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TOLL-MANAGED LANES: BENEFIT-COST ANALYSES OF SEVEN PROJECTS

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TOLL-MANAGED LANES:
BENEFIT-COST ANALYSES OF SEVEN PROJECTS

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Abstract

Toll managed lanes are expressway lanes where tolls are used--often in combination with preferred access for high occupancy vehicles and other special traffic management techniques--to improve the highway's capacity, speed or reliability. Such lanes, and particularly a variant called High Occupancy Toll (HOT) lanes, have become popular with transportation policymakers as a way of maintaining free-flowing traffic on existing lanes while also, in some cases, financing the construction of new lanes in congested urban areas.

This study examines whether toll-managed lanes are as beneficial as they are popular. The heart of the analysis is the application of a simplified social benefit-cost analysis to seven projects. In brief, the results suggest that toll-managed lanes, while promising, are not a surefire strategy for managing congestion. Only two of the seven projects have benefit-cost ratios above 1.0 using our base case assumptions about the value of travel time saved and the discount rate, although three others approach or exceed 1.0 with more optimistic but plausible assumptions. The most successful generate not only a significant savings of around 4 to 5 minutes per trip for motorists who switch to the managed lane but also smaller per-trip savings for the large majority of motorists who continue to use the general-purpose lanes. It is important to acknowledge, however, that these calculations depend upon some uncertain assumptions about the value of travel time savings and improved reliability.

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I. The Study in Overview

Toll-managed lanes, and especially a variant called High Occupancy Toll (HOT) lanes, have become popular with transportation policymakers as a way of squeezing more capacity out of existing expressway lanes and/or financing the construction of new lanes in congested urban areas. HOT lanes were introduced only in the early 1990s, but they are a member of a family of managed lanes, variants of which have been around for decades.

Managed lanes are defined as expressway lanes where special traffic management techniques are used to improve traffic capacity, speeds or reliability (Federal Highway Administration, 2012, pp. 1-4-1-6). Usually, these lanes operate alongside, and as alternatives to, the general-purpose lanes of the expressway. Three strategies are used alone or in combination to manage the traffic:

1. Restricting access to vehicles of particular types or occupancies, the most common example being High Occupancy Vehicle (HOV) lanes;
2. Restricting entrances and exits to the lanes, such as special express, contraflow or reversible lanes or through expressway ramp metering; and
3. Requiring users to pay a toll or congestion charge for access to the lanes.

HOT lanes, which are a variant of toll-managed lanes, are restricted to motorists willing to pay a toll and to drivers of high occupancy vehicles, such as carpools or buses, who are allowed to use the lane for free or for a discount off the normal toll. Often these HOT lanes are former HOV lanes that were opened later to toll-paying traffic because they were underutilized, but increasingly the HOT lanes are purpose-built. Managed lanes that are tolled but do not allow high-occupancy vehicles discounted or free access are sometimes called Value Pricing Lanes or Express Toll Lanes (ETLs).

There has been an explosion of interest in managed toll lanes since the first example opened in 1995. The pioneer was State Route (SR) 91 Express Lanes, a pair of lanes serving commuters who live in Riverside County and work in Orange County, California. The ten-mile facility was built alongside and within the right of way of the SR-91 freeway by private investors who had won a contract from the State of California for a concession to build and operate the lanes for 35 years. The concession was the result of state legislation that enabled California's transportation agency to contract with private entities to build expressways and collect tolls from the motorists using them. The SR-91 lanes cost only $125 million to build and generated as much as $40 million in revenue per year at their peak, just before the investors were bought out by Orange County when it wanted to add more lanes to the expressway. (Adding lanes was prohibited under the original contract in an effort to limit the amount of competition the entity would face.) In the first ten years after the opening of SR-91 only two other HOT lane projects were deployed in the United States. However, by 2010 the number of HOT lane projects in operation increased to nine and by 2016 the number had ballooned to 39 with many more under construction. The HOT lanes in operation were concentrated in Texas (10), California (7), Colorado (3), Minnesota (3), Florida (2) and Washington (2). Some of the facilities are very extensive and required investments of billions of dollars. Appendix A lists the projects by year opened.

Toll-managed lanes are of two distinct types, depending on whether the objective in collecting tolls is only to regulate congestion or also to raise revenues needed to finance the construction of the managed lanes or other related highway facilities. The schemes designed primarily to manage congestion are typically conversions of existing and underutilized HOV lanes. The schemes designed to raise revenue as well are often new HOT lanes or ETLs built through Public Private Partnerships (P3s) in which private investors are awarded a concession to build the managed lanes and then operate them for a fixed term, usually of 30 to 50 years.

One of the main attractions of toll-managed lanes is that they provide a less controversial means of introducing tolling on roads, particularly if the managed lanes are new and not converted general-purpose lanes. Most of the toll expressways in the United States predate the establishment of the Interstate and Defense Highway System in 1956. Tolls are prohibited by law on the vast network of expressways that were built with Interstate System funding on the grounds that motorists already paid for them through the federal gasoline tax. Managed lanes that are new avoid the prohibition against tolls on existing Interstate System facilities. Additionally, these lanes promise not only to provide a faster option for motorists who are pressed for time, but also to reduce congestion in the general-purpose lanes by diverting traffic to the tolled lanes.

This study examines whether toll-managed lanes are as beneficial as they are popular. The heart of the analysis is the application of a simplified social benefit-cost analysis to seven projects. Benefit-cost analyses have been published for a number of managed lane projects but they are hard to compare because they vary in the costs and benefits they include and in the ways those benefits and costs are estimated[1]

The seven cases were selected in part because the implementing agency collected and was willing to share the detailed data on travel volumes, speeds and tolls by time of day and lane that are required to do the benefit-cost analysis. They were also selected to represent a variety of types of toll-managed lanes.

The analysis focuses on the benefits and costs to society as a whole rather than the financial viability of the project for the implementing public agency or private firm. The primary benefits considered are the travel time savings and reliability improvements enjoyed by the users of the managed lanes, however, and all or much of that value could, at least in theory, be captured by

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[1] An exception is FHWA (2015) which compared six congestion pricing demonstrations in six metropolitan areas and included benefit-cost analyses for five sites. We included four of the sites among our seven (Atlanta, Los Angeles, Minneapolis and Seattle) because the more detailed reports on the individual metropolitan areas included good before and after data on speeds and volumes. We performed our own benefit-cost analyses, however, to be sure that the assumptions and methodologies were reasonable and consistent across cities.

the implementing agency through the tolls it charged. Thus, if the benefits exceed the costs for a project as we measure them, then it is likely that the project could be self-financing from tolls (especially if you could toll the general-purpose as well as the toll-managed lanes). The opposite is not necessarily true, however. A project may be socially beneficial but not financially viable particularly if the implementing agency or firm keeps tolls artificially low.

It is difficult to generalize about the circumstances favoring managed lanes with only seven cases, but three conclusions emerge. First, toll-managed lanes, although promising, are not a sure-fire strategy for managing congestion. Only two of the seven projects have benefit-cost ratios above 1.0 using our base case assumptions about the value of travel time saved and the discount rate, although three others approach or exceed 1.0 with more optimistic but plausible assumptions. Moreover, success does not appear to depend on the scale of the project or the investment required—some costly projects are beneficial, and some inexpensive projects are not.

Second, a necessary key to success is a significant time savings for users of the managed lanes over users of the general purpose lanes. Our more successful projects typically offer users who shift to the managed lanes time savings of around 4 to 5 minutes on road segments that previously required around 15 minutes to traverse, or enough to make the gain noticeable. The best projects also offer savings of 1 to 2 minutes per trip for motorists who continue to use the general-purpose lanes. Even small time gains and losses in the general-purpose lanes can have an important effect on the net benefits because the general-purpose lanes typically carry several times the traffic as the tolled lanes. Many other researchers have reached similar conclusions, noting that the time savings depends upon the existence of chronic congestion in the general purpose lanes, excess capacity in the HOT lane and a long enough lane to make the speed difference result in a noticeable time savings (see, for example, Ungemah and Swisher 2006, Fitch 2017).

The third conclusion is that an improved understanding of the value that motorists place on reducing travel time and improving reliability is important in evaluating managed lanes. The value travelers place on time saved has been studied for many years, and the consensus is that commuters value time saved at between 30 and 70 percent of their wage rate. The value travelers place on improved reliability has been as much less studied and there is little consensus about how reliability should be measured as well as on the value of reliability improvements. Simple calculations of the implicit value that the managed lane users place on time and reliability in our seven cases suggest, however, that we have been underestimating the value of this benefit of managed lanes.

2: A Brief History of Managed Lanes

HOV facilities were first deployed in World War II as part of a fuel rationing program, but did not reappear until the early 1970s and then as exclusive bus lanes (FHWA 2016a, 2016b). The pioneers included a bus-only lane on the Shirley Highway in northern Virginia and contra-flow bus lanes on the approaches to the Lincoln Tunnel between New York and New Jersey. In many cases, the bus lanes increased public transit ridership, as intended, but not enough to use more than a small fraction of the lane's vehicle carrying capacity. Motorists stuck in the congested general purpose lanes were often angered to observe only a few buses per minute whiz by in the adjacent bus lane. To improve utilization the bus lanes were opened initially to carpools of three or more people (HOV3+) and later, if there was still capacity, to carpools of two or more (HOV2+). The Federal Highway Administration estimates that there were over 2,500 lane-miles of HOV lanes in operation in the United States in 2016 (FHWA 2016a)

Several factors combined to encourage the conversion of HOV lanes to HOT lanes and the construction of new purpose-built HOT lanes. The first was the gradual decline in carpooling due to growing incomes and the increase in single-parent and two-worker households whose complex family schedules made carpooling difficult. In its guidelines on HOT lane conversions, FHWA (2016a) concluded that

> …many HOV lanes do outperform adjacent general purpose highway lanes in terms of person throughput, especially during peak hours of service. By themselves, however, the extent to which HOV lanes induce new ridesharing beyond preexisting levels is debatable … When new carpool formation is low, HOV lanes may go underutilized and not meet expectations about congestion relief benefits.

The second factor was the development and spread of electronic toll collection and video enforcement, technologies that allowed tolls to be collected without slowing traffic on ramps between the general purpose and HOT lanes. Electronic collection also made it easier to vary tolls by time of day or by actual levels of congestion to ensure that the HOT lanes maintained their speed advantage over the general-purpose lanes.

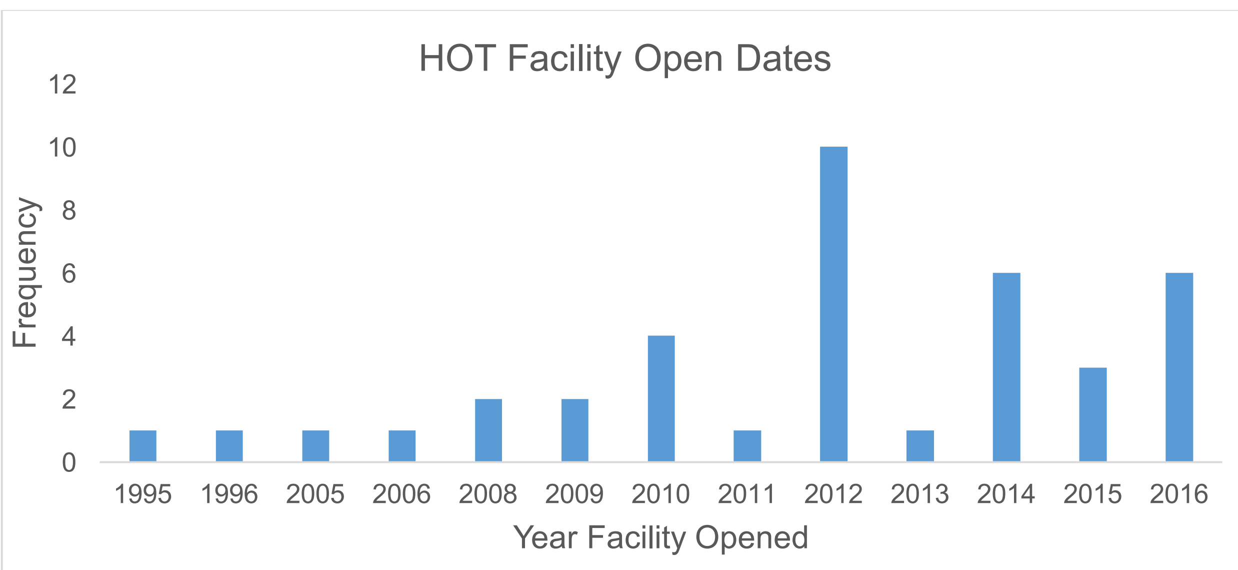
Finally, HOT lanes were also encouraged by state and local governments' search for new sources of revenue to fund the construction and rehabilitation of new and worn out highways and bridges. For almost a century federal and state motor fuel taxes have been the major source of funding for highway construction and maintenance. As noted earlier, in 1956 Congress established the Interstate and Defense Highway System designating a network of 32,000 miles to be built and maintained by the states with the inducement of federal grants to cover 90 percent of the construction cost. The grants were funded by a federal tax on fuels, and Congress prohibited the states from collecting tolls on the Interstates on the grounds that motorists had already paid for them through the federal fuels tax. The only exceptions were roughly a dozen toll roads in the East that had been built before the program and were grandfathered into the Interstate System. At the state level there was popular resistance to tolling state highways that were not part of the Interstate System on similar grounds.

Interest in tolling revived in the 1980s and 1990s. By then the Interstate System was essentially complete but state and local governments were looking for sources of revenue to fund the rehabilitation of older segments and the extension of expressways to areas where the original Interstate planners had not anticipated development. Anti-tax sentiment in the 1980s made it increasingly difficult to raise federal or state fuel taxes even though the proceeds typically would be earmarked for transportation. Moreover, transportation planners were becoming increasingly interested in the potential for using tolls to manage severe congestion on existing highways instead of building costly new capacity.

Over the last decade or two the U.S. Congress has relaxed the restrictions on tolling Interstate highways somewhat. Tolls can be collected on bridges that are being rebuilt, for example, presumably on the grounds that bridges are unusually costly. Tolls also now can be applied to convert HOV lanes to HOT lanes or to rebuild or widen existing Interstates as long as the number of untolled lanes is not reduced. These last two exemptions have been particularly important in the spread of toll-managed lanes.

By 2016, two decades after the practical demonstration of toll managed lanes on SR-91 in California, a total of 39 toll managed lane projects had opened in the United States. Managed lanes got off to a slow start, but since 2010 an average of roughly five new facilities have opened per year, as shown in figure 1. The projects—listed in Appendix A—are concentrated in five states: California, Texas, Florida, Colorado, and Minnesota.

Figure 1



These five states were early adopters of HOT lanes because a combination of rapid growth and popular resistance to raising gasoline taxes was causing significant budget shortfalls and growing congestion. The experiences of the five states are summarized briefly in Appendix B. Each state passed legislation directing their transportation agencies to pursue alternative funding mechanisms, although the structure of the legislation differed by state. In California, Texas, and Florida, for example, the legislature required that transportation agencies pursue a variety of innovative financing mechanisms, including HOT lanes. In other states, such as Colorado and Minnesota, legislation directed the transportation agencies to pursue HOT lanes specifically as a means to manage congestion and generate new revenue streams.

Although the nuances of enabling legislation differed slightly, the implementation process was similar. In all instances, the state transportation agencies conducted feasibility studies to determine which facilities were candidates for tolling and for HOT lanes specifically. Both Florida and Colorado created new tolling "enterprises" within their state transportation agencies to lead the analysis and implementation of tolling projects. California already had gained experience with SR-91, but the other states implemented pilot HOT lane projects--including the Katy Freeway in Texas, I-95 in Florida, I-394 in Minnesota, and I-25 in Colorado—whose success spurred them to pursue additional HOT lane projects.

The degree to which states have incorporated toll-managed lanes into their long-term transportation planning varies. Most of the five pioneer states are implementing HOT lane projects on a case-by-case basis. But some states, notably Florida and Minnesota, have drafted regional HOT lane feasibility studies to identify facilities best suited for HOT lanes; so far, however, few of the many projects identified in these studies have been implemented. Although Colorado lacks a state-wide HOT lane agenda it has systematically expanded its HOT lane facilities across the Denver region. California is unique in that the highways are primarily managed at the regional level by regional transportation agencies in conjunction with the state transportation agency. State legislation has enabled these regional agencies to pursue HOT lane projects, which all the large urban areas are doing. However, each regional agency is required to report its HOT lane projects (either implemented or planned) to the state agency. Texas is similar to California in its use of regional transportation agencies to manage state highways and these agencies are able to pursue HOT lane projects. Unlike California, however, Texas does not have a state-wide reporting requirement. Further, each urban area in Texas – Dallas/Ft. Worth, Houston, and Austin – is financing and managing its HOT lane projects differently.

3. The Challenges of Toll- Managed Lanes

Designing a toll-managed lane system whose social benefits exceed its costs is challenging for several reasons. The first is that the toll-managed lanes almost always compete with parallel and free general-purpose lanes. Tolling only a subset of the lanes is an inherently inferior strategy for maximizing social welfare compared to tolling all lanes. In particular, if only the managed lanes can be tolled there will be more traffic in the general-purpose lanes and less in the managed lanes than would be socially optimal.

A second source of difficulty is that managed lanes are used when traffic volumes are close to the highway's capacity. In those circumstances speeds are very sensitive to fluctuations in volumes. This makes it harder and more important for the managed lane operator to estimate in advance what the optimal toll should be, and strengthens the case for using dynamic pricing in which the toll is adjusted frequently in response to real-time changes in traffic volumes and speeds.

A corollary is that corridors where highways are operating close to capacity are also the corridors where the cost of building managed lanes is likely to be high. If the existing right of way is not wide enough to accommodate the lanes then costly land acquisition, elevated structures or below grade facilities may be required

Ensuring that social benefits exceed social costs is also challenging because tolls are often expected advance other goals besides the efficient use of the highway. In many cases the tolls are also being used to generate revenue to build the managed lanes or to subsidize improvements to general-purpose lanes as well. Revenues generated by the optimal toll on a congested highway probably fall short of covering the costs of building an efficient-sized version of that highway, although by how much would be difficult to determine (Gomez-Ibanez 1999). In any event, adding a revenue requirement to an already complicated problem is likely to make it harder to ensure that benefits exceed costs.

Political constraints on pricing can further complicate efforts to gain net benefits. In many states some of the HOT lane capacity is given away free or sold at a discount. In particular, many HOT lanes allow carpools of three or even two persons to travel for free and California passed a law exempting zero emissions vehicles from tolls. These discounts might be justified by the environmental benefits generated from carpooling and cleaner vehicles. It is doubtful, however, that the discounts induce significant increases in carpooling or the purchase of clean cars unless congestion is particularly high. Further these discounts potentially displace motorists that would have valued that capacity more (Poole 2017).

HOT lanes can also be victims of their own success if toll rates needed to control congestion increase rapidly and increases must be approved by public officials. For example, I-95 in Florida, which is one of our case studies, saw peak tolls needed to achieve reasonably free-flowing traffic increase from $2 per car in August 2012, shortly after its HOT lane opened, to $10 per car by March 2017. Tolls must be allowed to increase with congestion if the managed lanes are to remain free-flowing. Managed lane projects that are PPP's typically include provisions in their contracts that protect their right to, or even oblige them to, raise tolls as needed to maintain free-flowing speeds in the managed lanes. Absent such protections, public officials might reduce the benefits of managed lane schemes by holding down tolls. High tolls may be economically advantageous in highly congested situations but they are seldom politically popular (Regan 2017).

While financial viability is not the main focus of this study it is worth noting that many of the factors that make it harder to ensure that social benefits exceed costs also make it hard to ensure that the revenues exceed financial costs (Fitch 2013 and 2017, Moody's 2013). The presence of free parallel general-purpose lanes makes revenues more volatile than they would be on a conventional toll road in which all lanes were tolled. Additionally, because the managed lanes are more attractive when the general-purpose lanes are congested, the majority of revenue generation takes place only during a half-dozen hours of the day when traffic peaks.

4. Three Types of Projects

Conversions

The most common type of toll-managed lane project is designed to increase the utilization of existing HOV lanes by opening them to toll-paying SOVs. The primary concern in toll setting is to ensure that the managed lane is not congested rather than to raise revenue to offset the costs. Typically, conversions are implemented by public agencies rather than through public-private partnerships (PPPs) because the cost to convert 10-15 miles of lanes is often less than $100 million, which is not enough to justify the transactions costs associated with a partnership.

One of our cases—I-680 Southbound Express Lane—opened in September 2011 as the first conversion of an HOV lane to a HOT lane in Northern California. It was part of a demonstration program funded in part by the State of California so its experience has been carefully documented by the primary implementing agency, the Alameda County Transportation Commission (2013). Converted at a cost of only $36.6 million, the lane runs south 14 miles along I-680 from the intersection with SR-84 in Alameda County to the intersection with SR-237 in Santa Clara County. Access to the original HOV lane was limited to HOV2+ and vehicles that had been certified as low emissions or electric powered. These vehicle types are exempt from tolls in the new HOT lane. While the time savings on the lane were not very impressive, they were enough to convince Alameda County to move forward with the design of a parallel northbound project.

Our case studies also include one of the earliest and most influential conversions: Phase One of the Florida's 95 Express lanes. The project, which opened in two sub-phases in 2008 and 2010, involved the replacement of one HOV lane with two HOT lanes on a 7.2-mile section of I-95 stretching north from Miami. The existing four general purpose lanes were retained and a second managed lane created simply by restriping the roadway to make traffic lanes and shoulders a bit narrower. The cost, including toll collection and enforcement equipment, was only $139 million, and the effect on traffic speeds in this congested corridor was dramatic. Phase Two of the 95 Express Lanes was completed in 2016, which extended the express lanes to 22 miles, and Phase Three is currently underway.

At the other extreme is the case of the I-85 Express Lanes in Georgia, which performed poorly when the Facility opened in October 2011. At a cost of $61 million, that project involved the conversion of a 16-mile stretch of HOV lanes on I-85W north of Atlanta to HOT lanes. The standard for HOVs exempt from tolls was tightened from HOV2+ to HOV3+, unlike 95 Express in Florida which maintained an exemption for HOV2+'s. This policy change contributed to disappointing usage of the lanes and to a decision by state officials to expand Atlanta's planned managed lane network by building new managed lanes rather than converting existing lanes (US DOT, 2015, p. 42).

New lanes

The second type of project involves the construction of new toll-managed lanes alongside the existing general-purpose lanes. In these cases, tolls are usually set both to manage congestion and to finance all or most of the cost of building the new lanes, which can be as high as several hundred million dollars. SR-91 in California is the pioneering and best-known example of new lane construction.

None of our case studies involves new lanes alone. New toll-managed lanes are usually built in conjunction with conversions of HOV lanes or with the rebuilding of existing general-purpose lanes. One of our case studies, I-405 in Seattle, Washington, involves the conversion of 17 miles of HOV lanes between Bellevue and Lynnwood, as well as the construction of a second HOT lane from Bellevue to Bothell. The project is part of a 2010 plan to build a 40-plus mile system of HOT lanes to serve the Eastside Corridor—second only to I-5 as the most congested north-south artery in the Seattle metropolitan area (WDOT 2010). The project began construction in 2012 and opened in September 2015.

Another of our cases, I-35W in Minnesota, involves a complex mixture of converting HOV to HOT lanes, constructing new purpose-built HOT lanes and rebuilding an existing expressway while adding HOT lanes (Buckeye 2014, p. 4). The I-35W lanes connect the southern suburbs with downtown Minneapolis. The first six miles consists of one HOV lane in each direction that was converted to a HOT lane (still allowing HOV2+). The next 8 miles is an existing three-lane expressway called Crosstown Commons that was rebuilt to add both a general-purpose lane and a HOT lane in each direction. The third and final 2-mile section involves the conversion of a north-bound shoulder lane that had been open to HOV's in the peak period to a HOT lane that Minnesota officials christened the Priced Dynamically Shoulder Lane, or PDSL for short. The conversion of the southern HOV lanes and the northern PDSL lanes to HOT lanes cost only $40 million but the reconstruction of Crosstown Commons cost $228 million (US DOT 2013, p. J-5).

Rebuilds

The most ambitious projects involve the construction of additional managed lanes in conjunction with the rebuilding of the existing general-purpose lanes. The rebuilding may be required to fit the added lanes within a relatively narrow existing right-of-way or because the basic roadway and structures are reaching the end of their lives. But the rebuilding also offers the possibility of better integrating the managed lanes with the general-purpose lanes by, for example, connecting expressways through high-speed ramps or other measures. Rebuilding projects typically cost $1 to $3 billion, sums large enough to make it attractive to incur the transaction costs of procuring the facilities through a public-private partnership. The scale of these projects stems from the fact that most are part of a larger regional plan for a network of managed and improved general purpose lanes. The Federal Highway Administration (2012, p. 1-8) lists Seattle, Austin, Salt Lake City, San Diego, Houston, Dallas-Fort Worth, Miami and Northern Virginia as incorporating managed lanes in major highway expansion program. Early influential examples include the Katy Expressway in Houston Texas and the I-95/I-495 express lanes in Virginia; the former is a publicly-managed project while the latter is a public-private partnership.

Among our case studies, the middle third of I-35W in Minnesota (the Crosstown Commons) is essentially a rebuild project but the larger scale examples are the LBJ and North Tarrant expressways in Texas. These two expressways are part of a larger project to build an extensive network of toll-managed lanes in the Dallas-Fort Worth metropolitan area. Some segments are being built by public agencies while others, including the LBJ and North Tarrant, are being built by private concessionaires as public-private partnerships. The 13.3-mile North Tarrant Expressway project, completed in late 2014 at a cost of $2.1 billion, involves the construction of two new managed lanes and the rebuilding of two to three existing general-purpose lanes and two frontage roads lanes in each direction. Also 13.3 miles long and completed in late 2015 at a cost of $2.6 billion, the LBJ Expressway consists of a 3.6-mile segment with two-to-three new managed lanes in each direction and a 9.7-mile segment with two-to-three new managed lanes, four rebuilt general-purpose lanes and two new frontage road lanes in each direction.

5. Assumptions of the Simplified Social Benefit-Cost Analyses

Before and after timeframe

With a few exceptions, we estimate the effects of the managed lanes by comparing data on the performance of the lanes the year before and the year after they opened for service. The short timeframe is used in an effort to control for other factors that may influence the utilization of the highway such as an economic recession or recovery or the improvement of a parallel or a feeder road. The shorter the timeframe, the more likely these potentially confounding factors will be the same before and after the opening of the managed lanes.

The main drawback of the short timeframe is that it is likely to underestimate the net benefits of the managed lanes if traffic increases rapidly after the first year. The underestimate may be modest, however, since the increase in the number of motorists enjoying higher speeds would be offset at least in part by the reduction in speeds caused by the added traffic. Moreover, managed lanes are typically proposed for heavily congested highways that serve already built up areas of the metropolis. Therefore, the potential for sustained rapid growth is more modest than it would be for a less congested highway serving a "greenfield" area that is relatively underdeveloped but ripe for build out. In the former situation, most residents presumably respond to the new lanes by deciding whether or not to use the lanes for their current commute rather than by making more fundamental and long-term choices about where to work or live. Nevertheless, several of our cases, including two highways in Dallas, have experienced sustained and rapid traffic growth. Our short time frame of analysis likely fails to capture their continued ramp up in traffic, almost certainly resulting in the underestimation of their net benefits.

Travel times by time period and segment

Travel times are estimated using speed and volume data from the agency that supervises the managed lanes. Time savings are assumed to occur only during the morning and evening peak periods on weekdays. The specific hours used are typically the two three-hour periods which the supervising agency defines as its peaks. We assume 250 weekdays in a year.

It is critical that the speed and volume data are for the same time periods and highway segments. Segment-specific speed and volume data are used where they are available. If average speed and volume figures are available only for the entire facility then we assume that managed lane users travel the entire length of the lane, an assumption which almost surely exaggerates the effects of the lanes.

Note that these data and subsequent calculations are for vehicles rather than for individual travelers largely because most highway agencies do not report average vehicle occupancy in much spatial or temporal detail.

Minutes of travel time saved

The principal benefit of the managed lanes is the minutes of travel time the motorists save. Conversely any increase in travel time is a cost. If motorists used the highway before the toll-managed lanes were opened and continue to do so, then their savings is simply the difference between their travel time before and their travel time after the managed lanes become operational. If motorists did not use the highway before but use either the general purpose or managed lanes after, then we follow the conventional practice of estimating their savings as one-half the difference between the time they would have spent had they used the road before and the time they spend now. The reasoning is that the decision of motorists not to use the road before indicates that they value the trip at less than the travel time before while their decision to use the road after indicates that they value the trip by at least the travel time after. If the time before is the upper bound and the time after is the lower bound, then one-half the difference is a reasonable approximation.

One simplification in our analyses is that we do not calculate the time savings or losses separately for HOV users but rather treat all toll-managed lane users as if they were toll paying single-occupant vehicles (SOVs). We make this assumption because we do not have data on the mix of SOVs and HOVs in the managed lanes for several of our cases. Moreover, the assumption causes no problems in projects that involve the construction of managed lanes where there were none before. In projects where HOVs had been allowed to use managed lanes before but not afterward, however, the assumption typically overstates the benefits since the speeds in the managed lanes are typically faster than the speeds in the general purpose lanes the HOVs now must use.

Another complication, particularly for projects involving new lanes rather than conversions, is that we have no data on how many of the new managed lane users are former users of the general-purpose lanes and how many are new users of the road. The usual assumption is that they are new users to the road and thus benefit by one-half the difference between the travel times on the general purpose lanes before and the managed lanes after. But, if one assumes instead that they are former users of the general-purpose lanes, then they benefit by the full difference between general-purpose time before and managed lane time after rather than by half the difference. We adopt the latter assumption since it seems likely that the managed lanes would draw more from existing road users than those who had not made the trip before. This assumption, however, significantly increases the benefits of projects that generate a big increase in managed lane use.

The dollar value of travel time savings

Since reduced travel time is one of the principal benefits, the dollar value travelers place on travel time saved is obviously a critical assumption in our social benefit-cost analyses. There is an extensive body of empirical research that suggests that commuters' value travel time savings at 35 to 60 percent of their wage rate with a median estimate of about 50 percent (USDOT

2014, pp. 10-13 and Table 2). This would imply a value of $12.50 per hour for a typical managed lane user with an annual income of $50,000 working 2000 hours per year. [2]

To translate estimates of time value per traveler hour to time value per vehicle hour we need to make assumptions about average vehicle occupancy as well. The U.S. Census reports an average of 1.1 commuters per automobile. Assuming an overall average vehicle occupancy of 1.2 for all types of trips and an hourly wage of $12.50, implies an average value per vehicle hour of $15. If 9 percent of the traffic were trucks, which have a value of time of $40 per hour, then the overall value is $17 per vehicle hour. This Figure, which we use as our base case, compares reasonably well with the value of time savings guidelines of the US Department of Transportation (2014, Table 4 and 5).

We also assume that travelers using the toll-managed and the general-purpose lanes place the same value on travel time saved. If motorists vary in the value they place on time savings then the users of the toll-managed lanes will be the ones who value time savings more highly. Small and Yan (2001, p. 324) demonstrated how important the heterogeneity of motorist preferences might be by simulating motorists' behavior in a hypothetical managed lane modeled after California's SR-91. They estimated that the benefits gained by the sorting of motorists across traffic lanes by value of time can offset as much as a third of the inefficiencies of applying tolls on only the managed lanes.

The operators of the North Tarrant Express in Texas argue that the patterns of use of their managed lanes suggest that preferences are very varied. The top 10 percent of the subscribers to their transponders are regular users who take 10 or more trips per month and account for 55 percent of trips. The bottom 50 percent of subscribers take an average of only 1 trip a month and account for only 13 percent of trips and presumably include many who use the Express Lanes only when the speed and reliability are particularly important. If true ignoring the heterogeneity of users will understate the benefits of managed lanes even if the average value of time savings is correctly estimated.

Value of increased reliability

Many operators and researchers of managed lanes suspect that the benefits from improved reliability are as important as the benefits from reduced travel times. Unfortunately, reliability benefits are hard to include. Most agencies with managed lanes do not collect or report reliability data and there is little consensus among transportation researchers as to the appropriate measure of reliability to use or the value to place on reliability gains (US DOT 2014b, p. 3)

Reliability benefits are likely to be particularly large when new HOT lanes are added alongside expressways that are operating so close to capacity that small changes in traffic volumes cause

[2] A study of Georgia's I-85W Express Lanes reported average household incomes of $54,000 in 2011 (US DOT 2014, p. L-6)

large changes in speeds. One sign that reliability benefits may be large comes from surveys of the motorists using the managed lanes on the North Tarrant and LBJ expressways which show that they systematically overestimate the savings in travel time they enjoy. Users of the HOT lanes on the North Tarrant Express overestimate the savings by a factor of two, for example, reporting an average of 9.5 minutes saved when the actual savings was 4.4 minutes (Sanchez 2016).

Another sign that reliability is important comes from estimates of the minimum values of travel time saved that are implicit in the decisions by motorists to use HOT lanes. In the cases we studied these implicit measures of the value of time are typically much higher than the $17 per hour suggested by conventional estimates. The implicit values are estimated by simply dividing the tolls paid by SOVs using the managed lanes by the minutes saved and are minimums in that some SOV users presumably would be willing to pay more than the toll charged. The resulting values, shown in Table 5.1, vary from $6.47 to $82.47 with no obvious relation to the type of project or its benefit-cost ratio (calculated using $17 per hour).

Table 5.1: Implicit Value of Time in Decisions of Motorists

Case	Implicit value per hour	Type	B/C ratio (at $17/hour)
Florida I-95 phase 1	$6.47	Conversion	3.96
California I-680 south	$65.34	Conversion	0.23
Georgia I-85	n.a.	Conversion	-0.56
Washington I-405	$15.31	Conversion and new	0.29
Minnesota I-35W	$79.57	Conversion and rebuild	1.32
Texas LBJ	$77.94	Rebuild	0.03
Texas North Tarrant	$82.47	Rebuild	0.24

Sources: Authors' calculations based on data from Florida Department of Transportation (2010a; 2010b, section 3.3; 2010c, tables 3.2 and 3.3); Alameda County Transportation Commission (2013, tables 6, 44 and appendix 9.5 tables 60-69); Washington State Department of Transportation (2016); US Department of Transportation (2013, tables A-6, A-7, A-23 and A-24); and unpublished data supplied by Cintra US.

Given the uncertainty about the value of travel time and reliability we test the sensitivity of our benefit-cost ratios to three assumptions:

- The base case is $17 per hour, a figure consistent with current research on the value of commute time.
- The second case is $34 per hour and assumes that the value of improved reliability is comparable to the value of reduced travel times on highways that are candidates for HOV lanes. An equal weight is justified because the most careful study of the value motorists place on reliability (based on an analysis of the choices of SR-91 users) reports that the value per hour of improved reliability is comparable to the value per hour of

travel time savings.[3] An equal weight is also consistent with the surveys showing that managed lane users in Texas overestimate the time savings by a factor of two.

- The final case is $70 per hour and is justified as consistent with the evidence that the value of time varies considerably and is higher among managed lane users. Seventy dollars is also consistent with the higher implicit values of time reported in Table 5.1.

The role of toll revenues

Tolls are considered neither a benefit nor a cost in benefit-cost analyses of highways but rather a transfer from the motorists who pay them to the agencies that collect and use them. Tolls reflect benefits, however, in as much as a motorist using a tolled facility must enjoy enough benefits to make it worth his or her while to pay the toll. But if those benefits take the form of savings in time or reliability then including both tolls collected and travel time saved in the analysis would double-count the benefits motorists enjoy. Because the willingness to pay tolls reflects time savings, however, toll revenues can provide a check on the accuracy of the other benefit estimates. In particular, the estimated value of the time and reliability savings should be greater than the toll revenues collected.

Our estimates of time savings benefits do reasonably well by this standard, but cast further doubt that the value of time savings is as low as $17 per hour. A value of time of $70 per hour gives the best results, which is not surprising given that the implicit value of time is around that level for many of our cases. As Table 5.2 shows, at $70 the estimated benefits to managed lane users exceed toll revenues in four of the six cases for which we have the needed data and are very close on the remaining two. At $17 per hour, however, estimated benefits on managed lanes exceed tolls charged in only two of six cases: Florida's I-95 Express and Washington's I-405. Florida in particular charges very low tolls relative to the estimated value of the services provided. But if $17 per hour is correct then the users of managed lanes on the other four facilities are irrational in that they are paying more in tolls than they benefit in time savings.

Other excluded benefits

Several other benefits of managed lanes are left out of our simplified benefit-cost analyses, either for lack of consistent data or because they are more modest and offsetting to some degree. Many managed lane systems are used by public transit buses as well as private cars. The benefits to transit users are ignored, however, because transit riders are usually greatly outnumbered by the motorists. To be consistent, costs of any transit facilities, vehicles or operations are also excluded.

[3] Small and colleagues (2005, p. 1378) estimate that users of SR-91 in California value savings in travel times and reliability both at around $20 per hour where reliability is measured by the extra commuting time the traveler endures to make sure that he doesn't arrive 10 minutes or more early or late. The reliability savings are about half of the travel time savings on SR-91, so that reliability is about one-third of total travel and reliability savings.

Table 5.2: Comparison of Toll Revenues with Estimated User Time Savings

Case	Toll revenues			Value of time saved per year in managed lanes in peak($000)		
	Toll /vehicle	Vehicles/day in peak	Tolls/year peak ($000)	At $17/hour	At $34/hour	At $70/hour
Florida I-95 phase 1	$1.80	14,880	$6,712	$59,075	$118,150	$276,376
California I-680 south	$3.09	1,275	$985	$256	$512	$1,055
Georgia I-85	n.a.					
Washington I-405	$2.40	11,097	$6,658	$7,355	$14,709	$30,283
Minnesota I-35W	$1.19	12,117	$3,605	$770	$1,540	$3,171
Texas LBJ			$32,391	$7,065	$14,130	$29,012
Texas North Tarrant			$37,638	$29,147	$58,294	$102,018

Sources: see sources for table 5.1.

Safety may be affected as well, although it is unclear whether on net it is likely to be improved (perhaps because of the reduction in stop-and-go traffic) or reduced (perhaps because of weaving across the general purpose lanes to access or exit the managed lanes). A study of Minnesota's I-35W managed lanes was an outlier in reporting 9.4 percent fewer fatal and injury crashes and 25.6 percent fewer property damage crashes in the first six months of operation. Assuming the savings were sustained, the dollar value of the safety benefits were estimated to be roughly two and one-half times the value of the user time savings. However, the authors of the Minnesota study acknowledged that six months was a short time to identify changes in rates for relatively rare events like traffic fatalities and recommended that the safety record be monitored further (US DOT 2013, pp. 5-23, 5-24 and J-16).

Whether to expect vehicle operating costs and emissions to decline or not is also unclear since they may fall with the reduction of stop-and-go traffic or increase if the managed lanes encourage more travel. But where the benefits are estimated they are relatively small. In the I-35W study, for example, the savings in fuel and emissions were only four percent of the user travel time savings (US DOT 2013, p. J-16).

Construction and operating costs

The data on construction and operating costs are drawn from the implementing agency. Several of the managed lanes studied under evaluation were parts of larger programs and measures to control congestion, such as improvements to public transit and parking policies, and an effort was made to exclude the costs of these other measures.

The most difficult and important cost allocation issues arise with projects that involve the rebuilding of general purpose lanes as well as the construction of new managed lanes, such as I-35W in Minneapolis and the LBJ and North Tarrant expressways in Dallas-Fort Worth. In all three cases, the original expressways were reportedly reaching the end of their lives and would have had to be rebuilt soon. One could argue that in such cases the managed lanes should not be charged with the cost of rebuilding the original general purpose lanes, or, at most, should only be responsible for the costs of rebuilding the lanes a little earlier than they would have been otherwise. The issue is further complicated by the fact that the original lanes were rebuilt with design standards that were updated and improved to the point where the operator of the Texas projects claims that each lane can carry 20 percent more throughput in the peak period (Sanchez 2016, slide 12). If so, then part of the time savings observed should be attributed to the rebuilding of the original lanes rather than the construction of the managed lanes. Finally, if the costs of rebuilding are included one should include the benefits of rebuilding as well, and these benefits must be enormous since the closure of these expressways would presumably create gridlock in the corridors they serve.

There is no easy answer to this cost and benefit allocation problem. To cope with this issue, we report the results of two sets of assumptions. The base case attempts to separate the rebuilding from the managed lanes by charging the managed lanes with only 40 percent of the construction costs, roughly the proportion of managed to total lane miles on the two Texas projects. The alternative assumes that the general purpose lanes would not have to be rebuilt were it not for the desire to fit new managed lanes in the right of way and thus charges the costs of both the building the new managed lanes and the rebuilding of the existing general-purpose lanes to the project.

Asset life and discounting

To simplify matters, we assume that all assets have a life of 30 years, a compromise figure which is very high for toll collection equipment, a little high for pavement and very low for structures and base.

Costs and benefits are discounted at a rate of seven percent per year in real terms, the discount rate recommended by the U.S. Office of Management and Budget. Discount rates of three percent are also tested as sensitivity analyses. Costs and benefits are presented both as present values for the 30-year life of the managed lanes and as amortized annual values for a typical year during the 30-year life.

In sum, the key uncertainties are the hours of travel time saved and the value to place on each hour. We underestimate the hours saved by assuming that all savings occur during the weekday peak periods and that there is no traffic ramp up after the first year, but, as we shall see, relaxing those assumptions does not change the benefit-cost ratios greatly. We underestimate the value of hours saved by using a base case of $17 per hour that ignores reliability benefits and the heterogeneity of users and, as we shall also see, relaxing this assumption has a more serious impact on our results.

6. Results and Sensitivity Analyses

Conversions

One might expect that conversions of HOV lanes to HOT lanes would have a high benefit-cost ratio. After all, the opportunity cost of the conversion is typically only a poorly performing HOV lane and the construction cost of the conversion is typically modest as well. However, the benefit-cost ratios of our three conversion cases range from 3.96 for Florida's I-95 express lanes to 0.23 for California's I-680 and -0.56 for Georgia's I-85 project. As expected, the per lane-mile capital costs of the conversions were rather modest, ranging from $3.8 million (Georgia I-85) and $5.2 million (California I-680) to $9.6 million (Florida I-95). But with the exception of Florida, the time savings on both the general-purpose and the managed lanes were relatively trivial, typically less than a minute or two on a ten to fifteen-minute trip. In short, it appears that the circumstances that lead to a poorly performing HOV lane may also result in a poorly performing HOT lane.

Florida's I-95 Express Lanes: The extraordinary performance of Florida's 95 Express reflects reported average peak travel speeds ranging from 15 to 20 mph the year before opening to 41 to 64 mph the year after (Florida Department of Transportation 2011, p. 7). As shown in Table 6-1, this results in average savings 7.5 to 8.8 minutes on trips that formerly took 14 to 17 minutes. The Florida Department of Transportation (2014) estimated a benefit-cost ratio of 6.97 for 95 Express largely because they used a higher value of travel time saved and higher average vehicle occupancy than assumed in our estimates. The study also included safety and fuel savings benefits, although they were relatively small.

California's I-680 southbound Express Lanes: Our analysis of California's I-680 southbound Express Lanes, summarized in Table 6-2, is based on comparing traffic volumes and speeds with 2008 with those in 2012, years when employment levels and gas prices in Alameda County were relatively similar.[4] The I-680 experience is one of very small time savings leading to very modest changes in lane volumes. Motorists who continued to drive in the general purpose lanes saved only 0.9 minutes (from 13.5 to 12.6 minutes) while those who stayed in the managed lanes saved only 0.3 minutes (from 11.5 to 11.2 minutes). The managed lanes were only 1.4 minutes faster than the general purpose lanes, too small a savings to encourage switching. The benefit-cost ratio for the base case is only 0.23 although it approaches or exceeds one if the value of travel time saved is $70 per hour.

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[4] The southern section of the southbound lane is thought to have lost traffic in 2009-2010 to the improvement of a nearby intersection which, if true would cause the simple 2009-2012 comparison to overstate the benefits of the conversion to HOT (Alameda County Transportation Commission, 2013, pp. ES 9-12)

Table 6-1: Florida's I-95 Express Lanes Performance Summary

TRAFFIC IN PEAK	General purpose lanes			Managed lanes		
	Before	After	Change	Before	After	Change
Vehicles/day in peak	67,417	71,316	3,899	19,741	25,926	6,997
Time, minutes/vehicle	17.1	8.3	(8.8)	14.5	7.0	(7.5)
BENEFITS	General	Managed	Total			
Minutes saved/day	576,544	257,461	834,005			
Time saved $000/yr	40,838	18,237	59,075			
	Present value	Typical year				
Total benefits $000	733,069	59,075				
COSTS $000						
Investment	(132,000)	(10,637)				
Operating	(53,052)	(4,275)				
Total	(185,052)	(14,912)				
NET BENEFIT	548,017	44,163				
B/C RATIO	7% (base case)	3%				
$17/hour (base case)	3.96	5.37				
$34/hour	7.92	10.73				
$70/hour	16.31	22.09				

Table 6-2: California's I-680 Southbound Express Lanes Performance Summary

TRAFFIC IN PEAK	General purpose lanes			Managed lanes		
	Before	After	Change	Before	After	Change
Vehicles/day in peak	21,316	22,911	1,595	3,095	3192	98
Time, minutes/vehicle	13.5	12.6	(0.9)	11.5	11.2	(0.3)
BENEFITS	General	Managed	Total			
Minutes saved/day	20,908	3,806	24,714			
Time saved $000/yr	1,481	270	1,751			
	Present value	Typical year				
Total benefits $000	21,723	1,751				
COSTS $000						
Investment	(36,634)	(2,952)				
Operating	(55,841)	(4,500)				
Total	(92,475)	(7,452)				
NET BENEFIT	(70,752)	(5,702)				
B/C RATIO	7% (base case)	3%				
$17/hour (base case)	0.23	0.27				
$34/hour	0.47	0.55				
$70/hour	0.97	1.13				

Georgia's I-85 Express Lanes: Georgia's I-85 Express Lanes are estimated to have a benefit-cost ratio of negative 0.56, which means the users collectively lost rather than benefited and that their losses were 0.56 times the construction and operating costs of the lane conversion. Motorists traveling in the managed lanes in the peak period and peak direction saw their travel time decline by only 0.4 minutes (from 14.2 to 13.8 minutes) as toll paying SOVs replaced most of the HOV2s that had used the lanes previously. Meanwhile, motorists in the general-purpose lanes, whose vehicles out-numbered the vehicles in the managed lanes by almost ten to one, saw times increase by 1.3 minutes (from 16.1 to 17.4 minutes). The SOVs who switched to the managed lane saved 2.3 minutes (16.1 minus 13.8) but the HOV2s who they replaced lost 3.2 minutes (14.2 minus 17.4). Moreover, volumes decreased on both the managed and general purpose lanes. The decrease in the general-purpose lanes is inconsistent with the reduction in travel times in those lanes; this suggests either measurement error or that some other factors were suppressing traffic besides the conversion, possibly the financial crisis, although it had been underway for two years before. If one blames all of the travel time losses in the general-purpose lanes to other factors, then the conversion has a benefit-cost ratio of 0.11, much better but hardly encouraging.

Table 6-3: Georgia's I-85 Express Lanes Performance Summary

TRAFFIC IN PEAK	General purpose lanes			Managed lanes		
	Before	After	Change	Before	After	Change
Vehicles/day in peak	71,496	68,802	(2,694)	9,429	8,608	(821)
Time, minutes/vehicle	16.1	17.4	1.3	14.2	13.8	(0.4)
BENEFITS	General	Managed	Total			
Minutes saved/day	(95,029)	15,866	(79,163)			
Time saved $000/yr	(6,731)	1,124	(5,607)			
	Present value	Typical year				
Total benefits $000	(69,582)	(5,607)				
COSTS $000						
Investment	(52,768)	(4,254)				
Operating	(71,839)	(5,789)				
Total	(124,625)	(10,043)				
NET BENEFIT	(194,207)	(15,650)				
B/C RATIO	7% (base case)	3%				
$17/hour (base case)	-0.56	-0.66				
$34/hour	-1.12	-1.32				
$70/hour	-2.30	-2.72				

Mixed projects

Washington's I-405 Express Lanes: The evaluations of the Washington I-405 and Minnesota I-35W projects are complicated by the fact that they involve mixed approaches. The simpler of the two is Washington I-405 which is dominated by conversions but includes some new lanes as well. Our analysis, summarized in Table 6-4, suggests a benefit-cost ratio of only 0.29 based on a comparison of performance just before the lanes opened in the fourth quarter of 2014 with performance a year later. The capital costs per lane mile were rather modest, but so were the changes in travel times and traffic volumes. Travel time improvements in both the managed and general-purpose lanes amounted to only 3.1 to 2.3 minutes respectively, on trips that took between 16 and 24 minutes. Motorists who switched from general-purpose lanes to managed lanes once tolling began saved 8.1 minutes (24.2-15.9). But this was a net gain of only 5.8 minutes (8.1-2.3) given that speeds were increasing in the general-purpose lanes anyway, and this savings was apparently not enough to induce many people to pay the toll.

Table 6-4: Washington's I-405 Express Lanes Performance Summary

TRAFFIC IN PEAK	General purpose lanes			Managed lanes		
	Before	After	Change	Before	After	Change
Vehicles/day in peak	50,715	51,671	956	11,354	14,422	3,068
Time, minutes/vehicle	24.2	21.9	(2.3)	19.0	15.9	(3.1)
BENEFITS	General	Managed	Total			
Minutes saved/day	109,060	106,303	215,363			
Time saved $000/yr	7,725	7,530	15,255			
	Present value	Typical year				
Total benefits $000	189,289	15,255				
COSTS $000						
Investment	(155,500)	(12,531)				
Operating	(490,778)	(39,550)				
Total	(646,278)	(52,081)				
NET BENEFIT	(456,979)	(36,826)				
B/C RATIO	7% (base case)	3%				
$17/hour (base case)	0.29	0.32				
$34/hour	0.59	0.64				
$70/hour	1.21	1.32				

Minnesota's I-35W Express Lanes: As explained earlier, the I-35W project essentially consists of three projects in sequence on the southern approaches to downtown Minneapolis: the conversion of an existing HOV lane into a HOT lane, the rebuilding of an existing four-lane Crosstown Commons expressway with an added HOT Lane, and, finally, the creation of a new HOT Lane on the shoulders of the existing center city expressway. Time savings are considerable despite large increases in traffic volumes, particularly on Crosstown Commons section. During the morning inbound peak, motorists who stay in the general-purpose lanes or who switch from the general-purpose to the managed lanes save roughly 5 minutes, slightly more than half on the southernmost HOT lanes and a half on the Crosstown Commons while time is lost on the PDSL. Motorists traveling during the evening outbound peak save slightly less than 4 minutes, again a half on the Crosstown Commons and a half on the southernmost HOT lanes. These figures are similar to those reported elsewhere (US DOT 2015, p. 13)

Overall, the project has a respectable benefit-cost ratio of 1.32. It is difficult to separate the contributions of the different segments, especially since the several HOT lanes are in sequence so that if one were missing the traffic would presumably backup in the system. Nevertheless, if one ignores the potential to form bottlenecks and simply allocates the capital costs and the travel time savings to the different segments, then it appears as if both the converted lanes to the south and the new lanes in Crosstown Commons are contributing roughly equally to the system performance. If the Crosstown Commons is considered separately, for example, the benefit-cost ratio is 1.56, virtually the same as for the system as a whole.

Table 6-5: Minnesota's I-35W Express Lanes Performance Summary

TRAFFIC IN PEAK	General purpose lanes			Managed lanes		
	Before	After	Change	Before	After	Change
Vehicles/day in peak	33,197	42,051	8,854	-	4,656	-
Time, minutes/vehicle	18.6	14.9	(3.8)	-	13.7	-
BENEFITS	General	Managed	Total			
Minutes saved/day	158,729	10,874	169,602			
Time saved $000/yr	11,243	770	12,013			
	Present value	Typical year				
Total benefits $000	149,076	12,013				
COSTS $000						
Investment	(96,616)	(7,786)				
Operating	(10,381)	(837)				
Total	(106,997)	(8,623)				
NET BENEFIT	42,078	3,391				
B/C RATIO	7% (base case)	3%				
$17/hour (base case)	1.32	2.08				
$34/hour	2.79	4.17				
$70/hour	5.74	8.58				

North Tarrant and LBJ Express Lanes: The North Tarrant Expressway and LBJ Expressway projects are very similar in that they both are 13.3 miles long, cost in excess of $2 billion and involve a mix, depending on the segment, of the construction of 2 to 3 new managed lanes, the rebuilding of 3 to 4 general purpose lanes and the construction of 2 frontage lanes in each direction. The North Tarrant was fully operational in October 2014 and the LBJ in September 2015. 2010 is used as the before year and 2016 as the after year because of extensive construction disruption in the years before opening. As noted earlier, the base case assumes that the general-purpose lanes would have had to be rebuilt anyway and thus assigns only 40 percent of construction and operating costs to the managed lanes.

One potentially important difference between the North Tarrant and LBJ managed lanes and the other five cases, however, is that the former connect two metropolitan centers—Dallas and Fort Worth—rather than one and thus are heavily used during the midday as well as during peak commuting directions and hours. To see how this might affect the results, we estimated benefit-cost ratios for a 12-hour day (6 am-6 pm) as well as for the six peak hours (6-9 am and 4-7 pm). On the North Tarrant expressway the six-hour benefit-cost ratio is 0.24 or roughly two-thirds to one-half of the 12-hour benefit-cost ratio of 0.41.[5] Lacking twelve-hour volumes and speeds from most of our sample, we can't rule out the possibility that our focus on the six peak hours significantly affects the benefit-cost ratios on some types of HOT lanes.

The North Tarrant expressway consists of two connecting East-West segments and their combined daily traffic during the six peak hours increased by slightly more than half from 97,255 to 149,228 vehicles with two-thirds of the increase on the managed lanes (33,390 vehicles) and one-third on the general-purpose lanes (18,633 vehicles). These shifts in traffic were stimulated by savings of 4 to 6 minutes on trips across the two segments that previously required 14 to 18 minutes. Eastbound in the afternoon peak, for example, travel times dropped from 16.7 to 12.7 minutes on the general-purpose lanes and to only 10.7 minutes on the managed lanes for a savings of 4 minutes for motorists who stayed in the general lanes and 6 minutes for those who switched to the managed lanes. The resulting benefits were enough to offset roughly half of the operating expenses and make a small contribution to the considerable capital expenses.

The LBJ has performed much more poorly with six-hour and twelve-hour benefit-cost ratios of 0.3 and 0.004 respectively.[6] The LBJ has four general purpose lanes instead of three and is divided in three segments: a North-South segment connecting with two East-West segments. During the six peak hours travel on all three segments increased by only one eighth (from 256,050 to 288,676 vehicles) with the managed lanes attracting roughly a fifth of the users (56,335 vehicles) while the general purpose lanes actually lost users, falling to four-fifths share (232,341 vehicles).

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[5] On the North Tarrant the annual time savings increase from $18,165 thousand for the six peak hours to $30,878 thousand for the 12 hour day. Given costs of $75,693 thousand the benefit-cost ratios are 0.24 and 0.41.

[6] On the LBJ the annual time savings fall from $2,814 thousand for the six peak hours to $406 thousand for the 12 hour day. The savings fall because travel times increase rather than fall in many segments during the midday. Given costs of $91,810 thousand the benefit-cost ratios are 0.08 and 0.004.

Table 6-6: North Tarrant Expressway Performance Summary

TRAFFIC IN PEAK	General purpose lanes			Managed lanes		
	Before	After	Change	Before	After	Change
Vehicles/day in peak	48,305	57,807	9,502	-	16,762	-
Time, minutes/vehicle	8.2	6.8	(1.4)	-	5.4	-
BENEFITS	General	Managed	Total			
Minutes saved/day	156,701	99,744	256,446			
Time saved $000/yr	11,100	7,065	18,165			
	Present value	Typical year				
Total benefits $000	225,409	18,165				
COSTS $000						
Investment	(840,000)	(67,693)				
Operating	(99,272)	(8,000)				
Total	(939,272)	(75,693)				
NET BENEFIT	(713,863)	(57,528)				
B/C RATIO	7% (base case)	3%				
$17/hour (base case)	0.24	0.36				
$34/hour	0.48	0.71				
$70/hour	0.99	1.47				

Table 6-7: LBJ Expressway Performance Summary

TRAFFIC IN PEAK	General purpose lanes			Managed lanes		
	Before	After	Change	Before	After	Change
Vehicles/day in peak	85,489	78,450	(7,039)	-	20.107	-
Time, minutes/vehicle	5.3	5.7	0.3	-	3.9	-
BENEFITS	General	Managed	Total			
Minutes saved/day	(69,577)	109,302	39,725			
Time saved $000/yr	(4,928)	7,742	2,814			
	Present value	Typical year				
Total benefits $000	34,917	2,814				
COSTS $000						
Investment	(1,040,000)	(83,810)				
Operating	(99,272)	(8,000)				
Total	(1,139,272)	(91,810)				
NET BENEFIT	(1,104,335)	(88,996)				
B/C RATIO	7% (base case)	3%				
$17/hour (base case)	0.03	0.05				
$34/hour	0.06	0.09				
$70/hour	0.13	0.19				

These disappointing results stem from the fact that the weighted average time savings per segment on the LBJ are lower than those of the North Tarrant expressway (compare Tables 6-6 and 6-7). The LBJ's third segment performs particularly poorly with travel times in the general purpose lanes during the PM peak actually increasing by 2.7 minutes westbound and 1.6 minutes eastbound.

The operators of the LBJ blame construction by the Texas Department of Transportation on another expressway that connects with the third segment for creating backups on the LBJ. If so the performance should improve when the other expressway is finished. Sensitivity analyses in which the segments and times when there are time losses are excluded suggest that the LBJ may not perform as well as the North Tarrant once the backups are eliminated, however.[7]

Sensitivity Analyses

Sensitivity analyses, summarized in Table 6-8 and Appendix C, shows that the benefit-cost ratios are far more sensitive to the value of time saved and the proportion of costs that are assigned to managed lanes than to the discount rate. Assuming $17 per vehicle hour and 7% only two of the seven projects have a benefit cost-ratio above 1.0 (Florida I-95 and Minnesota I-35W). Increasing the value of time to $70 vehicle hour three more cases have benefit cost-ratios of 1.0 or very close to 1.0. Keeping the value of time at $70 but dropping the discount rate to 3% has no effect on the number of cases that have a benefit-cost ratio of one or more.

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[7] Ignoring the segments and hours when travel times increase, instead of decrease raises the user time savings for a 12-hour day from $406 thousand to $7,742 thousand. With costs of $91,810 thousand, the benefit-cost ratio increases from 0.004 to 0.08. (In Table 6-8 compare the optimistic and base cases if only 40 percent of the costs are assigned to managed lanes.)

Table 6-8: Summary of Estimates of B/C Ratios

Project	Benefit Scenario	Cost Scenario	Scenarios (VOT, Discount Rate)					
			$17, 7%	*$17, 3%*	*$34, 7%*	*$34, 3%*	*$70, 7%*	*$70, 3%*
1. Florida's I-95 Express Lanes	*Base Case*	*100% of Total*	3.96	5.34	7.92	10.73	16.31	22.09
2. California's I-680 Southbound Express Lanes	*Base Case*	*100% of Total*	0.23	0.27	0.47	0.55	0.97	1.13
3. Georgia's I-85 Express Lanes	*Optimistic Case*	*100% of Total*	0.11	0.13	0.22	0.26	0.46	0.55
	Base Case	*100% of Total*	-0.56	-0.66	-1.12	-1.32	-2.30	-2.72
4. Washington's I-405 Express Lanes	*Base Case*	*100% of Total*	0.29	0.32	0.59	0.64	1.21	1.32
5. Minnesota's I-35W Express Lanes	*Base Case*	*25% of Crosstown*	1.32	2.08	2.79	4.17	5.74	8.58
	Base Case	*100% of Total*	0.54	0.83	1.07	1.66	2.21	3.41
6. Texas' North Tarrant Express Lanes	*Base Case*	*40% of Total*	0.24	0.36	0.48	0.71	0.99	1.47
	Base Case	*100% of Total*	0.10	0.14	0.19	0.29	0.40	0.59
7. Texas' LBJ Express Lanes	*Base Case*	*40% of Total*	0.03	0.05	0.06	0.09	0.13	0.19
	Optimistic Case	*40% of Total*	0.08	0.13	0.17	0.25	0.35	0.52
	Base Case	*100% of Total*	0.01	0.02	0.02	0.04	0.05	0.08
	Optimistic Case	*100% of Total*	0.03	0.05	0.07	0.10	0.14	0.21

7. Conclusions

Judging at least from the rate of adoption, toll-managed lanes have been a political success. They have rapidly spread relatively rapidly from a half-dozen states--including California, Florida and Texas--that were suffering from growing traffic congestion caused by a combination of rapid population and income growth and popular resistance to increased taxes. Toll-managed lanes were seen by public officials as a way of squeezing out more capacity from existing expressway lanes and/or financing the construction of new expressway lanes in congested urban areas.

It is conceivable, although hardly certain, that managed lanes are as socially worthwhile as they are politically successful. Our base case scenarios are rather discouraging in that five of the seven projects studied here have benefit-cost ratios that are below one, well below in most cases. But a number of key assumptions made in the base case cause us to underestimate the benefits of toll managed lanes. For example, the assumption that all the time savings would occur during the weekday peak hours understates the hours saved by as much as one-third in the case of one expressway. And the assumption that the effect of a managed lane on traffic will be apparent in the first year of operation likely further understates traffic attributable to the managed lanes, although not necessarily the hours saved.

But the most important way which the base case probably understates the benefits of managed lanes is by understating the value of an hour of travel time saved. Many transportation planners believe that motorists care about the reliability of travel time as much as they care about average travel time. And there is evidence that motorists vary in the value they place on time and reliability and that those who value time and reliability the most use managed lanes. Our base case assumption of $17 per hour excludes any benefit for reliability and does not recognize any variation in value or any sorting by value between managed and general-purpose lanes. Doubling the value to $34 per hour to recognize reliability is not enough to significantly affect the number of our cases with benefit-cost ratios above one. But if one could assume a value closer to $70 an hour on the basis of heterogeneity and sorting, then five out of seven projects have benefit-cost ratios of better than, or very close to, one. The two whose benefit-cost ratios are still less than one are either very poorly designed (Georgia I-85) or suffering from congestion on connecting highways (LBJ Expressway).

it is hazardous to generalize about the characteristics of managed lane facilities that are most desirable from a sample of only seven projects. Nevertheless the most important, and obvious, criteria for success is a noticeably large time savings for the users of the toll-managed lane--perhaps five minutes or so on a trip of 15—and a smaller but still significant time savings for the motorists who remain in the general purpose lanes.

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APPENDICES

APPENDIX A: HOT Lanes Opened as of 2016

U.S. TOLLED MANAGED LANE PROJECTS | OPERATIONAL

NAME	STATE	FACILITY	CONSTRUCTION TYPE	NEW FACILITY/ EXTENSION	YEAR OPENED	EXEMPTION	ORIGINAL OPERATOR	DELIVERY METHOD	LENGTH (MILES)	INVESTMENT ($M)
SR 91 Express Lanes	CA	SR-91	New Lane	New Facility	1995	HOV 3+	Private	P3	10	$135
I-15 Express Lanes	CA	I-15	Conversion/New	New Facility	1996	HOV 2+	Public	Phased	20	$1,400
MnPass Express Lanes	MN	I-394	Conversion	New Facility	2005	HOV 2+	Public	DB / ITS hybrid	22	$10
I-25 HOV Express Lanes	CO	I-25	New Lane	New Facility	2006	HOV 2+	Public		7	$9
SR-167 HOT Lanes	WA	SR-167	Conversion	New Facility	2008	HOV 2+	Public	DBB	9	$18
95 Express	FL	I-95	Conversion/New	New Facility	2008	HOV 3+	Public	DBF		$132
Katy Managed Lanes	TX	I-10/US 59/US 290	Conversion/New	New Facility	2009	HOV 2+	Public	DBB	12	$266
MnPass Express Lanes	MN	I-35W	Rebuild/Conversion/New	New Facility	2009	HOV 2+	Public	DB / DBB	16 S, 14 N	$66 / $37
95 Express	FL	I-95	Conversion/New	Extension	2010	HOV 3+	Public	DBF		
I-680 Southbound Express Lanes	CA	I-680	Conversion	New Facility	2010	HOV 2+	Public	DBB	13.7	$26
I-15 Express Lanes	NV	I-15	New Lane	New Facility	2010	HOV 2+	Public			
I-15 Express Lanes	UT	I-15	Rebuild/New	New Facility	2010	HOV 2+	Public	DBM		$16.40
I-85 Express Lanes	GA	I-85	Conversion	New Facility	2011	HOV 3+	Public	DBB	15.5	$60
I-15 Express Lanes	CA	I-15	Conversion/New	Extension	2012	HOV 2+	Public	Phased	20	
I-15 Express Lanes	UT	I-15	Rebuild/New	Extension	2012	HOV 2+	Public	DBM		$16.40
SR-237 / I-880 Express Lanes	CA	SR 237 / I-880	Conversion	New Facility	2012	HOV 2+	Public	DBB	6.6 W, 4.5 E	$5.60
I-110 MetroExpress Lanes	CA	I-110	Conversion	New Facility	2012	HOV 2+	Public	DBOM	10.8	
Metro HOT Lanes (IH 45 South Gulf)	TX	I-45	Conversion	New Facility	2012	HOV 2+	Public	DB	15.5	
Metro HOT Lanes (IH 45 North Freeway)	TX	I-45	Conversion	Extension	2012	HOV 2+	Public	DB	20.6	
Metro HOT Lanes	TX	US 290	Conversion	New Facility	2012	HOV 2+	Public	DBB	14	
Metro HOT Lanes (Southwest Freeway)	TX	US 59	Conversion	Extension	2012	HOV 2+	Public	DB	23.3	
495 Express Lanes	VA	I-495	Rebuild/New	New Facility	2012	HOV 3+	Private	DBFOM-Toll	14	$2,006
US 36 Express Lanes	CO	US 36	Rebuild/New	New Facility	2012	HOV 2+	Public			$497
I-10 Metro ExpressLanes	CA	I-10	Conversion	New Facility	2013	HOV 2+	Public	DBOM	14.2	$79
595 Express	FL	I-595	New Lane	New Facility	2014	ETL	Public	DBFOM-AP		
I-95 Express Toll Lanes*	MD	I-95	Rebuild/New	New Facility	2014	ETL	Public	DBB	7	$103
NTE TEXPress Lanes	TX	I-820	New Lane	New Facility	2014	HOV 2+ disc	Private	DBFOM-Toll	13.1	$2,100
Metro HOT Lanes (North Eastex Freeway)	TX	US 59	Conversion	New Facility	2014	HOV 2+	Public	DB	20	
95 Express Lanes*	VA	I-95	Rebuild/New	New Facility	2014	HOV 3+	Private			
I-70 Mountain	CO	I-70	Conversion	New Facility	2015	ETL	Public		13	
LBJ TEXPress Lanes	TX	I-635/I-35E	New Lane	New Facility	2015	HOV 2+ disc	Private	DBFOM-Toll	13.3	$2,600
DFW Conntector TEXPress Lanes	TX	SH 114/SH 121	New/Rebuild	New Facility	2015	HOV 2+ disc	Public		4	
95 Express	FL	I-95	Conversion/New	Extension	2016	HOV 3+	Public	DBF	22	
I-15 Express Lanes	UT	I-15	Rebuild/New	Extension	2016	HOV 2+	Public	DBM	35	$16.40
US 36 Express Lanes	CO	US 36	Rebuild/New	Extension	2016	HOV 2+	Public		18	
MnPass Express Lanes	MN	I-35E	Conversion/New	Extension	2016	HOV 2+	Public			
I-580 Express Lanes	CA	I-580	Conversion	New Facility	2016	HOV 2+3+	Public			
I-30 TEXPress Lanes	TX	I-30	New Lane	New Facility	2016	HOV 2+ disc	Private		9	
I-405 Express Toll Lanes	WA	I-405	Rebuild/New	New Facility	2016	HOV 3+	Public		17	

APPENDIX B: Pioneer States in HOT Lane Development

CALIFORNIA

California is home to the United States' first managed toll lanes on SR-91, which opened in 1995. The state has since built over 200 roadway miles of managed toll lanes in the state's three largest metropolitan areas. The first project was built in response to southern California's rapid population growth, and resulting congestion levels, in the 1980s. The California Department of Transportation (Caltrans) proposed constructing HOV lanes on the congested freeway, SR-91, which connected, at the time, rapidly growing areas of Riverside and Orange Counties (Gómez-Ibáñez and Meyer, 1993). The project was stalled, however, due to controversy over HOV lanes, and its funding was eventually redirected to other projects. (USDOT, 2014)

In 1989, the California legislature enacted AB 680, which authorized Caltrans to enter into agreements with private entities for the construction of up to four highway demonstration projects throughout the state, and required that at least one project be located in southern California and one project in northern California. The bill included provisions to allow private entities to charge tolls for the privately constructed facilities, and to allow private entities to identify specific highway projects where a privately constructed and operated facility would perform well. As a result, private investors organized the California Private Transportation Company (CPTC) which proposed to Caltrans to construct the planned SR-91 HOV lanes as express toll lanes under the new legislation. CPTC and Caltrans negotiated a build-transfer-operate franchise agreement for the project, which was awarded in December 1990. Construction of the new lanes began in 1993 and the new facility opened to traffic in December 1995. (USDOT, 2014) Following the success of SR-91, San Diego Association of Governments (SANDAG) converted HOV facilities on Interstate 15 to HOT lanes in 1996, which became the second HOT lane project in the United States.

California's third HOT lane project was another of the projects selected under the AB 680 demonstration program, and the only selected project in northern California (Gómez-Ibáñez and Meyer, 1993). This 85-mile HOT lane project, which opened in 2007, connects south San Francisco with south Sacramento along I-680. Between 2005 and 2012, both SANDAG and OCTA extended HOT facilities on both SR-91 and I-15. With congestion continuing to increase throughout California's urban regions and with the overall success of HOT lanes, Caltrans adopted its HOV/Express Lane Business Plan in 2009, to provide local transportation agencies, "the direction and flexibility needed to aggressively initiate innovative congestion management strategies." This plan, which was developed in collaboration with regional transit authorities, FHWA, and California Highway Patrol (CHP), outlined a framework for 2009 through 2011 to guide the development of HOV lanes and tolled managed lanes throughout the state. Specifically, the business plan provided direction, "on those aspects of HOV and express lane development and operations that can and should be addressed at a state level to increase California's ability to manage congestion with HOV and express lanes" (Caltrans, 2009). This business plan differed from the plans of other states, such as Minnesota and Colorado, in that it detailed a framework for providing regional agencies with the support and flexibility they need to pursue congestion management projects and private partnerships, rather than specifically providing a blueprint for target conversion facilities. In May 2015, Caltrans issued a directive stating that all districts, along with their regional transit agencies, that currently operate or expect to operate toll-managed lane facilities must develop a Managed Lanes System Plan, which must be updated every two years. Of the five states discussed in this appendix, only California requires its districts to prepare planning documents. As of 2014, Caltrans reported that there are 1700 roadway miles of HOT lanes proposed or planned by both Caltrans and regional agencies (Rouse, 2015). As of 2017, there were 50 miles of HOT lanes under construction.

Timeline

- 1989: California State Assembly passes Bill No. 680.
- 1993: Construction of HOT lanes began on SR-91
- 1995: First managed toll lane opens in the United States on SR-91 in Orange County.
- 1997: Managed toll lane opens on I-15 in San Diego.
- 2002: Orange County Transportation Authority (OCTA) purchased the lease from CPTC for $208 million in order to address the non-compete clause and build additional general purpose lanes.
- 2007: I-680 managed toll lane project opens in northern California.
- 2009: Caltrans launched its HOV/Express Lane Business Plan detailing a framework for how Caltrans, regional transit agencies, FHWA and CHP can collaborate to prepare for future managed lane development.
- 2015: Caltrans issued a directive stating that each district that operates or intends to operate a tolled managed lane project must develop and update a regional plan.

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TEXAS

Texas opened its first managed toll lane project in Houston in 2009. Since then, it has constructed over 130 miles of HOT lanes in the Houston, Dallas - Fort Worth, and Austin metropolitan regions, with another 20 plus miles under construction. By the early 2000s, Texas faced increasing highway maintenance and construction needs as its metropolitan populations grew while the overall revenue from the state's gas tax declined due to inflation and improving fuel efficiency of cars (Williamson, 2010). Raising the gas tax was not a politically viable option for Texas, so it sought alternative methods for delivering needed highway improvement projects, including both reconstruction and expansion of existing highways and construction of new highways.

In 2000, the Texas Transportation Institute, with support from the Texas Department of Transportation (TxDOT) and FHWA, launched a study to provide preliminary guidance on how to plan and operate managed lanes in Texas. In 2003, the legislature passed several bills that authorized Texas transportation agencies to create HOT lanes and to pursue alternative financing mechanisms (Kuhn, 2005). Most notably, House Bill 3588 enabled transportation agencies to use new financing mechanisms aimed at accelerating project delivery and generating additional cash flow, which included comprehensive development agreements with private entities. It also allowed private entities to fully design, build, operate, and finance toll roads. Further, the bill authorized the Texas Transportation Commission to create regional mobility authorities (RMAs) to enable localities to approve and generate revenue from regional transportation projects. Revenue from these projects can be used to fund future infrastructure investments (Ellis, 2014).

Before the passage of the legislation in 2003, the Katy Freeway (Interstate Highway 10), a highly congested freeway in Houston, had already been assessed as obsolete by TxDOT with, "maintenance costs at four times the average expressway segment and inadequate to carry the

200,000 vehicles daily demand" (Goodin, 2013). In 1998, in advance of HOT lanes legislation, TxDOT piloted a QuickRide Program, which allowed single occupancy vehicles to use the HOV lanes for $2 per trip. The pilot was effective in that it relieved congestion in the general purpose lanes and provided customers with a choice of how to travel during commute hours. Given the limited available transportation funds and recent Texas legislation, TxDOT elected to implement HOT lanes on the Katy Freeway in order to fully reconstruct a 12-mile portion of the roadway. Harris County Toll Road Authority (HCTRA) assumed responsibility for financing, constructing, operating and maintaining the managed lanes portion of the freeway, while TxDOT maintained responsibility for operating the general purpose lanes (Goodin, 2013). HCTRA, with support from TxDOT, has since implemented three HOT lane projects in the Houston metropolitan region and has extended two of these facilities.

HOT lanes projects have also become common in the Dallas area. These projects, however, are primarily being implemented through public-private partnerships. The history of HOT lanes in northern Texas begins with the Texas Turnpike Authority (TTA), which was formed in 1953 to construct and operate the Dallas-Fort Worth Turnpike. Althought, the agency was tasked with constructing toll roads throughout Texas, the bulk of its projects were constructed in the Dallas-Fort Worth metropolitan region. In 1997, Assembly Bill 370 converted the TTA, which had been an independent state agency, into a division of TxDOT. The same bill established the North Texas Tollway Authority (NTTA) as the regional toll authority and transferred all of TTA's assets and liabilities to the NTTA.[8] As the local toll authority, NTTA is tasked with financing, constructing, and overseeing turnpike projects in the region. Under Assembly Bill 370, NTTA has the first option to develop planned toll roads. When it is not feasible for NTTA to construct a toll road, however, the agency may waive its primacy (NTTA, 2017), which it did in the cases of the Dallas' North Tarrant Expressway and LBJ Freeway.

By the early 2000s, the 10-lane LBJ Freeway (I-635) in Dallas reached its peak capacity of 270,000 vehicles per day and TxDOT estimated that demand would eventually increase to 500,000 vehicles per day. The roadway needed to be expanded, but given the limited public funding there was a risk that the project would be delayed or never built (Williamson, 2010). TxDOT submitted a proposal for the LBJ Freeway to be included in FHWA's Express Lanes Demonstration Project, which was approved in 2008 and allowed TxDOT to manage congestion on the aging LBJ Freeway using HOT lanes. Due to limited public funding, TxDOT elected to rebuild the freeway as a public-private partnership. TxDOT competitively awarded the contract, which includes a 50-year concession agreement, to the LBJ Infrastructure Group, led by Cintra, and construction began in 2011. In the same time period and for the same reasons, NTTA elected to relieve congestion on North Tarrant Expressway (I-820) by constructing HOT lanes along a 12-mile section. As with TxDOT and the LBJ Freeway, NTTA decided to construct this

[8] NTTA was the only regional toll authority established in Texas as a result of this bill. In addition to this regional toll authority, Texas has seven county toll authorities (such as HCTRA) and eight regional mobility authorities that have a similar structure as the NTTA.

project, NTE TEXpress Lanes, as a partnership and awarded the contract to the LBJ Infrastructure Group, whose primary investor is Cintra. The first section of NTE TEXpress Lanes opened in 2014.

Since the initial reconstruction of the LBJ Freeway and NTE TEXpress Lanes, LBJ Infrastructure Group/Cintra has been implementing a system of HOT lane facilities across the Dallas-Fort Worth Metropolitan region, including the expansion of the NTE TEXpress Lanes. As of 2017, there were a total of four HOT lane facilities in the Dallas-Fort Worth Area with five more projects underway (four of those projects are extensions of existing facilities).

Timeline

- 1997: Texas legislature voted to dissolve the Texas Turnpike Authority and replace it with a division in TxDOT.
- 1998: TxDOT piloted the QuickRide program on Katy Freeway ($2/trip for SOVs)
- 2000: Texas Transportation Institute, with support from TxDOT and FHWA, initiated a multi-year study on optimizing managed lane efficiency.
- 2003: Legislation passed to enabled TxDOT and other local agencies to design and operate managed lanes, and to allow private entities to finance, build, and operate toll projects.
- 2003: Construction of Katy Managed Lanes project began.
- 2008: FHWA approves proposed I-635 Express Lanes project in Dallas as Express Lanes Demonstration Project.
- 2009: Katy Managed Lanes project opens.
- 2009: TxDOT awards LBJ Infrastructure Group LLC, led by Cintra, to develop LBJ Express lanes on I-635.
- 2010: Construction on NTE TEXpress Lanes begins.
- 2011: Construction of LBJ Freeway begins.
- 2014: First section of NTE TEXpress Lanes open on I-820.
- 2015: LBJ Freeway opens.

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FLORIDA

The first managed toll lane in Florida opened in 2008 on Interstate 95, which cuts through Miami-Dade, Palm Beach and Broward Counties. By 2014, the managed toll lane on Interstate 95 had been extended twice and now totals 22 miles. As of 2017, Florida is constructing four additional managed toll lane projects on three new facilities, two of which are in Miami-Dade County and the other two in Northeast and Central Florida. Florida is also in the planning stages for two additional projects in Tampa and Northeast Florida.

The groundwork for managed toll lanes in Florida began in 2002 when Governor Jeb Bush signed House Bill 261, which created Florida’s Turnpike Enterprise (FTE), a business unit of the Florida Department of Transportation (FDOT), to manage and operate tolled highways throughout Florida. Governor Bush directed the FTE “to pursue innovation and best private-sector businesses practices, to improve cost-effectiveness and timeliness in project delivery, to increase revenues and expand its capital program, and to improve quality of service to its customers.” (Florida Turnpike Enterprise website) Florida’s Office of Toll Operations was merged into the newly created FTE. In 2017, FTE managed 600 miles of roadway and 80 percent of all tolled facilities in Florida (FDOT website).

In 2003, FDOT hired Robert Poole, inventor of the concept of managed toll lanes and the founder of the Reason Foundation, to study the viability of toll lanes in South Florida. In 2008 Poole published a report titled “A Managed Lanes Vision for South Florida,” which became “a primer for toll lane plans across the state” (Barton, 2014). The report envisioned toll lanes throughout the Miami area by 2030. Poole’s report specifically identified Interstate 95 as a candidate for managed toll lanes because congestion during peak hours was so high that its single HOV lane was overcrowded with an average speed of 18 mph. FDOT, in partnership with USDOT and FTE, moved forward with this project and opened its first managed toll lane on Interstate 95 in Miami in 2008. Although I-95 was implemented by FDOT rather than the then newly-created FTE, this first managed toll lane project was put forth because FDOT, like FTE, was seeking alternative strategies for addressing increasing congestion and funding new capital projects.

When Governor Rick Scott was elected in 2011, he selected Poole as a transportation advisor for his transition team, which, following the success of the I-95 project and with revenue from gas taxes on the decline, solidified tolled managed lanes as Florida's strategy for transportation funding. Poole expanded on his 2008 managed lanes report and published a second report outlining a network of toll lanes in southeast Florida connecting Miami-Dade, Broward, and Palm Beach counties. As of 2017, the state was pushing ahead with plans to toll portions of Interstate 4 in Orlando, Interstates 275 and 75 in Tampa and extend the existing toll facilities on Interstate 95 in Miami into Broward County.

Timeline

- 2002: Florida's Turnpike Enterprise was created by the Florida Department of Transportation.
- 2003: FDOT hired Robert Poole to study the viability of tolled managed lanes in southern Florida.
- 2008: First managed toll lane opened on I-95 in Miami-Dade County/Broward/Palm Beach Counties.
- 2010: Extension of the I-95 managed toll lane opened.
- 2011: Governor Rick Scott takes office and selects Poole as his transportation advisor on his transition team. Governor Scott appoints Ananth Prasad as transportation secretary.
- 2014: Additional extension of the I-95 managed toll lane opened.
- 2014: Managed toll lane added to I-595 in Broward County.

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MINNESOTA

The first managed toll lane opened in Minnesota on Interstate 394 in 2005. Minnesota opened its second managed toll lane project on Interstate 35W in 2009 and its third project on Interstate 35E in 2016. As of 2017, Minnesota's network of express lanes, called MnPass, includes 60-lane miles of roadway.

I-394 became a candidate for managed toll lanes in 2001 when a study completed by the Minnesota Department of Transportation (MnDOT) found that the highway's existing HOV lane was underused while the general purpose lanes were becoming increasingly congested. The study stimulated public pressure to allow single-occupancy vehicles to use the HOV lane. The study had concluded that converting the HOV lane to a general purpose lane would not be cost-effective and would ultimately increase congestion. Conversion to HOT lanes, on the another hand, would be both cost-effective and congestion-reducing.

In 2003, after nearly a decade of controversy, the Minnesota Legislature enacted High Occupancy Toll Lane Legislation, which authorized the MnDOT commissioner to implement user fees on HOV lanes. As in other states,the legislation won support as a result of growing transportation costs and highway congestion and declining gas tax revenue. In 2005, MnDOT launched the MnPass project with the primary goals of 1) improving the efficiency of I-394 by increasing the carrying capacity of HOV lanes, in terms of both individuals and vehicles, and 2) maintaining free-flow speeds (45 mph) for transit and carpools in the express lanes. Once opened, the newly converted HOT lanes added 30 percent more trips to the previously underutilized HOV lanes.

The 2003 legislation, directed MnDOT to prepare a MnPASS System Study to examine the "impacts of overlaying a MnPass toll lane system in the Twin Cities metropolitan region of Minneapolis and St. Paul" with the primary objective of identifying a regional tolling system (MnPass System Study, 2005). In 2007, MnDOT was awarded $133.3 million for congestion management and transit projects from the USDOT as part of the Urban Partnership Program.

Following the success of I-394 and the MnPass System Study findings, MnDOT used a portion of this funding, which included $50 million in state-matched funding, to convert and construct HOT lanes on I-35W and I-35E. These projects opened in 2009 and 2016, respectively.

A second phase of the MnPass System Study was completed in 2010, and evaluated whether one could design and build a less expensive MnPASS system that still provided significant benefits. The result was a list of MnPASS expansion priorities, which was adopted into the Metropolitan Council's[9] 2040 Transportation Policy Plan as the vision for the development of the MnPASS system. Since the completion of the MnPASS System Study Phase 2, the MnPASS Transportation System has expended and MnPass has stated that there will be a Phase 3 study.

Timeline

- 2001: Study found I-394 HOV lane to be underused.
- 2003: MnDOT selected Wilbur Smith Associates (WSA), Raytheon, SRF Consulting, Cofiroute USA and Frank Wilson & Associates in a consortium to develop the HOV-to-HOT conversion on I-394 as a public-private partnership.
- April 2005: MnDOT releases MnPass System Study examining additional opportunities for HOT lanes in the Twin Cities region.
- May 2005: First MnPass Express Lane (HOT) project opened on I-394
- 2009: MnPass Express Lane (HOT) opened on I-35W
- 2010: MnPass System Study Phase II published
- 2016: MnPass Express Lane (HOT) opened on I-35E

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COLORADO

Like all states, Colorado's road infrastructure has been funded primarily by gas taxes, but Colorado residents have not voted to increase gas taxes since 1993. Colorado began considering managed toll lanes in 2002 with the creation of the Colorado Tolling Enterprise (CTE), a division of the Colorado Department of Transportation (CDOT). Through CTE, the state sought to identify toll road opportunities in order to provide additional revenue to fund increased highway capacity and transportation infrastructure in the rapidly growing Denver area. Specifically, the purpose of CTE was to "finance, construct, operate, regulate, and maintain a system of tolled highways in Colorado."

In 2003, CTE initiated a statewide traffic and revenue feasibility analysis to identify potential toll projects based on financial feasibility. The analysis found that revenue from HOT lanes on Interstate 25 near Denver would be able to fully fund the cost to convert the HOV lanes, as well as additional transportation improvements. The analysis also identified I-70, US-36, and C-470 as potential HOT corridors that would offer similar financial benefits. As a result of this study, CDOT, along with CTE and local agencies, converted the I-25 HOV lanes to reversible HOT lanes, which opened in 2006. This first HOT lane project was developed and financed by the Colorado

Department of Transportation (CDOT) using the traditional public sector design-bid-build model.

In 2009, with gas tax revenue further on the decline due to inflation and increasing use of fuel-efficient vehicles, the State of Colorado replaced the CTE with the High-Performance Transportation Enterprise (HPTE) through the state's Funding Advancements for Surface Transportation and Economic Recovery (FASTER) legislation. HPTE was tasked specifically to pursue public-private partnerships and other innovative financing mechanisms that could be used to more proactively address the state's growing congestion and capital improvements needs (Colorado Senate Bill 09-108). HPTE was also created to help address Colorado's growing unemployment during the recession by providing jobs in construction through capital projects. With leadership from HPTE.

In 2012, CDOT opened its second HOT lane project in Denver on US-36 as a public-private partnership. This project included building a new express lane in each direction and reconstructing the highway's existing pavement. Most recently, Colorado has used public-private partnerships to open HOT lanes on Interstate 70 and extend the US-36 HOT lanes. Another HOT project is currently under construction on C-470 and an additional project is proposed for Interstate 70 east.

Timeline

- 2002: Colorado established the Colorado Tolling Enterprise, a division of CDOT.
- 2003: CTE initiated a tolling system traffic and revenue feasibility analysis.
- 2006: I-25 Express Lanes opened in the Denver.
- 2009: High-Performance Transportation Enterprise replaced CTE within CDOT.
- 2012: US 36 Express Lanes opened in Denver.
- 2015: I-70 Mountain HOT opened.
- 2016: US 36 Express Lanes extension opened. The HOT lanes are now 18 miles total
- 2017: CDOT and HPTE changed the HOV requirements to HOV 3+ for US 36 and I-25

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GA I-85 (Optimistic)

TRAFFIC IN PEAK	General purpose lanes			Managed lanes		
	Before	After	Change	Before	After	Change
Vehicles/day in peak	71,496	68,802	(2,694)	9,429	8,608	(821)
Time, minutes/vehicle	16.1	17.4	1.3	14.2	13.8	(0.4)
BENEFITS	General	Managed	Total			
Minutes saved/day	-	15,866	15,866			
Time saved $000/yr	-	1,124	1,124			
	Present value	Typical year				
Total benefits $000	13,945	1,124				
COSTS $000						
Investment	(52,768)	(4,254)				
Operating	(71,839)	(5,789)				
Total	(124,625)	(10,043)				
NET BENEFIT	(110,680)	(8,919)				
B/C RATIO	7% (base case)	3%				
$17/hour (base case)	0.11	0.13				
$34/hour	0.22	0.26				
$70/hour	0.46	0.55				

GA I-85 (Base)

TRAFFIC IN PEAK	General purpose lanes			Managed lanes		
	Before	After	Change	Before	After	Change
Vehicles/day in peak	71,496	68,802	(2,694)	9,429	8,608	(821)
Time, minutes/vehicle	16.1	17.4	1.3	14.2	13.8	(0.4)
BENEFITS	General	Managed	Total			
Minutes saved/day	(95,029)	15,866	(79,163)			
Time saved $000/yr	(6,731)	1,124	(5,607)			
	Present value	Typical year				
Total benefits $000	(69,582)	(5,607)				
COSTS $000						
Investment	(52,768)	(4,254)				
Operating	(71,839)	(5,789)				
Total	(124,625)	(10,043)				
NET BENEFIT	(194,207)	(15,650)				
B/C RATIO	7% (base case)	3%				
$17/hour (base case)	-0.56	-0.66				
$34/hour	-1.12	-1.32				
$70/hour	-2.30	-2.72				

MN I-35W (Full Cost of Crosstown Reconstruction)

TRAFFIC IN PEAK	General purpose lanes			Managed lanes		
	Before	After	Change	Before	After	Change
Vehicles/day in peak	33,197	42,051	8,854	-	4,656	-
Time, minutes/vehicle	18.6	14.9	(3.8)	-	13.7	-
BENEFITS	General	Managed	Total			
Minutes saved/day	158,729	10,874	169,602			
Time saved $000/yr	11,243	770	12,013			
	Present value	Typical year				
Total benefits $000	149,076	12,013				
COSTS $000						
Investment	(267,616)	(21,566)				
Operating	(10,381)	(837)				
Total	(277,997)	(22,403)				
NET BENEFIT	(128,922)	(10,389)				
B/C RATIO	7% (base case)	3%				
$17/hour (base case)	0.54	0.83				
$34/hour	1.07	1.66				
$70/hour	2.21	3.41				

MN I-35W (Base: Adjusted Cost 25% of Crosstown Reconstruction)

TRAFFIC IN PEAK	General purpose lanes			Managed lanes		
	Before	After	Change	Before	After	Change
Vehicles/day in peak	33,197	42,051	8,854	-	4,656	-
Time, minutes/vehicle	18.6	14.9	(3.8)	-	13.7	-
BENEFITS	General	Managed	Total			
Minutes saved/day	158,729	10,874	169,602			
Time saved $000/yr	11,243	770	12,013			
	Present value	Typical year				
Total benefits $000	149,076	12,013				
COSTS $000						
Investment	(96,616)	(7,786)				
Operating	(10,381)	(837)				
Total	(106,997)	(8,623)				
NET BENEFIT	42,078	3,391				
B/C RATIO	7% (base case)	3%				
$17/hour (base case)	1.32	2.08				
$34/hour	2.79	4.17				
$70/hour	5.74	8.58				

LBJ (Base, 40% Cost)

TRAFFIC IN PEAK	General purpose lanes			Managed lanes		
	Before	After	Change	Before	After	Change
Vehicles/day in peak	85,489	78,450	(7,039)	-	20.107	-
Time, minutes/vehicle	5.3	5.7	0.3	-	3.9	-
BENEFITS	General	Managed	Total			
Minutes saved/day	(69,577)	109,302	39,725			
Time saved $000/yr	(4,928)	7,742	2,814			
	Present value	Typical year				
Total benefits $000	34,917	2,814				
COSTS $000						
Investment	(1,040,000)	(83,810)				
Operating	(99,272)	(8,000)				
Total	(1,139,272)	(91,810)				
NET BENEFIT	(1,104,335)	(88,996)				
B/C RATIO	7% (base case)	3%				
$17/hour (base case)	0.03	0.05				
$34/hour	0.06	0.09				
$70/hour	0.13	0.19				

LBJ (Optimistic, 40% Cost)

TRAFFIC IN PEAK	General purpose lanes			Managed lanes		
	Before	After	Change	Before	After	Change
Vehicles/day in peak	85,489	78,450	(7,039)	-	20.107	-
Time, minutes/vehicle	5.3	5.7	0.3	-	3.9	-
BENEFITS	General	Managed	Total			
Minutes saved/day	-	109,302	109,302			
Time saved $000/yr	-	7,742	7,742			
	Present value	Typical year				
Total benefits $000	96,074	7,742				
COSTS $000						
Investment	(1,040,000)	(83,810)				
Operating	(99,272)	(8,000)				
Total	(1,139,272)	(91,810)				
NET BENEFIT	(1,043,199)	(84,068)				
B/C RATIO	7% (base case)	3%				
$17/hour (base case)	0.08	0.13				
$34/hour	0.17	0.25				
$70/hour	0.35	0.52				

LBJ (Base, 100% Cost)

TRAFFIC IN PEAK	General purpose lanes			Managed lanes		
	Before	After	Change	Before	After	Change
Vehicles/day in peak	85,489	78,450	(7,039)	-	20.107	-
Time, minutes/vehicle	5.3	5.7	0.3	-	3.9	-
BENEFITS	General	Managed	Total			
Minutes saved/day	(69,577)	109,302	39,725			
Time saved $000/yr	(4,928)	7,742	2,814			
	Present value	Typical year				
Total benefits $000	34,917	2,814				
COSTS $000						
Investment	(2,600,000)	(209,525)				
Operating	(248,181)	(20,000)				
Total	(2,848,181)	(229,525)				
NET BENEFIT	(2,813,264)	(226,711)				
B/C RATIO	7% (base case)	3%				
$17/hour (base case)	0.01	0.02				
$34/hour	0.02	0.04				
$70/hour	0.05	0.08				

LBJ (Optimistic, 100% Cost)

TRAFFIC IN PEAK	General purpose lanes			Managed lanes		
	Before	After	Change	Before	After	Change
Vehicles/day in peak	85,489	78,450	(7,039)	-	20.107	-
Time, minutes/vehicle	5.3	5.7	0.3	-	3.9	-
BENEFITS	General	Managed	Total			
Minutes saved/day	-	109,302	109,302			
Time saved $000/yr	-	7,742	7,742			
	Present value	Typical year				
Total benefits $000	96,074	7,742				
COSTS $000						
Investment	(2,600,000)	(209,525)				
Operating	(248,181)	(20,000)				
Total	(2,848,181)	(229,525)				
NET BENEFIT	(2,752,107)	(221,782)				
B/C RATIO	7% (base case)	3%				
$17/hour (base case)	0.03	0.05				
$34/hour	0.07	0.10				
$70/hour	0.14	0.21				

NTE (Base, 40% Cost)

TRAFFIC IN PEAK	General purpose lanes			Managed lanes		
	Before	After	Change	Before	After	Change
Vehicles/day in peak	48,305	57,807	9,502	-	16,762	-
Time, minutes/vehicle	8.2	6.8	(1.4)	-	5.4	-
BENEFITS	General	Managed	Total			
Minutes saved/day	156,701	99,744	256,446			
Time saved $000/yr	11,100	7,065	18,165			
	Present value	Typical year				
Total benefits $000	225,409	18,165				
COSTS $000						
Investment	(840,000)	(67,693)				
Operating	(99,272)	(8,000)				
Total	(939,272)	(75,693)				
NET BENEFIT	(713,863)	(57,528)				
B/C RATIO	7% (base case)	3%				
$17/hour (base case)	0.24	0.36				
$34/hour	0.48	0.71				
$70/hour	0.99	1.47				

NTE (Base, 100% Cost)

TRAFFIC IN PEAK	General purpose lanes			Managed lanes		
	Before	After	Change	Before	After	Change
Vehicles/day in peak	48,305	57,807	9,502	-	16,762	-
Time, minutes/vehicle	8.2	6.8	(1.4)	-	5.4	-
BENEFITS	General	Managed	Total			
Minutes saved/day	156,701	99,744	256,446			
Time saved $000/yr	11,100	7,065	18,165			
	Present value	Typical year				
Total benefits $000	225,409	18,165				
COSTS $000						
Investment	(2,100,000)	(169,231)				
Operating	(248,181)	(20,000)				
Total	(2,348,181)	(189,231)				
NET BENEFIT	(2,122,772)	(171,067)				
B/C RATIO	7% (base case)	3%				
$17/hour (base case)	0.10	0.14				
$34/hour	0.19	0.29				
$70/hour	0.40	0.59				

I-405

TRAFFIC IN PEAK	General purpose lanes			Managed lanes		
	Before	After	Change	Before	After	Change
Vehicles/day in peak	50,715	51,671	956	11,354	14,422	3,068
Time, minutes/vehicle	24.2	21.9	(2.3)	19.0	15.9	(3.1)
BENEFITS	General	Managed	Total			
Minutes saved/day	109,060	106,303	215,363			
Time saved $000/yr	7,725	7,530	15,255			
	Present value	Typical year				
Total benefits $000	189,289	15,255				
COSTS $000						
Investment	(155,500)	(12,531)				
Operating	(490,778)	(39,550)				
Total	(646,278)	(52,081)				
NET BENEFIT	(456,979)	(36,826)				
B/C RATIO	7% (base case)	3%				
$17/hour (base case)	0.29	0.32				
$34/hour	0.59	0.64				
$70/hour	1.21	1.32				

I-680

TRAFFIC IN PEAK	General purpose lanes			Managed lanes		
	Before	After	Change	Before	After	Change
Vehicles/day in peak	21,316	22,911	1,595	3,095	3192	98
Time, minutes/vehicle	13.5	12.6	(0.9)	11.5	11.2	(0.3)
BENEFITS	General	Managed	Total			
Minutes saved/day	20,908	3,806	24,714			
Time saved $000/yr	1,481	270	1,751			
	Present value	Typical year				
Total benefits $000	21,723	1,751				
COSTS $000						
Investment	(36,634)	(2,952)				
Operating	(55,841)	(4,500)				
Total	(92,475)	(7,452				
NET BENEFIT	(70,752)	(5,702)				
B/C RATIO	7% (base case)	3%				
$17/hour (base case)	0.23	0.27				
$34/hour	0.47	0.55				
$70/hour	0.97	1.13				

I-95

TRAFFIC IN PEAK	General purpose lanes			Managed lanes		
	Before	After	Change	Before	After	Change
Vehicles/day in peak	67,417	71,316	3,899	19,741	25,926	6,997
Time, minutes/vehicle	17.1	8.3	(8.8)	14.5	7.0	(7.5)
BENEFITS	General	Managed	Total			
Minutes saved/day	576,544	257,461	834,005			
Time saved $000/yr	40,838	18,237	59,075			
	Present value	Typical year				
Total benefits $000	733,069	59,075				
COSTS $000						
Investment	(132,000)	(10,637)				
Operating	(53,052)	(4,275)				
Total	(185,052)	(14,912)				
NET BENEFIT	548,017	44,163				
B/C RATIO	7% (base case)	3%				
$17/hour (base case)	3.96	5.37				
$34/hour	7.92	10.73				
$70/hour	16.31	22.09				

Sensitivity Analysis

			Scenarios (VOT, Discount Rate)					
Project	**Benefit Scenario**	**Cost Scenario**	*$17, 7%*	*$17, 3%*	*$34, 7%*	*$34, 3%*	*$70, 7%*	*$70, 3%*
1. Florida's I-95 Express Lanes	*Base Case*	*100% of Total*	3.96	5.34	7.92	10.73	16.31	22.09
2. California's I-680 Southbound Express Lanes	*Base Case*	*100% of Total*	0.23	0.27	0.47	0.55	0.97	1.13
3. Georgia's I-85 Express Lanes	*Optimistic Case*	*100% of Total*	0.11	0.13	0.22	0.26	0.46	0.55
	Base Case	*100% of Total*	-0.56	-0.66	-1.12	-1.32	-2.30	-2.72
4. Washington's I-405 Express Lanes	*Base Case*	*100% of Total*	0.29	0.32	0.59	0.64	1.21	1.32
5. Minnesota's I-35W Express Lanes	*Base Case*	*25% of Crosstown*	1.32	2.08	2.79	4.17	5.74	8.58
	Base Case	*100% of Total*	0.54	0.83	1.07	1.66	2.21	3.41
6. Texas' North Tarrant Express Lanes	*Base Case*	*40% of Total*	0.24	0.36	0.48	0.71	0.99	1.47
	Base Case	*100% of Total*	0.10	0.14	0.19	0.29	0.40	0.59
7. Texas' LBJ Express Lanes	*Base Case*	*40% of Total*	0.03	0.05	0.06	0.09	0.13	0.19
	Optimistic Case	*40% of Total*	0.08	0.13	0.17	0.25	0.35	0.52
	Base Case	*100% of Total*	0.01	0.02	0.02	0.04	0.05	0.08
	Optimistic Case	*100% of Total*	0.03	0.05	0.07	0.10	0.14	0.21