Pricing and Occupancy Scenarios

Task 2

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HOUSTON HOT LANE NETWORK

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Executive Summary

In this task, TTI researchers examined the 5 potential HOT lanes (Northwest, Eastex, Gulf, Southwest, and North freeways) for potential HOT lane revenues and costs. To calculate potential revenues detailed traffic data were obtained for each HOT lane. These data were used to estimate the potential travel time savings offered by the HOT lanes, and thereby estimate the toll charged and revenues obtained. Estimated costs of the HOT lanes were primarily from recent estimates produced by Houston Metro and their consultants as they proceed towards HOT lane implementation.

The total estimated cost of the five HOT lanes is:

1. $50,000,000 for construction plus toll equipment
2. 8,250,000 per year for operations plus maintenance
3. 3,000,000 per year for enforcement

Over a 20 year time frame, assuming costs inflate at a rate similar to the discount rate, the total costs are $275,000,000 (in 2008 dollars).

For revenue estimates, researchers developed a detailed traffic and revenue estimation spreadsheet in Excel. This tool calculates predicted revenues from the five HOT lanes over a 20 year period. It uses survey data to estimate how much travelers are willing to pay for travel time savings on the HOT lanes. It uses historical volume and speed data, along with commonly used speed-flow equations calibrated to Houston traffic data, to estimate current and future travel time savings. It then calculates the toll (and revenues) from filling the HOT lane to capacity based on the toll estimated to move just enough paying SOV GPL travelers to the HOT lane. Almost every input of the spreadsheet can be adjusted by the user. Using the default values, we estimated total 20 year revenues of (in 2008 dollars) $408,000,000.

These estimates indicate total net revenue of $133,000,000 over the 20 year period. Note that this estimate is highly dependent on many traffic and revenue assumptions that are very difficult to predict for future years. It is also dependant on all of the five freeways remaining basically as they are now – with no major reconstruction or widening – which is unlikely.

Also note we assumed one toll rate for travel on a HOT lane at a given time of day. This rate would be the same regardless of where the traveler entered or exited the lane. This greatly simplifies the tolling process for the user and discourages quick/short trips on the HOT lane. At the same time we assumed a toll rate that varies by time of day, which was essential to ensure free flow conditions on the lane.

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1.0 Introduction

In this task, TTI researchers examined the 5 potential HOT lanes (Northwest, Eastex, Gulf, Southwest, and North freeways) for potential HOT lane revenues and costs. To calculate potential revenues detailed traffic data were obtained for each HOT lane. These data were used to estimate the potential travel time savings offered by the HOT lanes, and thereby estimate the toll charged and revenues obtained. Estimated costs of the HOT lanes were primarily from recent estimates produced by Houston Metro and their consultants as they proceed towards HOT lane implementation.

2.0 Costs

The costs to adapt these HOV lanes to operational HOT include all costs required to add SOV charging to the lanes plus all operation and maintenance costs of the lanes. This includes all costs of operating and maintaining the lanes - not just these costs associated with the charging of SOVs. This was done from the perspective of a third party (such as TxDOT) such that all costs of the lanes are compared to the toll revenues – not just the incremental costs that the current operator (METRO) would face.

2.1 Construction Costs

There will be a significant onetime cost for construction to allow for tolling of SOVs. This includes widening or altering approximately 38 locations along the HOV lanes so that two lanes exist, one for HOVs and one for toll paying SOVs. This will allow for more efficient enforcement of the HOT lanes and is common for HOT lanes around the country to have a HOV 'declaration' lane and a toll-paying SOV lane.

Additionally, tolling will require gates, sensors, toll readers, communications, signs, etc. as detailed in Houston METRO's cost estimate from their *White Summary Paper Response to TxDOT's April 18, 2006 letter (WSPR)* and subsequent discussions with METRO. All of these items are expected to cost approximately $50,000,000.

2.2 Operations and Maintenance Costs

Next, operations and maintenance costs must be considered. These include the many necessities of operating multiple toll collection facilities as outlined in METRO's RFP. This was estimated, by METRO and their consultants to be approximately $8,250,000 per year. Note that this specifically excluded enforcement of the lanes.

2.3 Enforcement Costs

Costs for the enforcement of the lanes were estimated based on the WSPR. This included current level of enforcement plus six new officers. The total estimate for enforcement costs was approximately $3,000,000 per year.

The operation, maintenance and enforcement costs total $11,250,000 per year for the 5 HOT lanes totaling 83.4 miles in length. This equates to $135,000 per lane-mile or $2,250,000 per HOT lane. In Technical Memorandum 6 (August 2008) the back office operations from other HOT lanes were examined. This included obtaining costs from several of the lanes (see Table 1).

Table 1: Back office Operation Costs for Other HOT Lanes

Facility	Back Office Operations Costs ($/year)	Lane-Miles	Cost per Lane Mile	Active Transponders	Notes
I-394, Minnesota	1,064,000	14	76,000	12,000	
I-15, San Diego	850,000	16	53,125	25,000	
91X, Los Angeles	5,700,000 (all functions)	40	142,500	176,000	
I-25, Colorado	518,000	14	37,000	260,000	Accounts for multiple facilities
SR-167, Seattle	720,000 (O&M& enforcement)	19	37,895		1600 trips per day

The estimated cost per lane mile for Houston's HOT lanes is in the range of these other estimates. Note that Houston's costs are on the high end of these estimates, plus Houston's estimates include enforcement costs while most other sites did not. Therefore, the cost estimate for the Houston HOT lanes was in line with results from the other HOT lanes.

2.4 Total Costs

Therefore, the total estimated cost of the five HOT lanes is:

4. $50,000,000 for construction plus toll equipment
5. 8,250,000 per year for operations plus maintenance
6. 3,000,000 per year for enforcement

Over a 20 year time frame, assuming costs inflate at a rate similar to the discount rate, the total costs are $275,000,000.

3.0 Revenues

Revenue estimates, like cost estimates, were also available from Houston METRO and their consultants. However, researchers had the data and the expertise to develop an alternative revenue estimate using more advanced techniques that used HOT lane travel time savings. Researchers felt this was a more reliable estimation technique.

3.1 Data

Studies of HOT lanes and toll roads have concluded that travelers pay to use these lanes primarily for the travel time savings offered by these lanes. Other characteristics of the lanes such as travel time reliability, safety, convenience, etc. also influence this decision. However, for modeling and estimation purposes, researchers frequently use only travel time savings and assume the other characteristics are accounted for in the amount a traveler is willing to pay for these travel time savings. This is often referred to as a traveler's willingness to pay (WTP) or value of travel time savings (VTTS).

Each traveler has a unique WTP or VTTS. Additionally a traveler's WTP can vary from trip to trip. For example, a traveler may have a very low WTP for a toll road on an average trip to the office, but on a day with a critical meeting first thing in the morning that same traveler may have an exceptionally high WTP.

Therefore, to estimate the traffic and revenue potential of the five HOT lanes researchers needed data on both:

- the potential travel time savings offered by the HOT lane versus the general purpose lanes (GPLs): this is found in section 3.2: Traffic Data
- how WTP or VTTS varies over the traveler's on that freeway on average: This is found in section 3.3: Traveler Data

3.2 Traffic Data

To begin, traffic speed and volume data were obtained from TxDOT (see Table 2). These traffic data were entered into a spreadsheet (Houston HOV to HOT T&R) in 15-minute increments during the hours that the HOV lanes were open (See Appendix A for example screen of data). Since these lanes were only open in the peak direction of traffic, data were only for inbound traffic in the morning (generally 5:00 am to 11:00 am) and outbound traffic in the afternoon (2:00 pm to 8:00 pm).

Table 2: Traffic Data Sources

Road	Speeds		Volume	
	GPL	**HOV**	**GPL**	**HOV**
I-45 North	TxDOT 2007 AVI	TxDOT 2007 AVI	TxDOT 2004 Loop	TxDOT tube counts during the quarterly HOV lane counts for December 2007, March 2008, and June 2008
I-45 Gulf	TxDOT 2006 AVI	TxDOT 2006 AVI	TTI 2008 Wavetronix	
US-290 Northwest	TxDOT 2007 AVI	TxDOT 2007 AVI	TxDOT 2004 Loop	
US-59 Southwest	TxDOT 2006 AVI	TxDOT 2006 AVI	TxDOT 2004 Loop	
US-59 Eastex	TxDOT 2006 AVI	TxDOT 2007 AVI	TTI 2008 Wavetronix	

The travel time savings (TTS) offered by the HOT lane for any given 15 minute period of time could then be estimated using equation 1.

$$\text{Travel Time Savings} = 60 \times L\left(\frac{1}{S_{GPL}} - \frac{1}{S_{HOT}}\right) - AT \qquad \text{...(1)}$$

Where,

L= length of the HOT lane (miles)

S=speed of the lane (mph)

AT= Access Time (minutes).

The access time (AT) is the average additional time required to access the HOT lane above what would be required to access the GPLs. This term was necessary as travel through the Park and Ride lots can be time consuming. Default AT values, based on travel time runs, are in the spreadsheet. However, this is one of many variables the user can adjust for each HOT lane (See Appendix A for the data input screen and the many variables the user can adjust).

Next, the software compares this travel time savings (TTS) to a minimum viable travel time savings (MVTTS). If the actual TTS is less than the MVTSSS then no one is assumed to use the lane. This is a very conservative assumption since many HOT lanes and MLs have a small number of patrons even when there are no travel time savings. The default value is 3 minutes, but this variable can be adjusted by the user. If the TTS is greater than the MVTSSS then the software examines traffic volume on the HOT lane and subtracts that from the capacity of the lane, 1500 vehicles per hour (vph). This is the room available for paying SOVs. This maximum capacity of the HOT lane can be adjusted by the user. For these traffic and revenue estimates researchers used the goal of filling the HOT lane to the set capacity. This capacity is still low enough that the lanes will operate at a high level of service, over 50 mph. The other potential goal, revenue maximization, was not examined.

The number of toll paying SOVs (equal to the HOV lane capacity minus the current HOV lane volume) is then divided by the total volume of vehicles using the GPLs. This provides the percentage of GPL travelers that switch to the HOT lanes. For example, assume there were 1000 HOVs using the HOT lane and 5000 vehicles on the GPLs. In this case we would price the HOT lane to encourage 10 percent ((1500-1000)/5000) of GPL travelers to switch to the HOT lanes. The most challenging aspect was to determine the toll that would encourage these GPL travelers (10 percent in this example) to use the HOT lane for the TTS calculated in Equation 1[1]. This is dependent on those travelers VTTS and how this varied over the driving population - since only the 10 percent with the highest VTTS would switch to the HOT lanes.

The potential revenues, and operational efficiency of the lanes, greatly depends on the speed of vehicles on the HOT lanes. The speeds on the HOT lanes are generally controlled by (a) the speed limit when traffic volumes are light and (b) traffic congestion when traffic volumes are high. One other potential issue is that of slow moving vehicles in the HOT lane blocking traffic. This is a particular concern in barrier-separated, single-lane, facilities like those in Houston. It is possible to set a minimum allowable speed. The following legislation describes the process:

> Acts 1995, 74th Leg., ch. 165, Sec. 1, eff. Sept. 1, 1995.
>
> Sec. 545.363. MINIMUM SPEED REGULATIONS. (a) An operator may not drive so slowly as to impede the normal and reasonable movement of traffic, except when reduced speed is necessary for safe operation or in compliance with law.
>
> (b) When the Texas Transportation Commission, the Texas Turnpike Authority, the commissioners court of a county, or the governing body of a municipality, within the jurisdiction of each, as applicable, as specified in Sections 545.353 to 545.357, determines from the results of an engineering and traffic investigation that slow speeds on a part of a highway consistently impede the normal and reasonable movement of traffic, the commission, authority, county commissioners court, or governing body may determine and declare a minimum speed limit on the highway.

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[1] Note that we did not attempt to adjust the speed of the lanes due to the shift of travelers from the GPLs to the HOT lane. We did this to simplify the analysis and knowing this shift in vehicles would have little impact due to the nature (single lane) of these HOT lanes. When the lanes are not congested both the GPLs and HOT lane will move at full speed. When the lanes are congested there is so little room in the HOT lane that too few GPL travelers move to cause a change in speeds.

(c) If appropriate signs are erected giving notice of a minimum speed limit adopted under this section, an operator may not drive a vehicle more slowly than that limit except as necessary for safe operation or in compliance with law.

Therefore, TxDOT, through the Texas Transportation Commission, has an avenue to set a minimum allowable speed on the HOT lanes and ensure reasonable travel speeds in low-volume conditions.

3.3 Traveler VTTS Data

To obtain travelers VTTS data researchers and practitioners often use a specific type of survey known as a stated preference survey. In stated preference surveys travelers are asked to select between multiple options based on the characteristics of those options. For this research, the survey asked travelers to select between:

- driving alone for free on the GPLs,
- travelling in a carpool for free on the GPLs, and
- traveling faster on a managed lane. This faster travel required a toll for SOVs and a smaller (or no toll) for HOVs.

The survey was conducted primarily online using two websites (www.houstontravelsurvey.org and www.dallastravelsurvey.org) and was available in both English and Spanish. The web survey facilitated customizing questions so that only relevant questions were asked to each respondent. For example, if the respondent indicated they never rode transit then the only transit related question the received was one asking why they chose not to ride transit. The web survey would also remind each respondent the values they had indicated earlier so that the chances of confusion regarding questions would be minimized. The biggest advantage was in stated preference questions as the toll rate and VTTS could very dynamically based on the options selected in the previous question.

The survey benefited in both content and exposure due to the help of several agencies which operate road facilities and/or have carried out work in this field. Meetings were carried out with Harris County Toll Road Authority (HCTRA), Houston-Galveston Area Council (HGAC), The Metropolitan Transit Authority of Harris County (METRO), Transportation Management Organization in Greenway Plaza and Uptown Houston (TREK), Texas Department of Transportation (TxDOT) Houston District, North Texas Tollway Authority (NTTA), North Central Texas Council of Governments (NCTCOG) which helped the survey by incorporating their views as well as help advertise the survey. The links to the pages were put on various government body sites.

Initial analysis of the survey respondents indicated that the share of low-income and minority respondents was not proportional to their share in overall population. This was perhaps due to unavailability of the internet to low income households. Therefore, laptop and paper surveys for low income households were undertaken at locations where such data could be collected. Specific Department of Public Safety (DPS) offices in Houston and Dallas plus a community center in Houston were selected for this purpose. The respondents were not all familiar with use of laptops and therefore a combination of paper surveys and laptop surveys were administered. Some respondents were illiterate and surveyors helped them by orally surveying the respondents, in both English and Spanish. These efforts resulted in sufficient additional respondents in both low income and minority categories to perform analyses. However, weighting factors would still need to be used since the survey sample still did not mirror city demographics.

Additionally, the number of respondents that were traveling on a toll road was approximately three times as high as expected based on average daily traffic volumes. This was likely due to the excellent job both HCTRA and NTTA did in advertising our survey. Other respondent characteristics, such as age and gender, were similar to the overall population. Therefore, weights were developed to adjust the survey sample to more accurately reflect income, ethnicity and use of toll/non-toll roads in both Houston and Dallas. The 64 groups (strata) that would be used to weight the data to mirror actual populations were:

- City (2: Houston or Dallas)
- Road Type (2: tolled or non-tolled)
- Annual Household Income (4: <$25,000, $25,000-$50,000, $50,000-100,000, over $100,000)
- Ethnicity (4: Caucasian, African-American, Hispanic, Other)

Since the sampling weights were developed post-stratification there were specific methodologies that had to be used in order to avoid inappropriately reducing the standard error of the estimates. In this research replicate weights were employed. The survey started in early May and ended in early July 2006. A total of 4635 responses were collected, including approximately 350 at DPS offices and the community center. Table 3 summarizes the weighted and un-weighted respondents for each freeway.

Table 3: Number of Respondents on Each Freeway

Road	Respondents (Un-weighted)		Respondents (Weighted)	
I-10 Katy Freeway	652	35.3%	608	30.6%
I-45 Gulf Freeway	218	11.8%	265	13.3%
I-45 North Freeway	268	14.5%	335	16.9%
US-59 Eastex Freeway	96	5.2%	146	7.3%
US-59 Southwest Freeway	264	14.3%	325	16.3%
US-290 Northwest Freeway	349	18.9%	308	15.5%
Total	1847	100.0%	1986	100.0%

3.4 Descriptive Statistics

To further analyze the behavior of the respondents traveling on each freeway descriptive statistics were developed for their socioeconomic and commute characteristics. The weighted data was used to generate the descriptive statistics. The detailed results are provided in Table 4. When asked about the trip purpose, the majority of respondents on all the freeways were commuting to or from work. The highest proportion of respondents was making at least 10 or more trips per week. Most of the respondents were traveling between 10 to 20 miles per day, except for the North Freeway and Eastex Freeway, for which majority of respondents were traveling more than 20 miles. When asked about vehicle occupancy, about 71 percent of respondents were traveling as a single occupant and 29 percent were carpooling. Both males and females were evenly distributed on each freeway. Also, when asked about interest in using managed lanes, almost 68 percent of respondents were interested in using them.

Table 4: Descriptive Statistics for Respondents Traveling on Five Major Freeways in Houston

Characteristic	N	I-10 Katy Freeway	I-45 Gulf Freeway	I-45 North Freeway	US-59 Eastex Freeway	US-59 Southwest Freeway	US-290 Northwest Freeway	Total
Trip Purpose								
Commute	1301	67.2%	70.3%	58.0%	43.2%	67.1%	76.0%	65.6%
Recreational	280	13.5%	12.9%	12.9%	26.7%	17.5%	8.1%	14.1%
Work (Work related, not commuting)	251	13.2%	11.4%	13.8%	17.8%	12.3%	9.4%	12.7%
School	102	4.1%	0.4%	12.9%	9.6%	1.5%	4.5%	5.1%
Other	48	2.0%	4.9%	2.4%	2.7%	1.5%	1.9%	2.4%
Total	1982	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Number of Trips Per Week								
2 or Less	127	6.2%	4.6%	4.2%	14.3%	10.1%	3.9%	6.5%
Between 3 and 5	631	29.8%	40.2%	41.7%	32.9%	25.3%	27.5%	32.3%
Between 6 and 9	244	10.7%	16.6%	8.8%	12.9%	13.3%	15.7%	12.5%
10 or more	950	53.3%	38.6%	45.3%	40.0%	51.3%	52.9%	48.7%
Total	1952	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Typical Trip Length								
Short (0-3 miles)	44	1.7%	0.8%	3.8%	0.7%	6.0%	0.3%	2.3%
Medium (4-9 miles)	192	12.3%	3.1%	6.6%	4.4%	15.2%	13.2%	10.1%
Long (10-20 miles)	889	47.4%	52.4%	44.5%	36.5%	49.7%	46.3%	47.0%
Very Long (more than 21miles)	768	38.7%	43.7%	45.1%	58.4%	29.1%	40.2%	40.6%
Total	1893	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
No. of Persons in Vehicle								
1	1120	73.3%	71.8%	74.6%	56.0%	65.3%	73.4%	70.8%

Characteristic	N	I-10 Katy Freeway	I-45 Gulf Freeway	I-45 North Freeway	US-59 Eastex Freeway	US-59 Southwest Freeway	US-290 Northwest Freeway	Total
2	317	17.3%	21.3%	13.1%	32.1%	24.0%	21.9%	20.0%
3 or more	145	9.4%	6.9%	12.3%	11.9%	10.7%	4.7%	9.2%
Total	1582	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
No. of Vehicles								
0	31	0.7%	5.4%	0.0%	7.1%	1.0%	0.0%	1.6%
1	491	25.1%	27.1%	26.2%	17.9%	27.7%	27.2%	25.8%
2	856	44.6%	40.7%	48.3%	43.6%	45.0%	46.3%	44.9%
3 or more	528	29.7%	26.7%	25.6%	31.4%	26.4%	26.5%	27.7%
Total	1906	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
No. of People in Household								
1	335	20.0%	21.1%	10.7%	14.7%	20.2%	17.6%	17.9%
2	554	28.8%	33.5%	26.6%	27.9%	30.3%	31.2%	29.6%
3	378	20.0%	16.7%	21.1%	27.1%	19.9%	20.0%	20.2%
4 or more	355	31.0%	28.7%	41.6%	30.2%	29.6%	31.2%	32.2%
Total	1870	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Household Type								
Single	545	27.5%	32.7%	27.1%	12.9%	37.4%	22.1%	27.9%
Unrelated	127	6.2%	8.7%	3.4%	5.8%	7.2%	8.3%	6.5%
Married with No Child	343	19.8%	12.9%	14.3%	18.7%	18.7%	18.8%	17.6%
Married with Children	685	34.2%	31.9%	38.4%	34.5%	30.2%	41.3%	35.1%
Single Parent	172	9.0%	9.5%	11.6%	21.6%	3.1%	5.0%	8.8%
Others	82	3.3%	4.2%	5.2%	6.5%	3.4%	4.6%	4.2%
Total	1954	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Characteristic	N	I-10 Katy Freeway	I-45 Gulf Freeway	I-45 North Freeway	US-59 Eastex Freeway	US-59 Southwest Freeway	US-290 Northwest Freeway	Total
Gender								
Female	1041	44.4%	61.0%	57.2%	66.0%	48.9%	55.2%	52.8%
Male	931	55.6%	39.0%	42.8%	34.0%	51.1%	44.8%	47.2%
Total	1972	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Age								
Between 16 to 24	270	8.6%	11.0%	21.0%	21.4%	18.8%	8.8%	13.7%
Between 25 to 34	683	33.7%	35.2%	35.0%	29.7%	36.7%	35.2%	34.6%
Between 35 to 44	461	22.4%	24.2%	20.4%	32.4%	17.0%	30.0%	23.3%
Between 45 to 54	391	25.4%	19.7%	16.8%	11.7%	18.2%	17.6%	19.8%
Between 55 to 64	147	7.8%	9.5%	6.9%	4.1%	7.4%	7.2%	7.4%
65 and over	24	2.0%	0.4%	0.0%	0.7%	1.9%	1.3%	1.2%
Total	1976	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Ethnicity								
Caucasian	924	57.1%	41.8%	40.2%	29.3%	41.9%	59.4%	48.0%
Afro-American	237	6.7%	14.6%	14.4%	21.4%	18.4%	8.4%	12.3%
Hispanic	456	17.8%	35.6%	34.4%	36.4%	15.6%	15.8%	23.7%
Asian	173	8.5%	5.7%	9.2%	0.7%	18.7%	6.0%	9.0%
Native American	19	0.3%	0.0%	0.9%	7.1%	0.3%	1.0%	1.0%
Others	116	9.6%	2.3%	0.9%	5.0%	5.1%	9.4%	6.0%
Total	1925	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Education Level								
High School or Less	72	1.2%	2.3%	10.3%	16.1%	0.0%	0.7%	3.7%
HS Graduate	272	8.9%	24.7%	18.5%	11.9%	11.0%	13.5%	13.9%
Vocational	639	36.4%	32.3%	35.2%	37.1%	27.8%	26.7%	32.8%

Characteristic	N	I-10 Katy Freeway	I-45 Gulf Freeway	I-45 North Freeway	US-59 Eastex Freeway	US-59 Southwest Freeway	US-290 Northwest Freeway	Total
College Graduate	680	38.7%	30.4%	24.5%	22.4%	40.1%	42.9%	34.9%
Post Graduate	287	14.8%	10.3%	11.5%	12.6%	21.1%	16.2%	14.7%
Total	1950	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Occupation								
Professional	802	46.4%	33.1%	33.9%	29.4%	40.6%	53.6%	41.5%
Technical	248	15.5%	8.6%	11.3%	10.3%	13.8%	13.1%	12.8%
Sales	76	3.7%	3.5%	3.4%	8.8%	3.8%	3.3%	3.9%
Administrative	350	18.2%	26.1%	17.9%	11.0%	15.9%	17.0%	18.1%
Service	8	0.2%	1.9%	0.3%	0.0%	0.0%	0.3%	0.4%
Manufacturing	36	1.3%	1.9%	4.1%	0.7%	0.0%	2.9%	1.9%
Stay at home	50	0.5%	3.5%	7.5%	2.2%	2.2%	1.3%	2.6%
Student	151	6.1%	3.9%	11.6%	17.6%	9.4%	4.6%	7.8%
Self Employed	84	3.7%	4.7%	1.3%	11.0%	8.4%	1.3%	4.4%
Unemployed	32	0.7%	0.0%	6.0%	6.6%	0.0%	0.0%	1.7%
Retired	27	1.0%	1.9%	0.6%	0.7%	3.1%	1.0%	1.4%
Others	67	2.7%	10.9%	2.2%	1.5%	2.8%	1.6%	3.5%
Total	1931	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Income								
Less than 25,000	462	18.6%	26.9%	35.0%	40.3%	28.5%	15.2%	25.3%
25,000 to 50,000	507	25.6%	32.5%	27.7%	27.3%	30.2%	25.3%	27.7%
50,000 to 100,000	521	32.8%	26.9%	25.4%	18.7%	24.7%	33.6%	28.5%
More than 100,000	339	22.9%	13.7%	11.9%	13.7%	16.6%	26.0%	18.5%
Total	1829	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Interested in using Managed								

Characteristic	N	I-10 Katy Freeway	I-45 Gulf Freeway	I-45 North Freeway	US-59 Eastex Freeway	US-59 Southwest Freeway	US-290 Northwest Freeway	Total
Lanes								
Yes	1333	72.2%	68.0%	60.1%	55.7%	73.1%	68.4%	68.0%
No	628	27.8%	32.0%	39.9%	44.3%	26.9%	31.6%	32.0%
Total	1961	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

3.5 Mode Choice Modeling

Using the results from respondents on the 6 roadways in Houston that may adopt or have adopted HOT lanes (Katy, Northwest, Eastex, Gulf, Southwest, and North freeways) researchers then analyzed the mode choice of the travelers on these freeways. Table 5 provides the details of mode choice of these respondents for the stated preference questions. Note that each respondent was asked four stated preference questions. Therefore, the number of answers (7571) was approximately four times the number of respondents (1986).

Table 5: Mode Choice of Respondents on the Six Roadways in Houston

Mode Chosen	N	I-10 Katy Freeway	I-45 Gulf Freeway	I-45 North Freeway	US-59 Eastex Freeway	US-59 Southwest Freeway	US-290 Northwest Freeway	Total
ML SOV	1590	22.0%	19.4%	20.9%	19.2%	20.0%	22.2%	21.0%
ML HOV2	1135	13.6%	16.8%	15.2%	20.0%	13.6%	15.4%	15.0%
ML HOV3+	603	8.0%	4.1%	10.5%	5.1%	9.6%	7.9%	8.0%
GPL SOV	3573	48.0%	50.5%	44.3%	44.0%	47.0%	47.4%	47.2%
GPL HOV2	499	6.5%	8.1%	3.4%	9.4%	8.7%	5.5%	6.6%
GPL HOV3+	171	1.9%	1.1%	5.6%	2.2%	1.1%	1.6%	2.3%
Total	7571	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Using the survey data for the same group of respondents, researchers developed logit models to predict traveler responses to the GPL versus HOT lane options. Various logit models were tested like multinomial logit model, nested logit model but a random parameter logit model with costs standardized using hourly wage (hourly wage was calculated by dividing income by 2000 hours per year) variables worked best. The logit model for this research is shown in Table 6.

Each equation yields the relative utility (benefit) of each travel choice for a specific traveler. For example, a Caucasian male traveler with a household income of $135,000 per year, who travels frequently on Gulf Freeway, may have a travel time of 10 minutes. Therefore, the utility of HOV3+ on GPL for that traveler would be:

$$U(HOV3 + on\ GPL) = -2.769 - 0.010 \times 10 - \frac{1.493 \times 0}{\left(135000/_{2000}\right)} - 1.499 \times 1 - 0.878 \times 1 \quad \ldots(2)$$

$$= -5.246$$

Table 6: Mode Choice Model

Mode	Variable	Coefficient	P-Value
All	Travel Time (min)	-0.010	0.00
	Toll Cost ($)	-1.483	0.00
SOV on the MLs	Alternative Specific Coefficient	-0.991	0.00
	Caucasian	0.263	0.00
	Household Income between $10,000 and $15,000	-0.467	0.02
	Household Income between $15,000 and $25,000	-0.263	0.00
HOV2 on the MLs	Alternative Specific Coefficient	-1.214	0.00
	Household Income between $35,000 and $50,000	-0.477	0.00
HOV3+ on the MLs	Alternative Specific Coefficient	-1.492	0.00
	Education: Graduate Degree	-0.675	0.00
	Use Eastex Freeway Frequently	-0.821	0.00
	Use Gulf Freeway Frequently	-1.014	0.00
SOV on the GPLs	Base Mode		
HOV2 on the GPLs	Alternative Specific Coefficient	-2.268	0.00
	Household Type: Married with Children	0.733	0.00
	Household Type: Married with no Children	1.138	0.00
	Household Income between $50,000 and $75,000	-0.854	0.00
	Aged between 45 years and 54 years	-0.580	0.00
HOV3+ on the GPLs	Alternative Specific Coefficient	-2.769	0.00
	Male	-1.499	0.00
	Use Gulf Freeway Frequently	-0.878	0.00
Standard Deviation	Travel Time (min)	0.003	0.00

Summary	
Number of Observations	6462
Log Likelihood	-9528
$\bar{\rho}^2$	0.22
Percent Estimated Correctly	30.9%

The higher the utility the more likely the traveler will choose the mode. The exact probability is given by equation 3.

$$P_{it} = \frac{e^{u_{it}}}{\sum_{i=1}^{all\ modes} e^{u_{it}}} \qquad \text{...(3)}$$

Where: P_{it} = the probability that person t chooses to use mode i

U_{it} = the utility (from Equation 2) of mode i for person t

Another important feature of logit models is the relationship between the independent variables. We know that if the total utility for a mode does not change then the probability of that mode does not change. Therefore, if one portion of the utility equation increases by X and another portion of the utility equation decreases by the same amount then there has been no change in the overall utility of that mode. That also means that the traveler feels these two changes in the utility equation are equal. For example, the same traveler might have the option of traveling as an SOV on the HOT lane for a $2 toll. This would result in a utility for that mode of -0.87:

$$U(SOV\ on\ HOT) = -0.991 - 0.010 \times 10 - \frac{1.483 \times 2}{\left(135000/_{2000}\right)} + .263 \times 1 - 0.467 \times 0 - 0.263 \times 0$$

= -0.87

Then, for example, if the toll were raised to $5 but travel time decreased to 6.6 minutes there is no change in utility:

$$U\ (SOV\ on\ HOT) = -0.991 - 0.010 \times 6.6 - \frac{1.483 \times 5}{\left(135000/_{2000}\right)} + .263 \times 1 - 0.467 \times 0 - 0.263 \times 0$$

= -0.87

Therefore, this traveler found that an additional $3 toll was equivalent to a 3.4 minute travel time savings. His value of time was $53 per hour. Calculating this relationship over hundreds of travelers provided researchers with the distribution of travel time savings over the population (see Figure 1). The cumulative distribution of those values is shown in Figure 2.

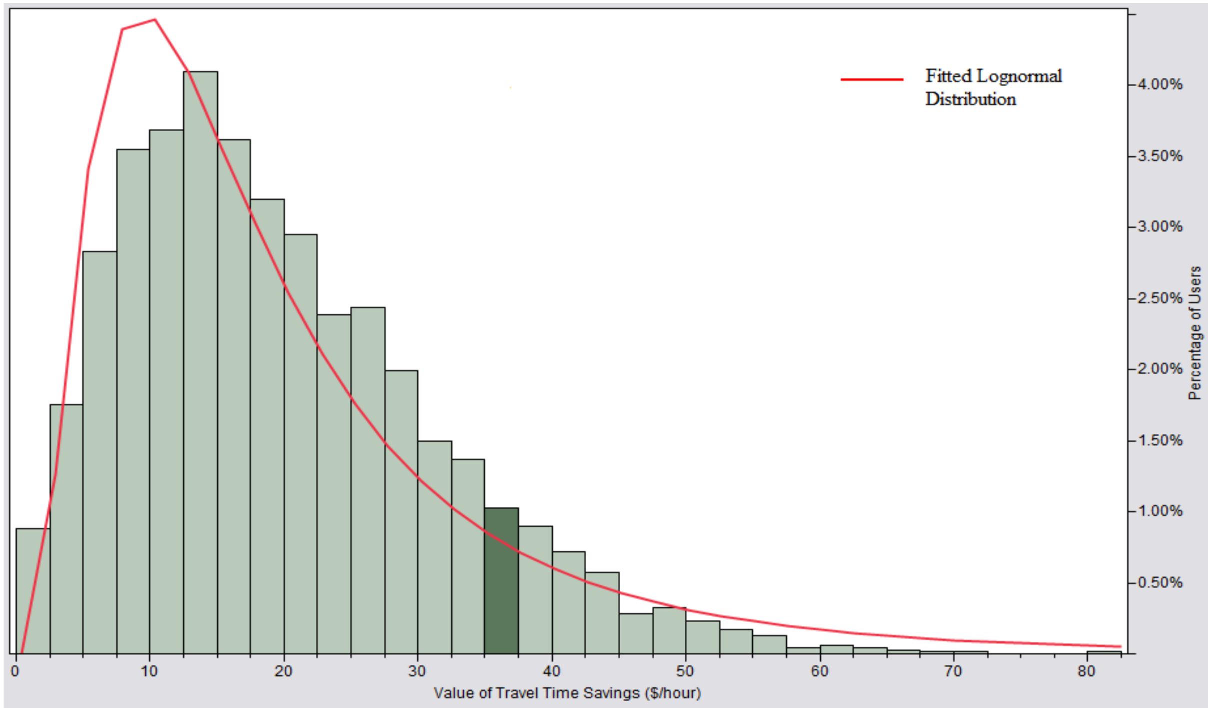

Figure 1: Value of Travel Time Distribution with Fitted Lognormal Distribution

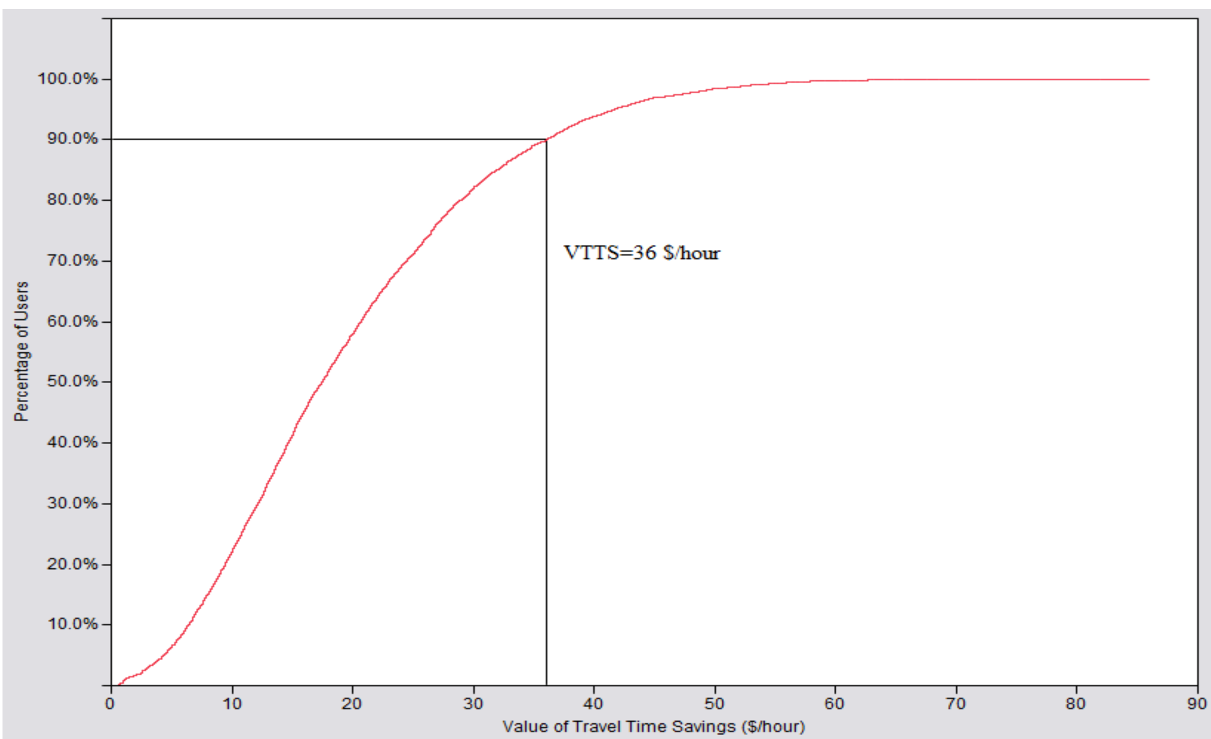

Figure 2: Cumulative Distribution for Value of Travel Time Savings

Researchers also investigated the potential differences in the distribution of the value of time for travelers on the six different roadways. There was almost no difference in the value of time for travelers from the multiple freeways, so all six freeways have the same default value of time distribution as shown in Figures 1 and 2. Note that this is another variable the user can adjust in the Traffic and Revenue spreadsheet.

In section 3.2 we began an example where 10 percent of SOV travelers on the GPLs could be accommodated on the HOT lane. Assume, in this case, the travel time savings was 8 minutes. We can use Figure 2 to determine the proper toll rate. From Figure 2 only 10 percent of travelers have VTTS greater than $36/hour or $0.6 per minute. For 8 minutes of travel time savings the appropriate toll rate would be $4.8. This would be rounded to the nearest 25 cents, in this case $4.75. This is the toll displayed in the traffic and revenue spreadsheet. This toll is multiplied by the number of toll paying SOVs to get total revenue in each 15–minute block of time. A total of 250 revenue days per year was assumed.

3.6 Future Year Estimates

To estimate future year traffic volumes and revenues many assumptions were made based on existing historical data from the freeway facilities. However, since the future is exceedingly difficult to predict, most of these variables can be modified by the user of the traffic and revenue spreadsheet. To begin, the roadways were assumed to continue to exist as they are in 2009. No major changes, like a roadway widening, can be entered into the spreadsheet.

Traffic and congestion on these roadways has generally grown over time. The spreadsheet assumes a traffic growth rate of 3 percent per year on the GPLs and 1.5 percent per year on the HOV lanes. Both of these can be modified by the user for each roadway. The growth in traffic will directly impact travel speeds on the lanes (and therefore toll rates and revenues). For the GPLs historical speed-flow data was examined to determine the relationship between traffic volumes and travel speeds. This relationship generally follows the trends shown in Figure 3.

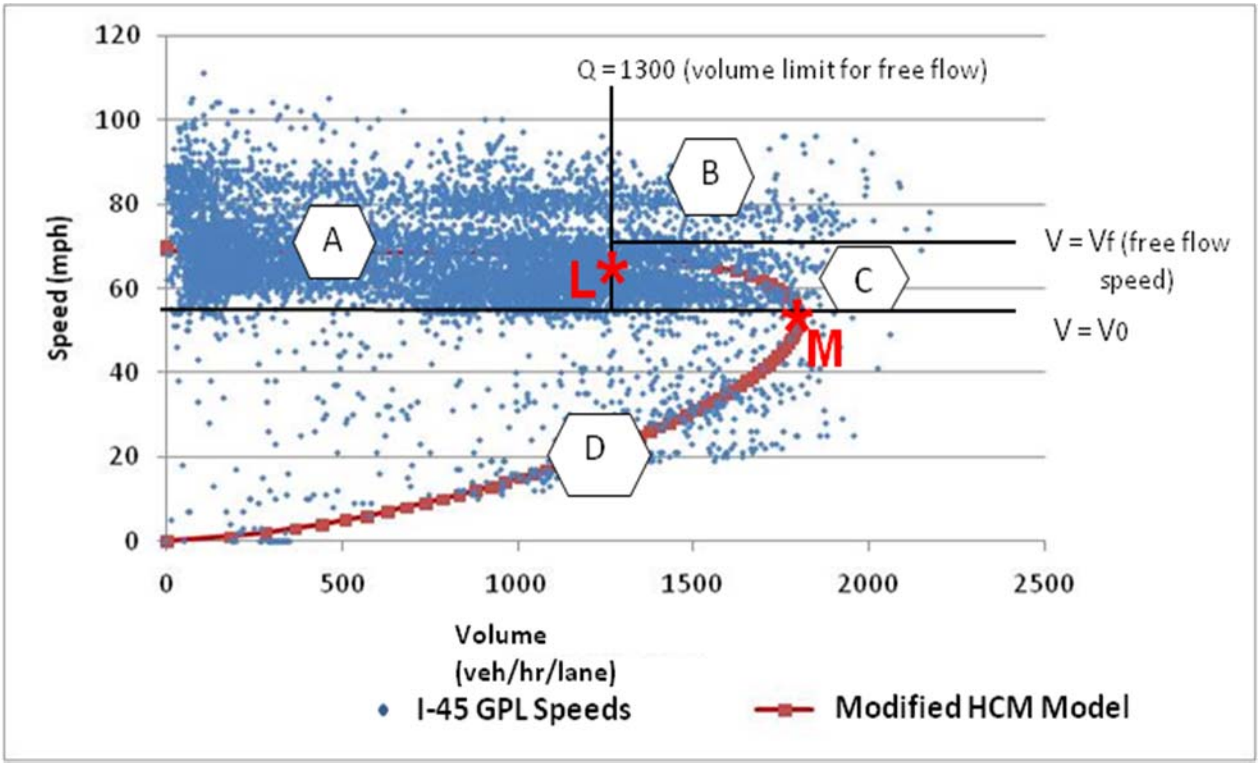

Figure 3: Speed-Flow Relationship for the GPL Traffic

To adjust the speeds on the GPL, the graph was divided into four different sections, labeled A, B, C and D in Figure 3. Table 7 provides the details for each section. The speeds are derived using these relationships until they drop to a minimum GPL speed. At that point the speeds remain at that minimum level. Without this 'floor' speeds would continue to decrease over the 20 year period to unrealistically low levels. In practice there is generally some minimum speed at which freeways bottom out. However, this can be set to whatever speed the user wants (including 0 mph). The default minimum average speed over a 15-minute period is 30 mph.

The speed flow relationship on the HOT lanes was considerably easier to develop. Based on HOT lane speed–flow data the relationship in Equation 4 was derived. A constant speed reduction of -0.01 mph/vehicle was used to adjust the speeds with growth in traffic, however the user can change this value in the Traffic and Revenue file as an input value. No minimum was required as volumes were set not to exceed 1500 vph.

$$Adjusted\ Speed = Old\ Speed + (New\ Volume - Old\ Volume) \times (-0.01) \quad \ldots(4)$$

Finally, whenever predicting cash flow in future years a discount rate must be used. The default rate was used in the spreadsheet is 3 percent – this can be modified by the user.

Table 7: Description of Implementation of Traffic Stream Model

Section	Specification	Description
A	Q<=1300, V>=Vo	No change in speed as long as volume was equal to or below 1300 vph.
B	Q>1300, V>Vf	When volume increased above 1300 vph, but speeds remained higher than the assumed free flow speed, a constant speed reduction factor based on the slope of the line joining the point L and M was used.
C	Q>1300, Vo<=V<=Vf	A modified HCM model was used to predict the change in speed with increased volume. The user can change the parameters according to any situation on any roadway. Modified HCM model: $$Q=Q_o \left(\frac{V}{V_0}\right)^{\alpha}\left(\frac{V_f - V}{V_f - V_0}\right)^{1/\beta} \quad \ldots 5$$ where, α and β are parameters such that, $\alpha \leq 1$ and $\beta > 0.$ Qo = Maximum flow level (veh/hr/lane) Vo = Corrosponding speed at Qo (km/hr) Vf = Free-flow speed (km/hr)
D	V<Vo	When speeds drop below the assumed speed at maximum flow, it was difficult for the model to predict the speed decrease with the increased volumes since according to the model both speed and volumes should decrease at the same time. Hence, for the simplicity a constant arbitrary speed reduction coefficient was assumed for this section, user can also modify it according to the needs in the T&R file.

3.7 Occupancy Requirements

Researchers examined the traffic data to identify any time periods where the HOV lanes may have to adjust occupancy levels. Currently, only the Northwest Freeway requires an occupancy level greater than 2 people at any time of day – and this only occurs from 6:45 to 8:00 am. Otherwise all lanes are open to HOV2+, motorcycles, buses, vanpools and law enforcement vehicles.

The impetus behind adjusting Northwest Freeway's occupancy requirement to HOV3+ during the morning peak, and the reason to adjust any of these lanes to more restrictive occupancy requirements, would be congestion in the lanes. This can be measured by travel speeds in the lanes. Based on the 2007 speed data collected, there were only three time periods where average speeds on the HOV lanes dropped below 50 mph (see Table 6).

Table 8: Slow Speeds on the HOV Lanes

HOV Lane	Time of Day	Average Speed (mph)
I-45 North	7 to 8 am	46
I-45 Gulf	7:15 to 8 am	47.6
US 290 Northwest	5 to 6:30 pm	39.5
US 59 Southwest	None	
US 59 Eastex	None	

These three time periods are therefore potential candidates for increasing occupancy requirements to HOV 3+. However, based on the amount of violations that occur on these lanes, combined with the fact that the traffic volumes did not exceed 1500 vph by much, researchers recommend not going to HOV 3+ yet. The first step should be to convert to HOT lanes and increase enforcement – fully expecting no extra room for paying SOVs during these time periods. If, after this increased enforcement has had an opportunity to work, there still exists time periods of degraded service the authority should consider raising the occupancy requirements.

3.8 Impact of Violators

Since there were a significant percentage of violators on the HOV lanes, it was important to take violation rates into consideration to make the correct estimates of traffic and revenues on the HOT lanes. It is likely that after the implementation of HOT lanes, violation rates will go down with increased law enforcement. This was assumption is based on the additional funds spent on additional officers (see Section 2.3). Additionally, the fact that current violators could now pay a toll and use the HOT lanes as an SOV would cause some to switch from violators to toll paying customers. However, to develop a conservative estimate, the default value for the current violation rate was assumed to be 10 percent and 10 percent was used for the future violation rate. Note that the traffic and revenue spreadsheet allows users to change both current and future violation rates as an input value. Equation 5 is how violation rates would be used to adjust the volumes on the HOT lanes. If the user changes these default values to where violators decrease, this would result in additional space for paying SOVs.

$$\text{Adjusted HOT Volume} = \text{Current HOT Volume} \times \left(1 - \frac{\text{Current Violation rate} - \text{Future Violation Rate}}{100}\right) \quad \dots(6)$$

Based on all of these assumptions, the total revenues were calculated to be $408 million over 20 years (in 2008 dollars).

4.0 Results and Conclusions

Using the traffic and revenue spreadsheet with the default values discussed in previous sections of this technical memorandum, the total 20–year revenues (in 2008 dollars) is $408 million. This estimate is based on a number of relatively conservative assumptions, including:

- HOV lane entry penalty of 2 minutes on each lane
- a minimum travel time savings of 3 minutes on each lane
- 250 revenue days per year
- lanes only open from 5:00 am to 11:00 am and 2:00 pm to 8:00 pm.

It also assumes:

- no significant changes to the GPLs. An expansion to these lanes will greatly decrease potential revenues.
- most travelers are traveling the full length of the HOT lane and receive all of those travel time savings.

Costs were based on Houston METROs own estimate and totaled $275 million for the 20 years. Therefore, these estimates predict $133 million in revenues from these lanes over 20 years. Of course this is dependent on many assumptions, including those listed above and no significant changes in the economy or the operation of transportation system in Houston.

Appendix

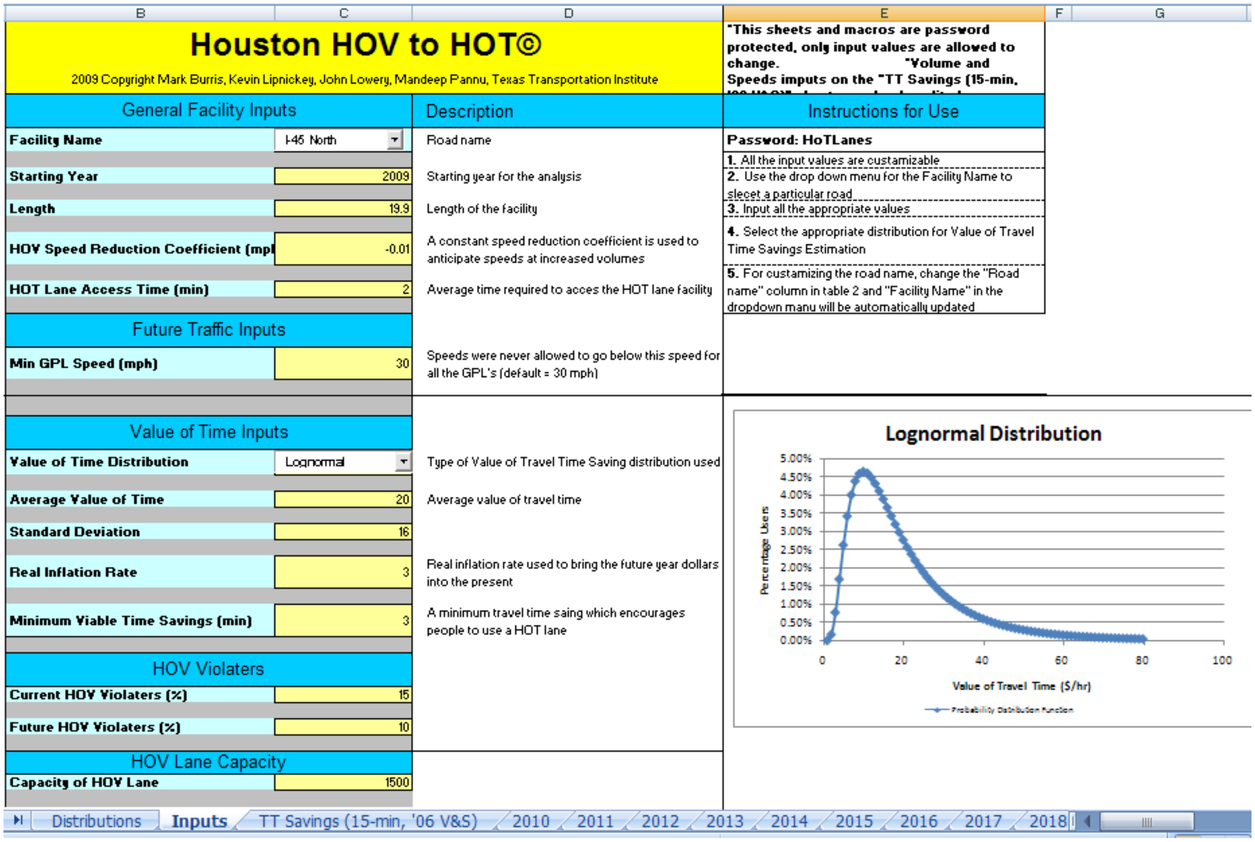

Figure 4: Screenshot of Input Worksheet of T&R Spreadsheet File

B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
I-45 North	**GPL**		HOV				Calculations							
Time	TTI 2007 Wavetronix GPL Volume (veh/hr)	TxDOT 2007 AVI GPL Speed	TxDOT HOV Vol - Dec 2007, Mar 2008, June 2008 Avg (veh/hr)	HOV Capacity (veh/hr)	HOV Remaining Space (veh/hr)	TxDOT 2007 AVI HOV Speed	GPL Travel Time (hr)	HOV Travel Time (hr)	Travel Time Savings (min)	TTS minus Access Time (min)	Min VOT of those who will switch ($/hr)	Toll Rate ($)	Equivalent Toll Rate ($)	Revenue ($/day)
5:00	1488	68.1	348	1500	1152	70.8	0.29	0.28	0.67	0.00	9.20	0.00	0.00	0.00
5:15	2108	67.9	532	1500	968	68.8	0.29	0.29	0.23	0.00	16.79	0.00	0.00	0.00
5:30	2754	66.8	654	1500	846	67.6	0.30	0.29	0.21	0.00	22.27	0.00	0.00	0.00
5:45	3303	64.0	730	1500	770	65.1	0.31	0.31	0.33	0.00	26.08	0.00	0.00	0.00
6:00	3972	56.9	1029	1500	471	62.4	0.35	0.32	1.83	0.00	35.85	0.00	0.00	0.00
6:15	4439	48.3	1194	1500	306	59.4	0.41	0.34	4.60	2.60	44.36	1.92	2.00	152.81
6:30	4529	45.1	1500	1500	0	55.7	0.44	0.36	5.05	3.05	0.00	0.00	0.00	0.00
6:45	4720	42.2	1500	1500	0	52.6	0.47	0.38	5.61	3.61	0.00	0.00	0.00	0.00
7:00	4930	39.2	1309	1500	191	48.6	0.51	0.41	5.88	3.88	54.05	3.50	3.50	167.29
7:15	5251	35.4	1431	1500	69	43.3	0.56	0.46	6.11	4.11	74.52	5.11	5.00	86.32
7:30	5410	35.0	1254	1500	246	43.3	0.57	0.46	6.54	4.54	51.25	3.88	4.00	246.48
7:45	5097	38.1	1026	1500	474	47.3	0.52	0.42	6.08	4.08	39.59	2.69	2.75	325.90
8:00	4720	41.3	977	1500	523	53.0	0.48	0.38	6.39	4.39	36.90	2.70	2.75	359.49
8:15	4727	43.1	796	1500	704	58.3	0.46	0.34	7.25	5.25	32.48	2.84	2.75	484.12
8:30	4359	45.0	683	1500	817	61.8	0.44	0.32	7.20	5.20	29.15	2.53	2.50	510.82
8:45	4080	47.9	489	1500	1011	64.8	0.42	0.31	6.52	4.52	25.21	1.90	2.00	505.72
9:00	4084	51.0	365	1500	1135	66.0	0.39	0.30	5.30	3.30	23.64	1.30	1.25	354.65
9:15	4047	55.0	325	1500	1175	66.5	0.36	0.30	3.73	1.73	23.04	0.66	0.75	220.26
9:30	4213	56.4	252	1500	1248	66.7	0.35	0.30	3.25	1.25	22.76	0.47	0.50	156.00
9:45	4356	58.0	192	1500	1308	66.9	0.34	0.30	2.75	0.00	22.57	0.00	0.00	0.00
10:00	4066	59.3	89	1500	1411	67.1	0.34	0.30	2.34	0.00	20.59	0.00	0.00	0.00
10:15	4074	60.0	90	1500	1410	67.5	0.33	0.29	2.22	0.00	20.63	0.00	0.00	0.00
10:30	3824	60.7	87	1500	1413	67.8	0.33	0.29	2.05	0.00	19.74	0.00	0.00	0.00
10:45	3539	61.4	64	1500	1436	67.9	0.32	0.29	1.84	0.00	18.47	0.00	0.00	0.00
TOTAL:														11850.12

I-45 Gulf														**I-45 Gulf**
Time	TTI 2008 GPL Wavetronix Volume (veh/hr)	TxDOT 2006 AVI GPL Speed	TxDOT HOV Vol - Dec 2007, Mar 2008, June 2008 Avg (veh/hr)	HOV Capacity (veh/hr)	HOV Remaining Space (veh/hr)	TxDOT 2006 AVI HOV Speed	GPL Travel Time (hr)	HOV Travel Time (hr)	Travel Time Savings (min)	TTS minus Access Time (min)	Min VOT of those who will switch ($/hr)	Toll Rate ($)	Equivalent Toll Rate ($)	Revenue ($/day)
5:00	1656	67.9	10	1500	1490	68.5	0.23	0.23	0.13	0.00	6.36	0.00	0.00	0.00
5:15	2345	67.7	35	1500	1465	66.9	0.23	0.23	-0.17	0.00	12.49	0.00	0.00	0.00
5:30	3216	66.0	81	1500	1419	65.2	0.23	0.24	-0.16	0.00	17.33	0.00	0.00	0.00
5:45	3880	62.9	175	1500	1325	63.7	0.25	0.24	0.19	0.00	20.81	0.00	0.00	0.00
6:00	4412	54.7	307	1500	1193	62.4	0.28	0.25	2.11	0.00	24.02	0.00	0.00	0.00
6:15	4878	42.8	600	1500	900	59.9	0.36	0.26	6.20	4.20	29.38	2.06	2.00	449.80

Distributions / Inputs / TT Savings (15-min, '06 V&S) / **2010** / 2011 / 2012 / 2013 / 2014 / 2015 / 2016 / 2017 / 2018

Figure 5: Screenshot of the T&R File for Traffic and Revenue Estimation for any Particular Year