potential rail corridor. Other parties did not see this as a priority, and because METRO was not as financially invested in the project, the request was not a priority. However, because the original HOV lane had been constructed with

FTA funds, they were able to negotiate to keep buses in the corridor. Additionally, METRO did make financial contributions to ensure that several of the overpasses would support future rail operations. The stakeholders disapproved of the use of rail in the corridor and pushed for a redesign without it.

The original plan allotted three lanes at each of the three toll plazas, but that limited room for enforcement. There was recognition that manual enforcement would be the only viable option for the foreseeable future. There was also a capacity consideration for the third lane. Now, the HOV traffic goes through one lane, and everyone else goes through the second lane at the toll gantry. Although there was a concern for lane balance, this arrangement seems to be working at this point. However, it is acknowledged that the corridor is quickly reaching capacity in certain locations at certain times. Operational changes may be needed to prevent further decline of service.

Operations

As noted previously, there was one reversible HOV lane previously operating in the corridor. The QuickRide program was also deployed in the corridor. During the peak hours (6:45 to 8:00 AM and 5:00 to 6:00 PM), the HOV requirement on the Katy HOV lane was 3+. Two-person carpools were allowed access to the facility for a $2 toll. At other times, the minimum HOV requirement was 2+ when the lane was open. SOVs were prohibited at all times. The single HOV lane was over capacity with two-person carpools but underutilized with 3+, hence the QuickRide program. However, with the addition of an extra lane, there would be much more capacity.

As the project progressed, HCTRA consultants analyzed various operating scenarios for financial viability. This goal had to be balanced with mobility goals. TxDOT took the lead on developing operating agreements. It was felt that TxDOT had the best information and overall best knowledge. Developing the operating agreements was an arduous process. An operations committee of TxDOT, HCTRA, and METRO formed to complete the agreements.

Enforcement

The Harris County Constables conduct enforcement of the managed lanes. Officers regularly patrol the managed lanes and randomly perform occupancy inspections from enforcement areas located adjacent to the tolling gantries. Typically, an officer stationed at one area will radio the officer at the next area regarding the violator's vehicle and license number. The second officer then makes the stop. There is a strict "no pen on the paper" rule on the managed lanes. Tickets are issued electronically. In the event of an accident or crime, the vehicles are escorted off the facility where paperwork is completed. Toll violations are issued most, as opposed to occupancy violations. But the most commonly written ticket on the managed lanes is for speeding. Observation booths are located in the enforcement areas as well. Other HCTRA personnel often count vehicles/occupancy from these booths, but they are not tasked with enforcement duties. It is often difficult to determine occupancy from the booth. There is some concern that enforcing a 3+ occupancy will be very difficult. Already, one in four cars pulled over has a child in the backseat.

The officers on the facility recognize that there is a delicate balance between enforcement and mobility. When enforcement is too aggressive, it can impact traffic flow in the managed lanes. Often angry commuters will call to complain of slowdowns presumably caused by an officer's presence in the lane.

CONCLUSIONS

This chapter examines the results of a 2012 survey of Katy Freeway travelers. The survey examined respondents' most recent trip on the Katy Freeway, their typical travel on the Katy Freeway, their use, or non-use, of the managed lanes (MLs), their reasons for using, or not using, the MLs, and their socioeconomic characteristics. Additionally, respondents answered three stated preference (SP) questions regarding their use of the MLs.

A total of 1067 surveys were completed with a high percentage (58 percent) that had used MLs at least once. Thus, most of our sample had firsthand experience using the lanes. There were few differences between SOVs and carpools with respect to their use of MLs. Even the reasons for using, or not using, the MLs were similar for the two groups. The most cited reason for not using the MLs was the cost—even though the MLs are free for carpoolers during most of the day. The next most cited reasons were not enough travel time savings and the respondent avoids tolls whenever possible. The main reasons cited for using the MLs were saving time, less stressful, and not congested.

Most travelers who used the MLs for their most recent trip perceived an average travel time savings of over 10 minutes—well above the average travel time savings of just under 4 minutes. This may be because our survey respondents just happen to be the travelers who saved much more time than average. However, it is more likely that our respondents perceive their time savings to be much greater than actual. This has happened on other ML facilities. The annual household income for ML users was higher than non-users, but both groups exceeded $100,000 per year. In addition, a smaller percentage of minorities used the lanes.

Lastly, models of lane choice were developed using the data from the SP questions in the survey. Based on these models, respondents had an average value of time of $20.80/hour and a value of reliability of $2.20/hour. These are much lower than the results from the actual usage of the Katy MLs where the average value of time was close to $60/hour. This is likely due to travelers who sometimes pay for very small travel time savings in reality but would not answer that way on a survey question.

CHAPTER 12. PROJECT DELIVERY MECHANISM

The KML project took place within a complex environment of multiple public agencies involved, stakeholders pressing for influence, and a public dissatisfied with a congested freeway. This environment created a need for close collaboration and coordinated efforts to reconstruct the Katy Freeway. The agencies created several agreements that forged the formal relationship that enabled them to successfully navigate the development, construction, and operations of the Katy Freeway and managed lanes. This chapter analyzes how the relationships succeeded and the way conflicts were handled. The assessment provides lessons learned and highlights practices that will aid future project developments with public-public partnerships.

The process can be divided into three distinct periods:

- 2002 and earlier: before the formalized agreements.
- 2002 to 2009: the project development period.
- 2009 to 2012: the project implementation and operation period.

This chapter describes the most relevant events and issues during these periods. Some of the information discussed here originates from a series of interviews the TTI research team performed with members of the partnering agencies and other stakeholders in the process.

2002 AND EARLIER: BEFORE THE FORMALIZED AGREEMENTS

Prior to the 2002 MOU, several important events occurred that illustrate some of the opportunities and challenges that occur when agencies collaborate. During the late 1980s and early 1990s, it became apparent that the Katy Freeway did not have sufficient capacity to handle growth. During this period, TxDOT operated the freeway, and METRO operated the single reversible HOV lane.

Throughout the early stages of the process, there were differing opinions surrounding the design of the future freeway. The differences primarily involved two groups: METRO and local stakeholders. METRO, with $40 million in backing from FTA, wished to pursue the installation of rail in the corridor. At the time, the public was uncertain about whether METRO had the ability to manage a complex and large project like the installation and operation of rail in the corridor. METRO attempted to purchase ROW along the Katy Freeway. Several stakeholders in the community did not want this to occur because they felt that expanding the freeway's capacity for traditional vehicles was a better approach to managing congestion. The stakeholders stymied METRO's attempt to purchase the ROW.

During the early stages of the design and construction process, there was a great deal of uncertainty due partly to the pressure on TxDOT to finish the project as quickly as possible. Some of this pressure was the result of the local stakeholders and the public (who were dealing with heavy congestion on the Katy Freeway). The pressure resulted in TxDOT undertaking the project in a nontraditional fashion. For example, the schematics for the road were developed concurrently with environmental assessment, and TxDOT purchased ROW throughout the construction process. Both of these practices are unorthodox.

During the MIS period, TxDOT realized that the available funding was insufficient for the project. Later in the process, local stakeholders identified HCTRA as a potential source of funds and encouraged HCTRA to become involved. HCTRA ultimately contributed $250 million to the project, which helped to expedite the project.

As previously noted, METRO managed the HOV lanes on the existing freeway and operated the QuickRide program (which charged a toll to HOV-2 vehicles during the peak periods). But, METRO's inability to contribute financially to the project diminished their influence on operations of the facility. Conversely, because HCTRA made a significant financial contribution to the project, it was recognized that the agency would require a return on its investment. Operating and managing the facility provided a mechanism to achieve this objective.

2002 TO 2009: THE PROJECT DEVELOPMENT PERIOD

Two agreements were signed during this period: the MOU and the tri-party agreement. The MOU signatories included:

- TxDOT.
- Harris County.
- METRO.

The impetus for this agreement stemmed from the need to formally establish the working relationships and planned operations for the future Katy Freeway and Tollway. The agreement laid out responsibilities for each of the involved entities:

- TxDOT was responsible for construction.
- Harris County was responsible for incident management, maintenance, and operation of the toll facility.
- METRO operated buses and support vehicles freely on the facility.

The second agreement, the tri-party agreement, was a legally binding agreement between:

- TxDOT.
- Harris County.
- FHWA.

The agreement legally established the responsibilities of the partnering agencies:

- The state leased the managed lanes to Harris County. Harris County was responsible for operating and maintaining the toll facility. The county used toll revenues to repay debt, as well as operate and maintain the facility.
- TxDOT audited the toll operations annually and report the findings to FHWA.

In the initial MOU, METRO "reserve[d] the right to provide future light rail transit" on the Katy Freeway corridor (*39*).

This clause was tempered with the statement that the state would "consider adding provisions into the current highway construction to facilitate this future operation." METRO was not guaranteed rail in the corridor, and the decision was left to the state. This language reflects the previous discussions and each entity's vision for the corridor. Ultimately, the ability to provide a financial contribution significantly affected the decision outcomes.

At a later time, METRO and FTA became concerned about the role that transit would play in the corridor. They wanted to ensure that the public would receive adequate transit service. FTA was consulted during the tri-party agreement and concurred with the final agreement.

Some of the interviewees commented that the process of developing the tri-party agreement was difficult. Some of the difficulties arose from the lack of precedence for establishing this sort of agreement. Strong political support and the public's demand for improvements encouraged the parties to quickly negotiate many items that typically would have been debated tirelessly. They recognized that this agreement would provide a framework for moving forward, and specifics could be refined in subsequent operating agreements.

Following the agreement, some issues still had yet to be worked out. Various stakeholders felt a need for concrete barriers used to cordon off the managed lanes from the GPLs. They believed that concrete barriers would provide more safety for enforcement officers than pylons. However, other stakeholders opposed using concrete barriers because they felt it would produce a "concrete canyon" effect. Eventually, TxDOT and HCTRA agreed to using pylons due to their low cost compared to concrete barriers.

TxDOT, as the lead agency, occasionally made unilateral decisions when issues arose that were difficult to coordinate. For example, the process of deciding which entity would handle maintenance and reimbursements was difficult. TxDOT set up jurisdictions for the entities to maintain and resolved the reimbursement conflict.

2009 TO 2012: THE PROJECT IMPLEMENTATION AND OPERATION PERIOD

Since the opening of the Katy Freeway and Tollway, HCTRA has operated and maintained the tollway, and TxDOT has operated and maintained the GPLs. METRO operates the transit buses on the managed lanes.

The agencies formed an operating committee to resolve any issues or disputes in a timely fashion. The novelty and innovative nature of the public-public partnership required a venue for agency staff to communicate and resolve issues in a timely manner. The operating committee meets this need. The committee does not meet regularly but instead meets on an as-needed basis. Initially, the operating committee was essential in developing processes for resolving disputes and dealing with unexpected issues. Over time, procedures have been developed in response to situations and documented in the operating manuals, thus mitigating the need for the operations committee to meet regularly.

There have been no indications of conflicts since the facility opened. If there were, presumably the operating committee met to manage the conflicts. This may be a sign that the agreements developed were successful at creating a strong working relationship between the agencies.

The tri-party agreement established procedures to amend the agreement. The amending process requires written notice to be given to the other parties. To date, the agreement has not been officially amended.

The innovative nature of the project may have required the agencies to nimbly respond to rapidly changing circumstances and unforeseen challenges. The original agreements laid the groundwork for the relationships, and the agencies used these agreements as a framework and then adapted to a dynamic world.

LESSONS LEARNED AND BEST PRACTICES

Several lessons can be learned from the KML case:

- **Conflicting visions:** Projects involving multiple agencies and stakeholders do not occur effortlessly. Throughout much of the project, each agency and stakeholder had its own unique vision for the project and felt a certain responsibility to get the project to address that vision. Each group had objectives and goals, and occasionally those conflicted. This leads to the second lesson.
- **Stakeholders and project champions:** Stakeholders and project champions can have a very powerful impact on and influence over the process. Interviewees from several different entities acknowledged the ability of the stakeholders to push the project through the various stages and ensure that it succeeded. They were instrumental in expediting the project and ensuring that it did not stall during various stages of the process. When conflicts occurred, the stakeholders advocated for their viewpoint and were often successful at achieving it. For example, when an agency took a stand on an issue that threatened to stall the project, the stakeholders intervened and mediated the dispute. They were also helpful at resolving problems when these occurred. For example, the project had difficulty finding funding, but the stakeholders identified HCTRA as a financial partner and were able to bring them into the process.

The best practices involve the collaboration between parties:

- **Agreements:** The establishment of agreements between the parties successfully enabled agencies to cooperate and collaborate. Several of the interviewees identified the operating agreements as a success. They felt that the agreements were difficult to establish but very helpful after the fact. The initial agreements served as a framework that allowed the development of the subsequent, more detailed agreements. They also felt that the operating committee helped to resolve unanticipated problems in a timely fashion.
- **Flexibility:** The changes from the initial agreements acknowledged the need to respond to dynamic circumstances. The agreements laid the framework for the working relationships, but the agencies had to adapt in light of unforeseen circumstances. Flexibility was an area several interviewees emphasized as vital to the project's success.

- **Leading agency:** When problems occurred with coordination, occasionally TxDOT stepped in and made unilateral decisions as the leading agency. This helped to progress the project and resolve thorny issues.
- **Strong working relationships:** Other individuals felt that the strong working relationships the agencies had were instrumental to the successful completion of the project. They felt that having people who trusted each other, would challenge each other, and were open and creative was vital to the project's success.

CONCLUSIONS

The development of the KML was a complicated and sometimes difficult process that required the collaboration and cooperation of many independent agencies. Staff at all agencies were challenged to define and develop the processes that enabled the project to move forward. This "out-of-the-box" attitude and a willingness to "do whatever it takes" exemplified the development of this project. The overriding sentiment to do something about the Katy Freeway was the common denominator between the agencies involved with the project development, the stakeholders in the corridor, and the public. This provided the focus necessary to forge ground-breaking agreements and implement innovative strategies to bring the project to fruition. Agencies throughout Texas and the nation will benefit from the model that resulted from the KML.

CHAPTER 13. FINDINGS AND LESSONS LEARNED

The Katy Freeway Managed Lanes on I-10 in Houston became fully operational in 2009. The managed lane facility, also referred to as the Katy Tollway, is the first constructed managed lane project in Texas and the first variably priced operation in the state since the implementation of the QuickRide program on US 290 and I-10 HOV lanes in Houston more than 10 years ago.

The four-lane facility, which was constructed within the center of the existing freeway, can be described as a "second-generation" managed lanes project that is more complex than earlier-generation HOV-to-HOT conversions. In addition to the facility's unique operating characteristics, TxDOT developed the project in partnership with other local entities in an innovative delivery process for funding, operating, and maintaining the managed lanes.

HAVE PROJECT GOALS BEEN ACHIEVED?

The purpose of this research study is to perform a comprehensive evaluation of the KML project. Table 55 illustrates the goals established during the KML project development process and as set forth in the multi-agency operating agreement. The measures of effectiveness that were the focus of this study are those related to traffic and system performance. As shown in the table, there are additional goals that were beyond the scope of evaluation for this study but are certainly important in gaining an overall understanding of the impacts of the corridor improvements.

Table 55. Evaluation Measures and Relationship to Katy Freeway Project Goals (*8*).

Goal	Description	Relevant Measures Evaluated under This Study
Project Goal 1:	Improve corridor mobility and safety in a cost-effective manner	Congestion, travel time, safety, enforcement, maintenance, access, lane separation, tolling
Project Goal 2:	Provide a transportation system that has minimal negative impact on aesthetics, environment, and community	Public perception, operational policy, project delivery
Project Goal 3:	Provide a balanced and coordinated transportation system	Not addressed under the scope of this study
Project Goal 4:	Provide a transportation system that serves the regional land use/development patterns now and in the future	Not addressed under the scope of this study
Operating Goal:	Maintain level of service C in the managed lanes	Travel time, congestion

During the interviews conducted under the study, two additional areas were highlighted for analysis not within the scope of this study:

- Evaluation of signing to assess driver understanding and comprehension of the static and dynamic signs associated with the KMLs.
- Determination of the economic impacts of the project, particularly related to land use and development in the corridor.

The high-level findings associated with the relevant measures are provided below, both in the context of a national framework of evaluation and in the unique circumstances of the Katy Freeway corridor.

NATIONAL EXPERIENCE

The interest and application of managed lanes in the United States has increased steadily over the past two decades. As of this writing, there are 16 operating projects representing a combination of HOV-to-HOT conversions and constructed new lanes, with eight more projects on the near-term horizon. In three of Texas' four major metropolitan regions, networks of managed lanes are envisioned in long-range regional transportation plans. The lessons learned from the applications of managed lanes to date have understandably advanced the practice. Nonetheless, it is clear from the experiences thus far that there is no "one size fits all" strategy. Each region and each corridor exhibit unique characteristics that require implementing agencies to adapt the previous project experiences to their own environments.

The KML are no different. Whereas the applications of certain elements of the Katy project are common to previous projects (e.g., time-of-day pricing, toll-free HOV-2+, pylons for lane separation, etc.), the Katy project has unique features that are not replicated in other national projects:

- Generous lane, shoulder, and buffer widths in the KML, and the addition of general-purpose capacity to the freeway that enhances non-toll travel in the corridor.
- Unique and varied access configurations, including one direct ramp from a park-and-ride facility, and a project terminus into a concurrent-flow HOV lane.
- An unusual path to implementation, with reliance on a public-public partnership model and very active involvement of project champions.
- Absence of a formal concept of operations and late adjustments to the tolling and HOV occupancy policies, which had no detrimental effect on operations at opening.

Because of unique conditions, the transference of best practices from national projects to the KML, and from the KML to other projects, has its limitations.

SCOPE OF EVALUATION

Evaluation of congestion pricing projects, especially those involving priced managed lanes, can be organized into eight categories (*40*):

- **Traffic performance:** describes the project's ability to provide mobility to people and goods.
- **Public perception:** assesses public knowledge of the project's existence and purpose, acceptance as a mobility option, and satisfaction with the service it provides.
- **Users (such as trip characteristics):** describes how drivers use the facility.
- **System operations (finance, enforcement, safety, customer service, and incident management):** includes operational aspects that are not directly related to measures of traffic performance.
- **Environment:** describes the facility's effect on the environment.
- **Transit:** provides aspects of transit and ridesharing services that operate in the corridor.
- **Economics:** describes the facility's effects on local businesses and regional competiveness.
- **Land use:** describes the facility's effects on land use (residential or commercial land use trends).

For this evaluation of the KML, attention was focused on the first four categories. A summary of the findings follows.

Traffic Performance

This evaluation has the following findings concerning traffic performance:

- Managed lane volumes have doubled compared to pre-opening usage, and isolated sections of congestion have emerged on the GPLs despite the increase in general-purpose capacity provided by the freeway expansion.
- Travel time savings are approximately 5 minutes in the morning and 14 minutes in the afternoon in the peak directions, and the travel time advantage over the GPLs has increased as volumes have grown.
- Off-peak speeds in the managed lanes ran consistently at 70 mph but dropped to a low of 52 mph in the morning peak and 50 mph in the afternoon peak. Both of these speed levels correspond to the most congested periods of travel in the GPLs.
- Off-peak volumes are growing at a rapid rate on the managed lanes.

Public Perception

This evaluation has the following findings concerning public perception:

- Travelers on the managed lanes use it to save time, avoid/reduce stress, and avoid congestion. The main reason for not using the lanes was the cost and limited travel time savings to justify the expense.
- Most travelers using the managed lanes estimated travel time savings that were more than twice the actual time saved.

Users

This evaluation has the following findings concerning users:

- Over 1.5 million different transponders were observed on the Katy Freeway in 2011; 68 percent of those only used the GPLs. Of the remaining half million who used the managed lanes, over 80 percent used them for 60 or fewer trips during the entire year, which averaged slightly over one trip on the managed lanes per week. Approximately 11 percent used the managed lanes for more than two trips per week. A small percentage of just over 3 percent use the managed lanes for all their trips on the Katy Freeway.
- There is traffic on the managed lanes even when there are no travel time savings. This is a very small proportion of traffic, but it does happen. In 2011, 1.1 percent of trips on the toll lanes were during times that the managed lanes were operating at a lower average speed than the GPLs.
- According to the user survey, 49 percent of the managed lane users change their usual freeway access point in order to reach the managed lanes.

System Operations

This evaluation has the following findings concerning system operations:

- A safety analysis of the corridor shows that the improved geometric design and reduction in congestion had a positive effect on reducing crashes, which dropped from 128.3 crashes per million vehicle-miles before construction to 57.3 crashes per million vehicle-miles after the project opened.
- The KML have a variety of access types, including at-grade slip ramps and direct connect ramps. The design of the studied access points was found to be sufficient to handle the expected demand of drivers entering and exiting the lanes.
- Most sections of the KML were built to have ideal conditions for optimal separation between concurrent-flow lanes, using a wide 20-foot buffer and plastic delineators. Because of the wide buffer, pylon hits and replacements have been low compared to other managed lane projects (25 percent replaced per year).

- Enforcement operations have evolved, both institutionally and operationally, to ensure a balance between deterring cheaters and disrupting flow.
- All agencies interviewed agree that active enforcement of lane use and having the physical space to conduct enforcement activities are beneficial elements in reducing maintenance and operational issues.

CONCLUSIONS

Based on the measures studied, the project is achieving its stated goals and is operating in a safe and effective manner. The success of the project offers overarching lessons learned for other projects planned in the state, with recognition that each corridor and implementation environment has unique attributes:

- Within the environment under which the Katy corridor was developed, multiple agencies and political leadership coalesced and applied available best practices for facility design and operation to achieve the project goals.
- Flexibility and focus on the outcome were factors that many of the agency partners identified as keys to successful project implementation.
- It is widely recognized that continual monitoring and adjustment of operating aspects of new managed lanes is required post-opening, especially during the ramp-up period in which drivers make travel adjustments to use the facility. The operating partners for the KML, and HCTRA in particular, have continuously monitored the performance of the lanes since opening and have made adjustments in toll rates, lane configuration at the tolling zones, and access operations at the western terminus. These adjustments are critical to ensuring that the performance standards for the lanes are maintained.

Some remaining issues not examined in this study could generate improvements and further best practices in the areas of signing, carpooling, transit, and economic impacts. These aspects were beyond the scope of this study effort but are important to achieving the project goals into the future.

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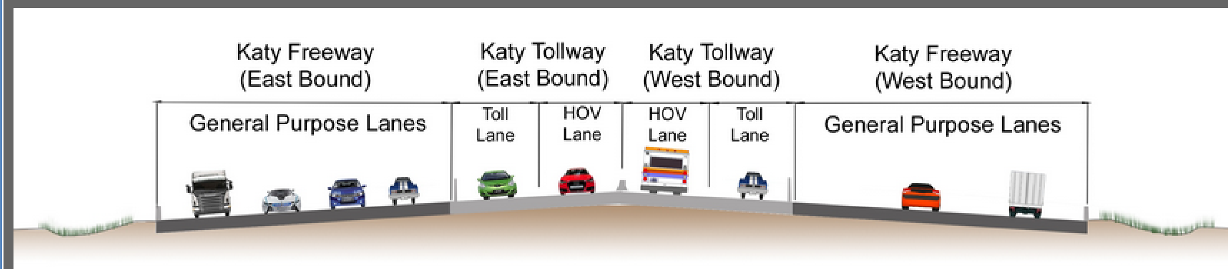
APPENDIX A: SURVEY QUESTIONNAIRE

A. Introduction to the New Managed Lanes

*The Katy Tollway begins west of SH 6 and ends at the I-10/I-610 interchange. The Tollway has 2 toll lanes in each direction and is operated by the Harris County Toll Road Authority (HCTRA) (See figure below). During the rush hour the toll is higher and during other times the toll is lower. Drivers have multiple entrances and exit locations to get on the managed lanes. The facility is an EZ or TX Tag only facility. Qualifying high-occupancy vehicles can travel for free during the peak hours. Metro buses will not be charged a toll at anytime.



Have you traveled on the Katy Freeway (I-10) or Katy Tollway lanes in the past six months?

Choose one of the following answers

- Yes
- No

B. Details of Respondent's Most Recent Trip

Please tell us about your most recent trip on the Katy Freeway (I-10) traveling towards downtown Houston during the work week (Monday through Friday). A "trip" is any time you traveled on Katy Freeway.

What was the purpose of your most recent trip?
Choose one of the following answers

- Recreational / Social / Shopping / Entertainment / Personal Errands
- Commuting to or from my place of work (going to or from work)
- Work related (other than to or from home to work)
- To attend class at school or educational institute
- Other

?

Where did you get ON and OFF the Katy Freeway (I-10)?

	ON	OFF
An exit west of FM 1463 (Katy Road)	◎	◎
FM 1463 (Katy Road)	◎	◎
Pin Oak Road	◎	◎
Katy Mills Blvd./Highway Blvd.	◎	◎
Katy-Fort Bend Road	◎	◎
Peek Road/Grand Parkway	◎	◎
Mason Road	◎	◎
Westgreen Blvd.	◎	◎
Fry Road	◎	◎
Greenhouse Road/Baker Road	◎	◎
Barker Cypress Road	◎	◎
Park Row/Park 10	◎	◎
Highway 6	◎	◎
Eldridge Parkway	◎	◎
Dairy Ashford	◎	◎
Kirkwood Road	◎	◎
Sam Houston Parkway/Wilcrest Drive	◎	◎
Gessner Road	◎	◎
Bunker Hill Road	◎	◎
Blalock Road/Echo Lane	◎	◎
Bingle Road/Campbell	◎	◎
Wirt Road	◎	◎
Antoine Drive/Chimney Rock	◎	◎
Silber Road/N. Post Oak Road	◎	◎
Loop 610	◎	◎
Washington Avenue/Westcott St.	◎	◎
TC Jester Blvd.	◎	◎
Durham Dr./Shepherd Dr./Patterson St.	◎	◎
Studemont St./Heights Blvd.	◎	◎
Taylor St.	◎	◎
I-45 Downtown Houston	◎	◎
An exit east of I-45 Downtown Houston	◎	◎

Where did you Enter and Exit the Katy Tollway?

	ON	OFF
State Highway 6 (SH 6)	◎	◎
Addicks Park and Ride	◎	◎
Between Dairy Ashford and Kirkwood	◎	◎
Between Gessner and Bunker Hill	◎	◎
Between Chimney Rock and Antoine	◎	◎
Between Antoine and Silber	◎	◎
East of Loop 610	◎	◎

Have you ever changed where you entered or exited the Katy Freeway in order to have an easier path to or from the Tollway?

Choose one of the following answers

◎ Yes

◎ No

On your most recent trip away from downtown Houston did you travel in the general purpose lanes or the Tollway lanes?

Choose one of the following answers

- General Purpose Lanes
- Tollway lanes (toll lanes or HOV lanes)

On what day of the week was your most recent trip away from downtown Houston?

Choose one of the following answers

- Sunday
- Monday
- Tuesday
- Wednesday
- Thursday
- Friday
- Saturday

You previously indicated your most recent trip away from downtown Houston was Commuting to or from my place of work (going to or from work). What time of day did that trip start? (for example, when did you leave your origin)

Choose one of the following answers

Please choose...

What kind of vehicle did you use for your most recent trip?

Choose one of the following answers

- Motorcycle
- Passenger car, SUV, or pick-up truck
- Bus

How much did you pay to ride the bus? Choose one:

Check any that apply

- $ per trip
- $ per day
- $ per week
- $ per month

How many people, including you, were in the Passenger Car/ SUV/Pick-up Truck?

Choose one of the following answers

- 1
- 2
- 3
- 4
- 5 or more

Were you the driver or a passenger on this recent trip?

Choose one of the following answers

- Driver
- Passenger

How much extra time did it take to pick up and drop off the passenger(s)? (minutes)

Only numbers may be entered in these fields

Minutes [ ]

Who did you travel with on this recent trip?

Check any that apply

- [ ] Co-worker / person in the same, or a nearby, office building
- [ ] Neighbor
- [ ] Another commuter in a casual carpool (also known as slugging)
- [ ] Child
- [ ] Adult family member
- [ ] Other: [ ]

What was your travel time on your last trip?

Only numbers may be entered in these fields

minutes [ ]

Have you ever used the Katy Tollway lanes?

(●) Yes
( ) No

What are the main reasons you use the Tollway?

Check any that apply

- [ ] Access to/from to the Tollway lanes is convenient for my trips
- [ ] The Tollway saves time
- [ ] During the peak hours the Tollway will not be congested
- [ ] The Tollway lanes are less stressful than the general purpose lanes
- [ ] Trucks and large vehicles are not allowed on the Tollway
- [ ] Someone else pays my tolls
- [ ] Travel times on the Tollway lanes are consistent and predictable
- [ ] Being able to use the lanes for free as a carpool
- [ ] The Tollway lanes are safer than the general purpose lanes
- [ ] Other: [ ]

What are the primary reasons you do NOT use the Katy Tollway?
Check any that apply

- [ ] It is too complicated/confusing to use the Tollway
- [ ] I do not feel safe traveling on the Tollway lanes
- [ ] I don't have anyone to carpool with
- [ ] The toll is too expensive for me
- [ ] I don't want to have a toll transponder in my vehicle
- [ ] I don't have a credit card needed to setup a toll transponder account
- [ ] I don't like that the toll changes based on the time of day
- [ ] I have the flexibility to travel at less congested times
- [ ] I avoid toll roads whenever possible
- [ ] Access to/from to the Katy Tollway lanes is not convenient for my trips
- [ ] The Tollway does not offer me enough time savings
- [ ] I can easily use routes other than the Katy Freeway, so I'll just avoid Katy Freeway if I think there is a lot of traffic
- [ ] Other:

Do you believe that law enforcement agencies are:
Choose one of the following answers

- ○ Providing the right level of enforcement on the Katy Tollway?
- ○ Providing too little enforcement on the Katy Tollway?
- ○ Providing too much enforcement on the Katy Tollway?

Thinking about the last work week (Monday through Friday), how many trips did you make on the Katy Freeway general purpose lanes, each direction counts as one trip?

Only numbers may be entered in these fields

Trips per week:

Thinking about the last work week (Monday through Friday), how many trips did you make on the Katy Tollway lanes, each direction counts as one trip?

Only numbers may be entered in these fields

Trips per week:

?

Did you have to pay to park in Houston?
Choose one of the following answers

- ◉ Yes
- ○ No

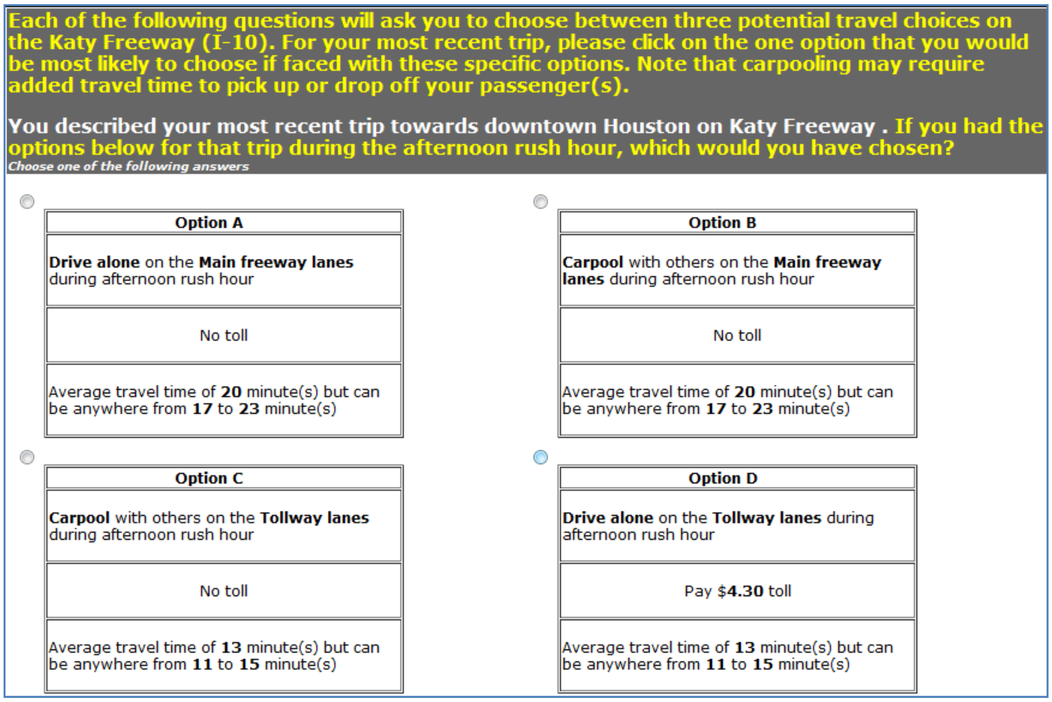
How much does parking cost per day (in $)?

Only numbers may be entered in these fields

per day $

?

C. Stated Preference Questions



Each of the following questions will ask you to choose between three potential travel choices on the Katy Freeway (I-10). For your most recent trip, please click on the one option that you would be most likely to choose if faced with these specific options. Note that carpooling may require added travel time to pick up or drop off your passenger(s).

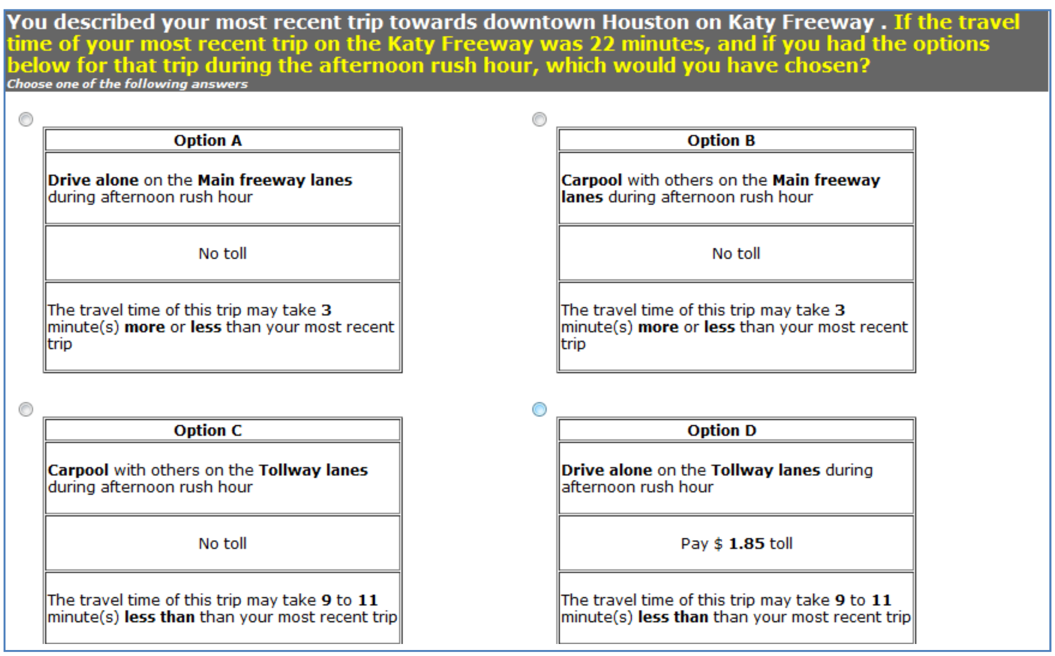
You described your most recent trip towards downtown Houston on Katy Freeway . If you had the options below for that trip during the afternoon rush hour, which would you have chosen?

Choose one of the following answers

Option A	Option B
Drive alone on the **Main freeway lanes** during afternoon rush hour	**Carpool** with others on the **Main freeway lanes** during afternoon rush hour
No toll	No toll
Average travel time of **20** minute(s) but can be anywhere from **17** to **23** minute(s)	Average travel time of **20** minute(s) but can be anywhere from **17** to **23** minute(s)

Option C	Option D
Carpool with others on the **Tollway lanes** during afternoon rush hour	**Drive alone** on the **Tollway lanes** during afternoon rush hour
No toll	Pay $**4.30** toll
Average travel time of **13** minute(s) but can be anywhere from **11** to **15** minute(s)	Average travel time of **13** minute(s) but can be anywhere from **11** to **15** minute(s)

Typical Scenarios of Survey Design with Uniform Travel Time Distribution (Format 1)



You described your most recent trip towards downtown Houston on Katy Freeway . If the travel time of your most recent trip on the Katy Freeway was 22 minutes, and if you had the options below for that trip during the afternoon rush hour, which would you have chosen?

Choose one of the following answers

Option A	Option B
Drive alone on the **Main freeway lanes** during afternoon rush hour	**Carpool** with others on the **Main freeway lanes** during afternoon rush hour
No toll	No toll
The travel time of this trip may take **3** minute(s) **more** or **less** than your most recent trip	The travel time of this trip may take **3** minute(s) **more** or **less** than your most recent trip

Option C	Option D
Carpool with others on the **Tollway lanes** during afternoon rush hour	**Drive alone** on the **Tollway lanes** during afternoon rush hour
No toll	Pay $ **1.85** toll
The travel time of this trip may take **9** to **11** minute(s) **less than** than your most recent trip	The travel time of this trip may take **9** to **11** minute(s) **less than** than your most recent trip

Typical Scenario of Pivot Design with Respect to Recent Trip (Gain and Loss in Travel Time) (Format 2)

You described your most recent trip towards downtown Houston on Katy Freeway . If you had the options below for that trip during the afternoon rush hour, which would you have chosen?

Choose one of the following answers

Option A	Option B
Drive alone on the **Main freeway lanes** during afternoon rush hour	**Carpool** with others on the **Main freeway lanes** during afternoon rush hour
No toll	No toll
7 time(s) out of 10 the trip takes **25** minute(s) **3** time(s) out of 10 the trip takes **18** minute(s)	**7** time(s) out of 10 the trip takes **25** minute(s) **3** time(s) out of 10 the trip takes **18** minute(s)

Option C	Option D
Drive alone on the **Tollway lanes** during afternoon rush hour	**Carpool** with others on the **Tollway lanes** during afternoon rush hour
Pay $ **4.00** toll	No toll
7 time(s) out of 10 the trip takes **12** minute(s) **3** time(s) out of 10 the trip takes **16** minute(s)	**7** time(s) out of 10 the trip takes **12** minute(s) **3** time(s) out of 10 the trip takes **16** minute(s)

Typical Scenario of Survey Design with Random Probabilistic Travel Time Distribution (Format 3)

You described your most recent trip towards downtown Houston on Katy Freeway . If the travel time of your most recent trip on the Katy Freeway was 22 minutes, and if you had the options below for that trip during the afternoon rush hour, which would you have chosen?

Choose one of the following answers

Option A	Option B
Drive alone on the **Main freeway lanes**during afternoon rush hour	**Carpool** with others on the **Main freeway lanes**during afternoon rush hour
No toll	No toll
8 times out of 10 the trip takes **3** minute(s) **more than** than your most recent trip **2** times out of 10 the trip takes **13** minute(s) **less than** than your most recent trip	**8** times out of 10 the trip takes **3** minute(s) **more than** than your most recent trip **2** times out of 10 the trip takes **13** minute(s) **less than** than your most recent trip

Option C	Option D
Carpool with others on the **Tollway lanes**during afternoon rush hour	**Drive alone** on the **Tollway lanes**during afternoon rush hour
No toll	Pay $ **5.55** toll
9 times out of 10 the trip takes **19** minute(s) **less than** than your most recent trip **1** times out of 10 the trip takes **15** minute(s) **less than** than your most recent trip	**9** times out of 10 the trip takes **19** minute(s) **less than** than your most recent trip **1** times out of 10 the trip takes **15** minute(s) **less than** than your most recent trip

Typical Scenario of Pivot Design with Respect to Recent Trip with Probabilistic Gain and Loss in Travel Time (Format 4)

D. Demographics of Respondents

The following questions will be used for statistical purposes only and answers will remain confidential. All of your answers are very important to us and in no way will they be used to identify you or released to any other person outside the research team.

What is the ZIP Code of that recent trip's Origin?

Only numbers may be entered in this field

What is the ZIP Code of that recent trip's Destination?

Only numbers may be entered in this field

Are you...

- Female
- Male

Which of the following age categories best represents your age?
Choose one of the following answers

- 18 to 24
- 25 to 34
- 35 to 44
- 45 to 54
- 55 to 64
- 65 and over
- Refused

What is your race/ethnicity?
Choose one of the following answers

- White/Caucasian
- Hispanic/Latino
- African American
- Asian American
- Native American
- Refused

What is your highest level of education?
Choose one of the following answers

- Less than high school
- High school graduate
- Some college or vocational school
- College Graduate
- Postgraduate degree
- Refused

What was your gross annual HOUSEHOLD income before taxes in 2011?
Choose one of the following answers

- Less than $10,000
- $10,000 to $14,999
- $15,000 to $24,999
- $25,000 to $34,999
- $35,000 to $49,999
- $50,000 to $74,999
- $75,000 to $99,999
- $100,000 to $199,999
- $200,000 or more
- Its easier to tell my hourly wage rate:
- Other

Feel free to provide any comments or suggestions related to transportation and travel here:

APPENDIX B: N-GENE CODE FOR GENERATING D_B-EFFICIENT DESIGN

(1) N-Gene Code for Generating D_b-Efficient Design (Deterministic Models)

```
;Design
;alts=gplda,gplcp,mlda,mlcp
;rows=15
;block=5
;eff=(rppanel,d)
;rep=1000
;rdraws=halton(400)
;cond:
if(mlcp.ttlvl_m <> mlda.ttlvl_m , mlcp.ttlvl_m = mlda.ttlvl_m)
,if(mlcp.var_minute_ml <>mlda.var_minute_ml, mlcp.var_minute_ml =
mlda.var_minute_ml)
,if(gplda.ttlvl_g <> gplcp.ttlvl_g , gplda.ttlvl_g = gplcp.ttlvl_g)
,if(gplcp.var_minute_gl <>gplda.var_minute_gl, gplcp.var_minute_gl =
gplda.var_minute_gl)
;model:
U(mlda)=c2[-2.11]+tt[n,-0.05,0.3]*ttlvl_m[13.09,13.71,14.40] + toll[n,-
0.10,0.1]*tlvl[16.67,33.33,50] + var[n,-0.06,0.5]*var_minute_ml[1.37,1.92,2.47]
/
U(mlcp)=c3[-3.53]+tt*ttlvl_m + var*var_minute_ml
/
U(gplcp)=c4[-3.72]+tt*ttlvl_g[20.57,22.15,24.00]+var*var_minute_gl[3.10,5.09,7.31]
/
U(gplda)=tt*ttlvl_g+var*var_minute_gl
$
```

(2) N-Gene Code for Generating D_b-Efficient Design

```
;Design
;alts=gplda,gplcp,mlda,mlcp
```

```
;rows=21
;block=7
;eff=(rppanel,d)
;rep=1000
;rdraws=random(400)
;cond:
if(mlcp.tt1lvl_m <> mlda.tt1lvl_m , mlcp.tt1lvl_m = mlda.tt1lvl_m)
,if(mlcp.pbtt1ml<> mlda.pbtt1ml, mlcp.pbtt1ml= mlda.pbtt1ml)
,if(gplcp.tt1lvl_gl <> gplda.tt1lvl_gl , gplcp.tt1lvl_gl = gplda.tt1lvl_gl)
,if(gplcp.pbtt1gl<> gplda.pbtt1gl, gplcp.pbtt1gl= gplda.pbtt1gl)
;model:
U(mlda)=c2[-2.11]+tt1[n,-
0.05,0.3]*pbtt1ml[0,0.10,0.20,0.50,0.80,0.90,1]*tt1lvl_m[11.08,12,13.09]+tt2[n,-
0.05,0.3]*pbtt2ml[fcn(1-mlda.pbtt1ml)]*tt2lvl_m[16]+toll[n,-
0.10,0.1]*t2lvl[16.67,33.33,50]
/
U(mlcp)=c3[-3.53]+tt1*pbtt1ml*tt1lvl_m+tt2*pbtt2ml[fcn(1-mlcp.pbtt1ml)]*tt2lvl_m
/
U(gplcp)=c4[-
3.72]+tt1*pbtt1gl[0,0.10,0.20,0.50,0.80,0.90,1]*tt1lvl_gl[24,28,36]+tt2*pbtt2gl[fcn(1-
gplcp.pbtt1gl)]*tt2lvl_gl[18]
/
U(gplda)=tt1*pbtt1gl*tt1lvl_gl+tt2*pbtt2gl[fcn(1-gplda.pbtt1gl)]*tt2lvl_gl
$
```