

Briefing Paper: Toward a BEST PRACTICE MODEL for **Managed Lanes** in Texas



BRIEFING PAPER: TOWARD A BEST PRACTICE MODEL FOR MANAGED LANES IN TEXAS

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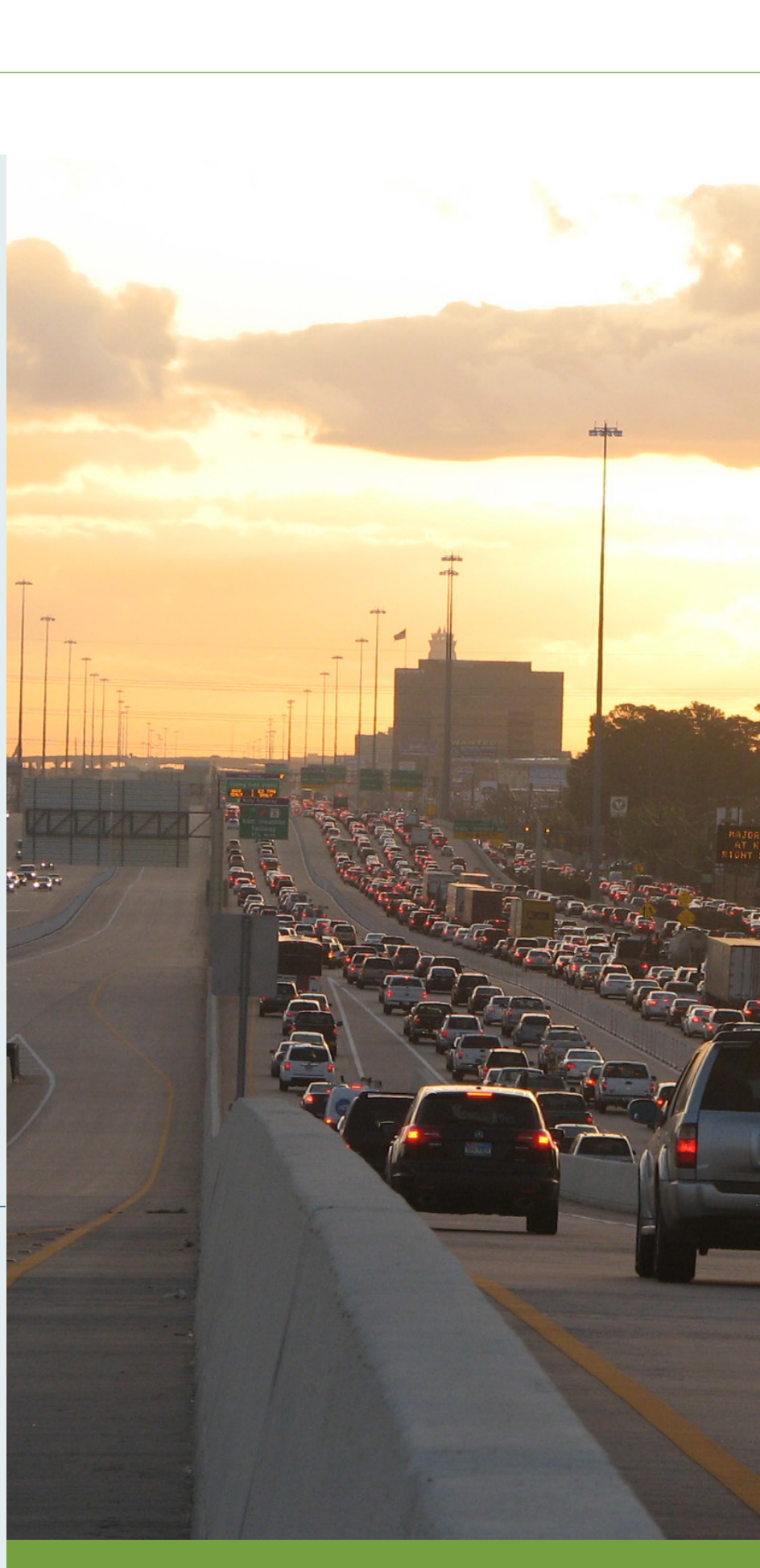
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Freeway Managed Lanes

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Over the past two decades, agencies have increasingly implemented managed lanes (MLs) to mitigate growing urban traffic congestion in the United States. Multiple operating projects—representing a combination of HOV-to-HOT conversions and constructed lanes—exist nationally, with more projects soon to be implemented. Three of Texas’ four major metropolitan regions currently envision networks of managed lanes in their long-range regional transportation plans.

Though lessons learned from existing ML facilities have advanced the practice of implementing new facilities, no one-size-fits-all strategy exists. Each region/corridor exhibits unique characteristics that require implementing agencies to adapt previous experiences to their own environments. Nevertheless, studying the development of the Katy Freeway Managed Lanes (KML) on I-10 in Houston, Texas, has yielded valuable insights that can benefit agencies implementing managed lanes in the future.

The KML (see [Figure 1](#)) became fully operational in 2009. Also called the Katy Tollway, the KML is the first operational, multilane managed facility in Texas. It is also 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 KML FACILITY

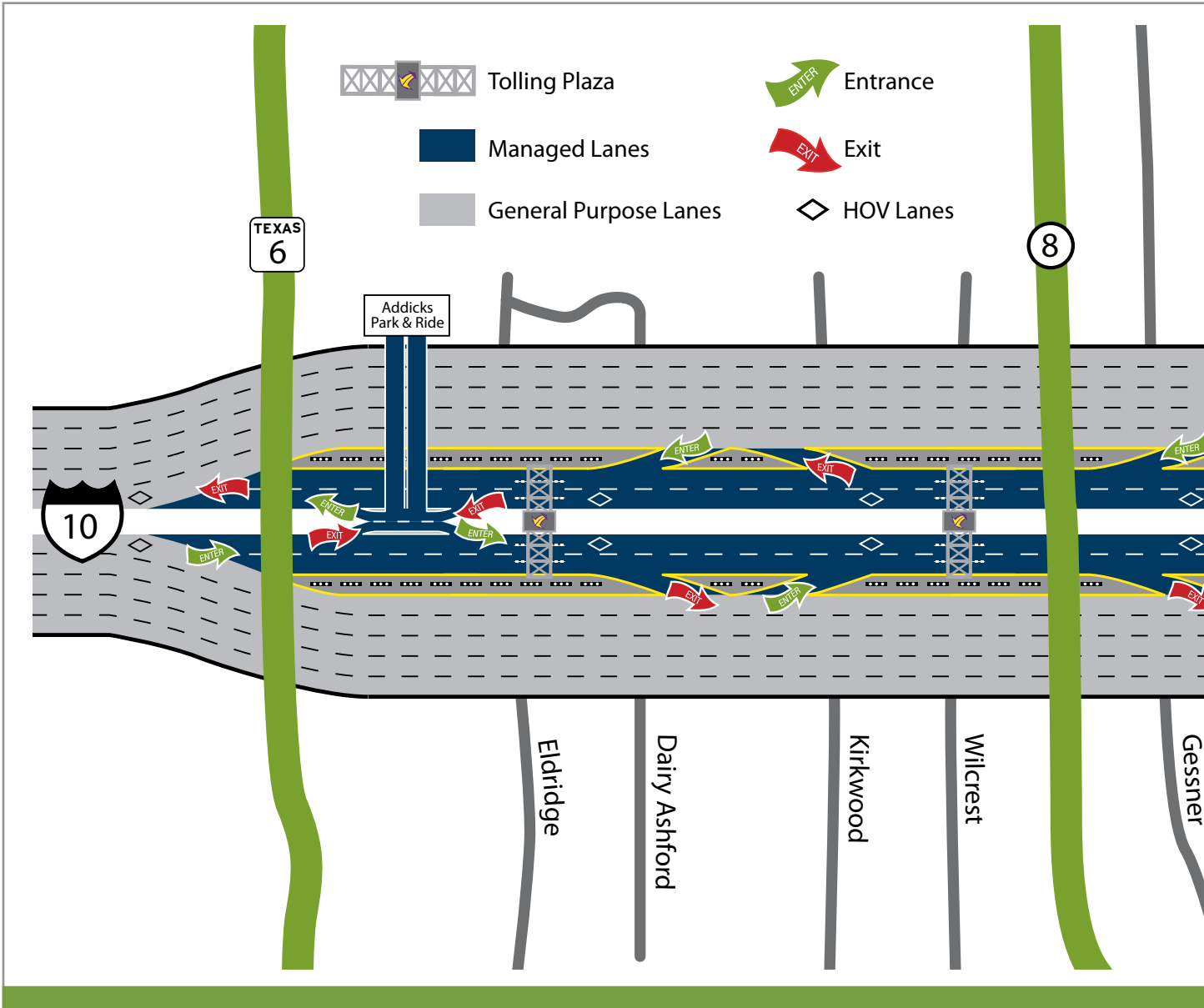
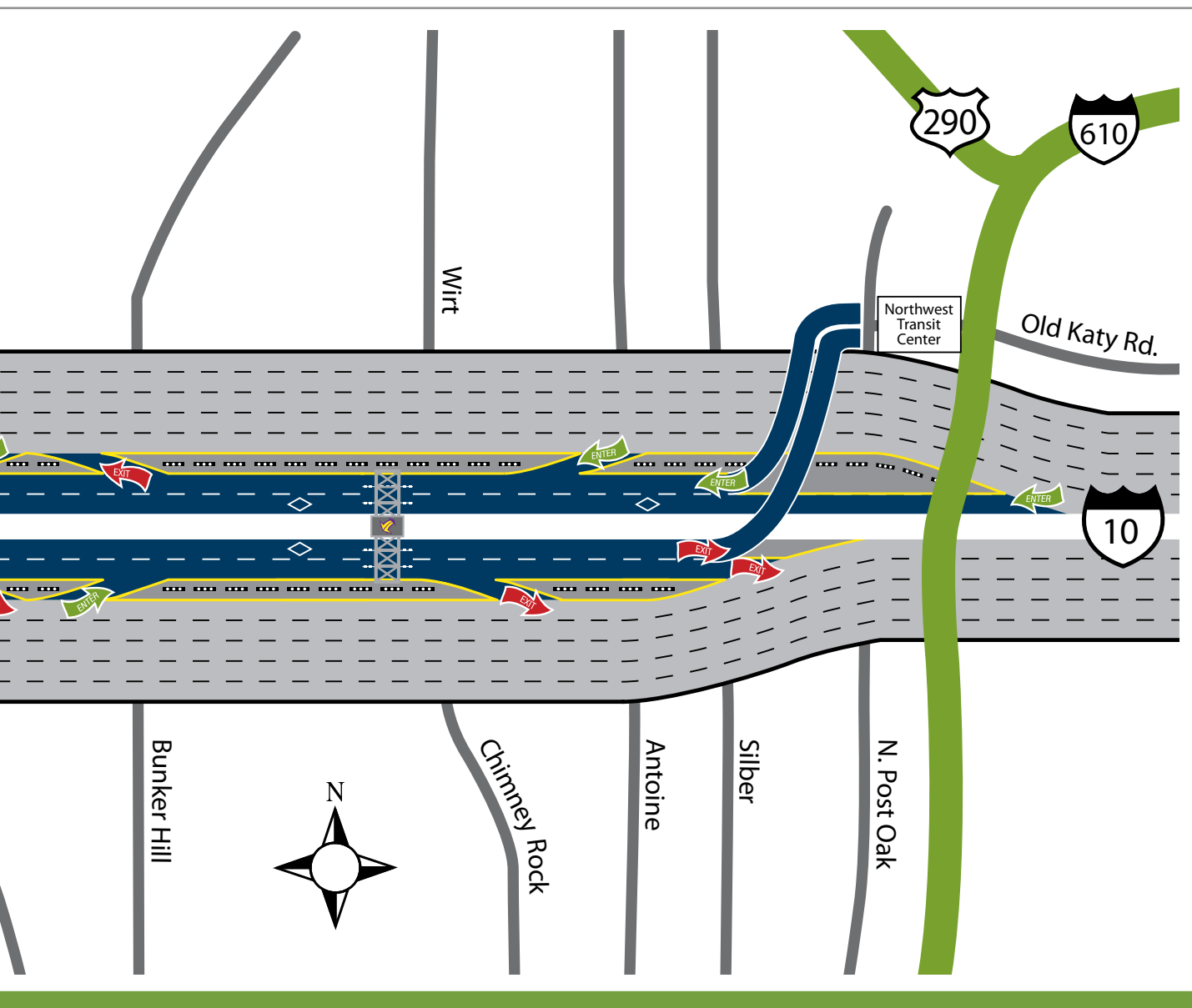
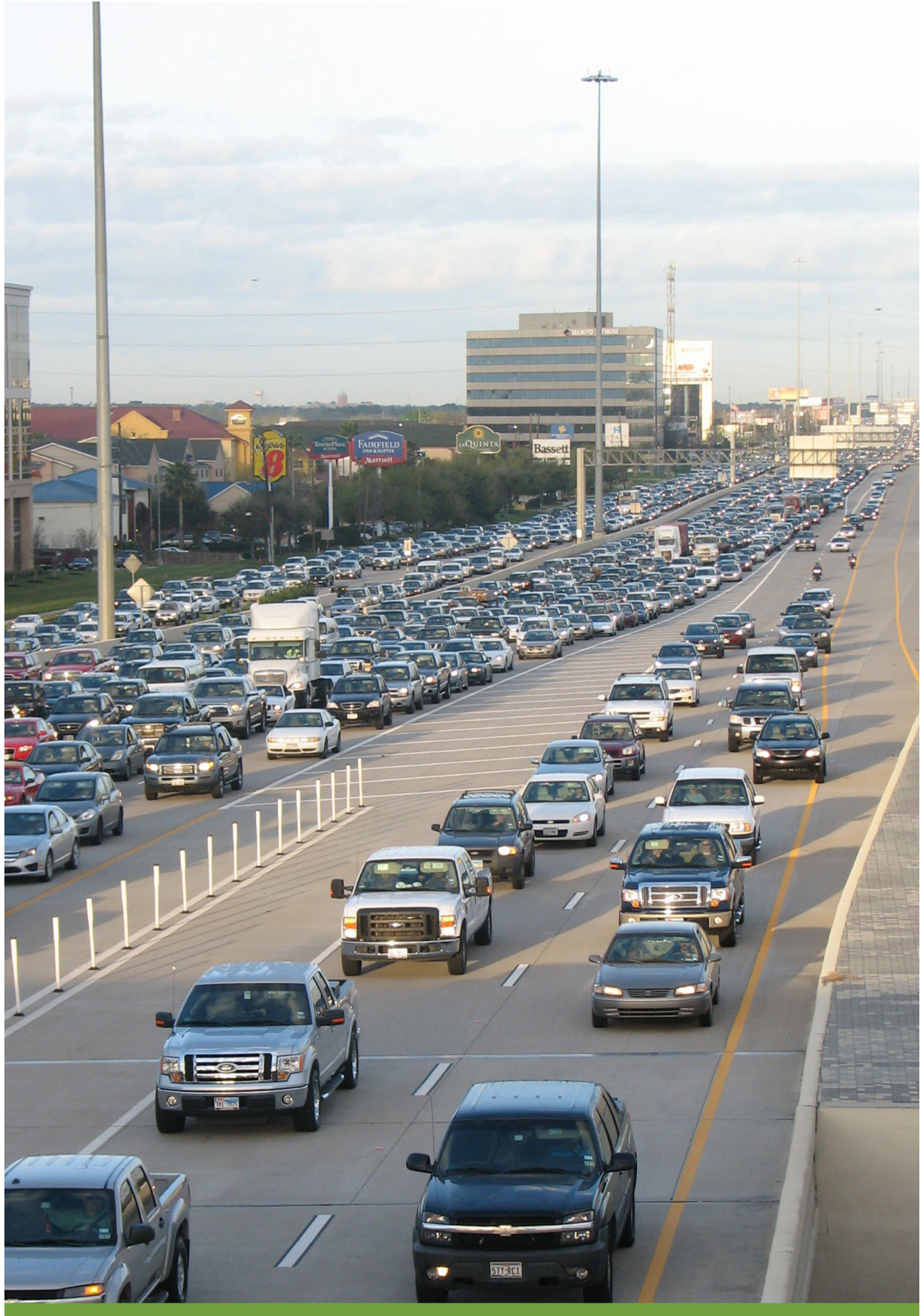


Figure 1. The 12-mile Long KML Facility, Including Tolling Plazas and General Purpose, Managed, and HOV Lanes. Source: HCTRA website.

In a unique partnership with The Harris County Toll Road Authority (HCTRA) and the Metropolitan Transit Authority of Harris County (METRO), the Texas Department of Transportation (TxDOT) developed the project in an innovative delivery process that comprised funding, operating, and maintaining the facility. Constructed within the center of the existing Katy Freeway during the major reconstruction effort, the KML has grown from a one-lane reversible,

bus-only lane to a four-lane toll facility. This project's development tracks with the evolution of managed lanes theory, making it an ideal candidate for best practices assessment. Understanding how the KML was successfully implemented provides an opportunity for TxDOT and its partnering agencies across the state to facilitate developing other projects based on those lessons learned.







Project 0-6688, Katy Freeway: An Evaluation of a Second-Generation Managed Lanes Project, represents a comprehensive evaluation of the KML. Researchers created a framework for evaluating the KML that yields best-practice recommendations comprising 10 distinct operational areas:

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

This white paper provides:

A summary of each of the operational areas listed above.



1 A history and operational description.

2 Findings and conclusions for the KML as a step toward establishing best practices for managed lanes in Texas.

The KML: History and Opera

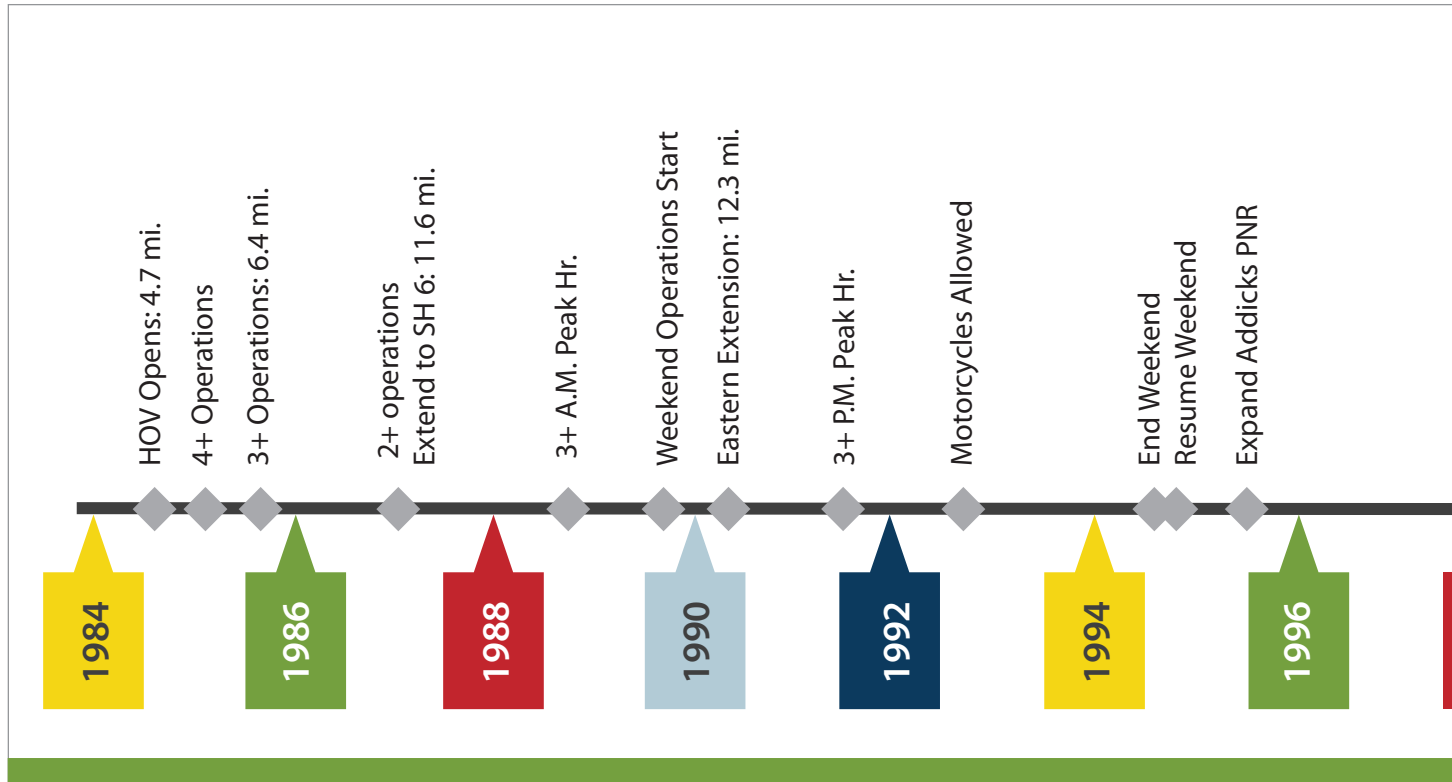


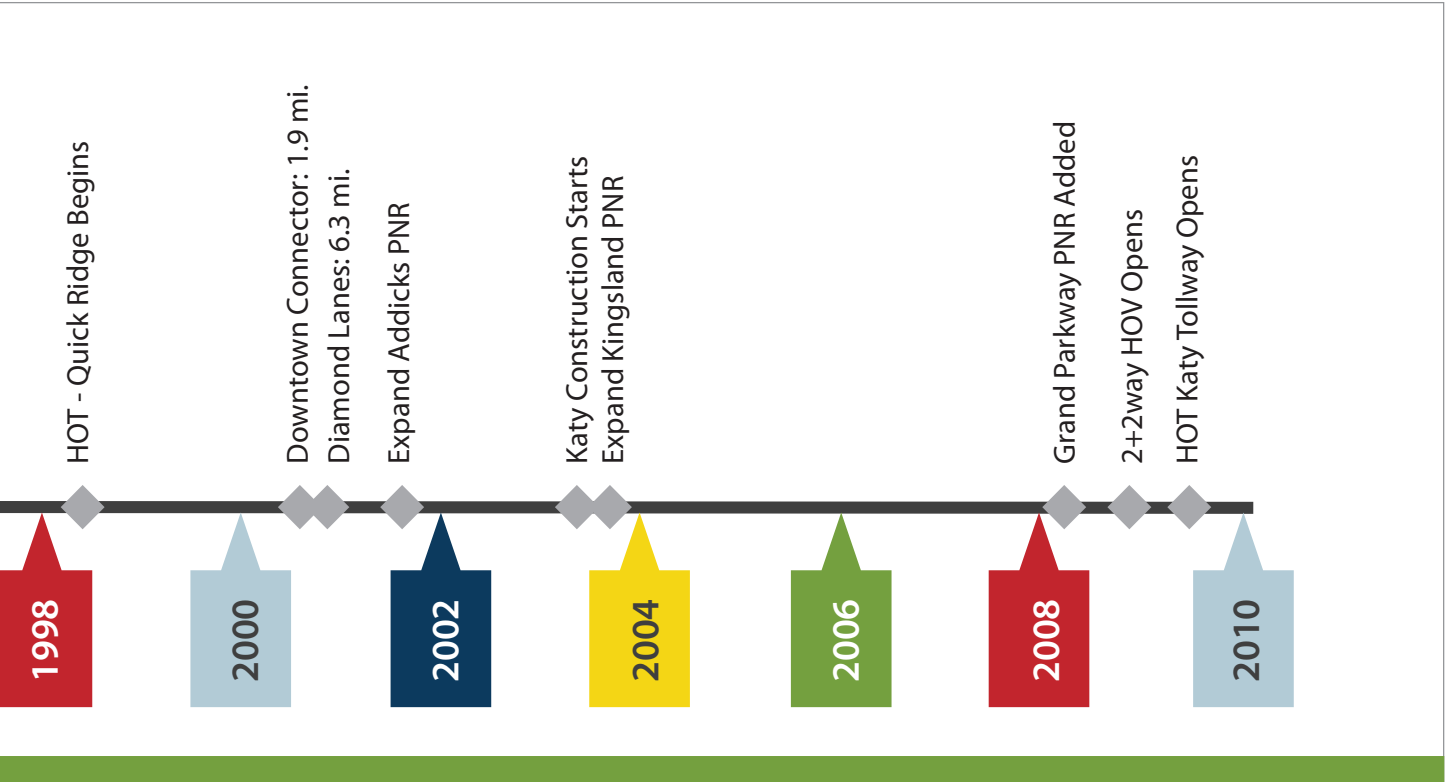
Figure 2. The Development of the KML over Time.

The 1980s–1990s

Figure 2 shows the development of the KML over time. METRO originally conceived an HOV lane on the Katy Freeway west of I-610 in 1982, when TxDOT was planning a pavement repair project to begin the following year. METRO suggested transforming the proposed repairs into a new construction project to convert the interior shoulders into a single, reversible bus lane. Leveraging their close working relationship, METRO and TxDOT finished the conversion in 30 months at a total project cost of \$12 million (\$28 million in 2011 dollars).

At first restricted to authorized buses and vanpools, the Katy Freeway HOV Lane opened in 1984. Between 1984 and 1987, METRO systematically relaxed authorization to include 4+ carpools, 3+ carpools, and finally 2+ carpools. By 1988, however, the facility had exceeded capacity, so METRO began raising occupancy requirements during peak travel times through 1991. Traffic volumes steadily decreased on the facility. In 1998, via implementation of the QuickRide program, METRO allowed 2+ carpools to use the Katy HOV lane during peak periods for a fee of \$2 per trip. Studies of the policy showed that while HOV-2 demand was modest

ational Summary



and infrequent, the pricing program was able to influence travel decisions significantly, with half of the HOV-2 carpools formed from single-occupancy vehicle (SOV) trips in the general purpose lanes. In 1995, TxDOT evaluated the Katy Freeway corridor. With maintenance costs at four times the average expressway segment in Texas—and inadequate to carry the 200,000 vehicles of daily demand present at the time—officials determined its design was obsolete. A major investment study identified the local community’s mobility needs and considered a wide range of investments across multiple travel modes to accommodate them.

When METRO allowed 2+ carpools to use the facility for a fee, studies showed that variable pricing can **substantially change** motorists’ mode choice and travel-time decision behavior.

Creation of the KML gave birth to the **first tri-party agreement** to operate toll lanes on an Interstate Highway in the United States.



2000 and Beyond: Building a Better Mouse Trap

Ultimately, in 2003, construction began on an alternative providing two special-use lanes in each direction from I 610 to SH 6. Also, additional general-purpose lanes (GP lanes) in each direction on the corridor (with auxiliary lanes at major interchanges) were built, as were additional continuous frontage roads. The improvements were designed to accommodate future growth and travel demand.

Creating the KML gave birth to the first tri-party agreement to operate toll lanes on an Interstate Highway in the United States. HCTRA assumed responsibility for financing, constructing, operating, and maintaining the managed lanes, while the general-purpose lanes remained under TxDOT's jurisdiction. A later pact with METRO allowed transit vehicles to use the tollway for free to further promote mobility on the corridor. Some of the key traits of the innovative 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 ML construction on an interstate through a county-based toll operator.** Until this agreement, most ML projects were basic HOV-to-HOT lane conversions and did not set primary financial goals for operation.
- **Using open road electronic tolling.** No manned toll booths were planned for the KML. All tolling would be accomplished via overhead gantries equipped with electronic toll equipment. Observation booths are included in the KML but are for electronic equipment and for an operator to do visual occupancy observation, not toll collection.

Construction finished in 2008. Originally planned as HOT-3+, but six months prior to opening the facility, the KML's occupancy requirement was lowered to allow 2+ carpools to travel for free because the toll agency believed the managed lanes could handle the additional volume. The KML became fully operational in 2009, when a detailed operating plan was signed by the three principal operating agencies: TxDOT, HCTRA, and METRO.

Facility Administration

With help from the HCTRA Incident Management Center (IMC), which operates independently of the Houston TranStar system (managed by TxDOT, HCTRA, METRO, and the City of Houston), HCTRA became responsible for actively managing incidents within the tolled managed lanes. An operating committee composed of the three principals and chaired by TxDOT reviews procedures related to the operations, safety, incident management, and scheduled maintenance or closure events of the KML. The committee produces a quarterly operations report providing an overview of data elements from the parent agencies. Closure requests of the general-purpose or managed lanes due to special events have to be provided to the operating committee at least one week before the event.

Facility Operations

As of 2012, KML volumes neared 2,200 vehicles per hour. HCTRA designed a toll-rate structure that sustains the movement of vehicles (without intermittent adjustment for six months following the change). The fee structure is a time-of-day pricing scheme that varies by day of week, time of day, and direction of travel similar to the 91 Express Lanes in Orange County, California.

During peak periods, the inside lane is designated as an HOV lane as indicated by a dynamic-message sign that displays “HOV only” overhead at each of the toll plazas. SOVs and commercial vehicles travel on the outside managed lane during peak periods. HOVs use the managed lanes toll free but only during peak periods (from 6 to 11 A.M. eastbound and 2 to 8 P.M. westbound) in both directions.

In late 2012, HCTRA changed the orientation of the lane striping at the Eldridge Toll Plaza to give space between the designated HOV and toll lanes. The former layout had only a lane line between the HOV and toll lanes, and HCTRA decided to create a large, 12-foot buffer between the lanes to discourage last-minute lane jumping. HCTRA also wanted to move the HOV lane closer to the enforcement area to increase passenger cab visibility, which would allow officers to better observe vehicle occupancy and detect potential violators more accurately. The buffer between the HOV and toll lanes is viewed as a pilot project, and if it is effective for operations, will be applied to both the Wirt and Wilcrest Toll Plazas.

HOVs are not required to have transponders to use the managed lanes. To enforce compliance with HOV requirements, law enforcement personnel position their vehicles on a wide inside shoulder at the tolling plazas to manually observe traffic.

DEFINITIONS

Time-of-day pricing refers to setting the toll rate on a time-based schedule, with higher fixed rates during peak periods.

Peak period refers to the time of day (e.g., 6 a.m. to 10 a.m.) when traffic volume is at its highest point.

Off-peak period refers to the time of day (e.g., 11 a.m. to 2 p.m.) when traffic volume is lower than the peak period.

KML Project Design Features

\$237.5

million construction cost
as part of the larger
reconstruction project
for the **Katy Freeway**

12-mile

corridor from
SH 6 to I-610

4

managed
lanes total

2 in each direction

8

general
purpose
lanes total

4 in each direction

3

entrances per
direction

18- to 20-foot

buffer with white pylons
spaced at 10-foot intervals
separates the managed and
general-purpose lanes

3

tolling plazas with electronic gantries
(both directions) and occupancy
observation booths

Provides **separate access ramps**
for the Addicks Park and Ride Lot
and the Northwest Transit Center

Unique Features of the KML

Though there are a number of shared characteristics with other ML facilities in the United States, the KML possesses distinguishing characteristics, including:

- **Generous lane, shoulder, and buffer widths**, along with 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 relying 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.

While these characteristics limit, to some extent, generalizing the KML developmental experience, valuable insights into how projects achieve success become evident.

Congestion and Travel Time

Researchers tracked and analyzed historical trends in traffic volume, travel time, and transit usage within the KML's HOV and managed lanes. Traditionally with these kinds of studies the peak hour or peak period in the peak direction is evaluated. However, since there was significant growth in volume and travel-time savings in the KML's off-peak direction, that direction was evaluated as well. [Figure 3](#) shows the historical trend, by vehicle type, for peak direction traffic volumes.

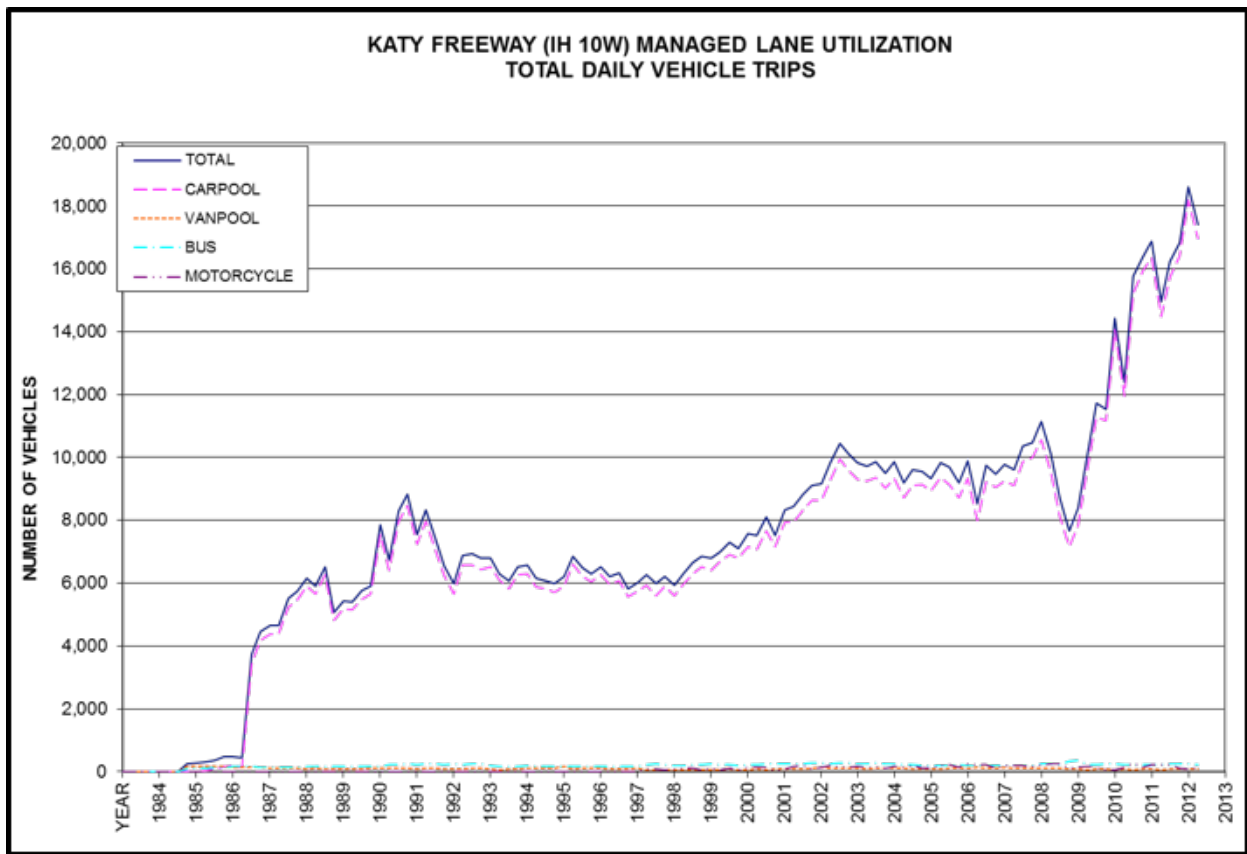


Figure 3. Quarterly KML Daily Peak-Direction (Eastbound A.M. and Westbound P.M.) Traffic Volumes.
Note: Construction occurred from 2003 to 2008, causing a dip in volume during 2008.



Generally speaking, peak-direction traffic volumes have more than doubled both in the peak hour and the peak period since the KML opened in 2009, with HOV volumes increasing slightly in the peak periods. However, it is the toll lane that has seen the majority of traffic volume growth. Thus, a toll increase aimed at mitigating congestion and facilitating better lane balance between HOV and toll users was instituted on September 8, 2012.

Specifically, the KML has seen the following trends since it opened:

- Increasing travel times reflect 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 period.
- 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 facility has experienced congestion at a few merge locations. In the eastbound 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—attempt to merge into traffic. As of the writing of this document, HCTRA is evaluating alternatives to alleviate this congestion. In the westbound direction, modifications to the managed lanes have improved the merge operations west of the North Post Oak entry ramp.

Safety

Traffic safety is always a concern with a new type of facility. In the case of the KML, HCTRA contracts with the Harris County Constable, which provided enforcement and incident response to patrol the KML.

The research team used TxDOT's Crash Record Information System (CRIS) data to determine crash trends for the managed lane and the general-purpose lanes before and after the implementation of the facility.

C.R.A.S.H.
Free. Simple. Secure.

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Why CRASH?

Crash Reporting and Analysis for Safer Highways (CRASH) is a secure website developed by TxDOT to allow law enforcement officers to submit the CR-3 crash report form electronically. CRASH is completely free to law enforcement agencies. TxDOT provides acquisition guidance and training along with on-going maintenance and support. CRASH has numerous built-in time savers allowing officers to complete the CR-3 accurately and quickly.

- It's free!
- Complete reports in 10-15 minutes
- Built-in smart text eliminates the need to remember codes
- No more paper returns with on-demand validation and error correction
- 24 hours, 7 days a week, 365 days a year help desk
- Easy to use embedded diagramming tools
- Training provided by TxDOT at no cost to agency

C.R.A.S.H. Video
Watch video of CRASH

Try C.R.A.S.H.
Sample the CRASH software

Training
Access the CRASH Training portal

FAQ/Help
Have questions?

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Comments or suggestions? Contact Us!

Figure 4. TxDOT's Crash Record Information System (CRIS).



Traffic volume often reflects the economy's health.



The KML is home to more than **78,000** employees and **300** energy companies.



Thus, the economic downturn is a significant context for understanding this analysis.

Contextual Factors

Reconstruction of the KML affected the roadway geometrics, traffic operations, and responsibilities among operating agencies. The changes affected the number of motorists who could use the managed lane, refocused enforcement priorities, and had other operational impacts. Other factors impacting the analysis of safety on the KML included 1) diversion of traffic from other corridors (US 290, Westpark Toll Road, and other arterial facilities) and 2) the economic downturn of 2008–2010.

More specifically regarding the economic downturn, it is worth mentioning that traffic volume often reflects the economy's health. In 2007–2008, Houston had just over 4 percent unemployment, a statistic which almost doubled by 2009. In 2010–2011, unemployment flattened after reaching a high of 8.9 percent and eventually started to decline, remaining above 7 percent. Also noteworthy is that the KML spans the Energy Corridor (SH 6 to Dairy Ashford Road), the third largest employment center in the region and home to more than 78,000 employees. Several of the largest international energy companies in the world and 300 multinational, national, and local companies are located in the corridor. Thus, the economic downturn, compounded by federal energy policies and the British Petroleum Deepwater Horizon explosion, is a significant context for understanding our findings.



Researchers found a **lower-corridor crash rate** due to improved geometrics and a reduction in congestion.

Analysis Results

CRIS data show a lower-corridor crash rate due to improved geometrics and a reduction in congestion. In general, the newer design implemented in 2009 has proven safer than the older design when looking at the entire corridor. The same crash patterns occur, with rear-end crashes being the most frequent followed by side-swipe crashes and object-struck crashes.

Comparing the HOV lane to the new KML shows the crash rates 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 consistent with the overall crash patterns.

More consistent data reporting from police and operating agencies could provide more accurate detail on crash location, object struck, and collision type. Current crash data retention policies limited our team in the amount of data and types of analyses we could conduct. Improving reporting policies and procedures should facilitate a more conclusive analysis for future research.

Enforcement

Researchers studied enforcement of the KML before and after the implementation of the managed lanes. The team conducted interviews and site visits to determine how the METRO Police Department and Harris County Constable Precinct 5, both responsible for facility enforcement at different times, approach their duties. We also compiled monthly HOV citation and toll violation statistics to measure driver compliance.

Prior to October 2008, METRO personnel enforced traffic laws on the Katy Freeway HOV lane. Once major construction was completed, Harris County Constable Precinct 5 took over. 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.

A significant finding was the difference in prioritizing enforcement goals between the METRO Police Department (when monitoring the HOV lane) and Precinct 5 (when monitoring the managed lanes). METRO emphasized the enforcement of vehicle occupancy requirements, whereas Precinct 5 prioritizes maintaining mobility within the managed lanes. However, METRO did recognize that their officers should “not impede the flow of traffic,” and Precinct 5 makes every attempt to “balance mobility with enforcement.”

The number of citations issued by type for each agency underscores these distinct approaches to enforcement policy. Overall, the monthly number of citations issued was sporadic, with low and high monthly totals being reported by each agency. METRO issued more citations for failing to meet vehicle occupancy requirements, whereas Precinct 5 issued more citations for speeding compared to, say, toll evasion. Specifically, HOV citations represented 54 percent of all METRO citations, and toll evasion citations represented 16 percent of all Precinct 5 citations.

Lane jumping is one possible explanation for fewer citations by Precinct 5. 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.



DEFINITIONS

Gore area refers to a triangular piece of the roadway where a road merges or splits at an entrance or exit ramp.

Driver workload refers to the required effort (physical and mental) that motorists must exert to accomplish the driving task.

Maintenance

Researchers interviewed maintenance supervisors from TxDOT, HCTRA, and METRO regarding activities and costs. Prior to implementation of the KML, TxDOT owned the Katy HOV lane but METRO operated it, with maintenance responsibilities split between the two. When KML opened, HCTRA took over maintenance.

Ongoing facility maintenance is critical when actively managing a tolled facility. Besides normal roadway maintenance, breakdown of other components of the facility—dynamic message signs, traffic flow monitoring sensors and systems, closed-circuit television, and the tolling infrastructure—can significantly impact mobility, enforcement, and of course commuter safety. The reverse is also true. For example, all agencies interviewed mentioned that active lane use enforcement can reduce the number of pylon hits and subsequent replacement. More generally regarding enforcement: providing consistent enforcement and having the physical space to conduct enforcement activities were cited as helping to reduce maintenance and operational issues.



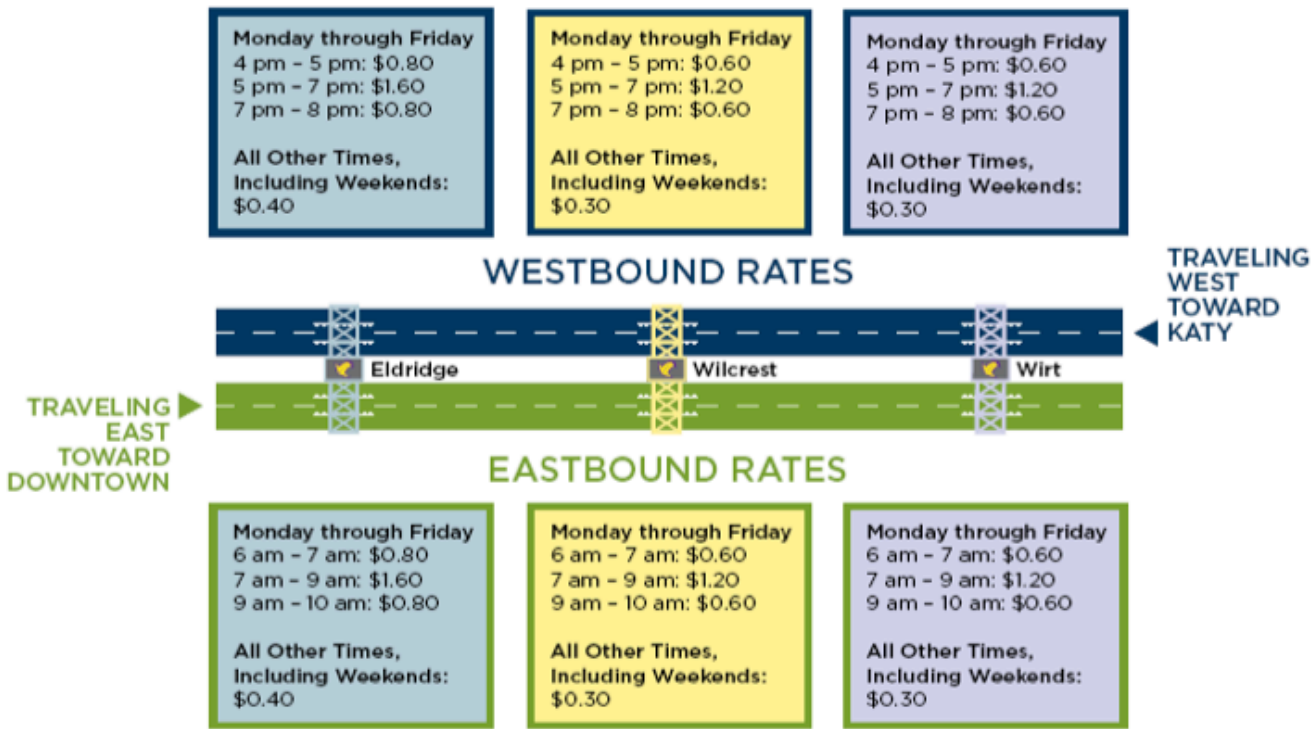
The interviews revealed that the most intensive maintenance activity, other than sweeping and debris pickup, is delineator replacement. The use of pylons (\$30 per unit, furnished and installed) on the KMLs provide insight to possible enhancements to existing and future facilities using them, including:

- | | | |
|--|---|--|
| <ul style="list-style-type: none"> • Pylons are one of the higher-cost and higher-intensity system maintenance items, and one of the items maintenance crews most often deal with. • Entry and exit gore areas typically have higher hit rates. Pylon hits in gore areas are attributed to driver workload (when making a decision) and distracted driving. • Enhanced enforcement can reduce pylon hits. • Though agencies originally thought contrast markings could reduce entrance and exit location pylon hits, they observed no actual reduction in hits. • Managed lanes typically have a lower per-lane maintenance cost due to fewer side-of-the-road maintenance items such as mowing, sign repair, and sign replacement. • The public expects that tolled facilities, including | <p>managed lanes, have a higher standard with regard to appearance, maintenance, and operations.</p> <ul style="list-style-type: none"> • A buffer width spacing 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 further reduces maintenance requirements. • Shorter, wider, and thicker profile pylons were reported to be more durable. • Raised pavement markings or profile markings might reduce pylon hits by enhancing the tactile and visual conspicuity of the pylon-treated area. • ML-related sign messaging, size, and placement are critical to safe operations and adequate warning time for helping motorists make appropriate decisions. The | <p>use of pylons can reinforce messages displayed through other signage methods (but are not a replacement for effective signing schemes) in areas where drivers make decisions.</p> <ul style="list-style-type: none"> • Retroreflective pavement marking tape is prone to edge curl if little to no traffic runs over it to keep it adhered to the pavement. This can be an issue around pylons, since less traffic runs over the tape near the pylons. Street sweepers can significantly damage tape markings that curl. Thus, agencies should consider using traditional paint or thermoplastic markings during application. • Horizontal signing can reinforce the lane assignment at entrance and exit locations, especially in areas where horizontal curvature can distort the lane/sign relationship. |
|--|---|--|

Tolling and Pricing

Researchers used the substantial number of traffic sensors on the Katy Freeway (equipped in both the general-purpose and managed lanes) to conduct a comprehensive analysis of managed lane use. The team assessed the number and percentage of Katy Freeway trips made on the KML, the conditions contributing to managed lane use, and the revenues deriving from managed lanes and travel-time savings. [Figure 5](#) shows toll rates on the KML prior to September 2012. After September 2012, toll rates increased.





HOV AND MOTORCYCLES 
CAR, TRUCK, VAN OR SUV
 Free during HOV hours:
 Monday through Friday, 5 am - 11 am and 2 pm - 8 pm
 Tolls apply at all other times.

SOV (SINGLE OCCUPANCY VEHICLES) 
CAR, TRUCK, VAN OR SUV
 Tolls apply by time of day as listed above.

3+ AXLES 
COMMERCIAL VEHICLES OR VEHICLES TOWING TRAILERS
 \$7.00 toll applies at all times for each tolling plaza.

Figure 5. Toll Rates Prior to September 2012 on the KML Used for Analysis (per the KML Website).

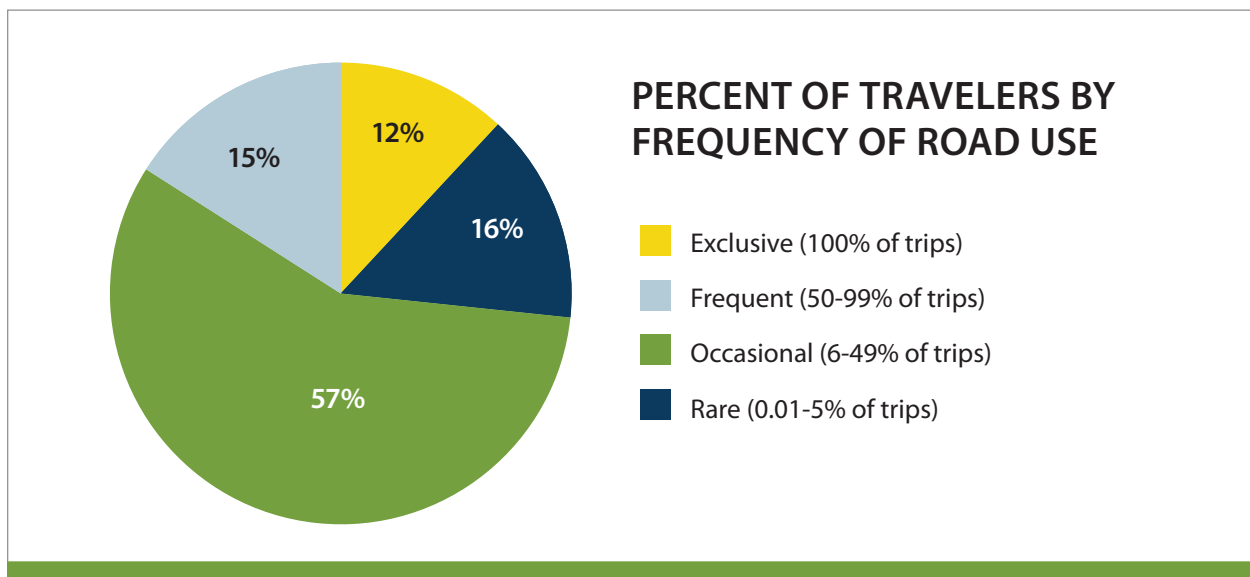
After travel-time savings (or traveling for free in carpools), survey respondents cited most often the following reasons for using the KML:

- **Less stress.**
- **Safer commute (perceived).**
- **Absence of trucks.**

Tollway lane users were broken into four categories:

- **Exclusive (daily):** those who only used tollway lanes.
- **Frequent (2-3 times per week):** Those whose trips in the tollway lanes comprised between 50 percent and 99 percent of their Katy Freeway travel.
- **Occasional (once per week):** those whose trips in the tollway lanes comprised between 5 percent and 50 percent of their Katy Freeway travel.
- **Rare (once per month):** those whose trips in the tollway lanes comprised between 0.01 percent and 5 percent of their Katy Freeway travel.

Based on all trips on the Katy Freeway (KML and GP trips) the percentage of trips taken by “day of week” and “time of day” were significantly different for the members of these four groups. However, there were few patterns to these differences. One of the few clear differences between the four groups was that the exclusive users were more often traveling during a weekday at peak times in the peak direction (7 to 9 AM eastbound and 5 to 7 PM westbound) than other groups, likely commuting to and from work. However, even for exclusive KML travelers, only 24 percent of trips were during the peak-period peak direction and, thus, 76 percent of exclusive KML drivers traveled in the non-peak period. This implies a tendency to use the tolled KML more often in the peak period, but also suggests plenty of use of this lane during other periods. Thus travelers are finding value in the lane for not just travel time savings, but also (according to the survey) reduced stress, feeling safer, and the absence of trucks on the KMLs.



Travel Time Savings of the Tollway

The team estimated the amount of travel time saved by vehicles on the KML based on the travel-time difference between the tollway lanes (not including the HOV lane) and the GP lanes. The dollar benefits shown here represent the total amount from 8.29 million trips. Westbound travelers saved more time on average than eastbound travelers. Both directions combined saved 270,393 total hours. Using TxDOT's value of \$20.99 per passenger car hour travel-time savings estimate, the toll lane saved travelers \$5,675,547 in travel-time savings in 2011.

Researchers also determined that revenues from the toll and HOV lanes combined exceeded \$7 million in 2011. The revenue exceeding the estimated value of travel-time savings indicates that the \$20.99 per hour figure greatly underestimates the value travelers are placing on the use of the toll lanes. The team used actual tolls and travel-time savings from paying customers to estimate more accurate figures of \$59.07 per hour for the users of the toll lane for SOVs and \$77.80 per hour for the users of the toll lane for HOVs. Using these figures yields a higher total benefit dollar amount of \$15.97 million per year. (Note: This value only represents the benefit from travel-time savings and ignores other benefits like reduced emissions and reduced vehicle operating costs.)

Time and Money

Commuters saved **\$5,675,547** in the toll lane in 2011 (using TxDOT's value of travel time savings of \$20.99 per passenger car hour).

Revenues equaled **\$7,025,185** (combining the toll and HOV lanes).



Access Design

Findings indicate that the **design of the access points** sufficiently accommodates the expected demand of drivers entering and exiting the KML.



REVIEWED
1,033
managed lane
access maneuvers

Researchers focused on four direct-merge access ramps (the most common ramp type on the KML) along 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. The team also evaluated access points at either end of the corridor and the direct-connect ramp at the Addicks Park and Ride Lot facility. Study considerations included traffic volumes in the managed lanes and GP lanes, elapsed time to complete the maneuvers, position of vehicles within the access ramps, and peak versus non-peak comparative performance.

The team reviewed 1,033 managed lane access maneuvers from 20 hours of peak and non-peak periods. Of those, 801 maneuvers took place on the direct-merge access ramps, and 232 occurred at the western entrance to the facility at the end of the diamond-lane section. Researchers also reviewed 37 cross-facility weaving maneuvers beginning at the managed lane exit ramp at Echo Lane. Findings indicate that the design of the access points sufficiently accommodates the expected demand of drivers entering and exiting the KML.

Direct-Merge Ramps

Access-point design meets expected demand at the sites studied, even during peak periods. Maneuvering to the managed lanes from the Addicks Park and Ride Lot T ramp proved most sensitive to peak-period traffic, due in part to traffic entering the ramp in platoons following release by the traffic signal at the park-and-ride facility.

Single lane changes typically required between 1 and 3 seconds, while drivers completed entire access maneuvers within 10 to 25 seconds. Most vehicles entered and exited the access points within the dotted line road markings, though some vehicles began maneuvering early or late, which occurred more frequently during peak periods.

Cross-Facility Weaving

Approximately 7,200 feet separates the ML exit at Echo Lane and the Katy Freeway exit to the Sam Houston Tollway, plus an additional 1,400 feet usable by drivers maneuvering early or late. Traveling from one access point to the other requires six to seven lane changes, which conforms to recommended design guidelines. Of 200 vehicles observed at the ML exit at Echo Lane, 37 completed a cross-facility weaving maneuver to exit to the Sam Houston Tollway. All but three of those 37 vehicles (one in the peak period and two in the non-peak period) completed their lane changes in less than 7,800 feet. The high rate of completed lane changes, combined with the moderate to high speeds of completed maneuvers, indicate that the design distance at this location is sufficient to accommodate these maneuvers.

Due to the additional distance traveled between the two ramps, typical overall elapsed times were around 2.0 minutes for peak-period maneuvers and 1.4 minutes for non-peak-period maneuvers. A high proportion of weaving vehicles entered the GP lanes “early” from the ML exit (particularly in the peak period). However, the distribution of elapsed times and position of final maneuvers was not much different from vehicles that exited within “normal” distance.



Single lane changes typically require **1 to 3 seconds**



Drivers complete entire access maneuvers **10 to 25 seconds**



“Funnel” Operations

The KML’s entrance at the boundary of the diamond lane section adds a through lane to the existing lane, making the entrance ramp proper very short; vehicles entering from the GP lanes do not need to merge. Thus, only initial lane changes were studied.

Traffic operations at the “funnel” proved unremarkable. Volumes (between 250 and 300 vehicles every 15 minutes) in the left GP lane remained fairly constant throughout peak and non-peak periods; however, the number of peak-period vehicles in the diamond lane and the number of access maneuvers increased approximately five-fold compared to the non-peak period. Given the consistent volumes and elapsed times, combined with a nearly 100 percent “normal” rate of ramp positioning, the design of this access point is sufficient to accommodate the expected demand.

Lane Separation

Lane separation usually relates to separating a preferential lane (e.g., HOV, HOT, or managed lanes) from GP lanes. The preferential lanes typically offer travel-time or congestion-relief benefits and have some kind of restriction (based on occupancy) or added fee (in the form of a toll) for their use. Each type of lane separation device has its advantages and disadvantages. When determining which type to deploy, designers should consider cost of construction, operational flexibility, enforcement and safety impacts, and maintenance.

Researchers focused the evaluation on concrete traffic barriers (CTBs) used on the Katy Freeway before versus pylon separation types used after. Pylons enhance—or emphasize and thus aid in—compliance with pavement markings. They are widely used on preferential lanes to aid in compliance with the double white line indicating not to cross. CTBs physically prevent vehicle encroachment, protect an immovable object, or separate two facilities in close proximity. Barriers are used, for example, to prevent encroachment down steep slopes or into buildings, bridges, or pedestrian facilities. [Table 1](#) shows a comparison of pylons to barriers in terms of design/operational, incident management, and maintenance considerations.



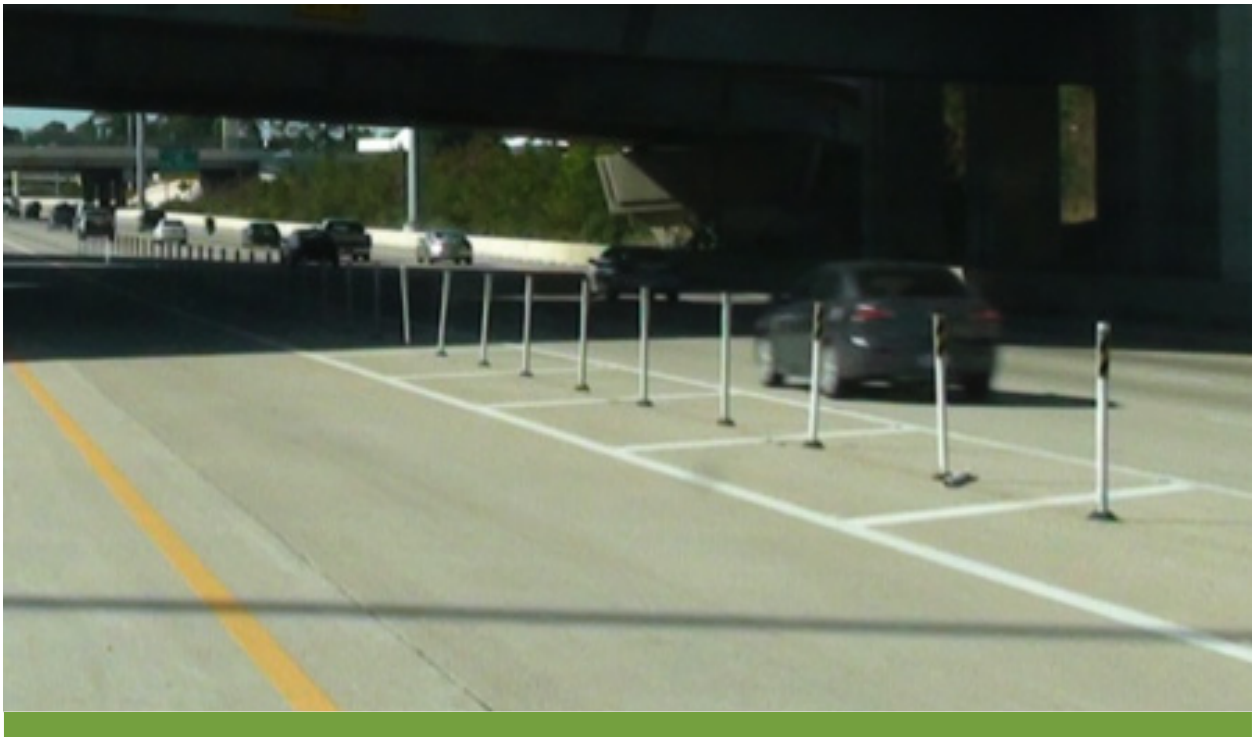
Feature	Barriers	Pylons
Design/Operational Considerations		
ROW/Buffer Width	4-foot minimum	1.5-foot minimum (maintenance is exponential)
End Treatment	Requires crash attenuator	None required but higher maintenance at entrance
Sight Distance	Perceived limitation	Perceived improvement—no walls to present obstruction
Vehicle Encroachment	None	High potential
Congestion	Managed lane not affected by GP lane congestion	Managed lane affected by GP lane congestion, difference in speed, and ability to cross over into the GP lanes
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 potentially costly
Ease of Enforcement	Occupancy—dependent on width	Occupancy—dependent on width
Installation Cost	High—\$16/linear foot	Low—\$3/linear foot
Crash Protection	Vehicles are physically separated from GP lanes	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 how close vehicles are to buffer, in terms of striking distance
Crash Cost	Dependent on severity	Dependent on severity—could go through pylons and hit median CTB

Table 1. Trade-Offs between Concrete Traffic Barriers (CTBs) and Pylons.

When comparing pylons to CTBs, some key highlights are clear:

- ROW (buffer space) and associated maintenance are two of the largest life-cycle deployment costs that can greatly influence the analysis and decision of which treatment to choose.
- ROW and maintenance are directly related. This study demonstrated the correlation between buffer space and maintenance replacement.
- Designers might consider other trade-offs regarding pylons versus CTBs:
 - o Incident management.
 - o Cost of enforcement.
 - o Consistency of design in the region and state (driver expectancy).
 - o Future flexibility.

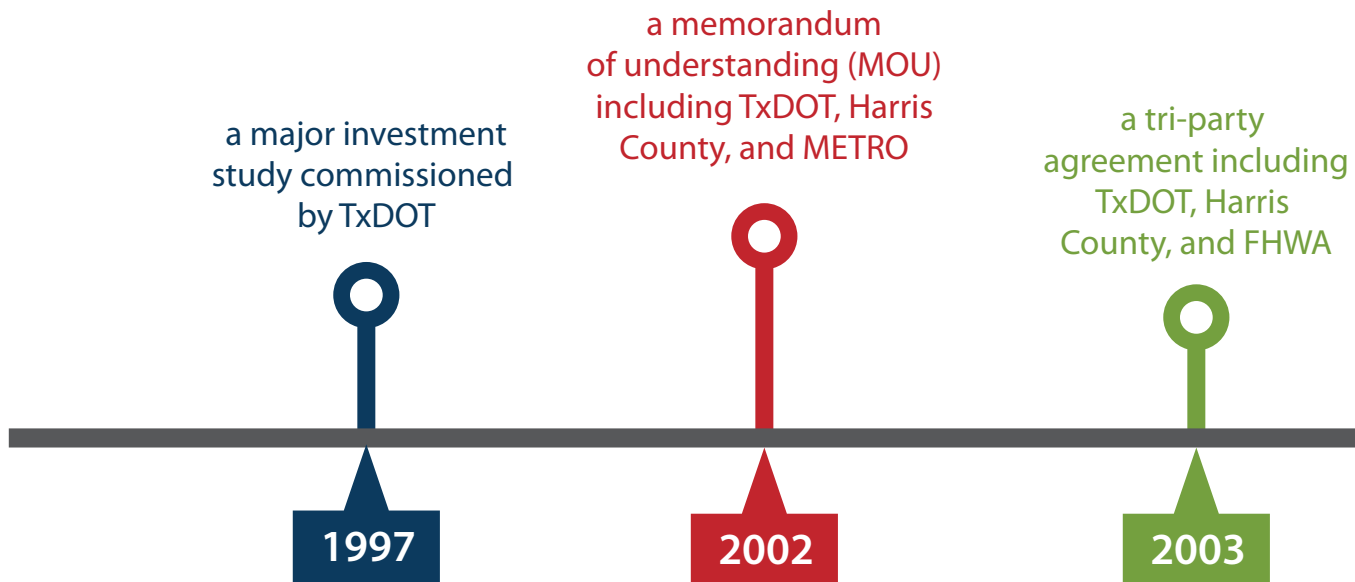
Many of the variables are site specific and can drastically change the cost of the design depending on the site. Designers should evaluate the needs of their specific project to determine the benefits and costs of the proposed treatments.



Operational Policy

Researchers examined the development of the KML from before it had managed lanes to its current configuration. They also looked at potential future tolling and HOV policies. “The KML: History and Operational Summary” portion of this document covers the essential history and development of the KML; this section focuses on policy evolution and future possibilities.

POLICY EVOLUTION



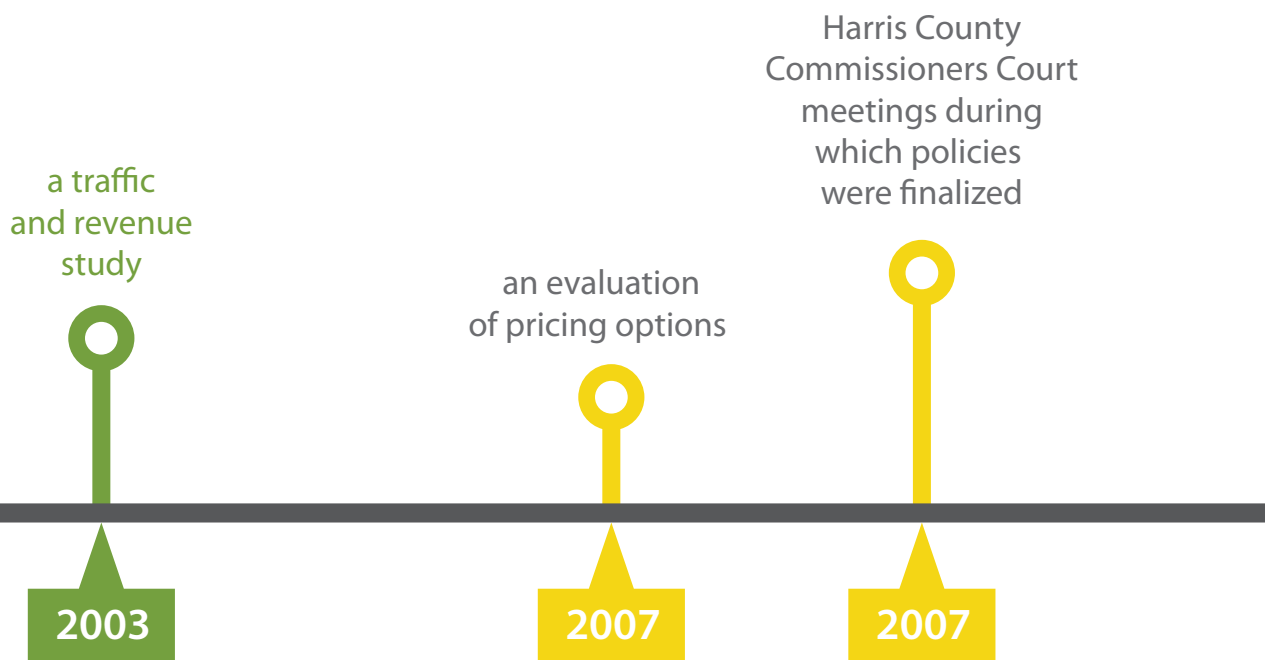
Policy Evolution

Changes in tolling and HOV policies took place gradually. Shown in the following list, new agreements and studies conducted over time charted the course for policy development:

- **1997:** a major investment study commissioned by TxDOT.
- **2002:** a memorandum of understanding (MOU) including TxDOT, Harris County, and METRO.
- **March 2003:** a tri-party agreement including TxDOT, Harris County, and FHWA.
- **May 2003:** a traffic and revenue study.
- **2007:** an evaluation of pricing options.
- **2007:** Harris County Commissioners Court meetings during which policies were finalized.

The HOV policy remained relatively consistent throughout much of the process. Policies consistently recommended or assumed commuters meeting the HOV-3+ requirement would freely use the toll road and those meeting the HOV-2 standard would pay. In the end, public pressure helped to influence the selection of the HOV policy. The public's influence is evident because many of the documents prior to the public's will being known consistently describe an HOV policy different than the one finally selected.

By contrast, the tolling policy changed multiple times, evolving from a general idea about using tolling as a strategy to generate revenue and manage demand, to time-of-day pricing, to dynamic pricing, and finally back to time-of-day pricing. The final pricing structure resulted from a site visit to the SR 91 Express Lanes in San Diego, California. This visit led HCTRA to decide that simplicity in tolling was best, so the agency selected time-of-day pricing.



Potential Future Policies

If congestion increases over time on the KML, HCTRA might consider various strategies to increase mobility on the corridor.

Table 2 highlights these potential strategies.

Potential Strategy	Characteristics and Notes
Introduce dynamic pricing	Uses sensors on the roadway to detect congestion.
	Changes the price at regular intervals to charge a rate commensurate with the traffic level.
	Discussed as an option in the 2007 pricing evaluation document.
Increase toll rates	Manages the demand on the roadway by reducing the number of motorists willing to use the priced option on the road.
	Represents a strategy HCTRA has already used on the Katy Freeway Managed Lanes (effective 9/7/12).
Increase occupancy requirements for HOVs beyond 2+	Manages demand by reducing the number of vehicles eligible to use the facility for free.
	Requiring HOV-3+ was discussed extensively prior to the KML opening, but public resistance kept it from happening.
Develop an automatic system that adjusts both tolling and HOV operations using performance measures and benchmarks	Would trigger rate changes (based on pre-approved policies) once an established threshold, such as traffic volume or speed, is exceeded.
	Policy shifts could be flexible enough to allow different vehicle types or occupancy requirements (e.g., requiring HOV-2 to pay).
	Since the policy changes would be pre-approved, individual rate fluctuations would not require a referendum or policy discussion prior to implementation.

Table 2. Future Policy Strategies for Consideration.

Public Attitudes and Perceptions

In 2012, the research team assessed the public's attitude and perceptions of the KML by surveying Katy Freeway travelers. Advertised by online and traditional media, the survey was available via the Internet between August 15, 2012, and September 19, 2012, and resulted in a total of 1,067 responses. Researchers also interviewed those involved with, or instrumental in, developing the KML and ongoing operations of the KML.

Summary of Survey Results

Most respondents (58 percent) had used the managed lanes at least once. In terms of how they used the lanes, few differences were evident between SOVs and carpools. The two groups even had similar reasons for using (or not using) the managed lanes. Cost was the most-often cited reason for not using the managed lanes (even though the managed lanes are free for carpoolers during most of the day).

The next most-cited reasons were:

- 1) Not enough travel time savings.
- 2) The respondent avoiding tolls whenever possible.

The main reasons cited for using the managed lanes were:

- 1) Less stress.
- 2) Safer Commute.
- 3) Avoidance of trucks.

Most travelers who used the managed lane for their most recent trip perceived an average travel time savings of over 10 minutes (well above the actual average travel-time savings of just under 4 minutes). As has been the case on other facilities in the nation, it was likely that the survey's respondents have a perception that was skewed by the difference in speeds.

Modeling Lane Choice Using Survey Results

The research team developed models of lane choice using the survey data. 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 results than those from the actual usage of the Katy managed lanes, where the average value of time was close to \$60/hour. The likely reason for this disparity is that travelers sometimes pay for very small travel-time savings in reality but would not answer that way on a stated-preference survey question. For example, some paid trips on the KML occurred when the trip on the KML was only a handful of seconds faster than on the GPs.

Project Delivery

The overriding sentiment to do something about the Katy Freeway was the **common motivator** among agencies involved, key stakeholders, and the driving public.

A complex environment of multiple public agencies, stakeholders, and a public dissatisfied with a congested freeway shaped the development of the KML. This environment required close collaboration and coordinated efforts to reconstruct the Katy Freeway. Several agency agreements helped manage this complicated relationship. 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.

Project Philosophy: Finding Common Cause

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 overcome obstacles were characteristic of how the project developed. The overriding sentiment to do something about the Katy Freeway was the common motivator among agencies involved, key stakeholders, and the driving public. This shared cause helped influence those involved to work together, find solutions, and build a better mouse trap through ground-breaking agreements, innovative strategies, and creative thinking. [Table 3](#) outlines issues and lessons learned from the KML case.

Lesson Learned	Description
Account for Conflicting Visions	Each agency and/or stakeholder had a unique project vision and carried a certain responsibility to address that vision. Each group had objectives and goals, and occasionally those conflicted.
Find Stakeholders and Project Champions	Stakeholders and project champions can have powerful influence, and this can come in handy in mitigating conflicts and pushing projects through to completion. For example, when an agency threatened to stall the project on principle, stakeholders mediated the dispute; when the project ran short of funding, stakeholders brought HCTRA onto the team as a financial partner.
Establish Agreements to Define Roles	As identified by several interviewees, though difficult to establish, interagency agreements enabled agencies to cooperate and collaborate. Initial agreements, such as memoranda of understanding, served as a framework to develop subsequent, more detailed agreements. Guided by these agreements, the operating committee helped resolve conflicts in a timely fashion.
Build in Flexibility	Not all events are foreseeable, and changes to the initial agreements acknowledged this. Supported by the framework establishing the working relationships, agencies had to learn to adapt to dynamic circumstances. Several interviewees emphasized how vital this was to the project’s success.
Agree on a Lead Agency	Coordination problems sometimes occurred. TxDOT would occasionally step in as the lead agency and make unilateral decisions to help resolve thorny issues and move the process forward.
Maintain Strong Working Relationships	Respecting the other agencies involved proved vital to success. Interviewees acknowledged that trusting each other and knowing they could challenge one another’s ideas helped them maintain an open perspective and craft creative solutions that served the project’s long-term best interests.

Table 3. *Project Delivery Lessons Learned.*

The KML: Lessons Learned for Future Efforts

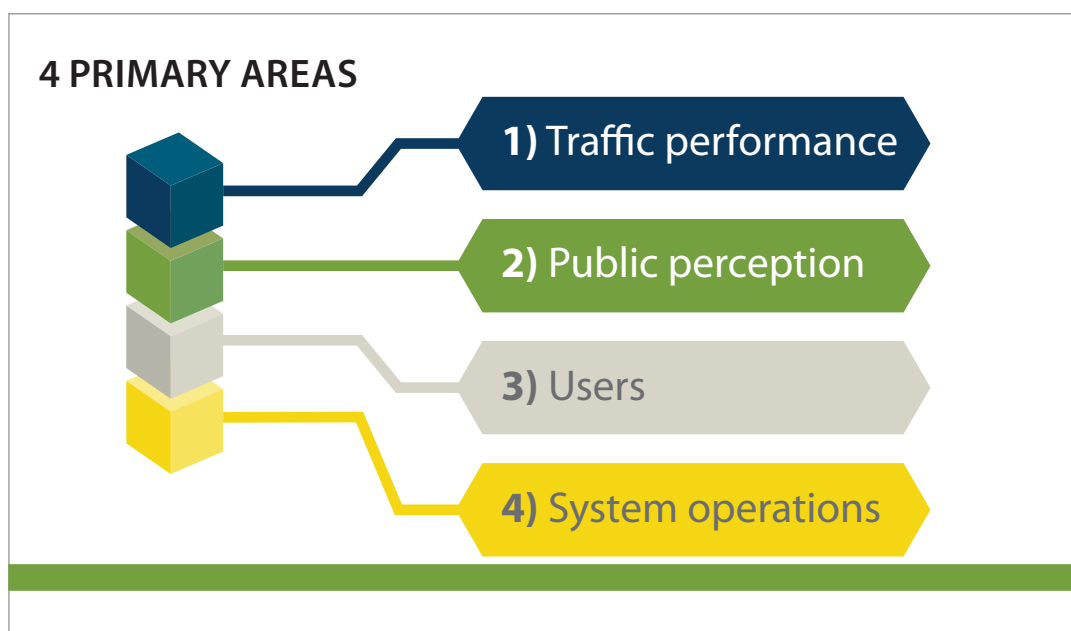
The four-lane KML,

constructed within the center of the reconstructed Katy Freeway, is viewed as a second-generation ML project, representing features not applied in earlier HOV to HOT lane conversions. Beyond the facility's unique operating characteristics described in the earlier sections, TxDOT partnered with other local entities on the project to create an innovative delivery process for funding, operating, and maintaining the managed lanes.

Researchers focused on four primary areas to determine best practices:

- 1) Traffic performance.
- 2) Public perception.
- 3) Users (e.g., trip characteristics).
- 4) System operations (e.g., finance, enforcement, safety, customer service, and incident management).

Table 4 summarizes their findings about each of these areas as it relates to the KML. In terms of future research, further examination of signing, carpooling, transit, and economic impacts could yield more recommendations for best practices.



In the Area of...	Here's What We Learned from the KML...
<p>Traffic Performance</p>	<p>Managed-lane volumes have doubled over time. Some congestion has emerged on the GP lanes despite the freeway's expansion. This is partly attributed to latent demand and partly to growth in the energy corridor.</p>
	<p>Travel-time savings are approximately 5 minutes (morning) and 14 minutes (afternoon) in peak directions, an advantage over the GP lanes that has increased as volumes have grown.</p>
	<p>Managed lane off-peak speeds ran consistently at 70 mph but dropped to a low of 52 mph (morning peak) and 50 mph (afternoon peak). Both speeds correspond to the GP lanes' most-congested travel periods.</p>
	<p>Off-peak volumes are growing at a rapid rate on the managed lanes.</p>
<p>Public Perception</p>	<p>Travelers use managed lanes to save time, reduce stress, and avoid congestion. They avoid managed lanes due to cost and limited travel time savings compared to the expense.</p>
	<p>Most ML travelers estimated travel-time savings at more than twice the actual time saved.</p>
<p>Users</p>	<p>Over 80 percent of the half million ML commuters used them for 60 or fewer trips annually (slightly more than one ML trip per week). Approximately 11 percent used the managed lanes more than twice per week. Just over 3 percent used the managed lanes for all trips.</p>
	<p>A small portion of commuters even use the managed lanes when no travel-time savings occur. In 2011, 1.1 percent of toll-lane trips occurred when the managed lanes operated at a lower-average speed than the GP lanes.</p>
	<p>Some 49 percent of ML users surveyed changed their usual freeway access point to reach the managed lanes.</p>
<p>System Operations</p>	<p>Improved geometric design and reduced congestion helped reduce crashes from 128.3 crashes (pre-construction) to 57.3 crashes (post-construction) per million vehicle-miles.</p>
	<p>The KML's various access types have proven sufficient to handle the expected demand of drivers entering and exiting the lanes.</p>
	<p>Using a wide 20-foot buffer and plastic delineators, most KML sections were built assuming ideal conditions for effectively separating traffic flowing simultaneously and in the same direction. Attributed to the wide buffer, pylon hits and needed replacements are less frequent (averaging 25 percent replaced per year) compared to other ML projects.</p>
	<p>Enforcement operations have evolved, both institutionally and operationally, to ensure a balance between deterring cheaters and enforcing laws at the cost of disrupting traffic flow.</p>
	<p>All agencies interviewed agree: active enforcement of lane use and having the physical space to conduct enforcement activities help to reduce maintenance and operational issues.</p>

Table 4. Best Practices from Studying the KML.

Overall, this evaluation shows that the KML is operating safely and efficiently achieving its project goals.

Overall, this evaluation shows that the KML is operating safely and efficiently achieving its project goals. To ensure that a facility like the KML meets commuters' needs, monitoring of project expectations via performance measures is key. This is particularly true during the critical ramp-up phase for a facility, when commuters are adjusting choices and behaviors to take advantage of their new traveling options. The KML's operating partners, especially HCTRA, have continuously monitored performance since opening. When needed, they have made adjustments in toll rates, lane configuration at the tolling zones, and access operations at the western terminus—adjustments critical to ensuring acceptable performance standards.

Historically speaking, the KML has represented the evolution of managed lanes theory across its development, making it a prime candidate for deriving best practices. General principles established through this research effort include:

- Finding the right stakeholders with a shared, vested interest in the project's success.
- Outlining clear partner roles and feedback mechanisms, including dispute resolution procedures.
- Gaining public trust, buy-in, and feedback throughout the facility's life.
- Setting quantifiable project goals and establishing performance measures to use in assessing how well the facility is meeting them.
- Building flexibility into planning and operational policies and procedures to ensure responsiveness dynamic situations and unforeseen future circumstances.

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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