Impacts of Increasing Vehicle-Occupancy Requirements on HOV/HOT Lanes

Requested by
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The Caltrans Division of Research and Innovation (DRI) receives and evaluates numerous research problem statements for funding every year. DRI conducts Preliminary Investigations on these problem statements to better scope and prioritize the proposed research in light of existing credible work on the topics nationally and internationally. Online and print sources for Preliminary Investigations include the National Cooperative Highway Research Program (NCHRP) and other Transportation Research Board (TRB) programs, the American Association of State Highway and Transportation Officials (AASHTO), the research and practices of other transportation agencies, and related academic and industry research. The views and conclusions in cited works, while generally peer reviewed or published by authoritative sources, may not be accepted without qualification by all experts in the field.

Executive Summary

Background

California's high occupancy vehicle (HOV) lane network is heavily used, and portions of it are becoming congested during peak periods. To address this congestion, Caltrans is exploring several solutions: increased enforcement, bottleneck reductions, hybrid/BEV exclusions, raising the minimum required occupancy of vehicles using these lanes from two to three persons (from HOV2+ to HOV3+ and converting lanes into high occupancy toll (HOT3+) lanes. However, the likely impacts of these measures on corridor performance are not easy to predict since existing travel demand models do not appear capable of predicting the numerous possible mode changes (for instance, the possibility that increasing occupancy requirements will lead to more single occupant vehicles in regular lanes).

Consequently, Caltrans is interested in conducting an investigation into the effects of raising HOV occupancy requirements or converting HOV to HOT lanes. To assist with this investigation, CTC and Associates conducted a literature review focused on the following high priority objectives of identifying:

- Studies of managed lanes in the United States.
- HOV facilities that have increased requirements (e.g., HOV2+ to HOV3+) on existing HOV lanes.
- Performance measures that were used (e.g., HOV/general purpose speeds, vehicle trips, person trips).
- Whether performance goals were set (e.g., to increase person throughput).
- Whether alternative modes were available (e.g., bus, train and vanpool) and whether new transit/TDM services were added.
- Mode changes that were detected (e.g., HOV2 to 2 single-occupant vehicle (SOV), HOV2 to HOV3).
- Whether specific criteria were used to decide to raise occupancy (e.g., volumes and vehicle-occupancy levels).
- Research work on transportation modeling that addresses possible mode changes.

- Published and unpublished reports available on the above questions.

The review also touches upon the following medium priority objectives:

- Public reaction to HOV/HOT changes and public outreach/education efforts.
- Whether any studies examined makeup of carpools on HOV lanes (e.g., coworker, family, neighbor).
- What factors motivated carpool formation on HOV/HOT lanes, and what incentives were effective.
- Whether there were any barriers encountered when moving from HOV2+ to HOV3+.

This review will serve as a reference during the TRB annual conference in mid-January, where Caltrans will develop a list of contacts for follow-up interviews.

Summary of Findings

We compiled a list of HOT lanes in the United States that are the result of conversions from HOV2+ facilities (in some cases, these conversions add an HOV3+ requirement) from a number of sources:

- http://www.metro.net/projects/expresslanes/expresslanes_us/.
- Page 4 of http://www.wsdot.wa.gov/NR/rdonlyres/2DA072CA-7D4A-4876-A58B-64DBE152D48D/0/SR167_AnnualPerformanceSummary_080812_web.pdf.
- http://en.wikipedia.org/wiki/User:Timsabin/List_of_HOT_and_ETL_lanes_in_the_United_States . (This list is not entirely up to date.)
- http://en.wikipedia.org/wiki/List_of_toll_roads_in_the_United_States.

These sources also include lists of numerous planned HOT lane projects (in most cases, conversions from HOV facilities).

HOT lane facilities that converted from HOV lanes include:

- I-15 near San Diego, CA (HOV2+): http://fastrak.511sd.com/.
- Metro Express lanes pilot project (I-110 and I-10) in Los Angeles, CA (HOV2+ for I-110, HOV3+ during peak hours for I-10): http://www.metro.net/projects/expresslanes/.
- SR 237/I-880 Express in Silicon Valley, CA (HOV2+): http://www.vta.org/expresslanes/.
- I-680 in Oakland, CA (HOV2+): http://www.680expresslane.org/I-680.asp.
- I-25 in Denver, CO (HOV2+): http://www.coloradodot.info/travel/tolling/i-25-hov-express-lanes.
- I-95 near Miami, FL (HOV3+): http://www.95express.com/.
- I-85 in Atlanta, GA (HOV3+): http://www.peachpass.com/.
- I-495 in northern Virginia (HOV3+): https://www.495expresslanes.com/.
- I-394 and I-35W in Minnesota (HOV2+): http://www.mnpass.org/.
- I-15 in Salt Lake City, UT (HOV2+; sells permits rather than collecting tolls): http://www.expresslanes.utah.gov/.
- I-10, U.S. 290 in Houston, TX (HOV3+ during peak hours): http://houstonvaluepricing.tamu.edu/quickride/.
- METRO HOT Lanes (currently IH 45, US 59 and US 290) in Houston, TX (HOV2+): http://www.ridemetro.org/Services/HOTLanes.aspx.

- SR 267 in Washington state (HOV2+): http://www.wsdot.wa.gov/Tolling/SR167HotLanes/default.htm.

We found one existing HOT facility that had been converted from a toll road rather than an HOV facility:

- SR-91 in Orange County, CA (HOV3+): http://www.91expresslanes.com/.

We did not find any cases of conversions of HOV2+ to HOV3+ facilities in the absence of the implementation of high occupancy tolling. There are a number of non-tolling HOV3+ facilities in the United States, but we found no information related to facilities increasing their occupancy requirements and no available related research concerning operational effects for cases in which there was a conversion from an HOV2+ facility to an HOV3+ facility without the implementation of tolling. In 2008, a Federal Highway Administration (FHWA) inventory of HOV lanes found that of 345 HOV lanes in the United States, 85 were purely HOV2+, 14 were purely HOV3+ and two were HOV3+ only at certain times of day. (See A Compendium of Existing HOV Lane Facilities in the United States in **Related Research**.) A more up-to-date database of HOV facilities is currently under construction at http://hovpfs.ops.fhwa.dot.gov/clearing.aspx.

In **HOV to HOT Conversions**, we detail performance measures, goals and outcomes, as well as related research for HOV to HOT conversions in the following target states: Florida, Georgia, Minnesota, Texas and Washington. Where information is available, we address the availability of alternative modes, mode changes detected, and other Caltrans high and medium priority objectives. We also highlight resources and studies for several HOT lane conversions in other states.

In **Related Research and Resources**, we compile information in the following topic areas:

- General resources for HOV to HOT conversion.
- Performance and mode choice.
- Performance Measures and assessment methods.
- Performance modeling.

Next Steps

CTC & Associates completed the first draft of this Preliminary Investigation in January, prior to the Transportation Research Board Annual Meeting. Caltrans and FHWA representatives then approached committees at the TRB conference to request additional resources related to HOV to HOT conversions. Based on the resources provided, CTC & Associates produced a companion Preliminary Investigation, Managed Lanes Case Studies, which captures state experiences with specific managed lanes projects. Caltrans will use the strategies identified in these two investigations to inform their planning for HOV to HOT conversions.

HOV to HOT Conversions

In what follows, we outline the performance measures, goals and outcomes, as well as related research for HOV to HOT conversion projects, in several states. The following study (which we found after producing the compilation below) covers some of the same ground for these and numerous other HOT conversion projects:

> **Performance Measurement and Evaluation of Tolling and Congestion Pricing Projects**, *NCHRP Web-Only Document 174*, March 2011.
> http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_W174.pdf
> See Section 2.2 for documentation of the performance and performance metrics for numerous HOT conversion projects. Chapter 3 outlines information gaps, which are related to three primary areas:
>
> - An incomplete understanding of why performance evaluation takes place and why certain metrics are tracked.
> - An incomplete understanding of how the information collected is used in practice and what changes have taken place as a result.
> - A need to resolve the challenge of compiling guidelines that encompass a broad set of congestion pricing projects, varying across a wide range of characteristics, but applicable to any individual facility's goals and circumstances.
>
> See also the related study, "Evaluation and Performance Measurement of Congestion Pricing Projects," in **Related Research**.

Florida

95 Express HOT Lanes Project

http://www.95express.com/
Related FHWA summary:
http://ops.fhwa.dot.gov/freewaymgmt/publications/documents/nrpc0610/workshop_materials/case_studies/miami.pdf
This project is opening in three phases:

- Phase 1A is open and runs northbound on I-95 from south of SR-112 to the Golden Glades area just north of 151st Street in Miami-Dade County.
- Phase 1B opened for tolling in January 2010 and runs southbound on I-95 from just south of Miami Gardens Drive/NW 186th Street to just north of I-395/SR-836.
- Phase 2 will extend the express lanes to provide a continuous facility between I-395/SR-836 in Miami-Dade County and Broward Blvd. in Broward County. Funding for Phase 2 has been identified, and construction began in late 2011 with a tentative completion date of late 2014.

Tolling prices are variable and range from $.025 to $7.10. Lanes are free for cars with three or more occupants, registered vanpools, county school buses, registered hybrid vehicles and motorcycles.

Performance Measures and Goals

FDOT includes monthly, midyear and annual reports on the performance of these lanes:
http://www.sunguide.org/index.php/tmc_reports/

- Most recent monthly report: http://www.sunguide.org/sunguide/images/uploads/tmc_reports/2012_11_29_95_EL_Monthly_October_2012_rjs_final.pdf.

- Midyear report (2009): http://www.sunguide.org/sunguide/images/uploads/tmc_reports/95X_1A_UPA_Eval_Midyear_Report__10_30_2009__FINAL.pdf.
- Most recent annual report: http://www.sunguide.org/sunguide/images/uploads/tmc_reports/95X_P1_UPA_Eval_FY_11_Annual_Report__02_17_2012_rjs__FINAL.pdf.

Performance measures include:

- Total trips.
- Exempt trips.
- Revenue.
- Average tolls.
- Volume.
- Speed.
- Reliability, as measured by the percentage of time lanes operated above 45mph.
- Transit ridership.

2011 Annual Report

From the annual report's general summary: The program has considerably improved the overall operational performance of I-95. Customers, including transit riders, choosing to use the express lanes (EL) have significantly increased their travel speed during the AM peak (6am-9am, southbound) and PM peak (4pm-7pm, northbound) periods—from an average speed in the high occupancy vehicle (HOV) lane of approximately 20 MPH (prior to program implementation) to a monthly average of 62 MPH and 56 MPH in the southbound and northbound directions, respectively. Drivers travelling via the general purpose lanes (GPL) have also experienced a significant peak period increase in average travel speed since implementation of 95 Express—from an average of approximately 15 MPH (southbound) and 20 MPH (northbound) to a monthly average of 50 MPH and 41 MPH, respectively. Probably more important than the improved speeds when it comes to operational performance are the improvements to the travel time reliability of the facility. Average volume along the express lanes in the AM and PM peak periods were nearly 8,300 vehicles (over 30% of the total I-95 traffic during peak periods); a 12.2% increase in volume over FY2010. These vehicles were traveling at speeds greater than 45 MPH during the AM peak period nearly 100% of the time and almost 92% of the time in the northbound direction during the PM peak period. The federal requirement for HOV to HOT lane conversion is a minimum of 90% for 45 MPH speeds during the peak period.

The report also makes note of a public opinion survey in which "31% of survey participants use 95 Express two to four times per week and 80.4% agree or strongly agree that the express lanes provide a more reliable trip than the I-95 general purpose lanes."

Performance goals (page 5 of the annual report) include improving safety, throughput and mobility reliability.

Transit Evaluation

The project introduced new bus rapid transit routes in January 2010 (see page 16); by November 2011, ridership has increased 145 percent since before the HOT lanes were introduced. It further increased with the addition of other routes.

FDOT's reports page includes more detailed transit evaluation reports, including the most recent November 2011 report:

http://www.sunguide.org/sunguide/images/uploads/tmc_reports/HOV_Report_Analysis_Memo_FINAL_3.14_.12_.pdf

Related Research

Managed Lane Operations—Adjusted Time of Day Pricing vs. Near-Real Time Dynamic Pricing, Volume I: Dynamic Pricing and Operations of Managed Lanes, University of Florida, Gainesville, 2012.
http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_TE/FDOT_BDK77_977-04_V-1_rpt.pdf
From the abstract: The Florida Department of Transportation recently implemented high occupancy/toll (HOT) lanes (known as 95 Express) in the Miami regional area on Interstate 95. This report investigates three aspects relevant to the operations and management of HOT lanes such as 95 Express. First, two questions concerning the impact and effectiveness of dynamic tolling are investigated. One is whether a managed-lane system exhibits hysteresis-like behavior that motorists periodically shift their departure times to cope with the volatility of the toll being charged. The other is whether dynamic pricing necessarily performs better than static or time-of-day pricing. Second, this report examines whether and how the reduced lane, shoulder widths, delineators, and designs of ingress/egress points have affected the capacity and operations of the toll lanes and the general-purpose lanes of 95 Express. Lastly, the report focuses on enhancement and evaluation of the tolling algorithms for the current and future 95 Express.

Improving Value of Travel Time Savings Estimation for More Effective Transportation Project Evaluation, University of South Florida, Tampa, 2011.
http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_PTO/FDOT_BDK85_977-21_rpt.pdf
Researchers estimated the value of travel time savings (VTTS) for the I-95 Express corridor. *From the abstract:*

> By using information from the first survey to collect trip-specific data on the 95 Express corridor in Miami, Florida, it was found that the estimated VTTS of those travelers is approximately 49 percent of their hourly wage based on annual household income, with a range of $2.27 to $79.32 per hour and a mean of approximately $32.00 per hour. This result is in the range of estimated values for VTTS found in the recent literature and represents actual behavior of the survey respondents rather than the more commonly found stated preferences. While the primary objective of this research is to estimate VTTS using revealed preference data from the 95 Express corridor, a significant secondary objective is to provide a synthesis of managed lane operations in the United States. The report contains information on several existing projects around the country as well as information on cities that have been named part of the federal Urban Partnership Agreement (UPA) or Congestion Reduction Demonstration (CRD) program.

Georgia

I-85 HOV to HOT Conversion Project

http://www.dot.state.ga.us/travelingingeorgia/expresslanes/I85expresslanes/Pages/default.aspx
http://www.georgiatolls.com/programs/i-85-express-lanes/
GDOT converted 16 miles of HOV lanes on I-85 in Atlanta into HOT lanes. Vehicles with three or more occupants, motorcycles, transit, emergency vehicles and alternative fuel vehicles may use the lanes for free. Lanes opened in October 2011.

Performance Measures and Goals

The Georgia State Road & Tollway Authority releases monthly travel data summaries for I-85: http://www.georgiatolls.com/programs/i-85-travel-data/. These summaries use the following performance measures:

- Monthly trips: 446,660 in October 2012.
- Percent of trips non-tolled: 14 percent.
- Weekday trips average: 17,701.
- Daily fare average: $1.51.

A February 2012 *New York Times* article (http://www.nytimes.com/2012/02/26/automobiles/hov-access-to-the-car-pool-lane-for-a-price.html?pagewanted=1&_r=1) cites the following weekly commute data published December 2011: http://www.peachpass.com/uploads/Commute_Data_Release_121211.pdf. This document (we were unable to find more recent examples of its kind, and it seems to have been replaced by the monthly travel data summaries cited above) details:

- Travel times.
- Highest toll rate posted.
- Average toll rate.
- Average speed.

The New York Times article notes that by January 2012, lanes were seeing 11,600 trips per weekday, and:

> In the first full work week of December, average speeds during the morning peak ranged from 39 to 63 m.p.h., compared with 30 to 57 m.p.h. in the general lanes. Toll rates reached no more than $3.75, and the daily trip averages for the month were $1.16.

News accounts, including *The New York Times* article and an October 2012 article from *The Atlanta Journal-Constitution* (http://www.ajc.com/news/news/local/first-year-of-i-85-hot-lane-brings-drivers-but-les/nSRyT/), suggest that the lanes are widely disliked (at least initially) and have not met their expected revenue targets.

The following document outlines a plan for evaluating the performance of I-85 HOT lanes:

> **Atlanta Congestion Reduction Demonstration National Evaluation Plan**, FHWA, April 2011. http://ntl.bts.gov/lib/42000/42800/42820/atlantaupa_R3_.pdf
> *From the abstract:* The Atlanta CRD national evaluation plan identifies major questions to be answered through the evaluation, the evaluation analyses to be used to address those questions, and the data needed for the analyses. It also outlines the test plans that will be used to collect and analyze the required data.
>
> This document notes (page xi) that the project also includes:
>
> - Transit enhancements, including the addition of 36 buses.
> - Automated enforcement systems.
> - Carpooling outreach.
>
> Performance Measures
>
> This document includes a large number of performance measures in 12 areas. Performance measures for congestion include:
>
> - Travel time and travel speeds:
> - Percent change in average, median and 95th percentile travel time.

    - Actual and percent change in average travel speeds in general purpose and HOV/HOT lanes during peak and off-peak periods.
    - Percent change in travel time index in general purpose and HOV/HOT lanes.
- Travel time reliability and variability (buffer time and planning index time):
    - Change in buffer time.
    - Change in planning time index.
- Spatial and temporal extent of congestion:
    - Change in the number of general purpose and HOV/HOT lane-miles operating at less than 45 mph.
    - Change in the number of general purpose and HOV/HOT lane-miles operating at less than 30 mph.
    - Change in the number of hours per day that the general purpose and HOV/HOT lanes are operating at less than 45 mph.
    - Change in the number of hours per day that the general purpose and HOV/HOT lanes are operating at less than 30 mph.
- Vehicle and person throughput:
    - Percent change in daily and peak period VT.
    - Percent change in PT during peak periods.
    - Percent change in the total peak period VMT in the corridor.
    - Percent change in the total daily VMT in the corridor.
    - Percent change in the peak period PMT in the corridor.
- Users' perceptions of congestion on I-85:
    - Percentage of respondents reporting a reduction in travel time.
    - Percentage of respondents reporting an improvement in travel reliability.
    - Percentage of respondents reporting a reduction in the duration of congestion.
    - Percentage of respondents reporting a reduction in the extent of congestion.

Other areas of evaluation include:

- Tolling: The effects of the I-85 HOT lanes on travel behavior, vehicular throughput and traffic congestion on I-85. Changes in usage will be measured by vehicle occupancy; person throughput; vehicle user groups; shifts of two person carpools (in terms of mode, route and time of travel); and formation of casual carpools (also known as "slugging") due to the new HOV3+ requirement.
- Transit: Including especially the identification and measurement of mode shift.
- TDM: The impact of the CAC's regular outreach and incentives on the use of commute alternatives in the I-85 corridor.
- Technology: The use of automated enforcement systems and their contributions to the level of enforcement in the corridor.
- Safety (frequency, type, and severity of collisions).
- Equity analysis (including the demographics of toll lane users).
- Environmental analysis.
- Goods movement analysis.
- Business impacts.
- Non-technical success factors.
- Cost benefit analysis.

Performance Goals

Performance goals (pages 3-5) include:

- Reductions in vehicle trips made during peak/congested periods;
- Reductions in travel times during peak/congested periods;
- Reductions in congestion delay during peak/congested periods; and
- Reductions in the duration of congested periods.
- Increases in facility throughput during peak/congested periods;
- Increases in transit ridership during peak/congested periods;

The HOT lanes on I-85 are expected to have positive outcomes on travel in the corridor, such as travel time reliability, increased throughput and reduced congestion. HOT lanes could also contribute to mode shift.

To evaluate HOT lane performance, Georgia Tech investigators are conducting the following study:

Effective Capacity Analysis and Traffic Data Collection for the I-85 HOV to HOT Conversion, Georgia Institute of Technology, ongoing.
http://transportation.ce.gatech.edu/hov2hot
Investigators are evaluating the effectiveness of this conversion by measuring traffic volume and speed as well as vehicle occupancy and license plate information (for demographic studies) before and after the implementation of the HOT lanes. (We could find no other information on the status of this project).

We also found the following related presentations:

- http://www.dot.state.ga.us/aboutGeorgiadot/Board/Documents/2009%20Meetings%20Presentations/June/MLSP.pdf.
- http://www.dot.state.ga.us/aboutGeorgiadot/Board/Documents/2009%20Meetings%20Presentations/April/9%20-%20Special%20Projects%20-%20%20Board%20Presentation%20HOV-HOT%20April%2016%202009%20bfr%20revisions.pdf.

Related Research

Demographics of HOT Lane Users

The following study evaluates the demographics of HOV lane users before implementation of HOT lanes:

A SocioDemographic Analysis of Northeast Atlanta I-85 Peak Period Commuters Likely to be Affected by Implementation of Value Pricing Along the Corridor, TRB Annual Meeting, 2010.
http://www.transportation.ce.gatech.edu/sites/default/files/files/a_socio-demographic_analysis_of_northeast_atlanta_i-85_peak_period_commuters.pdf
From the abstract: In the summer of 2007, data on peak period travelers on Interstate 85 in Metropolitan Atlanta were collected to provide insight on commuter behavior and demographics in preparation for potential value pricing activities to be implemented on the corridor. Over 120,000 license tags of vehicles in both HOV and general purpose lanes were recorded during the field study. 23,000 household locations corresponding to vehicles observed at three sites located along a 16-mile segment of I-85 slated to be a HOV-to-HOT demonstration project were further analyzed in terms of potential travel distance, travel time, and income characteristics. On average, vehicles seen at the field locations traveled at least 10 miles along I-85, much of it within the HOT lane corridor. Additionally, associated households exhibited higher incomes and longer travel times at a representative block group level than did the general population. Data on specific travel time,

distance, and income of daily commuters are helpful in assessing a proper pricing structure for tolls along the pilot corridor. Thus, methodology for identifying likely commuters from a field "snapshot" as well as basic pricing guidelines on a per-mile and per-corridor basis is included in this paper.

Minnesota

MnPASS Express Lanes—I-394 and I-35W

http://www.mnpass.org/systemstudy.html

In 2005, MnDOT deployed HOT lanes on a segment of I-394 in the Minneapolis/St. Paul region. Called MnPASS, this system adjusts pricing dynamically in response to traffic conditions. Lanes are free for cars with two or more occupants, transit buses and motorcycles.

The MnPASS site includes a page of related studies, including several on public perception. We found numerous other related reports online and in transportation databases.

Performance Measures

An early document exploratory report (http://www.mnpass.org/394/finalreport/finalreport.doc) lists the following potential performance measures for MnPASS evaluations:

Potential Primary Performance Measures (Before and After)

- Traffic flow and modal use: vehicles and person volumes by mode, time of day and vehicle occupancy.
- Speed/travel times by segment and time of day, on Express Lanes and general purpose lanes, and levels of service on both.
- Diversion of trips to/from I-394 and within I-394 on general purpose and express lanes.
- Level of bus service improvements in corridor.
- Level of enforcement and violations.
- Safety/crashes.
- Reliability of implemented technology.
- Impact on bus and transit operations at access points.

Potential Secondary Performance Measures (Before and After)

- Cost of delays, including enforcement.
- Noise levels.
- Emission levels.
- Capital and operations cost.
- Revenues.
- Use of TAD garages.

The following report gives a before-and-after assessment of MnPASS performance in its first year.

I-394 MnPASS Technical Evaluation, Minnesota Department of Transportation, November 2006.
http://www.mnpass.org/pdfs/394mnpass_tech_eval.pdf

MnPASS performance goals included:

- Improving the efficiency of I-394 by increasing the number of people and vehicles using the HOV lanes.
- Maintaining free-flow speeds for transit and carpools in the express lanes.

Data collected relevant to performance measures included (see Section 4.3):

- Vehicle volumes: traffic volumes on the newly implemented I-394 MnPASS lanes increased substantially, varying from 9 percent to 13 percent during the peak hours.
- Vehicle speeds (see tables on page 5-4).
    - HOT lane vehicle speeds: Despite the observed increases in traffic volume in the MnPASS lanes, travel speeds in the lane(s) have not been negatively impacted as most locations experienced no change or a slight increase in travel speed.
    - General purpose lane vehicle speeds: Speeds in the general purpose lanes were observed to experience a slight increase following the implementation of MnPASS for all locations tested when compared with similar periods from previous years.
- Vehicle occupancy/mode share: Carpool usage on I-394 also decreased as compared with pre-MnPASS levels. (See pages 5-7 to 5-9 for data.)
- Violation rates: decreased following implementation, in one segment from 20 percent to 9 percent. (See pages 5-11 to 5-13 for data.)
- Crash occurrence: decreased nearly 14 percent.
- Speed differential between general purpose and managed lanes: decreased at nearly all tested locations.
- Noise impacts: no significant changes.
- Emissions impacts: no substantial impacts on air quality due to traffic pattern changes.
- Transit ridership: increased by 10 percent systemwide.
- Transit operational impacts (based on interviews with transit provider representatives): According to three of four agencies, the deployment of MnPASS on I-394 has generally had a negligible impact on their operations in the I-394 corridor. One agency had serious concerns about added difficulty merging along with increased and more aggressive traffic in MnPASS lanes.

A more recent study includes travel demand modeling estimates for the (uniformly positive) effects of converting various other Twin Cities area HOV lanes to HOT lanes:

MnPASS System Study Phase 2, Minnesota Department of Transportation, August 2010.
http://www.dot.state.mn.us/mnpass/mnpass9-24.pdf
This study was conducted to make recommendations for additional MnPASS lanes in the Twin Cities metropolitan region. The following performance measures were used in travel demand modeling estimates for the (uniformly positive) effects of converting various HOV lanes to HOT lanes:

- Travel-Time Reliability, measured through vehicle-minutes of delay saved per trip both daily and during the peak period and for both managed and general purpose lanes. (See chart on page 6-2.)
- Throughput, measured as the change in vehicle throughput in a corridor as well as the change divided by the total centerline miles of the corridor. (See chart on page 6-3.)
- Travel-Time Reduction, measured by the reduction in vehicle-hours traveled for both general purpose and managed lanes in a corridor. (See chart on page 6-3.)
- Change in Congested Vehicle-Miles Traveled, measured directly system-wide and as a percentage of total vehicle-miles traveled. (See chart on page 6-4.)
- Transit suitability, evaluated by the following criteria (see chart on page 6-5):
    - Total number of daily bus trips.
    - Total number of peak-period bus trips.
    - Existing bus-only shoulder (BOS) facilities.
    - Amount of short bus trips (impact of BOS usage).
    - Future planned transit facilities (park-and-ride, bus rapid transit and express bus).
    - Future planned BOS facilities.

We found a more recent performance evaluation published in 2012, but this document is not available online without purchase:

> **"Performance Evaluation of I-394 MnPASS Express Lanes in Minnesota,"** *Transportation Research Record: Journal of the Transportation Research Board*, Issue 2278, 2012: 153–162.
> Abstract at: http://trid.trb.org/view/2012/C/1129517
> *From the abstract:* After more than 5 years of operational experience … [MnPASS] lanes are performing efficiently, are continuing to ensure free-flow speeds for all users, and are enhancing vehicle and person throughput. In addition, the lanes generate sufficient revenue to cover operational costs. A recent survey indicates that MnPASS Express Lanes are providing users with value for their money in time savings and overall customer satisfaction.

Related Research

Performance Modeling

"Safety Benefits of Converting HOV Lanes to HOT Lanes: Case Study of the I-394 MnPASS," *ITE Journal*, Volume 82, Issue 2, 2012: 32–37.
http://www.ite.org/membersonly/itejournal/pdf/2012/JB12BA32.pdf
From the abstract: In 2005, high-occupancy-vehicle (HOV) lanes on I-394 in Minnesota were converted to high occupancy toll (HOT) lanes. In order to evaluate the effect of HOV-to-HOT lane conversion on highway safety, this study uses an empirical Bayes method to examine the accident rate on the I-394 HOT lane before and after the conversion. The findings show that the number of crashes was reduced by 5.3% following the conversion, from an average total of 496 crashes before 2005 to an average total of 392.5 after 2005. The economic benefit of these reduced crashes for 2006 and 2008 was approximately $5 million. Limitations of this study and directions for future research are suggested.

Benefit and Cost Analysis of the I-394 MnPASS Program, University of Minnesota, Twin Cities, 2012.
http://www.tc.umn.edu/~cao/Cao%20et%20al%202012%20CTS12-03.pdf
From the executive summary: In this study, we conducted a benefit cost analysis to evaluate the net societal benefits and costs that were brought about by the I-394 MnPASS program. Where applicable, the implementation of this study followed the benefit-cost analysis (BCA) guidance of MnDOT. The study focused on the I-394 corridor, with a 10-year timeframe from 2006 to 2015. The benefits considered included travel time savings, safety benefits, and vehicle operating cost savings, and the costs consisted of capital costs and annual operating costs. In this study we considered the benefits of both travel time savings and travel time reliability and their valuations were derived from econometric models for individual drivers' behavior. We estimated safety benefits from crash reduction using the Empirical Bayes method. We showed that "naïve" approaches tended to overstate safety benefits. Overall, the BCA concludes that the I-394 MnPASS program is economically justified, with a benefit-cost ratio of 2.19. Specifically, travel time savings (not including reliability savings) can compensate only a very small share (about 7%) of total costs, and travel time reliability savings contribute to additional 23%. Different variations on these two savings do not materially change their contribution. Thus, travel time savings and travel time reliability savings are important sources of the benefits, but they are not the dominant sources. Safety benefits dominate the total benefits of the MnPASS, especially those from fatal crash reductions. The specific contribution of safety benefits to cost compensation also depends on the standard economic values used. It is worth noting that the safety benefits of the
I-394 MnPASS program are associated with converting underused HOV lanes to HOT lanes, accompanied by designating access points. Therefore, the safety benefits have limited generalizability for scenarios in which HOT lanes are added to existing freeways. Future BCA of HOT lane projects should

consider travel time reliability savings and safety benefits. Ignoring the two benefits could substantially skew the outcome.

Mode Choice

"Empirical Investigation of the Impact of High-Occupancy-Toll Operations on Driver Behavior," *Transportation Research Board 88th Annual Meeting Compendium of Papers*, 2009.
Abstract at http://trid.trb.org/view/2009/C/881189
From the abstract: This paper describes an empirical research investigation of SOV behavior in the I-394 HOT facility in Minneapolis, Minnesota, known as MnPASS. Using traffic and tolling data from March 2008, the research team conducted a visual time series analysis, price elasticity analysis, and developed a utility-based mode choice model for SOV behavior. The results indicated that HOT operations were successful in maintaining a high-level of service in the HOT lanes while providing an alternative for a large number of SOVs. However, the results also indicated that SOV behavior was insensitive to toll level. In addition, the mode choice model indicated that while SOV behavior is influenced by the combination of speed differential between HOT and general purpose lanes, and the level of toll, these variables alone do not allow for effective SOV behavior prediction.

Public Perception and Education

"**Willingness to Pay for HOT Lanes: Empirical Analysis from I-15 and I-394,"** Transportation Research Board 91st Annual Meeting, 2012.
Abstract at http://trid.trb.org/view/2012/C/1129481
From the abstract: This research examined travelers' willingness to pay for travel time savings (TTS) and the variability of toll prices on the I-394 MnPASS Express Lanes in Minnesota and the I-15 Express Lanes in San Diego. The findings from both facilities indicate many travelers are willing to pay a toll for small TTS. This resulted in revealed preference values of time for I-394 paying customers averaging $73/hr in the morning and $116/hr in the afternoon. Travelers on the I-15 Express Lanes received slightly higher TTS than on I-394 and typically had a lower willingness to pay. Their revealed preference values of time averaged $49/hr in the morning and $54/hr in the afternoon. Based on how large these values are it is likely travelers are paying for more than just TTS, possibly travel time reliability, meaning these lanes have added value to travelers beyond time savings. It was found that there was considerable variation in toll rates during the morning and afternoon peak hours with tolls ranging from $0.50 to $8.00. Conversely, off-peak times showed little to no variation. It was found that these trends were similar when looking at different days of the week and even from year to year. Additionally, it should be noted that these trends were common across both I-394 and I-15 Express Lanes, although more variation was found on I-15. Therefore, although dynamic tolling can be more difficult to implement, it was useful in regulating traffic during peak periods.

"Preliminary Before and After Results of I-394 HOT Lane Panel Survey," *Transportation Research Board 86th Annual Meeting Compendium of Papers*, 2007.
Abstract at http://trid.trb.org/view/2007/C/800899
From the abstract: This report documents the methods and results of the second wave of data collection for the
I-394 MnPASS Evaluation Attitudinal Panel Survey. The Wave 2 survey, conducted during November and December 2005, occurred one year subsequent to the first wave and about six months into the implementation of the I-394 MnPASS Express Lane project. Data were collected through 950 interviews to evaluate the attitudinal and behavioral impacts of allowing solo drivers to pay to use carpool lanes. Overall approval and satisfaction with the I-394MnPASS Express Lane project is strong and broad. Six out of ten believed that allowing single drivers to use carpool lanes by paying a toll was a good idea. Support was almost as strong among lower income households as it was among higher income households. Satisfaction among users with MnPASS operations, subscription elements, and

communications is high—whether users are paying (SOVs) or not (carpoolers and bus riders). Almost nine out of ten reported having no problems with merging into the tolled lanes. Finally, most users felt that paying the MnPASS toll to avoid congestion was a good value.

For attitudinal survey final reports, see:

- Wave 1 (2005): http://www.mnpass.org/pdfs/mnpass_attitude-study.pdf.
- Wave 2 (2006): http://www.mnpass.org/pdfs/attitudinalstudy0306.pdf.
- Wave 3 (2006): http://www.mnpass.org/pdfs/MnPassFinalReport%2027NOV06.pdf.

Minnesota Value Pricing Outreach and Education, Minnesota Department of Transportation, 2006.
http://www.lrrb.org/media/reports/200638.pdf
From the abstract: The State and Local Policy Program (SLPP) of the Humphrey Institute of Public Affairs, University of Minnesota, in partnership with the Minnesota Department of Transportation (Mn/DOT) and the Metropolitan Council originally designed a project that envisioned extensive research, outreach, and education activities leading to identification and support for a demonstration project by the end of the three year project period. With early acceptance and support for the I-394 MnPASS project by the Governor and Legislature, the Humphrey Institute in collaboration with the Minnesota Department of Transportation and the Federal Highway Administration revised the project to focus on research, outreach, and education activities focused specifically on the I-394 MnPASS project. The major findings of this project are detailed in the summary and supported by the appendices. The appendices include multiple papers submitted to the Transportation Research Board, final reports from the first two waves of the longitudinal panel survey, the community task force report, and an information booklet designed to quickly educate lawmakers.

Texas

Quickride HOT Lanes on I-10 (Katy Highway) and US 290 (Northwest Highway) in Houston

http://houstonvaluepricing.tamu.edu
http://ops.fhwa.dot.gov/tolling_pricing/value_pricing/projects/involving_tolls/priced_lanes/hot_lanes/tx_hotlane_i10us290.htm
HOV2+ lanes become HOV3+ during peak hours, and cars with two passengers may use lanes by paying a $2 toll.

From FHWA's description of this project: In January 1998, Houston's "QuickRide" pricing program was implemented on existing HOV lanes of I-10, also known as the Katy Freeway. It was implemented on US 290 in November 2000. The HOV lanes are reversible and restricted to vehicles with three or more persons during the peak hours of the peak periods. The pricing program allows a limited number of two-person carpools to buy into the lanes during the peak hours. Participating two-person carpool vehicles pay a $2.00 per trip toll while vehicles with higher occupancies continue to travel free. Single-occupant vehicles are not allowed to use the HOV lanes. The QuickRide project is completely automated and no cash transactions are handled on the facility. Results from surveys conducted on I-10 indicate that the primary source of QuickRide participants is persons who formerly traveled in single-occupant vehicles on the regular lanes. Toll revenues from several hundred vehicles each day pay for all program operational costs.

Performance Measures

Related reports are available at http://houstonvaluepricing.tamu.edu/reports/. None of these reports contain a before-and-after evaluation of the performance of Houston HOT lanes.

This early assessment includes charts describing travel time savings, speed distribution, average number of daily HOT lane trips and characteristics of HOT lane users:

> **"Hot Lanes in Houston—Six Years of Experience,"** *Journal of Public Transportation*, Volume 7, Issue 3, 2004.
> http://www.nctr.usf.edu/jpt/pdf/JPT%207-3%20Burris.pdf
> *From the abstract:* This research documents the findings of six years of experience with two HOT lanes in Houston, Texas. This includes an examination of the daily number of paying customers on the HOT lanes, benefits of the HOT lanes, socioeconomic and commute characteristics of HOT lane users, and their mode of choice when electing not to use the HOT lane.
>
> Researchers conclude (page 17):
>
> > The QuickRide program receives relatively modest usage (an average of 208 trips per day in 2003) partially due to the limited amount of room available on either of the single HOV lanes. This relatively limited usage is comprised of a large number of users taking advantage of QuickRide on an infrequent basis (less than 2.5 trips per month). Despite the limited usage, the program provides a net societal benefit, primarily due to travel-time savings obtained by QuickRide participants.

The following report contains some performance data for HOT lanes and a comparison to general purpose lanes:

> **Current HOT Lane Usage**¸ Texas Department of Transportation, September 2009.
> http://houstonvaluepricing.tamu.edu/reports/documents/techmemo_1.pdf
> This project measures speeds and volumes for Houston HOT lanes and adjacent general purpose lanes.
>
> *From the executive summary:* Based on these data it is clear that traffic speeds during the afternoon rush hour on the US 290 HOT lane often drop below 45 mph. … In comparing the speeds on the [general purpose lanes (GPLs)] and the HOT lanes it was clear the HOT lanes offered a much more reliable trip. Speeds on the US 290 HOT lane were generally between 56 mph and 66 mph, while the GPLs ranged from 12 mph to 64 mph. Katy Freeway speeds were similar. This lead to considerable travel time savings on the HOT lanes, exceeding 20 minutes in the afternoon on US 290.

The report also notes that there has been a decrease in QuickRide use since 2005 and that there are high violation rates, as high as 40 percent during time periods with HOV3+ requirements.

We found the following ongoing evaluation, due to be completed in 2013:

> **Evaluation of the I-10 Katy Freeway Managed Lanes**, Texas Department of Transportation, ongoing.
> Abstract at http://trid.trb.org/view/2011/P/1233949
> *From the abstract:* 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. 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.

Related Research

Performance Evaluations

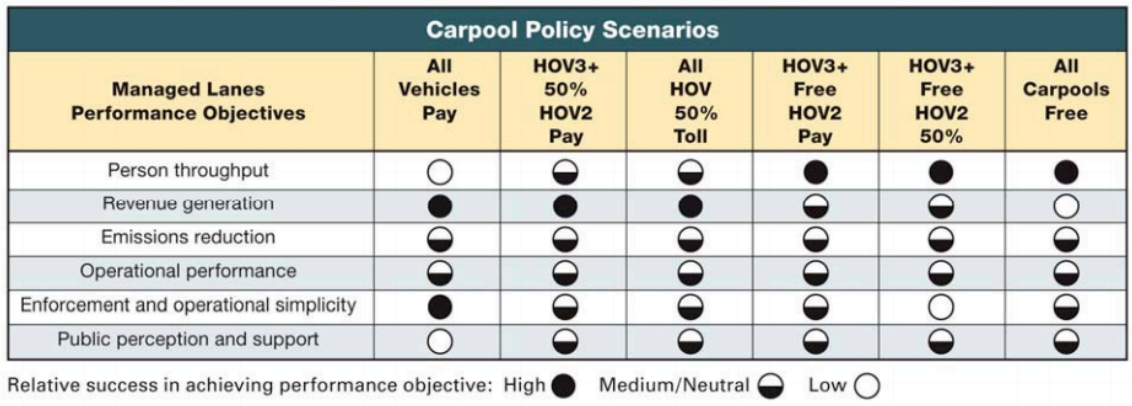
"Effectiveness of the Katy Freeway HOV-Lane Pricing Project: Preliminary Assessment," *Transportation Research Record*, Issue 1659, 1999: 97–104.
Abstract at http://trid.trb.org/view/1999/C/506978
From the abstract: The use of QuickRide during its first 6 months is reported, and an analysis of the program's effectiveness is presented. QuickRide usage and data from before and after implementation are employed to analyze users' travel patterns, observed travel time-savings, and changes in person-throughput in the Katy Freeway corridor. The results of this analysis show that the participation in the QuickRide program is too low to observe significant impacts on travel speeds and person-throughput in the general-purpose lanes and the Katy HOV lane. Also, the analysis indicates that use of the QuickRide program reached a plateau about two months after start-up. Participants seem to be using QuickRide occasionally or infrequently, and a majority of the participants do not use it at all in any given week. Most of the QuickRide users appear to be previous two-person carpool commuters, with a substantial minority of single-occupant vehicle (SOV) drivers now forming carpools to participate. Higher vehicle-occupancy modes are not losing many patrons to the QuickRide program. An analysis shows that travel time-savings for participants are substantial and are worthwhile for two-person carpools, with a value of time exceeding $6.57/hr. However, the analysis also indicates that, at this initial stage, the observed changes in vehicle- and person-throughput are not statistically meaningful. To improve participation in the program, a lower fee is recommended, and marketing efforts should be enhanced, especially to SOV drivers.

Performance Modeling

"HOV or General Purpose Lanes?," *Public Works Management & Policy*, Volume 14, Issue 2, 2009: 130–147.
Abstract at http://trid.trb.org/view/2009/C/908622
From the abstract: This paper uses extensive data sets to compare user costs, specifically time and fuel costs, for two scenarios over a variety of mode and time shifts for (1) a single reversible HOV lane and (2) a general purpose lane (GPL) in each direction on the Katy Freeway in Houston, Texas. … Findings show that in almost all examined scenarios, the two GPLs case had lower user costs than the HOV lane case. These benefits occurred for several reasons: congestion can be avoided altogether in the off-peak direction due to the fact that the off-peak direction gains an entire lane; demand in each direction is divided equally among all lanes; and the capacity of the single HOV lanes is lower than each GPL.

The Role of Preferential Treatment for Carpools in Managed Lanes, Texas Transportation Institute, 2009.
http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-5286-2.pdf
From the abstract: This study utilizes a state-of-the-practice review, a 4600-respondent survey of freeway users in Houston and Dallas, and simulation modeling of six alternative HOV scenarios at varying toll rates to identify the tradeoffs associated with carpool toll discounts in new managed lanes.

Table 46 (below and on page 115 of the report) provides a relative comparison of HOV policy options for various performance objectives:



Carpool Policy Scenarios						
Managed Lanes Performance Objectives	**All Vehicles Pay**	**HOV3+ 50% HOV2 Pay**	**All HOV 50% Toll**	**HOV3+ Free HOV2 Pay**	**HOV3+ Free HOV2 50%**	**All Carpools Free**
Person throughput	○	◒	◒	●	●	●
Revenue generation	●	●	●	◒	◒	○
Emissions reduction	◒	◒	◒	◒	◒	◒
Operational performance	◒	◒	◒	◒	◒	◒
Enforcement and operational simplicity	●	◒	◒	◒	○	◒
Public perception and support	○	◒	◒	◒	◒	◒

Relative success in achieving performance objective: High ● Medium/Neutral ◒ Low ○

"Investigating the Impact of Tolls on High-Occupancy-Vehicle Lanes Using Managed Lanes," *Transportation Research Record*, Issue 2099, 2009: 113–122.
Abstract at http://trid.trb.org/view/2009/C/881262
From the abstract: To determine the impact of different HOT lane operating strategies on their travel behavior, freeway travelers in the Houston and Dallas metropolitan areas of Texas were surveyed. A nested logit model was developed to estimate the mode choice for travelers. This model was used to predict the impact of converting an HOV lane to a HOT lane on which all travelers pay a toll. It was found that the overall percentage of HOV2 and HOV3+ vehicles in the traffic stream decreased by only a small amount when a toll was required for them to use the HOV lane. However, that decrease did represent a significant portion of those modes (more than 9%) and resulted in more than a 10% increase in HOT lane revenue. Therefore, elimination of preferential treatment for these vehicle types has significant implications and becomes a difficult policy decision—not just a straightforward choice.

"Potential Mode Shift from Transit to Single-Occupancy Vehicles on a High-Occupancy Toll Lane," *Transportation Research Record*, Issue 2072: 2008.
https://ceprofs.civil.tamu.edu/mburris/Papers/TRR%202072%20-%20Mode%20Shift%20from%20Transit%20to%20SOV%20on%20ML.pdf
This study involved a survey to determine whether the introduction of Houston HOT lanes negatively impacted transit ridership. Conclusions (as described in the abstract) are as follows:

> Passengers' responses to questions regarding their trip characteristics, their socioeconomic characteristics, and their stated preference scenarios were used to develop a mode choice model. Scenarios with varying tolls and travel time savings were simulated using this model. For all scenarios, only a small percentage of transit passengers would choose to switch to driving alone on the HOT lane. Transit passengers shifting to SOVs on the HOT lane would reduce average vehicle occupancy on the lane by only about 1% to 2%. SOV drivers shifting from the general purpose lanes to the HOT lanes are likely to affect AVO much more. However, as long as free-flow conditions are maintained, this analysis shows that the HOV lane can be successfully adapted to a HOT lane and move more people, even if a few transit passengers choose to drive alone.

The report also includes demographic information on HOT lane users.

"Multivariate Analysis of High-Occupancy-Toll Lane Usage in Houston," *Transportation Research Board 87th Annual Meeting Compendium of Papers*, 2008.
Abstract at http://trid.trb.org/view/2008/C/848639
From the abstract: Using a series of multivariate analysis techniques on survey data obtained from HOT lane users in Houston, Texas this paper identified (i) the toll elasticity of demand for QuickRide, (ii) an individual's support for the premium services provided by an HOT lane (value pricing), (iii) their general

travel behavior, (iv) level of appreciation of the value of travel time savings, (v) ability and willingness to pay for travel time savings, (vi) perceived benefits derived from HOT lane usage, and (vii) the impact of the shared toll rate on commuters as the seven most important factors underlying HOT lane usage. The factors were also useful for classifying HOT lane users into three "levels of users"—infrequent, midlevel, and frequent users.

"Benefit-Cost Analysis of Variable Pricing Projects: QuickRide HOT Lanes," *Journal of Transportation Engineering*, Volume 132, Issue 3, 2006: 183–190.
Abstract at http://trid.trb.org/view/2006/C/776083
From the abstract: Researchers identified a potential methodology for obtaining the incremental societal costs and benefits from a variable pricing project and applied that methodology to the QuickRide high occupancy/toll (HOT) lanes in Texas. This is one of the longest running variable pricing projects in the United States and, as such, it provided useful historical data and trends upon which to estimate future benefits and costs. This analysis found that the incremental societal benefits of QuickRide exceeded incremental societal costs for the time period considered. A companion paper that used the same methodology to examine the benefits and costs of the SR-91 Express Lanes found similar results. However, the differences between the benefits and costs were dramatically different for the two projects, indicative of the relative size of the two projects and the number of travelers impacted. On SR-91, tens of thousands of travelers were impacted on a daily basis where QuickRide's impact was limited to approximately 400 travelers per day. Interestingly, the benefit-cost ratios of the two projects were similar, both between 1.5 and 1.7.

Characteristics of HOT Lane Users

"Slugging in Houston—Casual Carpool Passenger Characteristics," *Journal of Public Transportation*, Volume 9, Issue 5, 2006: 23–40.
http://www.nctr.usf.edu/jpt/pdf/JPT%209-5%20Burris.pdf
This study uses survey data to examine demographics on Houston HOT lanes of "impromptu carpools formed among strangers to meet the occupancy requirements of HOV lanes." The abstract outlines the results as follows:

> Results of the analyses revealed that being on a commute trip, making more trips/week, being between the ages of 25 and 34, and having professional/managerial or administrative/clerical occupations all increased the likelihood of a traveler choosing to casual carpool. Additionally, having a household income between $25,000 and $35,000 significantly reduced the likelihood of casual carpooling. Understanding the types of travelers who casual carpool and the information gleaned in these analyses can be used to better evaluate HOV and HOT lane use and performance. Casual carpool passengers can comprise a significant portion of HOV/HOT lane person movement and should be considered when investigating HOV or HOT lane implementation.

Quantification of Casual Carpooling in Houston, Houston Value Pricing Project, March 2004.
http://houstonvaluepricing.tamu.edu/reports/documents/carpooling_updated.pdf
This project attempts to quantify casual carpooling on Houston HOT lanes, defined as "the practice of single drivers or two-person vehicles sharing their ride with others on an informal basis to satisfy high occupancy vehicle (HOV) lane occupancy requirements." Researchers conclude that "significant casual carpooling activity occurs on the Katy and Northwest Freeway corridors in Houston."

Equity Analysis of the Houston QuickRide Project, Texas A&M University, March 2003.
http://houstonvaluepricing.tamu.edu/reports/documents/equity_analysis_QR_trbformat.pdf
From the abstract: Survey data gathered on QuickRide enrollees, along with 1998 QuickRide usage data, was analyzed for potential equity issues that might exist with the QuickRide program. QuickRide usage did not vary significantly by respondent income, occupation, age, or household size. Additionally, the

difference between respondents stated and actual use of QuickRide did not vary significantly by respondent income, occupation, age, or household size. However, QuickRide enrollees were found to have significantly higher incomes and to be significantly younger than drivers on the Katy Freeway main lanes. Therefore, although income was not an indicator of the amount of QuickRide use amongst enrollees, it was a significant indicator as to whether or not an individual enrolled in the program.

An Examination of Houston's QuickRide Participants by Frequency of QuickRide Usage, Texas Transportation Institute, November 2003.
http://houstonvaluepricing.tamu.edu/reports/documents/txdot_user_survey_rept_v3.pdf
From the abstract: After 5 years in operation (3 years on US 290), the QuickRide program receives comparatively lower patronage than the two California projects. This implementation project used standard statistical methods and an ordered logit model to examine the characteristics of current and former QuickRide participants as a step in understanding the reasons for the relatively low patronage. … The primary issue limiting QuickRide use appears to be one of convenience rather than cost. Both current and former participants cited the inconveniences of carpooling as the greatest deterrent to QuickRide use while 73.4 percent of participants reported that the toll had little or no significant impact on their decision to use QuickRide. The average time spent picking up and/or dropping off carpool partners was significantly higher among former participants. Current participants spent on average 4.3 minutes picking up and/or dropping off their carpool partners, while former participants spent 12.2 minutes, supporting the finding that a deterrent to QuickRide use is the development of a carpool.

An Investigation of Former Quickride Users, Mark Burris and Donna Chen, undated.
http://houstonvaluepricing.tamu.edu/reports/documents/edited_former_user_paper.pdf
From the abstract: This paper investigates the low utilization rate of the Houston QuickRide program on the I-10 and US-290 High Occupancy/Toll lanes through the analysis of its former users' survey responses. … Two data sets from an April 2003 survey sent to both current and former users of QuickRide were analyzed for significant differences between the two populations' responses. Current and former users did not vary significantly in occupation, household type, average number of people per household, vehicles per household, age, and income. However, survey data supports the idea that current users take advantage of carpooling with family members more frequently than former users did. Additionally, current users' responses indicate that they value their trip time savings on the HOV lane more so than the former users.

Washington

SR 167 HOT Lanes Pilot Project

http://www.wsdot.wa.gov/Tolling/SR167HotLanes/publications.htm
WSDOT is currently evaluating the performance of a 2008 pilot project on SR 167 in which HOV lanes were converted to HOT lanes. (The original project end date was in 2012, but it has been extended into 2013.) Tolls are variable, and lanes are free for buses, motorcycles and vehicles with two or more persons.

Performance Measures

A performance report is produced annually:

- 2009: http://www.wsdot.wa.gov/NR/rdonlyres/31FB3D24-79CC-4332-82F7-EBECEBE1CA71/0/HOTLanesAnnualReport2009.pdf.
- 2010: http://www.wsdot.wa.gov/NR/rdonlyres/A43B9DD4-4228-482E-BF82-CEE31B315A0E/69599/2ndAnnualReport_167HOTLanes4.pdf.
- 2011: http://www.wsdot.wa.gov/NR/rdonlyres/C198671E-7B2F-4186-9912-A41A0B274103/0/SR167_AnnualPerformanceSummary_113011_FINAL_WEB.pdf.

- 2012: http://www.wsdot.wa.gov/NR/rdonlyres/2DA072CA-7D4A-4876-A58B-64DBE152D48D/0/SR167_AnnualPerformanceSummary_080812_web.pdf.

According to the 2012 report, the project has successfully met the following performance goals:

- Maintained freeflow conditions (HOT lane speeds of greater than 45mph, increased general purpose lane speeds, more reliable travel times).
- Reduced traffic congestions (reduced general purpose lane volumes, increased daily tolled volumes, increased corridor transit volumes).
- Improved safety (reduced collision rates and incident response times).
- Been able to finance improvements through tolls.
- Experienced equitable use of the facility by both low- and high-income drivers.

Performance metrics include:

- Average number of tolled trips (3,400 per weekday in April 2012).
- Average toll paid ($1.25 per trip).
- Average peak hour general purpose lane volumes (have decreased 5 percent since the pilot began, while speeds have increased more than 20 percent).
- HOT lane volumes (have doubled since 2009, with speeds remaining around the posted 60mph speed limit).
- HOT lane average speeds (greater than 45 mph 99 percent of the time).
- HOT lane travel times (11 minutes) and average general purpose lane travel times (19 minutes).
- Transit ridership (has increased).
- Revenue (exceeds operating costs).
- Enforcement (compliance is 95 percent to 96 percent).
- Safety: Preliminary data indicates that the average number of collisions is down 2 percent when compared to the five-year average prior to HOT lanes opening in 2008.
- Public opinion: More than 70 percent of surveyed HOT lane customers stated they are likely to use the lanes in the future.

Related Research

"Analyzing System Performance for Washington State Route 167 High-Occupancy Toll (HOT) Operations," *Transportation Research Board 89th Annual Meeting Compendium of Papers*, 2010. Abstract at http://trid.trb.org/view/2010/C/910749
From the abstract: This study aims at conducting a comprehensive performance analysis on the representative HOT lane system of State Route 167 in Washington State based on the field data collected from traffic sensors. Three critical issues are addressed in this study: 1) the speed-flow relationships in the HOT lane systems, 2) quantified travel time savings achieved system-wide, 3) Single Occupancy Vehicles (SOVs) tolling incentives. Based on the empirical analysis and evaluation results for the SR 167 HOT lane system, operational problems and challenges are also identified. Although the HOT lane system preserves favorable travel reliability, sufficient capacity exists to further accommodate SOVs to use the HOT lanes. The existing tolling strategy may be modified to address the HOT lane underutilization issue. The research findings greatly advance our understanding on HOT lane system operation mechanisms and are complementary to the freeway facility performance analysis provided by Highway Capacity Manual 2000.

Examination of SR 167 HOT Lane Violation Patterns, Washington State Transportation Center, 2011. http://depts.washington.edu/trac/bulkdisk/pdf/766.1.pdf
From the abstract: The HOT lanes on SR 167 south of Seattle, Washington, are separated from their respective general purpose lanes by a double white lane line. Legal access to the HOT lanes is limited to four locations southbound and six locations northbound. This study examined the frequency with which

motorists illegally cross the double white lane line, rather than waiting for one of the legal access points. The study determined the locations and operating conditions under which violations most commonly occur. The study showed that during most times of the day and along most portions of the corridor, the number of illegal entry and exit movements is negligible. However, at a small number of locations and under specific congestion conditions, violation rates can exceed 1 per minute. The worst violation location is northbound, north of the S. 180th St on-ramp, just before the end of the northbound HOT lane and after the last toll collection gantry. Violations at this location appear to be caused by the three main factors: 1) In anticipation of the lane becoming a general purpose lane in less than another 500 feet, some motorists "jump in early." 2) This location is often the point to which the queue from the I-405 interchange ramp backs up. Violation rates increase significantly near the upstream end of any queue. 3) Many vehicles entering the freeway at the S. 180th St ramp move as directly as possible to the left lane of the freeway and then merge into the HOT lane. In congested conditions, these movements result in lane-line violations because the slow, heavy traffic allows the weave process to occur in a short distance. Under faster free flow conditions, this weave movement requires a much longer distance, resulting in vehicle merges at the intended legal locations.

Other HOT Lanes

California

"Peak Period Use of I-15 Corridor in San Diego, California: Long-Term Impact of FasTrak Program," *Transportation Research Record*, Issue 2221, 2011: 64–73.
Abstract at http://trid.trb.org/view/2011/C/1093214
From the abstract: The results of the 1998 to 2008 peak period monitoring of [an] 8-mi FasTrak section of Interstate 15 (I-15) in San Diego, California, are reported in this paper. The paper examines changes in peak period utilization and volume distribution throughout the peak with the emphasis on the level of service (LOS) offered on both high-occupancy toll (HOT) lanes and the main lanes of I-15. The study revealed that the peak period volumes on the HOT lanes (both FasTrak and carpool) strongly depend on the LOS deficit on the main lanes. Carpool participation was not hurt by the growing FasTrak volumes. The law-mandated LOS C was effectively protected by the dynamic pricing mechanism on the HOT lanes. The Congestion Pricing Project in San Diego proved able to redistribute a portion of the peak period volumes on the HOT lanes from the middle of the peak to its shoulders and now plays an important role in improving operation of the entire I-15 corridor.

"Are Managed Lanes Worth It? Empirical Data on Time Savings and Tolls Paid from SR91, California," *Proceedings of the 16th International Road Federation World Meeting*, Lisbon, Portugal, Issue 361, 2010.
Abstract at http://trid.trb.org/view/2010/C/1150547
From the abstract: Managed lanes are fast becoming an important asset class within the toll road sector for private investors and public private partnership (PPP) projects. Managed lanes (also referred to as high occupancy toll lanes) provide several advantages over greenfield projects as they are typically built alongside existing congested (and free) highway sections thus somewhat reducing the traffic and revenue risk. In this paper we will present the results of research on the travel time savings achieved and the tolls paid at different times of the day on SR91 managed lanes in California. The results indicate that users of the managed lanes often pay high toll rates for minimal time savings for many parts of the day—indeed there are some time periods when the time savings are significant thereby justifying the high toll rates. This behavior of the users of managed lanes can be partially explained by the fact that many such users often overestimate their time savings and are often paying the tolls for the reliability that they will be able to reach a certain destination in a reasonable amount of time. The result of this research will be useful to the demand forecasting community and to the investor community that is planning for such projects.

Denver, Colorado, I-25 Express Lanes

Performance reports are available here: http://www.coloradodot.info/travel/tolling/i-25-hov-express-lanes/Reports

Salt Lake City, Utah, I-15 HOT Lanes

"High-Occupancy-Toll Lane Experiment on I-15 in Salt Lake City Metropolitan Region: Traffic Flow Evaluation," *Transportation Research Board 87th Annual Meeting Compendium of Papers*, 2008. Abstract at http://trid.trb.org/view.aspx?id=848269
From the abstract: Interstate 15 in Utah's Salt Lake City metropolitan region has 38 miles of High-Occupancy Vehicle (HOV) lanes. In September 2006, the HOV lanes became High-Occupancy/Toll (HOT) lanes. For a monthly fee of $50, Single-Occupant Vehicle (SOV) drivers could share the HOV lane. The 2-year experiment is a low-tech based assessment of the traffic impacts of expanding the scope of the HOV lanes. Drivers buy a sticker and are monitored by the Highway Patrol officers. If shown to improve traffic conditions, the Utah Department of Transportation (UDOT) will pursue electronic tolling and dynamic pricing options. This paper presents the traffic impact assessments. The most unexpected finding is that, while volumes have increased for all lanes, the mean speeds on the HOT lanes have also increased. The reduction in journey times on the HOT lanes shows that there is a pronounced advantage to road users on the HOT lanes compared to those traveling on the General-Purpose (GP) lanes for both morning and afternoon peaks. Further, despite the slight drop in the average vehicle occupancy when the HOV lane became an HOT lane, with an influx of fee-paying solo drivers, the overall number of people moved has increased. The paper concludes that the experiment of selling spare capacity to SOV drivers serves to improve speeds and Level of Service for all I-15 users in the region.

Related Research and Resources

General Resources for HOV to HOT Conversion

Converting High Occupancy Vehicle (HOV) Lanes to High Occupancy Toll (HOT) Lanes: A Guidebook, Federal Highway Administration, 2008.
Abstract at http://trid.trb.org/view/2008/M/904393
From the abstract: Growing traffic congestion has become an increasingly troublesome issue in urban areas throughout the nation, and state and local agencies are exploring new ways to manage new and existing highway facilities more effectively. Of special interest to transportation practitioners is the high occupancy toll (HOT) lane concept, an increasingly popular and common type of managed lane facility that adds electronic tolling to an existing HOV facility. How best to balance the desire to preserve existing HOV privilege with having enough excess capacity to sell to single occupant vehicles (SOVs) is a major challenge in planning and design of an HOT lane conversion.

A Compendium of Existing HOV Lane Facilities in the United States, Booz Allen Hamilton, Incorporated, 2008.
http://ops.fhwa.dot.gov/publications/fhwahop09030/fhwahop09030.pdf
From the abstract: The compendium provides an assembly of available information on existing high-occupancy vehicle (HOV) lane facilities in the United States. While it is comprehensive and thought to include virtually all existing facilities at this time, it is possible that there are isolated instances of facility information that had been omitted from sources used for this document. The compendium is intended as a reference resource for an audience of transportation professionals responsible for planning, designing, funding, operating, enforcing, monitoring, and managing HOV and high-occupancy toll (HOT) lanes, and other stakeholders in policy decisions for improving HOV lane and highway mainline operations through conversion to HOT lanes.

A Review of HOV Lane Performance and Policy Options in the United States, Booz Allen Hamilton, Incorporated, 2008.
http://ops.fhwa.dot.gov/publications/fhwahop09029/fhwahop09029.pdf
From the abstract: The report provides an assessment of performance of existing high-occupancy vehicle (HOV) lane facilities in the United States, and explores policy alternatives and effects related to conversion of existing HOV lanes to high-occupancy toll (HOT) lane operations. The report includes sketch planning tools for exploring policy alternatives, and is intended for an audience of transportation professionals responsible for planning, designing, funding, operating, enforcing, monitoring, and managing HOV and HOT lanes, and other stakeholders in policy decisions for improving HOV lane and highway mainline operations through conversion to HOT lanes.

Considerations for High Occupancy Vehicle (HOV) to High Occupancy Toll (HOT) Lane Conversions Primer, Booz Allen Hamilton, 2007.
http://ntl.bts.gov/lib/30000/30800/30822/FHWA_HOT_Primer.pdf
From the abstract: This primer presents key issues and challenges related to the conversion of high occupancy vehicle (HOV) lanes to high occupancy toll (HOT) lanes. The primer is intended for community leaders, administrators, the public, and other stakeholders responsible for making policy decisions for improving HOV lane and highway mainline operations through conversion to HOT lanes. More detailed information is available in the Considerations for HOV to HOT Lane Conversions Guidebook. The primary audience for the guidebook is transportation professionals responsible for planning, designing, funding, operating, enforcing, monitoring, and managing HOV and HOT lanes.

Consideration for High Occupancy Vehicle (HOV) to High Occupancy Toll (HOT) Lanes Study, Booz Allen Hamilton, Incorporated, 2007.
http://www.ops.fhwa.dot.gov/publications/fhwahop08034/fhwa_hot_lane.pdf
From the abstract: The intent of this study is to explore the planning, design, and ongoing operation and maintenance of High Occupancy Toll (HOT) facilities and to provide lessons learned and applicable technical guidance that will assist the state and local transportation planners and designers in determining the conditions where High Occupancy Vehicle (HOV) lanes conversion to HOT lanes is feasible. The study reviewed a broad range of operational HOT facilities from having been operational many years to recently being opened. The study reviewed the activities of each in the planning, design, implementation and operations with special attention given to institutional, design, and operational challenges. The guidebook provides a summary of the best practices and lessons learned from those HOT facilities currently in operation. The result is a "Best Practices Top 20" list that evolved as each of the facilities learned or re-learned what other HOT facilities had previously learned. The result was a re-occurring list of "to do"s and what "not to do" to minimize issues during the HOV to HOT transition process.

"So You Want to Make a High-Occupancy Toll Lane? Project Manager's Guide for Conversion from High-Occupancy Vehicle Lane to High-Occupancy Toll Lane," *Transportation Research Record*, Issue 1960, 2006: 94–98.
Abstract at http://trid.trb.org/view/2006/C/777126
From the abstract: Although high-occupancy toll (HOT) lanes have been studied or have existed for more than 10 years, the continuing developmental nature of these concepts means that there is little guidance for project managers on how to manage the process of converting a high-occupancy vehicle (HOV) lane to a HOT lane. Many guidelines have been published about the technical elements of HOT lane development and operations. A project manager of an HOV to HOT lane conversion process would face issues that differ from those of the typical highway construction project, and managing these issues can be difficult and arduous. The intent of this paper is to address issues from the perspective of the implementing agency's project manager. Eight specific issues to be addressed within the conceptual development of the HOT lane conversion process are identified here: (a) presence of significant and predictable excess capacity in the HOV lanes, (b) presence of significant and recurring congestion in the adjacent general purpose lanes, (c) nature of traffic separation on the HOV lanes, (d) primary means of funding for the HOV lanes, (e) identification of the HOT lane program's primary objective, (f) determination of the appropriate implementing agency, (g) avoidance of overwhelming public opposition, and (h) ability to build political support for the process. This paper has summarized the first of what the authors see as four steps to the successful conversion of an HOV lane to a HOT lane: conceptual development. Planned subsequent papers will address the remaining three steps: program design, implementation, and ongoing operations.

Managed Lanes: A Cross-Cutting Study, Texas Transportation Institute, 2004.
http://ops.fhwa.dot.gov/freewaymgmt/publications/managed_lanes/crosscuttingstudy/index.htm
From the abstract: The intent of the report is to review the state-of-the-art in managed lanes in order to increase the understanding of (1) what managed lanes are, (2) how to plan for implementation, (3) what operational and design issues are considered, and (4) how active management of the lanes over the life of the facility affect its implementation. This report describes operating managed lane projects through a case study approach, highlighting best practices of the projects the lessons learned. Emerging issues and knowledge gaps are also presented. The intent of the report is to provide a cross-cutting study of the issues and experiences of various agencies as managed lane projects are implemented and policies are drafted.

Guide for HOT Lane Development, FHWA, March 2003.
http://ntl.bts.gov/lib/jpodocs/repts_te/13668_files/images/13668.pdf
From the preface: This guide is intended to be a comprehensive source of collective experience gained from the nation's current and implemented high occupancy toll (HOT) lane projects. The guide presents a wide range of information on HOT lanes and is intended to assist transportation professionals contemplating specific projects, as well as others who wish to become more informed on the topic. While most transportation officials are familiar with the HOT lane concept, relatively few have had first hand experience with actual HOT facilities. Therefore, the need to learn from current experience is particularly important.

Performance and Mode Choice

"Measuring the Quality of Service for High Occupancy Toll Lanes Operations," *Procedia-Social and Behavioral Sciences*, Volume 16, 2011: 15–25.
Abstract at http://trid.trb.org/view/2011/C/1136376
From the abstract: This study aims at conducting a comprehensive performance analysis on two representative HOT lane systems of State Route 167 in Washington and I-394 MnPass in Minnesota based on the field data collected from traffic sensors and transponder toll tags. Performance measurements are proposed to quantify the quality of service for HOT lane operations. Three critical issues are addressed in this study: 1) the speed-flow relationships in HOT lane systems, 2) quantified system-wide travel time savings and travel time reliability achieved, 3) SOVs tolling incentives. Based on the empirical analysis and evaluation results for the SR 167 and I-394 MnPass HOT lane systems, operational problems and challenges are also identified. Although the HOT lane system preserves favorable travel reliability, under-utilized HOT lane capacities were observed. The existing tolling strategies may be modified for better SOV allocation for HOT lane usages and further optimize the overall HOT system operations. The research findings greatly advance our understanding on HOT lane system operation mechanisms and are complementary to the freeway facility performance analysis provided by Highway Capacity Manual 2000.

"HOT-Lane Policies and Their Implications," *Transportation Research Board 90th Annual Meeting Compendium of Papers*, 2011.
Abstract at http://trid.trb.org/view/2011/C/1091326
From the abstract: This research examined the major changes in a corridor due to high occupancy toll (HOT) lane implementation and the different impacts of those HOT lanes. Using three pairs of HOT lanes with similar design and operational characteristics, comparisons were made to examine the impacts of the similar HOT lanes in two different corridors. With strict registration requirements for free high occupancy vehicle (HOV)3+ travel on the I-95 Express lanes in Miami there were indications that some carpoolers switched to lower occupancy modes. Tolled access for HOV2s on I-95 and the SR-91 Express lanes near Los Angeles resulted in lower usage of those Express Lanes by the HOV2s as compared to most HOV lanes where HOV2 access is free. On the SR167 (Seattle) and I-25 (Denver) HOT lanes, exogenous factors like gas prices and the economic recession seemed to be the primary influence on the usage of those HOT lanes. In both cases, carpool usage was positively correlated to the gasoline prices. On I-25, the increasing unemployment rate coincided with a decrease in toll paying travelers. On SR 167 there were also indications of mode shifts among the transit, carpool and toll paying single occupancy vehicles (SOVs) due to fluctuating gas prices.

"Mode Choice Due to HOV to HOT Conversions," *Transportation Research Board 89th Annual Meeting Compendium of Papers*, 2010.
Abstract at http://trid.trb.org/view/2010/C/910621
From the abstract: This paper examines the nine High-occupancy/toll (HOT) lanes around the country for a variety of issues relating to their usage. This research focuses on how travelers reacted to the new option

of paid access to the HOT lanes. Factors examined for potential impact of HOT lane usage were grouped into three categories: (a) HOT lane characteristics (such as travel time savings, travel time reliability, and geometric design), (b) traveler characteristics (such as income, gender, age), and (c) alternative characteristics (such as transit, parallel facilities). One of the key issues examined was mode shift due to the HOT lanes. It was found that, in general, the vast majority of low-occupancy vehicles (LOVs)—paying customers—on HOT lanes were former single-occupant vehicles (SOVs) from the general purpose lanes (GPLs). There are similarities in the demographic characteristics of more likely/frequent users of HOT lanes. They were most often well educated, between 35 and 54 years old, with high incomes. However, many surveys of paying HOT lane customers show that people of all ages, income levels, and educational backgrounds use the lanes. Little is known about the impact of geometric design on the use of the HOT lanes—although many travelers did feel the design was adequate and felt safe in the lane. Overall, no safety concerns in the use of HOT lanes were found; in fact, safety of these lanes was a positive influence on the use of the lanes.

Value Pricing Pilot Program: Lessons Learned, FHWA, August 2008.
http://ops.fhwa.dot.gov/publications/fhwahop08023/vppp_lessonslearned.pdf
This report includes a section on HOT lanes, with findings summarized as follows (pages 2 to 4):

> The Travel and Traffic effects of HOT lane conversions are well documented and favorable. The most extensive evaluation was carried out on I-15 in San Diego. Before conversion in 1988, the I-15 HOV lanes were very underutilized with only 600 vehicles per hour per lane (representing less than half available capacity at high speeds) at peak while the mixed flow lanes were heavily congested. Average daily traffic was around 9,200. With the HOT conversion, average daily volume on Express HOT Lanes increased by approximately 125 vehicles per month. Evaluators concluded, "By the end of 1999, the Express Lanes were much better utilized than before the start of the project." There was a large increase in carpooling from the beginning. By 2004, total daily traffic on HOT lanes had gone up to more than 21,000. …
>
> Travel and Traffic evaluations of other HOT lane projects are also positive. On I-10 in Houston, the addition of the HOT caused HOV2 volume to increase 40 percent, while the HOV3 volume changed very little. Also on
> I-10, the total volume on the HOV lane increased by 21 percent during the AM peak. Average speed on general-purpose lanes was 25mph, while average speed on the HOT was 59 mph (over 17-minute time saving for 13 mile trip). On U.S. 290, relative travel time savings were 11 minutes for a 15-mile trip. Surveys indicate that most HOT users formerly traveled in single-occupant vehicles on the general purpose lanes, suggesting positive impacts on traffic there. Not unexpectedly, there also was a significant shift of 2-person carpools from the general purpose lanes to the HOT lane. Diversion of bus, vanpool and 3+ occupant carpoolers to the HOT was between 5 and 8 percent of the HOT lane trips. On the I-394 HOT lanes in Minneapolis, peak hour volumes increased from 9 to 33 percent of the corridor volume after HOT conversion, and despite increased volume, travel speeds in the lanes have not decreased. Speeds in the general-purpose lanes increased up to 15 percent during peak rush hours, with 600-1000 fewer vehicles at peak due to the shift to HOT lanes. On
> I- 25/US 36 in Denver, preliminary estimates indicate between 10-15 percent of all daily person trips occur in the HOT lanes at full highway speeds, while the adjacent general purpose lanes experience stop and go traffic during the peak periods. For SR 167, projections estimate throughput will increase, with about 13 percent more vehicles traveling the corridor daily. Estimates are 38 percent more vehicles will use the HOV/HOT lanes, while preserving high-speed express trip conditions for buses, vanpools and carpools.

The report also includes summaries of findings on:

- Revenues and financial feasibility: "Revenues can cover operating costs, typically are devoted to operations and corridor improvements and, in some cases, have been used to support transit and rideshare services."
- Public attitudes and involvement: "Projects typically are initiated after considerable public outreach and stakeholder involvement, with changes being made along the way in response to public reaction."
- Outreach: "… as part of initial feasibility studies often find neutral or skeptical reactions, or outright resistance, but these are later followed by acceptance as projects get underway."
- Equity and environmental issues: "… have not been a barrier to start up or continuation, and impact studies on both issues are generally positive. … Surveys of corridor users find a relatively small difference in income between those who do and don't own transponders: 75% of owners had incomes over $50K/year, compared to 68% of non-owners."

Appendix B of the report contains project summaries and information sources for HOT lanes on:

- I-15 in San Diego.
- I-25/U.S. 36 in Denver.
- I-394 in Minnesota.
- I-10 and U.S. 290 in Houston.
- SR 167 in Washington.

Performance Measures and Assessment Methods

Analysis of Managed Lanes on Freeway Facilities, *NCHRP Web-Only Document 191*, 2012.
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_w191.pdf
From the abstract: This report documents and presents the results of a study for evaluating the performance of Managed Lane (ML) facilities on freeways. A methodological framework is for analyzing freeway facilities with ML and General Purpose (GP) lanes operated in parallel. The framework acknowledges that the composition and behavior characteristics of the ML traffic stream are expected to be quite different from those for the GP lanes in terms of traffic volume, free-flow speed, capacity, vehicle type, etc. It further considers that there may still be certain levels of interactions between these two lane groups, especially for those facilities that do not have physical (barrier) separations, either en route or at access points, between them. Within that framework, different modules were developed based on sensor-measured or simulation-generated data, including the characterization of ML speed-flow relationship, the frictional effect of adjacent lane traffic speed, the adjustment for cross-weave effects, and the development of side-by-side facility-wide ML and GP performance measures. Thus, the proposed methodology is sensitive to different GP and ML segment types (basic, weaving, etc.) and separation styles (none, buffer, barrier), and is capable of analyzing extended facilities across multiple time periods.

Operational Performance Management of Priced Facilities, Texas Transportation Institute, 2011.
http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-6396-1.pdf
From the abstract: This study provides a framework in which operating decisions for priced facilities can be made and can guide the changes in operational strategies for a facility over time. The research process was initiated with a literature review and targeted interviews of toll and managed lane operators to assess the state of the practice in performance measurement for pricing and other operational changes. The research team then developed guiding principles for identification, selection, and communication of performance measures and targets. A conceptual framework was formulated and data collection infrastructure needs were also documented. The conceptual framework was then developed into a more detailed version in a web-based format. This report documents the research findings and results and provides guidance on the use of the web-based framework tool. In addition, several outreach products

were developed under this study to assist agencies in communication of performance management principles for proactive management of priced facilities.

Evaluation and Performance Measurement of Congestion Pricing Projects, *NCHRP Report 694*, 2011.
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_694.pdf
This report includes "detailed recommendations and key considerations on initiating congestion pricing project performance evaluation programs and selecting specific performance measures." See Table 3-1 on pages 23 to 24 for performance measures.

Monitoring and Evaluating Managed Lane Facility Performance, Texas Transportation Institute, 2005.
http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-4160-23.pdf
From the abstract: Much of the progress made in advancing the state of the practice in performance monitoring and evaluation has considered general freeway facilities and lacks specificity for managed lane facilities. Managed lane facilities are unique, typically requiring a higher degree of active (sometimes real-time) management, addressing goals and objectives that are inconsistent with the general freeway facility (i.e., revenue generation, person throughput), and accessing an exclusive set of management tools (i.e., gate closures). To address these potential differences between facilities, this investigation was conducted to isolate and document the best performance monitoring and evaluation practices and principles explicitly for managed lane facilities. Despite the novelty of managed lanes as a traffic management strategy, the diversity of managed lane facility types, and the breadth of motivating factors for managed lane implementation, some general consistency in practice was observed with respect to performance monitoring and evaluation. Common goals, objectives, and performance measures were observed across similar facility types. Significant differences were also observed across similar facility types with respect to observed performance outcomes and evaluation methodologies. Differences in observed performance outcomes are likely explained by the variety in facility design (i.e., length of facility, accessibility, etc.) and operation (i.e., eligibility requirements, toll rates, etc.), even within a similar facility type. Differences in the evaluation methodologies used to arrive at these observed performance outcomes are likely reflective of the available resources for analysis at the time of evaluation and the evolving state of analysis methodologies.

Performance Modeling

Simulation-Based Testbed Development for Analyzing Toll Impacts on Freeway Travel, Transportation Northwest Regional Center X (TransNow), 2012.
http://www.transnow.org/files/final-reports/TNW2012-16.pdf
From the abstract: Traffic congestion has been a world-wide problem in metropolitan areas all over the world. Toll-based traffic management is one of the most applicable solutions against freeway congestion. This research chooses two toll roads, the SR-167 high occupancy toll (HOT) lane and the SR-520 toll bridge (i.e. Evergreen Point Bridge), as study sites for simulation testbed developments to evaluate the toll impact on freeway operations. The research approach proposed in this study consists of three steps: first, external modules are developed to enable VISSIM models to simulate various traffic operations with complicated tolling schemes; then, a standardized calibration procedure is proposed for freeway traffic simulation to enhance the models' creditability; and finally, a statistical method is developed to analyze simulation outputs against data autocorrelation problems. Two VISSIM external modules were developed for evaluating toll impacts on freeway operations in this research. For the SR-167 HOT lane site, an external tolling control module using the Component Object Model (COM) interfaces was developed to dynamically adjust the toll rate based on real time traffic conditions. For the SR-520 Evergreen Point Bridge site, an external routing module using Car2X module is developed to dynamically update vehicle routing. These external modules enabled testing customized tolling strategies often needed in toll impact

studies. The simulation results from the SR-167 HOT lane study site found that among all the three operational strategies, HOT lane operation with dynamic toll outperforms the other two strategies under various traffic demand conditions. Compared with the high occupancy vehicle (HOV) lane operation, dynamic toll strategy makes significant improvement on general purpose (GP) lane performance at regular segments, merging areas, on-ramps, and off-ramps. Compared with the time-of-day toll rate strategy, dynamic toll strategy is more flexible under a variety of traffic demands. The simulation results of the SR-520 toll bridge found that with an increase in toll at SR-520, the travel speed on SR-520 tends to increase and the speed on I-90 tends to decrease as more vehicles are diverted to use the non-tolled alternative. However, the change on I-5 and I-405 after tolling is insignificant since the number of vehicles turning from SR-520 to I-90 is much smaller than the existing volumes on I-5 and I-405. The two simulation testbeds developed in this study were applied to the SR-520 Evergreen Point Bridge and the SR-167 HOT lane projects and the results were satisfactory. These testbeds are capable of studying various customized tolling strategies on freeway operations. The methodology developed in this study for external module development and simulation output analysis can be used for other simulation studies of similar kinds.

"Evaluation of Operational Effects of Joint Managed Lane Policies*," Journal of Transportation Engineering*, Volume 138, Issue 7, 2012: 882–892.
Abstract at http://trid.trb.org/view/2012/C/1216194
From the abstract: This paper presents a method to evaluate the operational effects of managed lane policies—vehicle eligibility, access control, pricing, and the number of managed lanes—that form a policy combination set. Two macroscopic methods are developed to prescreen the set via simple criteria, followed by integer linear programming with multiple objectives and constraints to identify the noninferior policies among the downsized set. The approach is demonstrated on the Southern California SR-57 corridor. The application eliminates twelve of possible twenty policy combinations by the macroscopic methods, and generates four noninferior policies—the existing high-occupancy vehicle lane operation and three additional potential high-occupancy toll lane policies—in terms of maximum vehicle and passenger throughput, minimum vehicle hour traveled, and travel time variance. The prescreening efficiency of the macroscopic stage, ranging from 0 to 95%, is affected by the initial policies and traffic conditions. It is concluded that the approach can substantially assess a larger policy set and effectively identify the operational effects of joint managed lane policies.

"Impacts of High Occupancy Toll Lane Operations on High Occupancy Vehicle Travelers," Intelligent Transportation Systems (ITSC), *Proceedings of the 2010 13th International IEEE Conference*, 2010: 1594–1599.
Abstract at http://trid.trb.org/view/2010/C/1096543
From the abstract: This study concentrates on investigating HOV travel conditions in the HOT lane system with various HOV proportions under different traffic conditions. A simulation-based HOT lane operation analysis is conducted. A microscopic traffic simulation software tool, VISSIM, is utilized and an external module to enable dynamic HOT lane operations is developed. The Washington State Route (SR) 167 HOT lane system is simulated. The research findings indicate that under current traffic demands HOT lane system can improve overall HOV travel conditions due to the overall system performance enhancement. However, negative impacts of HOT lane systems on HOV travelers become significant with increased traffic demands. This study demonstrates quantitative impacts of HOT lane systems on HOV travelers and provides in-depth analysis for HOT lane performance evaluations.

A Mathematical Model for Evaluating the Conversion of High Occupancy Vehicle Lane to High Occupancy/ Toll Lane, University of California, Davis Institute of Transportation Studies, 2007.
http://pubs.its.ucdavis.edu/download_pdf.php?id=1100
From the abstract: A methodology for evaluating and quantifying the benefits/costs of converting a given High Occupancy Vehicle (HOV) lane into a High Occupancy/ Toll (HOT) lane is presented in this study. A mathematical programming model that seeks the optimal pricing strategy, using a logit-like choice

model embedded as constraints, forms the core of the methodology. A salient feature of this study is the incorporation of equity into the planning process by imposing constraints thus enabling planners to limit the inequities in vertical as well as temporal dimensions. A HOV lane on a corridor on I-80 in the San Francisco Bay Area was studied for conversion under different objectives—revenue maximization, total vehicular travel time minimization, total passenger time minimization, total cost minimization and minimization of total vehicle miles traveled. It was found that converting the HOV lane into a HOT lane would improve the objective function in all programs except for total cost minimization. It was also found that the capital and operating costs can be recovered in a reasonable amount of time (three-five yrs). The analysis revealed that there can be significant differences in the pricing strategies across different objective functions. The variation in the system performance measures across different programs was also studied and it was found that revenue was the most sensitive performance measure. The results of all the programs revealed that there is an inverse relationship between equity and efficiency, with the exact nature of this relationship being a function of the objective. Furthermore, in situations where there is no redistribution of revenues, the vertical equity situation cannot be improved even though all the user groups can be made better off after the conversion. Additionally, Dynamic Programming models were constructed to solve for the optimal sequence/schedule of converting a given set of HOV lanes into HOT lanes. The optimal sequences here minimized the total conversion time for a self-sustaining/self-financing sequence or minimized the total funding needed to complete all the conversions by a certain deadline.