A NEW PARADIGM IN USER EQUILIBRIUM –

APPLICATION IN MANAGED LANE PRICING

by

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ABSTRACT

A NEW PARADIGM IN USER EQUILIBRIUM – APPLICATION IN MANAGED LANE PRICING

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Ineffective use of the High-Occupancy-Vehicle (HOV) lanes has the potential to decrease the overall roadway throughput during peak periods. Excess capacity in HOV lanes during peak periods can be made available to other types of vehicles, including single occupancy vehicles (SOV) for a price (toll). Such dual use lanes are known as "Managed Lanes." The main purpose of this research is to propose a new paradigm in user equilibrium to predict the travel demand for determining the optimal fare policy for managed lane facilities. Depending on their value of time, motorists may choose to travel on Managed Lanes (ML) or General Purpose Lanes (GPL). In this study, the features in the software called Toll Pricing Modeler version 4.3 (TPM-4.3) are described. TPM-4.3 is developed based on this new user equilibrium concept and utilizes it to examine various operating scenarios. The software has two built-in operating objective options: 1) what would the ML operating speed be for a specified SOV toll, or 2) what should the SOV toll be for a desired minimum ML operating speed.

A number of pricing policy scenarios are developed and examined on the proposed managed lane segment on Interstate 30 (I-30) in Grand Prairie, Texas. The software provides quantitative estimates of various factors including toll revenue, emissions and system performance such as person movement and traffic speed on managed and general purpose

lanes. Overall, among the scenarios examined, higher toll rates tend to generate higher toll revenues, reduce overall CO and NOx emissions, and shift demand to general purpose lanes. HOV preferential treatments at any given toll level tend to reduce toll revenue, have no impact on or reduce system performance on managed lanes, and increase CO and NOx emissions.

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CHAPTER 1

INTRODUCTION

The complexities involved in expanding roadway networks to accommodate traffic growth pose a challenge to transportation agencies. In order to improve traffic congestion, an effective solution needs to address several issues such as high construction costs, right-of-way constraints, and social and environmental impacts. These factors are primarily considered in many roadway improvement projects. Especially in the urbanized areas where demand increases rapidly but right-of-way is limited, these factors prevent capacity expansion, which leads to increasing traffic congestion, delays, fuel consumption, and emissions (Federal Highway Administration 2004).

Raising the capacity on congested corridors can be achieved by several options such as building a parallel elevated section or a tunnel along the corridors. Such approaches are generally very costly. Building completely new roads through congested urban corridors is also usually not viable due to a lack of right-of-way availability. As such, when new capacity is added, transportation planners use lane management strategies to manage flows on freeway networks. In many states, special uses of lanes such as express lanes, high-occupancy-vehicle (HOV) lanes, high-occupancy-toll (HOT) lanes and managed lanes (ML) are implemented to manage demand and reduce travel time, fuel consumption and emissions in urban areas.

As an alternative to reduce travel time, HOV lanes, which allow high occupancy vehicles to travel on these lanes for free, were introduced during a time of high fuel price and public demand for better mobility. These lanes provided priority to HOVs to encourage carpooling so that the number of cars on the road might be reduced and result in lower travel times, fuel consumption, and emissions. Even though this concept was somewhat successful in reducing overall congestion, these lanes were not necessarily operated to maximize the entire corridor throughput. Due to this reason, lane management concepts such as managed lanes were introduced.

Previous studies (Burris et al. 2007; Li and Cole et al. 2002; Sadabadi 2006) show a high level of interest in the managed lane concept in urbanized areas. The potential users on managed lanes refer to several user types such as single occupancy vehicles (SOV), high occupancy vehicles, van-pools, motorcycles, buses and trucks. The concept of managed lanes is to provide free access for certain user classes while offering any excess capacity to other classes for a toll. The widely known advantage of managed lanes is their utilization of an excess capacity of HOV lanes (Dahlgren 1999). The operation offers the flexibility of adjusting the tolls and policies depending on the traffic demands and regional objectives.

Recently, managed lanes have become the primary option in attempts to reduce traffic congestion by many agencies. This lane concept is suitable for implementing congestion pricing in corridors, for instance, a highway through a downtown area where adding new general purpose lanes (GPL) is not feasible. Instead, a GPL is converted for a special use, called the managed lane. On a typical setting, the freeway lanes are designated as either managed lanes or general purposed lanes.

1.1 Managed Lanes in the United States

Table 1.1 (TTI 2007) shows seven managed lane projects that are operating with a toll component in the United States in 2007. There are two projects in both Texas and California, and one project in Colorado, Minnesota and Utah. The I-15 Express Lanes project in Salt Lake City, Utah has the longest operating section of 38 miles. In the United States, the first managed lane project was the SR 91 Express Lane in Orange County, California (91 Express Lanes 2009). Currently, this project has four managed lanes that vary the tolls depending on the current condition on the roadway. Table 1.2 (TTI 2007) shows two managed lane projects that were under construction in the United States in 2007. The projects are in Texas and Maryland. The Katy Freeway (I-10) extension in Houston, Texas, is now finished and operated with the first multi-lane electronic toll collector in the nation (Katy Freeway 2009). Table 1.3 (TTI 2007) summarizes the managed lane projects that are being developed and will be implemented in the United States. As seen, many transportation agencies are considering managed lanes to alleviate the traffic congestion in their respective areas. The Texas Department of Transportation (TxDOT) is currently evaluating traffic demands and patterns to determine appropriate toll amounts and policies for their I-30 managed lane facility in Dallas-Fort Worth area.

Table 1.1 Operating managed lane projects with pricing component

Location	Name	Length (miles)	Total Lanes
Houston, Texas	Katy I-10 QuickRide	13	1
	Northwest US 290 QuickRide	13.5	1
Minneapolis, Minnesota	I-394 MNPASS	11	2
San Diego, California	I-15 FasTrak	8	2
Orange County, California	SR 91 Express Lanes	10	4
Denver, Colorado	I-25 HOT Lanes	6.5	2
Salt Lake City, Utah	I-15 Express Lanes	38	2

Table 1.2 Under-construction managed lane projects with pricing component

Location	Name	Length (miles)	Total Lanes
Houston, Texas	Katy I-10 QuickRide	23	4
Baltimore, Maryland	I-95 Kennedy Expressway Express Toll Lanes	9	4

Table 1.3 Developing managed lane projects with pricing component

Location	Name	Length (miles)	Total Lanes
Austin, Texas	Loop 1 (MoPac)	11	2
Dallas / Ft. Worth, Texas	I-635 LBJ Managed Lanes	24	4
	I-30 Managed Lanes	60	2
	I-820/SH183 Managed Lanes	27	2
	I-35W Managed Lanes	20	2
Houston, Texas	SH 288 Managed Lanes	18	4
Seattle, Washington	I-405 Managed Lanes	30	4
	SR 167 HOT Lanes	9	2
San Diego, California	I-15 FasTrak Expansion	20	4
	I-5 HOT Lanes	32	4+
	I-805 Managed Lanes	27	4
San Francisco Bay Area, California	I-680 HOT Lane	14	2
Denver, Colorado	US 36 Express Toll Lanes	25	4
	I-70 Express Toll Lanes	10	4
	C-470 Express Toll Lanes	14	4
	I-25 North Express Toll Lanes	26	2 to 4
	I-70 Mountain Corridor	35	2
Miami, Florida	I-95 HOT to HOT Express Toll Lanes	12	3
Ft. Lauderdale, Florida	I-595 Express Lane	13	2
Atlanta, Georgia	I-285 HOT Lanes	14	2
	I-75/I-575 HOT Lanes	36	4
	GA 400 HOT Lanes	20	4
Maryland	Intercounty Connector (ICC)	18.8	6
	I-270 Express Toll Lanes	23	2 to 4
	I-495 Capital Beltway Express Toll lanes	42	2
Raleigh/Durham, North Carolina	I-40 HOT Lanes	20	1
Portland, OR	Highway 217 Express Toll Lanes	8	2
Salt Lake City, UT	I-15 Express Lane Extension	9.5	2
Virginia	I-495 Capital Beltway HOT Lanes	12	4
	I-95/I-395 HOT Lanes	54	3 and 2

A variety of toll policies are implemented around the United States. For example, the QuickRide program in Houston (Burris and Stockton 2004) allows vehicles with two occupants (HOV2) to use the lanes for free in the off-peak and pay a toll to access the lanes during peak periods. In Minneapolis, the I-394 MNPASS (MnPASS 2009) operates their toll facility with a reversible managed lane. On their facility, HOVs are not charged to use the tolled lanes. However, SOVs are charged a toll based on the demand, and the toll varies in amount by time of day.

During the past few years, impact analyses of managed lanes in the United States indicate an improvement in traffic throughput when this lane management strategy is implemented (Berg et al. 1999; Burris et al. 2000; Cambridge Systematics, Inc. et al. 2005; Cambridge Systematics, Inc. et al. 2006; Fielding and Klein 1993; He et al. 2003; Hickman et al. 2000; Sullivan 2000; Supernak et al. 1999). This improvement results in reductions in travel time, fuel consumption and emission and an increase in revenue (Burris and Sullivan 2006). However, in many cases, the demand for managed lanes has been increasing and is forecast to exceed the existing facility's capacity (Swisher et al. 2002). Eventually, this will create a traffic problem on existing managed lanes. Therefore, more effective operating strategies may be needed to achieve the objectives of such facilities.

1.2 Managed Lane Operating Objectives

The TxDOT Research Monitoring Committee has given a definition of managed lane as *"A managed lane facility is one that increases freeway efficiency by packaging various operational and design actions. Lane management operations may be adjusted at any time to better match regional goals."* (Kuhn et al. 2005). This quote is a good indication that the objective of the managed lane operation is an important factor driving the projects and controlling the operating strategies.

The use of managed lanes as implemented today was based on several years of research and development. In 1995, California successfully implemented the express toll lane on State Route 91 in Orange County. This facility became the basis for the design of the managed lanes in many other venues. The development of managed lanes was the combination of roadway design and lane management by using a variety of strategies to meet the operating objectives. In 2004, the Federal Highway Administration (2004) documented the various operating objectives of the managed lane facilities in the United States as follows:

- To provide a travel option to road users without spending public dollars, for example, SR 91 Express lanes (91 Express lanes 2009)
- To utilize the available capacity in the HOV lanes, for example, I-15 FasTrak (FasTrak 2009)
- To generate the revenue to fund public transit, for example, I-15 FasTrak (FasTrak 2009)
- To increase or maintain a desired level of performance such as a minimum operating speed on tolled lanes, for example, I-10 QuickRide (QuickRide 2009) and I-394 MnPASS (MnPASS 2009)
- To shift the demand out of peak hours, for example, New Jersey Turnpike (E-Z Pass 2009)
- To minimize the overall travel time on the networks, for example, I-394 MnPASS (MnPASS 2009)

Due to the unique characteristics of the managed lane facilities, every project requires an appropriate operating strategy to manage the flows on the networks to meet the facility objectives. This operating strategy can combine several actions to optimize the lane utilization. The Federal Highway Administration (2008) summarizes the operational techniques employed by the managed lane facilities to manage the demands on the network and meet the project objectives as follows:

- Increasing toll rates on managed lanes to maintain a minimum speed

- Increasing the occupancy requirement to travel on managed lanes so that the operating speeds can be maintained
- Closing an on-ramp to the tolled lanes during peak hours to maximize the lane capacity

In addition to the operating strategy, an important element that supports the implementation of the toll lanes is electronic toll collection. This intelligent transportation system (ITS) technology is necessary in order to enhance the performance of managed lanes facilities. Many researchers (Chang et al. 2002; Li and Jie 2009) discovered that this technology helps in maintaining uninterrupted flows on the tolled lanes. Without automatic toll collection, the managed lane facility cannot effectively meet its objectives.

1.3 Toll Pricing Strategies

Previously, all motorists were allowed to use toll facilities and were charged a fixed toll rate. Many economists suggested other approaches and constraints for establishing a toll rate (Gross and Gavin 2009). For example, on uncongested roads, Sharp et al. (1986) proposed a toll rate to be set equal to operating costs. Ragazzi (2005) suggested that the operations-plus-capital-cost toll can subsidize the general lane users and taxpayers. As a result, these average-cost pricing models set a toll at a certain amount. This operating policy, which allows all vehicle classes to enter the toll road and pay a single rate, would simplify the operational requirements such as the toll setting, operating strategy, system complexity, operating cost, and technology deployment. However, allowing all travelers to access the toll lanes would eventually reduce the facility performance (Swisher et al. 2002).

Figure 1.1 (Federal Highway Administration 2008) illustrates an example of HOV traffic growth over time on managed HOV lanes. The study shows that the projection of managed lanes users increases over time and eventually reaches the road capacity. In other words, a managed lane facility that operates by giving free access to HOV2+ and charging the SOV will eventually become congested due to capacity being exceeded by the HOV2+. As a result, a new policy is needed to solve traffic congestion on managed lanes. In this case, a lack of ability to predict the potential users for each mode in the previous models make planning an optional operating policy difficult. Therefore, a pricing strategy should be capable of analyzing a plan that combines several toll policies among the modes. For examples, as proposed by some transportation agencies, HOV2 could be charged less than SOV and HOV3+ could get free access (NCTCOG 2009). If congestion problems continue on the corridor due to increases in the HOV2 volume, preferential access could only be provided to HOV3+ vehicles.

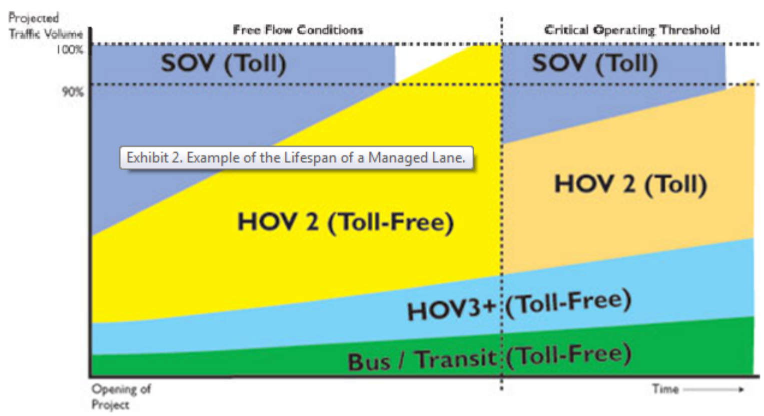


Figure 1.1 Life span of a managed lane.

As mentioned previously, due to the underutilization of the HOV facilities, toll pricing strategies have been implemented to utilize the excess capacity on the managed lane facility. However, a number of questions must still be addressed, including how many additional users should be allowed on managed lanes without reaching an unacceptable level of performance, and what should the toll value be corresponding to this level of additional users. These questions pose a challenge for toll pricing studies that attempt to predict the potential users based on toll charges.

Especially, the challenge increases for the facilities that operate using a variety of toll pricing scenarios. Examples may include allowing three classes of vehicles to access the ML and tolling them differently, as well as varying the toll amount by time of day and even day of week. Since flow rates on managed lanes are affected by dynamic toll rates, the pricing strategies become more complex and require a good understanding of changes in demand with respect to toll amounts. Even though previous pricing studies have proposed concepts for pricing the managed lanes to effect a desired level of demand, such concepts are not practical for facilities with various toll rates by class of vehicle and time of day.

Many of the previous studies incorporate an average value of time (VOT) to predict demands and tolls in their respective models. Parsons Brinckerhoff (2002) uses the average wage rate to determine the VOT. In their study, the overall network travel time is optimized. Then, one third the average is used as the "low VOT" and one-half the average wage rate is used as the "base VOT" to generate the toll rates for toll roads in Washington State.

Li and Govind et al. (2002) developed a tool for the evaluation of pricing strategies using users' willingness to pay as derived from survey data. Their study has shown that the willingness to pay differs among vehicle classes. Therefore, the assumption that all vehicle classes will have the same response at a certain toll rate seems unreasonable and thus does not allow an accurate prediction of the level of utilization of managed lanes.

He et al. (2003) presents a model to assess the impact of the managed lanes on the I-394 corridor in Minnesota. The proposed model is an analytical multiclass stochastic dynamic transportation network model with Monte Carlo simulation and the method of successive averages. They assume a homogenous population of users, so the differences in VOT between the modes are not captured. To achieve an accurate prediction for various classes, the specific VOT distribution of each vehicle class must be used to predict the travel demands.

More recently, Wilbur Smith has conducted a toll revenue estimation study for the I-30 Reversible Managed Lanes (WSA 2007). Their estimates are based on the travel demand model databases developed under basic assumptions provided by NCTCOG and micro-simulation using VISSIM. After the model is built, the median VOT is used and several scenarios are examined to measure the impact of different toll rates.

The Toll Pricing Model (TPM-3.1) (Ardekani 2008) is developed based on the concepts of price elasticity and the speed-flow-concentration model. TPM-3.1 uses the values for the percentage of users' willing to pay a certain toll based on data from "stated-preference" surveys. The software can do demand analysis based on one of two objectives. One objective is maintaining a minimum operating speed at a certain level while another is estimating the ML demand and the corresponding operating speed based on a pre-specified toll charge.

Recently, Yin and Lou (2009) proposed two toll pricing approaches for managed lane facilities. The first approach applies the concept of a feedback control to determine a toll rate. This concept is easy to implement and requires only one loop-detector. The second concept learns the managed lane users' willingness to pay and determines the pricing strategies to meet the facilities' objectives. This approach requires two sets of loop-detectors to measure the flow rates to be used in calibrating the model parameters.

A key element affecting the toll pricing study is the VOT of toll users. Due to a variety of VOTs across the user modes, the model should incorporate this variable based on the vehicle classes to predict the toll users. An accurate prediction can be obtained by using an appropriate distribution from a survey.

1.4 Use of Value of Time

Forecasting traffic demand on toll roads by using the value of time distributions increases the challenge for toll pricing studies. This is particularly the case for facilities that operate using value pricing concepts because toll rates must respond to demand (Burris 2003). Since more toll rates must be selected and examined during the day, the likelihood of errors increases. Depending on the analysis technique selected for setting the toll, these errors may be more pronounced.

As an input, the VOT distributions can be estimated and established to represent the users' willingness to pay. In recent years, toll pricing studies have emphasized the importance of the users' value of time. This is because the estimates of the mean and the users' VOT distribution are associated with inaccuracies in the travel demand forecast. The basic VOT distribution formulation considers the percentage of potential users that are willing to pay a certain cost for a given time saving. However, the formulation can be extended to consider variables other than time savings alone. Lake and Ferreira (2002) indicate that increasing income also increases VOT. Zamparini and Reggiani (2007) show that the business-related commute trip has a very high VOT compared to other trip proposes. These variables, such as trip purpose, income and time of day, are more likely to influence the importance of the travel time savings for a user as opposed to having a fixed value attributable to them.

Conducting toll pricing research is a resource and time demanding process that requires data collection and analysis. To achieve quality results, an effective analysis strategy is required; however, the data collection costs and analysis time must also be considered when selecting an analysis strategy. Therefore, a method that leads to an acceptable result without unnecessary time and financial costs is preferred in meeting the research goal.

A variety of techniques may be utilized to conduct toll road traffic demand forecasts. For a managed lane facility, the toll lane's demand, which is based on the VOT analysis technique and toll rate, is usually managed to maintain an operating objective. The operating objective could be a guaranteed minimum speed, which in turn depends on the observed demand. Depending on trip makers' characteristics and overall user volume, a toll can be precisely determined for the toll lane to meet the specified operating objectives. In Minnesota, Douma et al. (2005) derived a mean of about 10 dollars per hour and used an average VOT in the mode choice forecasting model for commute trips. Parsons Brinckerhoff (2002) used the average wage rate to determine the VOT. In their study, one third the average or $7.9 per hour was used as the "low VOT" and one-half the average wage rate or $11.8 per hour was used as the “base VOT” to generate the toll rates for toll roads in Washington State. An average VOT might not be the best input for a dynamic toll pricing model. Hensher and Goodwin (2004) summarized a total of four options for evaluating the VOT distribution used in demand forecasting models.

- Option I: Use the full distribution
- Option II: Take a number of points on the distribution as representative of the distribution
- Option III: Take areas of the distribution and convert to a single weighted average VOT, ensuring that all areas sum to the total area
- Option IV: Use unweighted average or median

Average values of time have been used to represent the distribution and generate the toll rates in past studies to forecast the travel demand. While this seems to be a preferable option due to its simplicity and ease of data collection, the accuracy of the estimate should be considered and verified to ensure realistic estimates.

1.5 Study Objectives

This study has two main objectives. The first is to develop a simulation model for volume assignment between managed lanes and general purpose lanes as a function of toll charged for various vehicle classes. As a result, this study proposes a new paradigm in user equilibrium for managed lane networks in order to examine the various operating scenarios to meet operating objectives. A software package known as the Toll Pricing Modeler version 4.3 (TPM-4.3) is developed based on this framework for determining the dynamic toll rates. The second objective is to characterize the impact of the VOT on user equilibrium assignment. This helps to better understand the volume assignments that are affected by the different VOT distributions. Each region is likely to require specific VOT distributions to examine the proposed operating policies. These specific VOT distributions imply probability of the potential toll users in the area

1.6 Organization of Dissertation

This research has a total of six chapters. In this chapter, managed lanes history and its elements are discussed; this is followed by a literature review and a discussion of study objectives. Chapter two proposes the concept of a new paradigm in user equilibrium and its components. Chapter three demonstrates a description of the VOT distribution estimates and inputs. Chapter four presents the details of a traffic demand model software package (TPM 4.3) that is developed based on this user equilibrium concept. Chapter five validates the model, proposes a number of scenarios examined and shows their results. Finally, the conclusions and recommendations are presented in chapter six.

CHAPTER 2

A NEW PARADIGM IN USER EQUILIBRIUM

In traffic theory, Wardrop's first principle (Wardrop 1952) applies to a network where all the used routes between an origin-destination (O-D) pair has the same travel costs under equilibrium conditions. In other words, no one can decrease their travel costs by unilaterally switching to another route. If time spent to drive on each route is the cost, all routes have an equal travel time under equilibrium. In a managed lane network, however, Wardrop's first principle cannot apply directly to determine the equilibrium flows because managed lanes are intended to have a lower travel time when compared to general purpose lanes. Therefore, a new user equilibrium paradigm for managed lanes is needed for incorporation into managed lane demand models.

2.1 Basic Concept and Components

Managed lanes are intended to provide a better level of service in the travel corridor. A typical managed lane travel corridor consists of two types of lanes: general purpose lanes and managed lanes, as illustrated in Figure 2.1. All travelers can use the general purpose lanes without paying tolls while the managed lanes are tolled with an occupancy restriction. However, the benefit of paying tolls is that the ML travelers are able to experience a higher speed (a lower travel time) relative to GPL travelers in the same travel corridor.

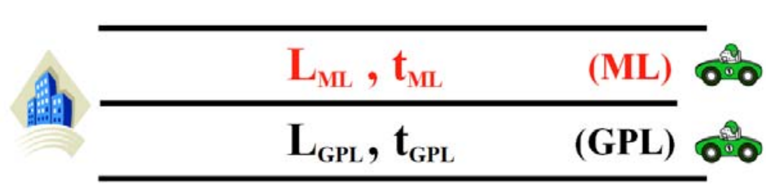


Figure 2.1 Managed lane network components.

A new paradigm entails two important components: Cost of Time Saving (CTS) and Value of Time (VOT). When commuters travel on managed lane networks, they can choose to travel on either managed lanes or general purpose lanes. CTS is the amount per mile that motorists pay for saving one unit of time (usually measured in minutes) if they choose to take the managed lanes. Mathematically, CTS for the ML can be stated as:

$$CTS = \frac{Toll\ \ per\ \ mile\,(\$)}{Travel\,Time\,Saving\ per\,mile} \tag{2.1}$$

$$CTS = \frac{T}{\left[(L_{GPL} \times t_{GPL}) - (L_{ML} \times t_{ML})\right]\ /\ L_{ML}} \tag{2.2}$$

In Equation 2.1, travel time saving per mile is an average travel time saving per mile that motorists can expect to gain when they travel on managed lanes. In Equation (2.2), T is a managed lane toll per mile. L_{GPL} and L_{ML} are corridor lengths of general purpose lanes and managed lanes, respectively. Due to this variable (L), this concept can be utilized to examine an impact of toll pricing on alternative toll versus free highway. Both facilities may have the same origin and destination with the different lengths. In this case, GPL inputs are used for the free highway and ML inputs are used for the alternative toll.

In Equation 2.2, t_{GPL} is the travel time spent for one mile if one chooses to travel on the general purpose lanes and t_{ML} is the travel time spent for one mile if one chooses to travel on managed lanes and pay a toll. The travel times are forecasted based on demand levels using the most common function called the Bureau of Public Roads (BPR) function (Fricker and Whitford 2004). If V is the volume per lane and C is the respective capacity per lane on either general purpose or managed lanes, the travel time (t) for each lane can be computed by the following equations:

$$t_{GPL} = 0.8 \times \left[1 + \left(\frac{V_{GPL}}{C_{GPL}} \right)^4 \right] \tag{2.3}$$

$$t_{ML} = 0.8 \times \left[1 + \left(\frac{V_{ML}}{C_{ML}} \right)^4 \right] \tag{2.4}$$

The second component is the Value of Time (VOT). VOT is the amount that users are willing to pay for one unit of time saved. In the current study, VOT data derived from previous studies in Texas (Mattingly et al. 2004; Goodin et al. 2009) are utilized. Those studies determine the VOT of the potential users of proposed managed lanes on the I-30 segment in Grand Prairie, Texas, between the cities of Arlington and Dallas. Figure 2.2 (Goodin et al. 2009) illustrates an example of the HOV2's VOT distribution derived from the surveys. In general, the VOT distribution can be derived by using survey data or other methods to estimate the value of time of the toll users (Brownstone et al. 2003; Kang and Stockton 2008).

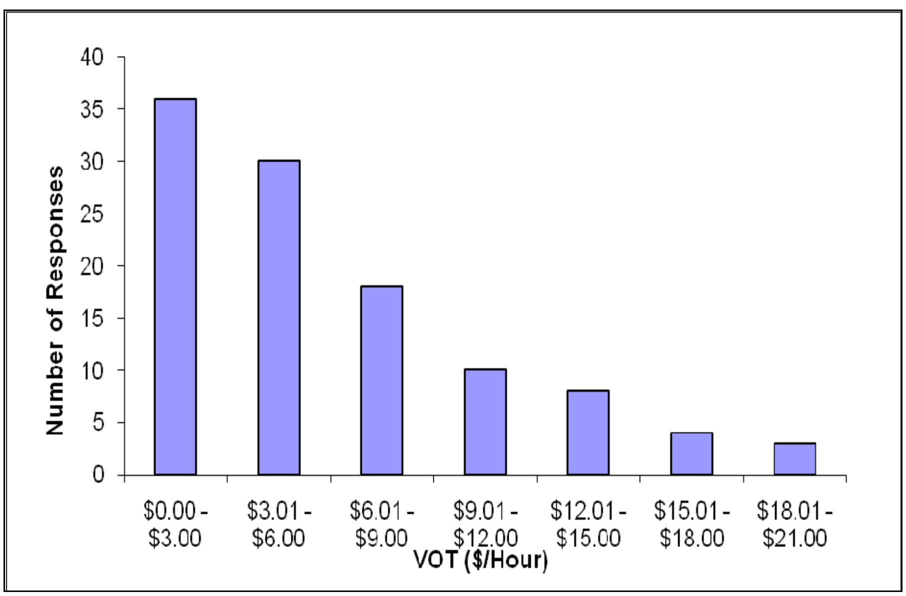


Figure 2.2 Example of HOV2's VOT distribution.

2.2 Initial and Equilibrium States

The basic concept and components involved in this new paradigm are presented in the previous section. These primary components are the significant factors controlling the volume assignments on the managed lane networks. At an initial state, when a toll is not charged on the managed lanes, the volume is assumed to be equally assigned on both managed lanes and general purpose lanes. In this case, the cost of time savings (CTS) of corridors does not play a role. Later, when a charge is implemented on the tolled lanes, drivers who have a value of time (VOT) higher than the CTS will use the managed lanes in order to save time. On the other hand, drivers who have a VOT lower than CTS will not use the managed lanes and will switch to the general purpose lanes. Due to the change in travel time savings when a motorist switches from ML to GPL or vice versa, CTS is recalculated and compared with the remaining ML users' VOT. The decision rules can be stated as follows:

- Zero toll (CTS = 0) → $V_A = V_B$ (Initial loading condition)
- CTS < VOT_i → ML is the choice
- CTS ≥ VOT_i → ML is not chosen

An individual decision (i^{th}) based on their VOT will continually be made on the corridor until the network is stable, i.e., no one else will switch to another lane. At this point, the network's equilibrium is reached and the conditions are satisfied. Under equilibrium conditions, the users' VOT will be equal to the corridor's CTS, i.e., the condition of equilibrium becomes,

$$CTS = VOT \tag{2.5}$$

The general concept of this new paradigm is that *under user equilibrium conditions, traffic arranges itself in such a way that managed lane users' VOT are equal to or higher than the corridor's CTS and the general purpose lane users' VOT are lower than the corridor's CTS.* If homogeneous travelers (No distinction between vehicle classes such as SOV, HOV2, or

HOV3+) are assumed on the corridor, an average VOT distribution can be used to estimate the volume assignments. In reality, however, various vehicle classes are allowed to travel on the managed lane facility. To approximate the volumes at the equilibrium condition on the managed lane networks, the users' VOT distribution has to be defined for each vehicle class and incorporated into the model.

2.3 Incorporation of Multiple Vehicle Classes

Chapter four describes the software features and input options of the managed lane model TPM-4.3. This software is developed as a tool to model the managed lane facility and study the impact of operating policies based on this new paradigm. In general, a managed lane facility can operate using different toll policies for multiple vehicle classes. In order to integrate multiple vehicle classes to the new equilibrium concept, additional procedures are developed as follows.

2.3.1 Value of Time Adjustment

Previous researchers (Goodin et al. 2009) have found that the characteristics of the VOT distributions are different among the vehicle classes. Many studies estimate the value of time functions in term of price and travel time saving. These can be converted into a term of VOT and their respective population by applying a travel time saving (see chapter three). Thus, the proportions of population ($a,b,c,\ldots,z$) based on their VOT can be generated for different vehicle classes (A,B,C,…,Z) and VOT ranges (1,2,3,…,n) as shown schematically in Table 2.1.

Table 2.1 Value of Time distributions

No.	VOT Range ($/hr)	Vehicle Class A	Vehicle Class B	Vehicle Class C	. . .	Vehicle Class Z
1	$0 - VOT_1$	a_1	b_1	c_1	. . .	z_1
2	$VOT_1 - VOT_2$	a_2	b_2	c_2	. . .	z_2
3	$VOT_2 - VOT_3$	a_3	b_3	c_3	. . .	z_3
. . .	. . .	. . .	. . .	. . .	. . . .	. . .
n	$VOT_{n-1} - VOT_n$	a_n	b_n	c_n	. . .	z_n

Theoretically, in the scenarios where tolls are charged differently for different vehicle classes, CTS must be separately calculated for each class due to unequal tolls (T) (Equation 2.2). However, the VOT distributions can be modified in order to utilize only one equilibrium equation by adjusting the percentages of population in each vehicle class. For example, if R_A is a ratio of toll rate of class A compared to the highest toll rate on the facility, an adjusted VOT percentage (a_{1Adj}) can be calculated as follows:

$$a_{1Adj} = a_1 \times R_A \tag{2.6}$$

Accordingly, $a_{2Adj}, a_{3Adj}, \ldots, a_{nAdj}$ can be computed as follows:

$$a_{nAdj} = \left[\frac{(VOT_n \times R_A) - VOT_{k-1}}{VOT_k - VOT_{k-1}} (a_k) + \sum_{i=1}^{k-1} a_i \right] - a_{n-1Adj} \tag{2.7}$$

k is the range number where the result of $VOT_n \times R_A$ falls into this range.

After the percentages of population in each vehicle class are adjusted, as shown in Table 2.2, an equilibrium state can be calculated by using one equation (Equation 2.5).

Table 2.2 Adjusted Value of Time distributions

No.	VOT Range ($/hr)	Vehicle Class A	Vehicle Class B	Vehicle Class C	. . .	Vehicle Class Z
1	$0 - VOT_1$	a_{1Adj}	b_{1Adj}	c_{1Adj}	. . .	z_{1Adj}
2	$VOT_1 - VOT_2$	a_{2Adj}	b_{2Adj}	c_{2Adj}	. . .	z_{2Adj}
3	$VOT_2 - VOT_3$	a_{3Adj}	b_{3Adj}	c_{3Adj}	. . .	z_{3Adj}
. . .	. . .	. . .	. . .	. . .	. . . .	. . .
n	$VOT_{n-1} - VOT_n$	a_{nAdj}	b_{nAdj}	c_{nAdj}	. . .	z_{nAdj}

2.3.2 Vehicle Conversion

To simulate the behavior of drivers on the managed lane facility, the actual number of vehicles must be known. In this model, the vehicles in all classes are converted into passenger car equivalents. When the passenger-car-equivalency (PCE), the total travel demand, and the percent of vehicles in the mix are given, a number of vehicles in each cell can be computed by the following equation:

$$Z_n = Demand \times Percent\, of\ Class\ Z\ Vehicles\ in\ the\ Mix \times PCE_Z \times z_{nAdj} \qquad (2.8)$$

where Z_n is the number of class Z vehicles in range n. This actual number of vehicles is computed by multiplying the percentage in each cell by the respective demand, vehicle mix percentage, and PCE. The resulting calculations are summarized in Table 2.3. For example, A_1 in this table would be the number of class A vehicles with a value of time range of 0 – VOT_1 dollars per hour.

Table 2.3 Vehicle conversion

No.	VOT Range ($/hr)	Vehicle Class A	Vehicle Class B	Vehicle Class C	. . .	Vehicle Class Z
1	$0 – VOT_1$	A_1	B_1	C_1	. . .	Z_1
2	$VOT_1 – VOT_2$	A_2	B_2	C_2	. . .	Z_2
3	$VOT_2 – VOT_3$	A_3	B_3	C_3	. . .	Z_3
. . .	. . .	. . .	. . .	. . .	. . . .	. . .
n	$VOT_{n-1} – VOT_n$	A_n	B_n	C_n	. . .	Z_n

2.3.3 Equilibrium Reaching Concept

The previous sections describe how the VOT percentages of multiple vehicle classes are adjusted and converted into an actual number of passenger car equivalents. This process is key to preparing the data for the model simulation. In this model, when a toll is charged on the managed lanes, a random vehicle from the lowest VOT range among vehicle classes is shifted from the ML to GPL until the equilibrium is reached. This vehicle is randomly selected from a random vehicle class. Internally, CTS and VOT are recalculated, and an equilibrium state is verified every time that a vehicle is shifted from ML to GPL. In conditions where the final volumes fall between the VOT ranges, the model linearly interpolates the VOT between lower bound and upper bound based on the volumes. However, if all the vehicles in this VOT range are shifted to the general purpose lanes and equilibrium is still not reached, the model will proceed to the next VOT range and continues to shift vehicles from ML to GPL until the equilibrium condition (VOT=CTS) is reached. The equilibrium reaching procedure can be demonstrated as shown in Table 2.4.

Table 2.4 Equilibrium reaching procedure

Iteration No.	Total number of vehicles shifted to GPL			ML Volume	GPL Volume	CTS ($/hr)		VOT ($/hr)
	Vehicle Class A	Vehicle Class B	Vehicle Class C					
1	0 (0)	1 (1)	0 (0)	Demand (D) - 1	1	CTS_1	>	VOT_1
2	1 (1)	1 (0)	0 (0)	D - 2	2	CTS_2	>	VOT_2
3	1 (0)	2 (1)	0 (0)	D - 3	3	CTS_3	>	VOT_3
. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
n	x (0)	y (0)	z (1)	D – (x+y+z)	x+y+z	CTS_n	=	VOT_n

Note: Vehicles shifted to GPL in each iteration are shown in ( )

2.4 Application of Flow-Density-Speed (q-k-u) model

Theoretically, the drivers choose to travel on toll lanes when their VOT is higher than the CTS. These decisions directly impact the facility performance. To characterize the performance impact, the flow, density and speed relationship should be derived for the proposed facility. In this study, the result from a traffic flow model study by Nepal (2008) is utilized for this purpose. He has found that the Drake (Drake et al., 1967) model has the best fit on the data collected for freeways in the DFW area. Therefore, the Drake Model is utilized to characterize the relationship between speed, flow, and concentration in the TPM-4.3. The general equation of the Drake Model is shown as Equation 2.9. However, the model parameters, -0.5 and 2, can also be calibrated through the model calibration process. If a model with new parameters shows a better result (higher R^2), these parameters (-0.5 and 2) can be changed.

$$u = u_f e^{[-0.5(k/k_c)^2]} \tag{2.9}$$

Where:

u = speed (mph)

u_f = free flow speed (mph)

k = concentration (pcpmpl)

k_c = concentration at capacity (pcpmpl)

The concentration at capacity (k_c) can be computed by Equation 2.10 with the given parameters including capacity per lane (q_c) and free-flow speed (u_f). The Drake Model (Equation 2.9) can be calibrated by obtaining the concentration value from Equation 2.10 and a given free-flow speed. The Drake Model also yields Equation 2.11 to estimate the flow (q) as a function of speed and concentration. After a model is calibrated, the TPM-4.3 utilizes Equation 2.11 to calculate the speed from the flow or the flow from a given speed.

$$k_c = \frac{q_c}{u_f e^{-0.5}} \tag{2.10}$$

$$q = uk_c \sqrt{-2\ln(u/u_f)} \tag{2.11}$$

In conditions where demand is higher than capacity but less than twice the capacity, speeds are expected to vacillate between $u = u_f e^{-0.5}$ (at $q = q_c$) and $u = 0$ (at $q = 2q_c$). In those cases, the TPM-4.3 model interpolates the speed between $u_f e^{-0.5}$ and zero for volumes between q_c and $2q_c$. For demands higher than $2q_c$, speed is considered to be zero due to the jam condition.

2.5 Solutions of Analysis Objectives

The operating objectives, including maximizing throughput or revenue, minimizing emissions, or guaranteeing an average speed, require different toll setting constraints. In the general pricing strategy, the overall network travel times are optimized as required by the specified objective and then the optimal volumes are incorporated into the toll optimizer. As a result, a toll rate will be generated based on an average value of time. However, the operating objectives will vary from one facility to another. In this model, the operator can select one of two proposed managed lane operational objectives. One option is to estimate demands and operating speeds on ML (and GPL) for a proposed SOV toll charge. A second option is to estimate what the toll charge should be for a desired minimum operating speed on the ML facility.

2.5.1 Toll Objective

In order to measure the impact of toll policies on demand and operating speeds, various SOV toll charges can be examined in the toll objective module. In general, an initial toll rate may be specified based on an existing toll facility in the area. Then, other toll scenarios can be examined to assess the impact on measures of effectiveness such as speeds, emissions and toll revenues. Figure 2.3 shows the flow chart for the toll objective module. This chart demonstrates the algorithm to compute the outputs. Under this option, the model uses the specified VOT distribution to determine the operational outcomes based on the toll amount specified in the objective option. In conjunction with the facility and user information, the software can then estimate the volumes and speeds on the managed lanes and general purpose lanes. Revenue is accordingly calculated by multiplying the ML volumes by the respective toll rates. Finally, the speed and volume estimates for each respective lane type are used to estimate the expected emissions.

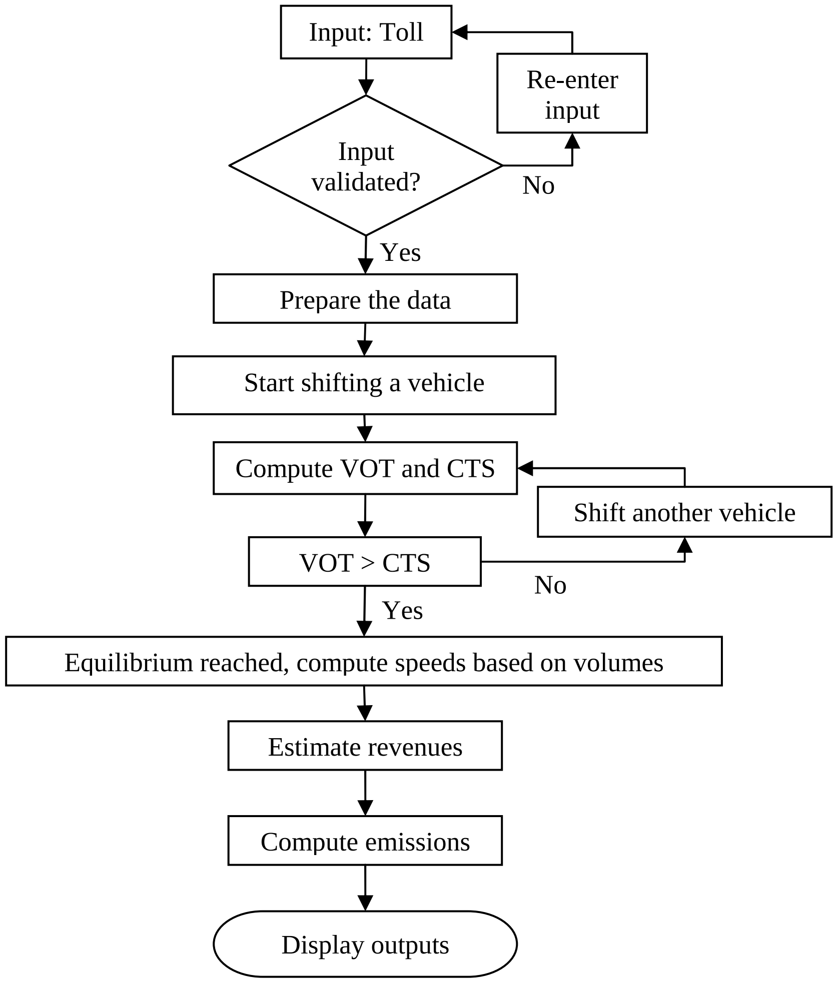


Figure 2.3 Flow chart for the toll objective module.

2.5.2 Speed Objective

A second option is to specify a desired average operating speed on managed lanes to determine the corresponding toll charge. For example, in the proposed scenarios, one of the operating objectives could be to maintain the minimum speed on the ML during peak period at 50 mph. This will limit the volume on ML so that the ML will maintain the speed at or above 50 mph. In this case, the model computes toll values, which maintain the desired average speed on the ML. Figure 2.4 shows the flow chart for the speed objective, illustrating the algorithm to compute the outputs. The program output includes the toll amounts to be charged for each vehicle class, the expected volumes and speeds on the both lane types, and the emissions estimates for the travel corridor.

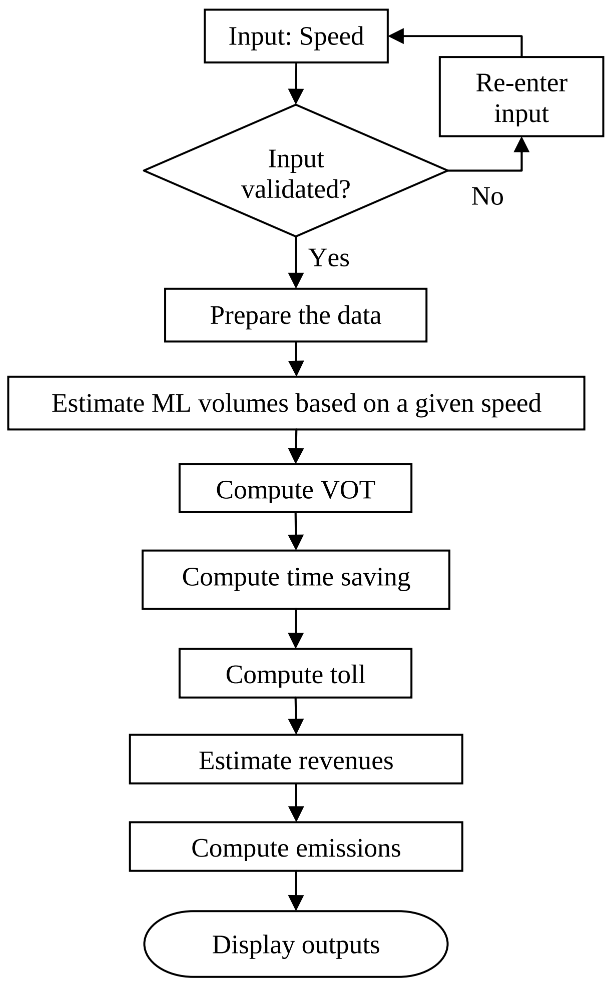


Figure 2.4 Flow chart for the speed objective module.

In this option, the model uses the VOT to determine the impact based on the minimum desired speed specified in the objective option. In conjunction with the facility and user information, the software can estimate the corresponding ML volume and GPL volume. The GPL speed can then be computed from the volume. As before, revenue is calculated by multiplying the volumes by the respective tolls. Finally, the speed and volume estimates for each respective lane type are used to estimate expected emissions.

2.6 Summary

In this chapter, a new paradigm in user equilibrium and its concept are described. The incorporation of the multiple vehicle classes is also explained. This study proposes the Drake model for the flow-density-speed relationship. Finally, the software algorithms are illustrated by schematic flow charts. In the next chapter, a description of the VOT distribution estimates and inputs are presented.

CHAPTER 3

VALUE OF TIME DISTRIBUTION

3.1 Value of Time Distribution

This research was not focused on the accuracy of the value of time (VOT) distribution; however, in order to present a new paradigm for the managed lane networks, a known or assumed distribution must be used. This study used a VOT distribution derived from a stated-preference survey as part of a Texas Department of Transportation (TxDOT) project to study the travel choice behavior of single occupancy vehicle (SOV) travelers between high-occupancy-toll (HOT) lanes and free lanes (Mattingly et al. 2004). This project surveyed a sample of potential HOT lane users in the Dallas-Fort Worth (DFW) area. A total of fifteen mode choice stated-preference questions based on hypothetical travel time savings and toll scenarios were utilized. The scenarios varied tolls at values of one, two, three, four and five dollars per ten miles and travel time savings at values of five, ten and twenty minutes. Each respondent was asked to choose between traveling on HOT lanes or free lanes; and those who chose to use HOT lanes would either pay the toll or convert to high occupancy vehicles (HOV).

Mattingly et al. (2004) used logistic regression models to predict the value of a binary dependent variable from a set of independent utility variables. These models estimated the probability that a driver made a decision to travel on a HOT lane under a given price and travel time scenario. The dependent variables in this model were the choice of HOT lane or free lane. The critical variables (travel time savings and toll) for this distribution were derived directly from the stated-preference survey. The SOV binary logit model from the HOT lane study is shown in Table 3.1. The distribution described by this model is used for generating the VOT input for the SOV class.

Table 3.1 SOV binary logit model

Description	Estimated Value
Constant	0.139
Travel Time Saving (mins/10 miles)	0.128
Toll ($/10 miles)	-0.785
-2Log Likelihood	6510.02
Chi-Square	1913.49
ρ^2	0.227
Percentage Correct Estimation	75.7
Percentage Correct Validation	78.8

The VOT distributions for the HOV class were derived from another TxDOT study (Goodin et al. 2009). The potential managed lane users in the DFW and Houston areas participated in an Internet survey conducted from May to July, 2006. The survey, tailored for two different cities, was available in both English and Spanish on separate DFW and Houston web sites. The survey asked respondents questions regarding their current travel patterns, reasons for choosing their travel modes, propensity towards managed lanes, as well as socio-demographic characteristics. An adaptive survey ensured that each respondent only received relevant questions. The policy scenarios were also randomized within the context of a previously selected structure for each respondent.

The research also used a stated-preference experiment to assess the decision-making behavior of drivers when choosing between the managed lane (ML) or general purpose lane (GPL). The study presented hypothetical travel time and toll scenarios through four stated-preference questions on mode choice. Each respondent was asked to choose one of six potential travel options: three involved traveling on managed lanes and three on general purpose lanes. The travel time and toll rate would vary in these six alternatives for each of the four scenarios presented to the respondents.

In the stated-preference questions, travel time savings were calculated depending on the input travel distance and randomly assigned speeds for both ML and GPL. A similar technique as for SOV was used to analyze the VOT distributions for HOV (Goodin et al. 2009).

Table 3.2 displays the results of the high occupancy vehicle with two occupants (HOV2) and high occupancy vehicle with three or more occupants (HOV3+) binary logit models. In general, except for travel distance, the significant variables included in the HOV2 and HOV3+ models are similar, namely the travel time saving and the toll amount.

Table 3.2 HOVs binary logit model estimate results

Description	HOV2	HOV3+
Constant	-0.553	0.142
Travel Distance (mile)	0.011	-
Travel Time Saving (mins/mile)	1.042	0.868
Toll($/mile)	-7.132	-8.803
Number of Observation	860	212
-2LL only constant	1182.35	264.51
-2LL with variable	1075.99	247.70
ρ^2	0.091	0.064
Percent Correct	66.2%	70.8%

The representative values of time distributions used for the model input are calculated from the binary logit model estimate results. Generally, the VOT distributions for SOV, HOV2 and HOV3+ can be written as Equations 3.1, 3.2 and 3.3, respectively:

$$P_T = \frac{1}{\left(1+e^{-\left(0.139+(0.128\times t)-(0.785\times T)\right)}\right)} \tag{3.1}$$

$$P_T = \frac{1}{\left(1+e^{-\left(-0.553+(1.042\times t)-(7.132\times T)+(0.011\times D)\right)}\right)} \tag{3.2}$$

$$P_T = \frac{1}{\left(1+e^{-\left(0.142+(0.868\times t)-(8.803\times T)\right)}\right)} \tag{3.3}$$

P_T represents a proportion of population who choose to pay a toll T dollars for travel time saving t minutes with travel distance D miles. In order to convert these equations in terms of VOT inputs, the researchers assume a travel time saving of one minute per mile and reformulate the equations in the form of Equations 3.4, 3.5 and 3.6, respectively:

$$P_T = \frac{1}{(1+e^{-1.419+(7.85xVOT)})} \tag{3.4}$$

$$P_T = \frac{1}{(1+e^{-0.5+(7.132xVOT)})} \tag{3.5}$$

$$P_T = \frac{1}{(1+e^{-1.01+(8.803xVOT)})} \tag{3.6}$$

VOTs in the above equations are in dollars per minute. The proportion of population who choose to pay a toll T dollars for a travel time saving of one minute on a one-mile section can now be defined as the proportion of population P who has a value of time greater than VOT assumed in the analysis. Equations 3.4, 3.5 and 3.6 specify the VOT distributions, and they are used to generate the VOT inputs in this study. As a result, the percentages of population are calculated for a total of ten intervals with the bandwidth of three dollars per hour, as shown in Table 3.3.

The absence of previous studies on the VOT distribution for the other vehicle classes is noted through the literature review. Therefore, this study assumes HOV3+'s VOT distribution for the remaining classes. However, if transportation planners are interested in analyzing impact of the other vehicle classes on the managed lane, a similar survey of SOV and HOVs can be conducted to obtain the VOT distribution for those modes.

Table 3.3 VOT inputs

VOT ($/hr)	Percentage of Population	HOV2	HOV3+
0.00 - 3.00	26.4%	46.4%	36.1%
3.01 - 6.00	8.3%	8.9%	10.6%
6.01 - 9.00	9.3%	8.6%	10.9%
9.01 - 12.00	9.8%	7.8%	10.2%
12.01 - 15.00	9.5%	6.7%	8.8%
15.01 - 18.00	8.6%	5.5%	6.9%
18.01 - 21.00	7.2%	4.3%	5.2%
21.01 - 24.00	5.8%	3.3%	3.7%
24.01 - 27.00	4.4%	2.4%	2.5%
> 27.00	10.7%	6.2%	5.0%

3.2 Summary

This chapter explains the VOT distributions derived from previous studies and how to incorporate them into the software as a key input. Next chapter describes the traffic demand model software (TPM-4.3) developed based on the proposed user equilibrium paradigm.

CHAPTER 4

THE TOLL PRICING MODEL

A toll pricing model (TPM-4.3) is developed based on the user equilibrium concept for managed lanes described in chapter two. This chapter describes the software features and algorithms to estimate the demands on the managed lane (ML) and general purpose lane (GPL), among other performance outcomes.

4.1 Facility Information

The facility information includes all the necessary details about the GPL and ML facilities such as number of lanes, corridor length and parameters to utilize the calibrated flow-density-speed models. Figure 4.1 shows an example of the facility information when the Drake model is chosen as the prevailing flow-density-speed relation for the facility. Greenshields (Greenshields 1933) and Underwood (Underwood 1961) models are also available as options in the drop-down box.

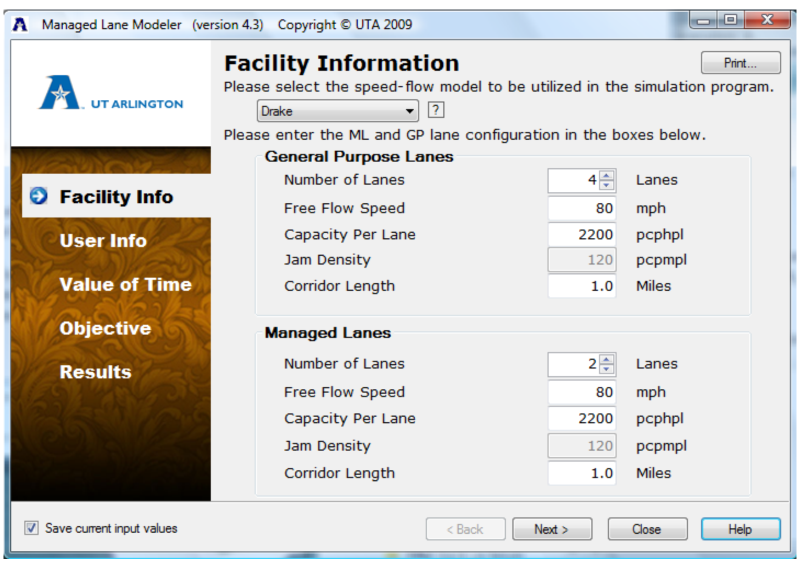


Figure 4.1 Facility Information for Drake model.

4.1.1 Flow-Density-Speed (q-k-u) model

Theoretically, drivers choose to travel on toll lanes when their value of time (VOT) is higher than the cost of time savings (CTS). These decisions directly impact the facility performance. To characterize the performance impact, the flow-density-speed relationship should be specified for a proposed facility. In this version, the result from a traffic flow model study by Nepal (2008) is utilized. He found that the Drake (Drake et al. 1967) model had the best fit on the data collected for two freeway sections in the Dallas-Fort Worth region. Therefore, the Drake Model was utilized to characterize the relationship between speed, flow, and concentration. In the TPM-4.3, Greenshields (Greenshields 1933) and Underwood (Underwood 1961) models are also provided as alternative q-k-u models. A number of other input parameters must also be specified, as follows:

4.1.2 Number of Lanes

The number of lanes is a total number of lanes for each lane type on the corridor. The inputs are separated for managed lanes and general purpose lanes.

4.1.3 Free-Flow Speed

Free-flow speed is an average free-flow speed (in mph) on the study corridor. This value should be established when calibrating the flow-density-speed model. In the absence of pertinent local data, it is recommended that the value be set at 70. The range of likely values is between 60 and 80 for freeway conditions.

4.1.4 Capacity Per Lane

Capacity per lane is a maximum lane flow (in pcphpl) for freeway conditions. The recommended value is 2000. The range of likely values is between 1800 and 2400.

4.1.5 Jam Density

Jam density is the concentration at which speeds approach zero (in pcpmpl). This value is required only when Greenshields model is chosen. The recommended value is 110 (Nepal 2008). The range of likely values is between 100 and 150.

4.1.6 Corridor Length

The corridor length is a total length (in miles) of the roadway segment. Although the lengths of the ML and the GPL are the same, they need not be. This allows analysis of two alternative travel corridors, one toll and one non-toll.

4.2 User Information

Figure 4.2 shows an example of user information. User information requires all the necessary details related to the corridor users such as the vehicle mix, Passenger Car Equivalency (PCE), toll policy, demand, and dead setter percentages. These input variables can be specified as shown in Figure 4.2.

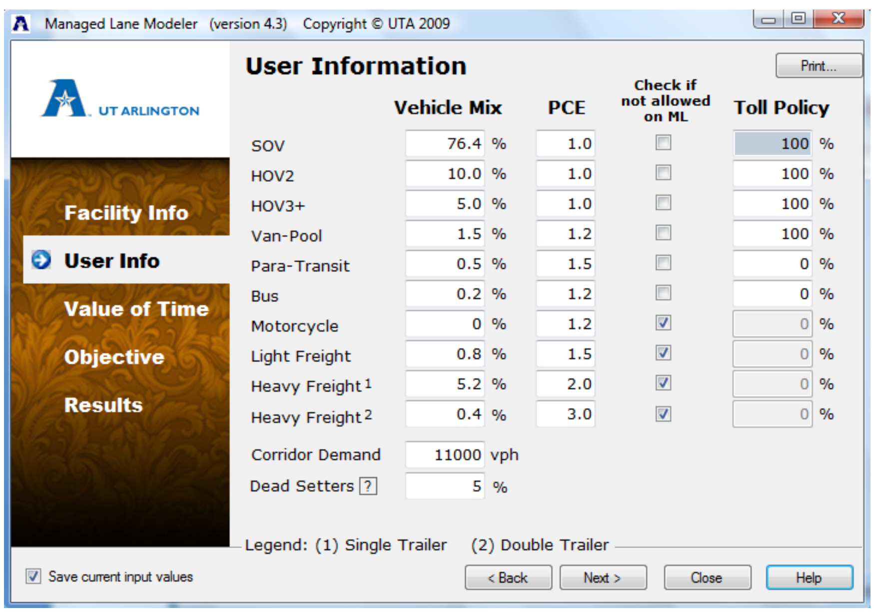


Figure 4.2 User Information.

4.2.1 Vehicle Mix

Vehicle mix is the percentage of each vehicle type in the travel corridors. It defines the total number of vehicles for each vehicle type presented in the traffic stream under investigation. In the TPM-4.3, the vehicle types are as follows:

- SOV: Vehicles with one occupant, other than those separately specified below
- HOV2: Vehicles with two occupants, other than those separately specified below
- HOV3+: Vehicles with three or more occupants, other than those separately specified below
- Para-transit: Vehicles carrying urban travelers for a fare on non-fixed routes and schedules. For example, taxis and airport shuttles
- Van-pool: Vehicles used for ride share, typically organized by employers, schools, churches or other civic groups
- Bus: Buses including transit, school, intercity and charter buses
- Motorcycle: All two- or three-wheeled motorized vehicles legally allowed on highways
- Light Freight: Single unit trucks
- Heavy Freight (single trailer): Tractor trailer combinations with a single trailer
- Heavy Freight (two or more trailers): Tractor trailer combinations with two or more trailers

4.2.2 Passenger Car Equivalency (PCE)

The passenger car equivalency factor (PCE) is a multiplier used to convert a mixed vehicle flow into an equivalent passenger car flow. The Highway Capacity Manual (Transportation Research Board 2000) is the recommended reference for more information and typical values of various vehicle classes.

4.2.3 Toll Policy

Toll policy defines the toll amount for each vehicle class allowed to travel on managed lanes. Toll policies for different classes of vehicles can be specified as a percent of the SOV toll. For example, if HOV2 pays the same as SOV, and HOV3+ and van-pool is required to pay one-half of the SOV toll, then the input values are 100%, 100%, 50% and 50% for SOV, HOV2, HOV3+ and van-pool, respectively.

4.2.4 Corridor Demand

Corridor demand is an expected total directional demand (in vph) including all vehicles in ML and GPL regardless of vehicle type.

4.2.5 Dead Setters

Dead setters are defined as the percent of each vehicle class, except SOV, choosing to use GPL regardless of the amount of toll on ML. This could be due to thier specific origin-destinations or other driver behavioral reasons.

4.3 Value of Time Distributions

VOT distributions reveal the time values for study areas and estimate the potential managed lane users. The value of time distribution is entered separately for each vehicle class. Figure 4.3 shows an example of the VOT input.

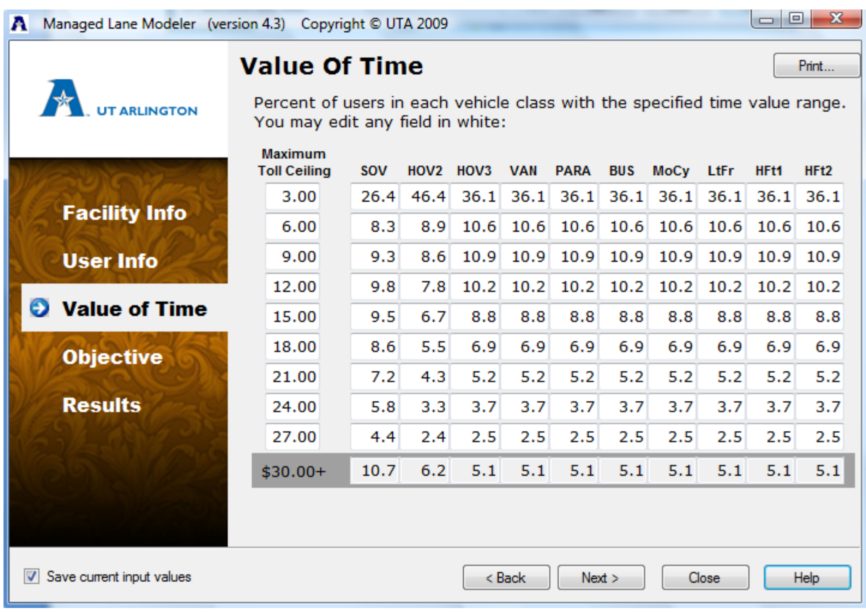


Figure 4.3 Value of Time.

4.4 Analysis Objectives

The operating objectives, including maximizing throughput or revenue and targeting the minimum revenue or average speed, require different toll setting constraints. In the general pricing strategy, the overall network travel times are optimized as required by the specified objective and then the optimal volumes are incorporated into the toll optimizer (Parsons Brinckerhoff 2002). As a result, a toll rate will be generated based on an average value of time. However, the operating objectives will vary from one facility to another. In this section, the operator can select one of two proposed managed lane operational objectives as shown in Figure 4.4. One option is to estimate demands and operating speeds on ML (and GPL) for a proposed SOV toll charge. A second option is to estimate what the toll charge should be for a desired minimum operating speed on the ML facility.

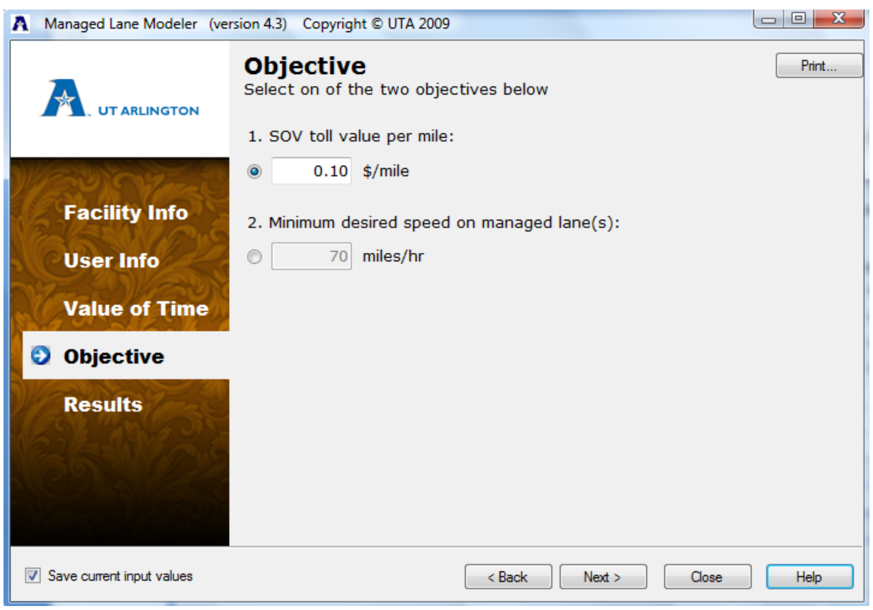


Figure 4.4 Objectives.

4.4.1 Toll Objective

In order to measure the impact of toll policies on demand and operating speeds, various SOV toll charges can be examined in the toll objective module. In general, an initial toll rate may be specified based on an existing toll facility in the area. Then, other toll scenarios can be examined to assess the impact on measures of effectiveness such as speeds, emissions and toll revenues. Figure 4.4, for example, specifies a toll amount of $0.10 per mile.

4.4.2 Speed Objective

A second option is to specify a desired average operating speed on managed lanes to determine the corresponding toll charge. For example, in the proposed scenarios, one of the operating objectives could be to maintain the minimum speed on the ML at 50 mph during the peak period. This will limit the volume on the ML not to exceed the maximum volume for maintaining the speed at 50 mph. In this case, the model output will be the estimated toll value, which maintains the desired average speed on the ML.

4.5 Software Output

After specifying the objective, the results are computed and presented in the output summary. An example of a complete set of output is shown in Figure 4.5. Figure 4.6 shows an output summary screen for the toll objective. If the speed objective is chosen, the header will show the speed condition that is being maintained. In the TPM 4.3, outputs can be exported into a comma separated value (CSV) file and opened in Excel.

Objective 1: SOV toll value per mile: $0.10
Speed-flow model: Drake
Number of Managed Lanes: 2 lanes
Number of General Purpose Lanes: 4 lanes
Length of Managed Lane corridor: 5 miles
Corridor Demand: 11000 vph

VOLUME AND TOLL SUMMARY:

Vehicle Class	VolumeML(vph)	VolumeGPL(vph)	ML Share(%)	Toll Value($/mile)	Total Revenue($/hr)
SOV	2898	5506	34.5	0.1	1449
HOV2	213	887	19.4	0.1	106.5
HOV3+	116	434	21.1	0.1	58
Vanpool	39	126	23.6	0.1	19.5
Para-Transit	55	0	100	Free	0
Bus	22	0	100	Free	0
Motorcycle	0	0	0	N/A	0
Light Freight	0	88	0	N/A	0
Single Trailer	0	572	0	N/A	0
DoubleTrailer	0	44	0	N/A	0
Total	3343	7657	30.4	-	1633

		ML	GPL
TotalVolume	(pc/hr)	3383	8385
Avg. Speed	(Mile/hr)	69	58

EMMISIONS SUMMARY: (grams/mile)

Vehicle Class	COML	COGPL	VOCML	VOCGPL	NOML	NOGPL	CO2ML	CO2GPL	SO2ML	SO2GPL
SOV	17869	27879	281	467	974	1649	451644	889316	19.6	37.2
HOV2	1313	4491	21	75	72	266	33195	143266	1.4	6
HOV3+	715	2198	11	37	39	130	18078	70099	0.8	2.9
Vanpool	268	711	5	13	15	43	7844	26235	0.3	1.1
Para-Transit	331	0	7	0	21	0	11062	0	0.4	0
Bus	5014	0	2	0	134	0	13084	0	0.6	0
Motorcycle	0	0	0	0	0	0	0	0	0	0
Light Freight	0	394	0	11	0	49	0	24074	0	1
Single Trailer	0	48472	0	46	0	1183	0	275119	0	11.5
DoubleTrailer	0	4719	0	7	0	195	0	24412	0	1
Total	25510	88864	327	656	1255	3515	534907	1452521	23.1	60.7

Figure 4.5 A complete set of output.

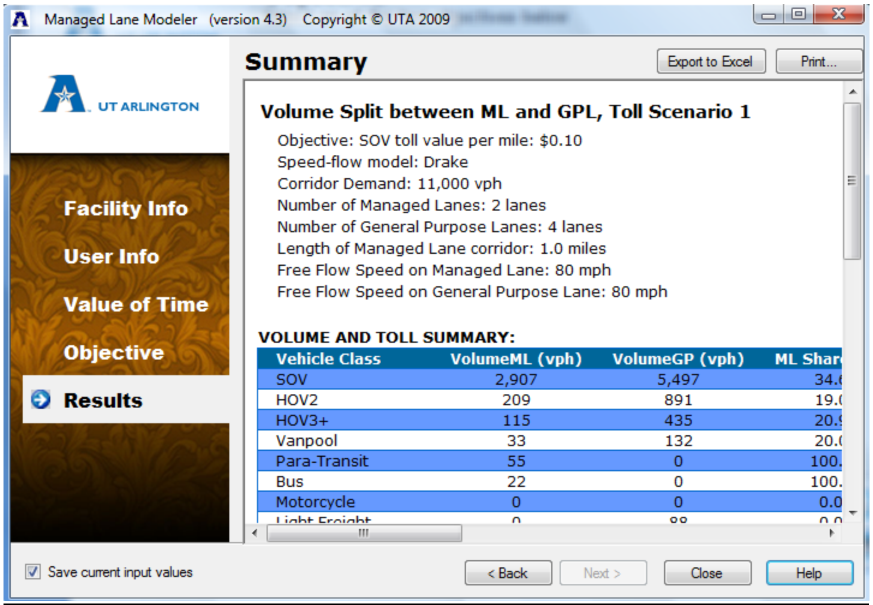


Figure 4.6 Output screen.

4.5.1 Volume

Volume is a measure of the demand (in vph). Volumes are shown for each lane type when the equilibrium is reached.

4.5.2 Speed

Speed is an average speed (in mph) computed for each lane. Speeds are computed based on the estimated volumes at equilibrium if the toll objective is chosen.

4.5.3 Percentage Share

Percentage ML share is a percentage of the total users who use the ML. It is calculated for each vehicle class separately.

4.5.4 Toll Charge

Toll charges are based on the SOV toll and the toll policies for other vehicle classes. Tolls are calculated according to the percentage of SOV charges specified.

4.5.5 Total Revenue

Total revenue is the total toll amount collected from all managed lane users. It is computed based on the toll users estimates.

4.5.6 Emission Summary

Emission estimates, except for the SO_2 emissions, are based on a number of regression equations which use the average speed as the predictor variable (Yerramalla, 2007). The SO_2 emission rates are obtained from the information provided by vehicle manufacturers and built into MOBILE6.2 (USEPA 2009). The regression models for CO, VOC and NOx are developed from the MOBILE6.2 run results. The regression equations for CO_2 are developed based on tailpipe field data from on-board measurements in a passenger car. After the regression equation for passenger cars (SOV&HOVs) is generated, the equations for remaining classes are developed based on the multiplying factors used in MOBILE6.2. The regression equations to estimate CO, HC, NOx, and CO_2 are presented in Tables 4.1 to 4.4, respectively. The SO_2 emission rates are summarized in Table 4.5.

Table 4.1 Regression models to estimate CO (grams/mile)

Vehicle Class	Regression Equation	R^2
SOV & HOVs	1.6915 + 30.0587 (1/Speed) + 0.0008483 $(Speed)^2$	0.99
Van-Pool	1.9579 + 29.85 (1/Speed) + 0.000942 $(Speed)^2$	0.99
Para-Transit	1.9579 - 29.85 (1/Speed) + 0.000942 $(Speed)^2$	0.99
Bus	70.8397 - 2.80546 (1/Speed) + 0.033 $(Speed)^2$	0.99
Motorcycle	-5.0 + 333.14 (1/Speed) + 0.003256 $(Speed)^2$	0.98
Light Freight	1.5321 + 24.5034 (1/Speed) + 0.0007499 $(Speed)^2$	0.99
Single Trailer	32.05 - 1.3199 (1/Speed) + 0.01567 $(Speed)^2$	0.96
Double Trailer	40.57 - 1.671 (1/Speed) + 0.01983 $(Speed)^2$	0.96

Table 4.2 Regression models to estimate HC (grams/mile)

Vehicle Class	Regression Equation	R^2
SOV & HOVs	$0.0267 + 1.184\ (1/Speed) + 0.0000111815\ (Speed)^2$	0.99
Van-Pool	$0.0326 + 1.6\ (1/Speed) + 0.000013754\ (Speed)^2$	0.99
Para-Transit	$0.0326 + 1.6\ (1/Speed) + 0.000013754\ (Speed)^2$	0.99
Bus	$0.4632 + 21.51\ (1/Speed) - 0.0000000014\ (Speed)^2$	0.97
Motorcycle	$0.2572 + 25.029\ (1/Speed) - 0.0000000015\ (Speed)^2$	0.99
Light Freight	$0.0274 + 1.88\ (1/Speed) + 0.000017849\ (Speed)^2$	0.99
Single Trailer	$0.1027 + 5.482\ (1/Speed) - 0.00003453\ (Speed)^2$	0.97
Double Trailer	$0.2258 + 10.451\ (1/Speed) - 0.000072833\ (Speed)^2$	0.97

Table 4.3 Regression models to estimate NOx (grams/mile)

Vehicle Class	Regression Equation	R^2
SOV & HOVs	$0.1579 + 2.229\ (1/Speed) + 0.000030664\ (Speed)^2$	0.99
Van-Pool	$0.1827 + 1.9855\ (1/Speed) + 0.00003747\ (Speed)^2$	0.98
Para-Transit	$0.1827 + 1.9855\ (1/Speed) + 0.00003747\ (Speed)^2$	0.98
Bus	$5.4089 + 0.04593\ (1/Speed) + 0.000144\ (Speed)^2$	0.99
Motorcycle	$0.5123 - 0.00454\ (1/Speed) + 0.0002082\ (Speed)^2$	0.98
Light Freight	$0.3422 + 2.878\ (1/Speed) + 0.000049308\ (Speed)^2$	0.98
Single Trailer	$1.8958 + 0.01606\ (1/Speed) + 0.000051098\ (Speed)^2$	0.99
Double Trailer	$4.0646 + 0.0344\ (1/Speed) + 0.000109\ (Speed)^2$	0.99

Table 4.4 Regression models to estimate CO_2 (grams/mile)

Vehicle Class	Regression Equation	R^2
SOV & HOVs	$94.416 + 3384.6\ (1/Speed) + 0.0026\ (Speed)^2$	0.88
Van-Pool	$122.476 + 4309.5\ (1/Speed) + 0.0034\ (Speed)^2$	0.88
Para-Transit	$122.476 + 4309.5\ (1/Speed) + 0.0034\ (Speed)^2$	0.88
Bus	$360.375 + 12918.7\ (1/Speed) + 0.0099\ (Speed)^2$	0.88
Motorcycle	$45.502 + 1631.2\ (1/Speed) + 0.0013\ (Speed)^2$	0.88
Light Freight	$159.924 + 5732.9\ (1/Speed) + 0.0044\ (Speed)^2$	0.88
Single Trailer	$281.246 + 10082.1\ (1/Speed) + 0.0077\ (Speed)^2$	0.88
Double Trailer	$324.389 + 11628.6\ (1/Speed) + 0.0089\ (Speed)^2$	0.88

Table 4.5 Rates for estimating SO_2 (grams/mile)

Vehicle Class	Rate
SOV & HOVs	0.00675
Van-Pool	0.0088
Para-Transit	0.00675
Bus	0.0261
Motorcycle	0.0033
Light Freight	0.0115
Single Trailer	0.0201
Double Trailer	0.0234

All emissions estimates, with the exception of CO_2, are based on MOBILE6.2 simulation runs for the following conditions:

- Projected 2010 vehicle mix freeway cruise speeds
- Exhaust emissions
- Month of July
- 7 AM sunrise and 8 PM sunset
- Temperature range = 74°F - 90°F
- Relative humidity range = 51% - 88%
- Barometric pressure = 29.4 inches of mercury
- Fuel program = 4
- Oxygenated fuels with fuel reid vapor pressure (RVP) = 6.8 psi
- Diesel sulfur content = 15.0 ppm and particulate size = 2.5 microns

The CO_2 estimates are based on field measurements of tail-pipe exhaust emissions for a 2007 Dodge Charger passenger car under average freeway non-cruise speeds with comparable ambient conditions as the MOBILE6.2 runs. The CO_2 emissions for other vehicle types are estimated by adjusting the passenger car rates from field measurements proportional to the CO_2 constant rates in MOBILE6.2 for passenger cars versus other vehicle types.

4.6 Summary

In this chapter, the features of input and output of the Toll Pricing Model Program version 4.3 (TPM-4.3) are presented. Various example input and output screens are also shown. In the next chapter, model validation, case study and the impact estimates are presented.

CHAPTER 5

MODEL VALIDATION, CASE STUDY AND IMPACT ESTIMATES

The main purpose of the impact analysis is to provide quantitative estimates of how different high occupancy vehicle (HOV) preferential treatments impact toll revenue, air quality, and system performance for the managed lanes (ML) and general purpose lanes (GPL). The Toll Pricing Model version 4.3 (TPM-4.3), a computer model developed under the new user-equilibrium paradigm described in the previous chapter, is used as a tool to estimate impacts of twenty-four pricing scenarios. To ensure the validity of the pricing evaluation tool, model estimates are compared with estimates from a study by Wilbur Smith Associates (WSA 2007), as well as field observations from the I-394 MnPASS program, operated by the Minnesota Department of Transportation (MnDOT 2006). The following section describes the model validation process and presents results of the model validation, followed by the estimated impact for the tested scenarios.

5.1 Model Validation

The main goal of the model validation is to ensure the accuracy of the TPM-4.3 predictions. To achieve its goal, the model validation entails comparing the TPM-4.3 model outputs to two data sets, one from the Wilbur Smith Associates (WSA) study and a second from the I-394 ML corridor in Minnesota. There are two main reasons for selecting these two datasets for validation purpose: (1) The WSA results are estimates based on the same facility conditions as this study but using different estimation methodologies. It is useful to cross-check the TPM-4.3 results with WSA's estimates to analyze variations between the two sets of estimates. (2) The field data from the I-394 ML corridor in Minnesota provide an opportunity for field validation. A comparison of TPM-4.3 outputs with the field data can help answer the question of how much the TPM-4.3 model simulation results differ from actual observations. To validate the model, facility conditions obtained from both sources are input into TPM-4.3. In addition, a 5% dead setters rule, which assumes that 5% of each vehicle class, except Single occupancy vehicle (SOV), would refuse to managed lanes if any toll is charged, is applied to the TPM model estimations for the I-394 ML corridor in Minnesota. The model results are then compared to the estimated or observed volume shares for the managed lanes and general purpose lanes.

5.1.1 The Wilbur Smith Associates Study

The estimates of the WSA study, "Level 2 Traffic and Toll Revenue Study: IH 30 Reversible Managed Lanes- June 2007" (WSA 2007), are based on the travel demand model databases developed under basic assumptions provided by the North Central Texas Council of Governments (NCTCOG) and micro-simulation using VISSIM. SOVs are charged a full toll depending on the time of day, but HOVs are charged different rates in each tested scenario. The facility being investigated in the WSA's study has four GPLs and two MLs. Specific facility information is displayed in Figure 5.1. User compositions and the eight toll pricing scenarios that are considered as part of this model validation effort are summarized in Table 5.1. The SOV toll is represented in the table as price per mile.

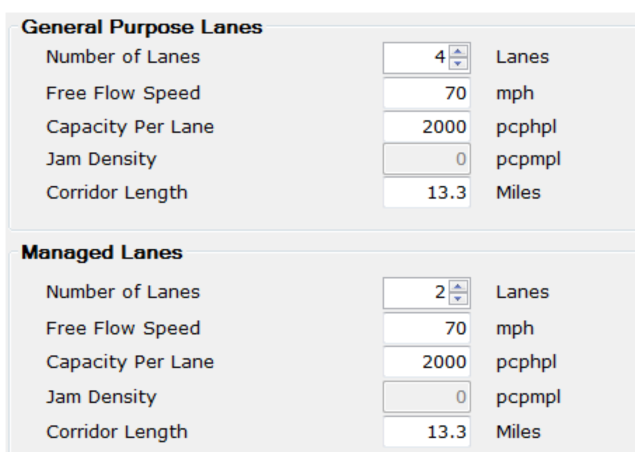


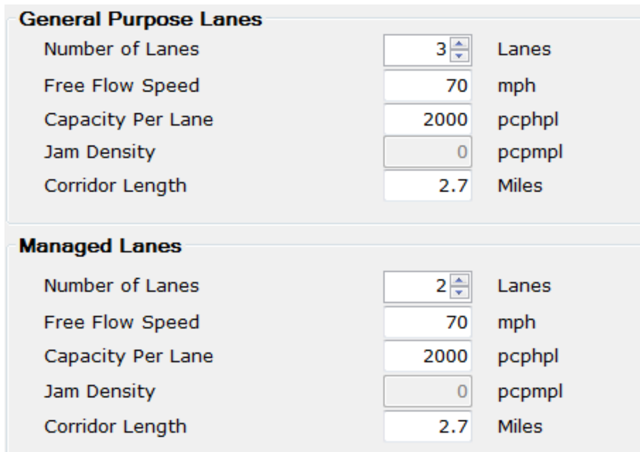
Figure 5.1 Facility inputs for the WSA model validation.

Table 5.1 Scenarios and user compositions for the WSA model validation

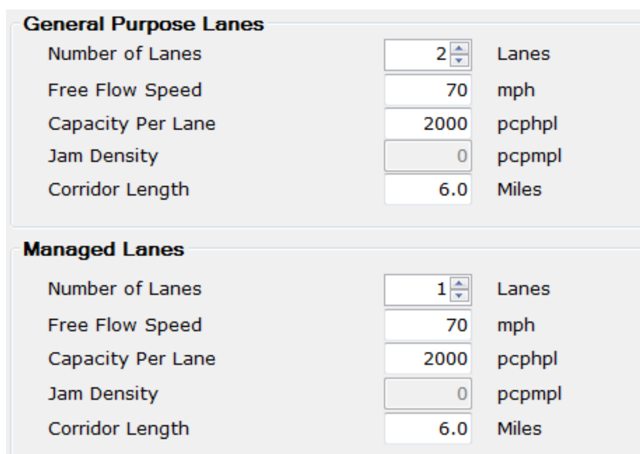
Scenario	Section	Time Period	Year	SOV Toll ($/mile)	HOV2+ Toll	User Composition		
						SOV	Trucks	HOV2+
1	I-30 at Belt Line Rd	AM	2015	$0.30	0.5xSOV	70%	5%	25%
2	I-30 at Belt Line Rd	PM	2015	$0.25	0.5xSOV	65%	6%	29%
3	I-30 at Westmoreland Rd	AM	2015	$0.30	0.5xSOV	73%	5%	22%
4	I-30 at Westmoreland Rd	PM	2015	$0.25	0.5xSOV	68%	6%	26%
5	I-30 at Belt Line Rd	AM	2015	$0.20	SOV	70%	5%	25%
6	I-30 at Belt Line Rd	PM	2015	$0.20	SOV	67%	6%	27%
7	I-30 at Westmoreland Rd	AM	2015	$0.20	SOV	73%	5%	22%
8	I-30 at Westmoreland Rd	PM	2015	$0.20	SOV	69%	6%	25%

5.1.2 The Minnesota Field Data

The Minnesota field data are obtained from the Minnesota Department of Transportation. The data, which are published in the I-394 HOV Report, 2006 - 3rd Quarter, July - September, Regional Transportation Management Center (MnDOT 2006), are recorded using loop detectors installed at Penn Avenue and Louisiana Avenue in both general purpose and managed lanes. The detectors count the number of vehicles that are passing at the location and convert them into hourly flows. The section at Penn Avenue has two MLs and three GPLs. The section at Louisiana Avenue has one ML and two GPLs. SOVs are charged the full toll based on the demand, although the full toll varies in amount by time of day. However, HOVs are free of toll on this facility. The I-394 facility information for each section is shown in Figure 5.2. User compositions and the policy scenarios for model validation with the I-394 field data are exhibited in Table 5.2. Like the WSA model validation, the SOV toll is represented in the table as price per mile.



(a)



(b)

Figure 5.2 Facility inputs for the I-394 model validation;
(a) at Penn Avenue, (b) at Louisiana Avenue.

Table 5.2 Scenarios and user compositions for the I-394 model validation

Scenario	Section	Time Period	Year	SOV Toll ($/mile)	HOV2+ Toll	User Composition		
						SOV	HOV2+	Buses
9	I-394 at Penn Ave	AM	2006	$0.27	Free	84%	15%	1%
10	I-394 at Penn Ave	AM	2006	$0.28	Free	83%	16%	1%
11	I-394 at Louisiana Ave	AM	2006	$0.30	Free	83%	16%	1%
12	I-394 at Louisiana Ave	AM	2006	$0.23	Free	82%	17%	1%

5.1.3 Validation Results

Tables 5.3 and 5.4 display the ML shares of the TPM-4.3 model outputs for the twelve simulated scenarios. Comparisons are discussed by SOV, HOV2+, and total volumes.

5.1.3.1 SOV Difference

As seen in the SOV outputs, the results from the TPM-4.3 show reasonable agreement with both data sets, with most values showing less than 7% and 4% difference for the WSA study (see Table 5.3) and the Minnesota field data (see Table 5.4), respectively. In the WSA study, the differences range from -7% to 6% with the greatest differences in scenario 5 at -7%. In the low volume AM scenarios (scenarios 1 and 3), MLs become less-attractive to SOV users if the ML travel times do not differ or are only slightly lower than the GPL travel times and travelers are likely to continue using the GPLs. As the volume increases during the PM to the point where volumes can greatly increase the travel time on the GPLs, the probability of using MLs will also increase. In the Minnesota field data, the SOV ML share differences range from 2% to 4% with the greatest difference in scenario 12 at 4%. The TPM-4.3 model estimates for SOV shares are generally lower than the field data. However, the TPM-4.3 shows a better predictive ability for the Minnesota field data.

5.1.3.2 HOV2+ Difference

HOV2+ volumes are also estimated and compared to the estimates from the WSA study and the field data of MnDOT. When comparing to estimates of the WSA study, the differences ranged from 25% to 32% with the ML share difference greatest in scenario 2 at 32%. The TPM-4.3 estimates for HOV2+ are generally lower than the WSA Study estimates. In contrast, the differences between TPM-4.3 estimates and the Minnesota field data range from 0 to -21%. There is no difference in HOV volumes between the model estimates and field observations for scenario 9. The greatest difference occurs in scenario 12 at -21% (see Table 5.4). The results indicate that the TPM-4.3 model outputs for HOV2+ are closer to the I-394 field observations than estimates of the WSA study.

5.1.3.3 Total Volume Difference

The total modal differences range from 2% to 12% when comparing the WSA study to the TPM-4.3 model outputs (see Table 5.3). The total AM differences range from 2% to 8% and the total PM differences range from 9% to 12%. When comparing the Minnesota field data to the TPM-4.3 model outputs, the total modal differences range from 0% to 1% (see Table 5.4). There is no difference in total volumes for scenario 12. The TPM-4.3 model estimates for the total volumes are generally closer to the Minnesota field observations than estimates of the WSA study.

Table 5.3 Managed lane share comparison with WSA estimates

		WSA			TPM-4.3			ML Share Difference
Scenario*	Mode	GPL	ML	ML share	GPL	ML	ML share	
1	SOV	5,044	72	1%	5,116	0	0%	1%
	Truck	391	0	0%	391	0	0%	0%
	HOV2+	1,011	810	44%	1,469	352	19%	25%
	Total	6,445	882	12%	6,976	352	5%	7%
2	SOV	4,475	606	12%	4,613	467	9%	3%
	Truck	451	0	0%	451	0	0%	0%
	HOV2+	1,038	1,204	54%	1,759	484	22%	32%
	Total	5,963	1,810	23%	6,823	951	12%	11%
3	SOV	4,986	170	3%	5,156	0	0%	3%
	Truck	359	0	0%	359	0	0%	0%
	HOV2+	905	633	41%	1,291	247	16%	25%
	Total	6,250	803	11%	6,806	247	4%	8%
4	SOV	4,519	540	11%	4,814	244	5%	6%
	Truck	428	0	0%	428	0	0%	0%
	HOV2+	926	989	52%	1,522	393	21%	31%
	Total	5,873	1,529	21%	6,764	637	9%	12%
5	SOV	4,880	275	5%	4,513	643	12%	-7%
	Truck	391	0	0%	391	0	0%	0%
	HOV2+	1,194	599	33%	1,688	104	6%	28%
	Total	6,465	873	12%	6,592	747	10%	2%
6	SOV	4,248	959	18%	4,316	892	17%	1%
	Truck	449	0	0%	449	0	0%	0%
	HOV2+	1,321	835	39%	1,981	174	8%	31%
	Total	6,017	1,794	23%	6,746	1,066	14%	9%
7	SOV	4,784	409	8%	4,710	482	9%	-1%
	Truck	363	0	0%	363	0	0%	0%
	HOV2+	1,059	463	30%	1,450	72	5%	26%
	Total	6,205	872	12%	6,523	554	8%	4%
8	SOV	4,344	808	16%	4,454	698	14%	2%
	Truck	427	0	0%	427	0	0%	0%
	HOV2+	1,170	690	37%	1,732	128	7%	30%
	Total	5,940	1,498	20%	6,613	826	11%	9%

*Scenarios defined in Table 5.1

Table 5.4 Managed lane share comparison with Minnesota field data

		Minnesota Field Data			TPM-4.3			ML Share Difference
Scenario*	Mode	GPL	ML	ML share	GPL	ML	ML share	
9	SOV	5,457	652	11%	5,563	546	9%	2%
	HOV2+	54	1,031	95%	54	1,031	95%	0%
	Buses	0	73	100%	0	72	100%	0%
	Total	5,511	1,756	24%	5,617	1,649	23%	1%
10	SOV	5,417	639	11%	5,586	470	8%	3%
	HOV2+	133	1,007	88%	57	1,083	95%	-7%
	Buses	0	42	100%	0	42	100%	0%
	Total	5,550	1,688	23%	5,643	1,595	22%	1%
11	SOV	3,714	417	10%	3,849	282	7%	3%
	HOV2+	147	646	81%	40	753	95%	-13%
	Buses	0	49	100%	0	48	100%	0%
	Total	3,861	1,112	22%	3,889	1,083	22%	1%
12	SOV	3,414	367	10%	3,574	207	5%	4%
	HOV2+	205	569	74%	39	735	95%	-21%
	Buses	0	26	100%	0	26	100%	0%
	Total	3,619	962	21%	3,613	968	21%	0%

* Scenarios defined in Table 5.2

5.1.4 Model Validation Observations

Overall, the TPM-4.3 model ML share estimates are closer to the Minnesota field data than the estimates of the WSA study. The TPM-4.3 model ML share estimates are generally lower than the WSA study. It should be also noted that the TPM-4.3 model outputs for the total volumes are much closer to the I-394 field observations, which are almost the same as the field observations (≤1%). In addition, the TPM-4.3 model outputs for SOV are close both to the I-394 field observations (≤4%) and the estimates of the WSA study (≤7%).

5.2 Case Study

As a case study, a future managed lane segment on I-30 in Grand Prairie, Texas, between the cities of Dallas and Arlington, is modeled to examine a set of proposed operating scenarios. The required inputs, including geometric configuration and the user composition of the facility, are presented below.

- The Drake model is used with the free-flow speed of 80 miles per hour and a lane capacity of 2200 passenger cars per lane per hour.
- This study section is five-miles long with two toll lanes and four free lanes.
- The vehicle mix includes 76.4% SOV, 10% HOV2, 5% HOV3+, 1.5% Van-Pool, 0.5% Para-Transit, 0.2% Bus, 0.8% Light Freight truck, 5.2% Single Trailer truck and 0.4% Double Trailer truck (Goodin et al. 2009).
- The PCE for SOV, HOV2, HO3+, Van-Pool, Para-Transit, Bus, Light Freight, Single Trailer and Double Trailer are 1, 1, 1, 1.2, 1.5, 1.2, 1.2, 1.5, 2.0 and 3.0, respectively (Goodin et al. 2009).
- SOV is charged at full toll rates based on the scenarios. HOV2, HOV3+ and Van-Pools are either half-price or free, and Para-Transit and Buses are free.
- The corridor demand is assumed to be 11,000 vehicles per hour.
- The dead setters are set at 5 percent.
- The VOTs are based on the values presented in chapter three.

A total of 24 policy scenarios are tested on the proposed managed lane section. The policies can be divided into four subsets: 1 to 6, 7 to 12, 13 to 18, and 19 to 24 as shown in Table 5.5. Each subset includes six different pricing scenarios with various preferential treatments for HOV2 and HOV3+ vehicles. Subsets one to three are analyzed by toll objectives, which cover prices ranging from \$0.10/mile to \$0.50/mile. The fourth subset is run by maintaining the managed lane speed at 65 mph, with the same preferential treatment scenarios as the first three subsets. The specific pricing policy scenarios studied are listed in Table 5.5.

These inputs will be entered into TPM-4.3 to estimate outcomes such as traffic volume, speed, revenue and emissions for the ML and GPL.

Table 5.5 Policy scenarios

Scenario	Corridor Length (miles)	Toll Amount ($/mile)				ML Speed (mph)
		SOV	HOV2	HOV3+	Trucks	
1	5	$0.10	SOV	SOV	Not on ML	-
2	5	$0.10	Free	Free	Not on ML	-
3	5	$0.10	0.5xSOV	0.5xSOV	Not on ML	-
4	5	$0.10	0.5xSOV	Free	Not on ML	-
5	5	$0.10	SOV	0.5xSOV	Not on ML	-
6	5	$0.10	SOV	Free	Not on ML	-
7	5	$0.25	SOV	SOV	Not on ML	-
8	5	$0.25	Free	Free	Not on ML	-
9	5	$0.25	0.5xSOV	0.5xSOV	Not on ML	-
10	5	$0.25	0.5xSOV	Free	Not on ML	-
11	5	$0.25	SOV	0.5xSOV	Not on ML	-
12	5	$0.25	SOV	Free	Not on ML	-
13	5	$0.50	SOV	SOV	Not on ML	-
14	5	$0.50	Free	Free	Not on ML	-
15	5	$0.50	0.5xSOV	0.5xSOV	Not on ML	-
16	5	$0.50	0.5xSOV	Free	Not on ML	-
17	5	$0.50	SOV	0.5xSOV	Not on ML	-
18	5	$0.50	SOV	Free	Not on ML	-
19	5	-	SOV	SOV	Not on ML	65
20	5	-	Free	Free	Not on ML	65
21	5	-	0.5xSOV	0.5xSOV	Not on ML	65
22	5	-	0.5xSOV	Free	Not on ML	65
23	5	-	SOV	0.5xSOV	Not on ML	65
24	5	-	SOV	Free	Not on ML	65

5.3. Impact Estimates

Table 5.6 displays the impact estimates of various HOV preferential treatment policies as presented in the Table 5.5. The first two scenarios for each subset begin with a scenario of the least preferential treatment (tolled same as SOV) and the most preferential treatment (free) for HOV followed by four more scenario variations for intermediate HOV preferential treatments.

5.3.1 Policy Scenarios 1 to 18

In Table 5.6, scenarios 1 to 6 have a SOV toll of $0.10/mile, scenarios 7 to 12 are at $0.25 /mile and scenarios 13 to 19 specify a SOV toll of $0.50/mile. CO and NOx emissions show little to no change within each subset regardless of the preferential treatment of HOV2 and HOV3+, but they are significantly reduced when toll amounts increase (Table 5.6). When compared with the first two subsets, subset three, which includes scenarios 13 to 18 results in an increase in CO_2 and VOC. Scenarios 13 and 17, which have ML volumes less than 1800 vehicles per hour, result in the lowest NOx emission, and a decrease in CO emissions when compared to other scenarios.

System performance varies little within scenario subsets, but it differs greatly across the scenarios. The peak-hour average speeds on the ML increase with larger charges. As expected, the GPL becomes more congested under higher toll scenarios due to decreasing use of ML. For ML, volumes vary from 1,723 to 3,472 vehicles per hour. For GPL, volumes vary from 7,528 to 9,278 vehicles per hour (Table 5.6). Scenarios 13 to 18, with tolls of $0.50/mile, show significant differences in the level of performance between ML and GPL. Among scenarios with a full toll price of $0.50/mile, the charge-all scenario (scenario 13) has the highest impact on speeds, with 77 mph for ML and 30 mph for GPL, and results in the lowest CO (76.9 kilograms/mile) and NOx (4.34 kilograms/mile) emissions, and the highest toll revenue of $4,115 per hour.

Peak hour revenues range from $832 to $4,115. Exempting the HOVs from paying tolls would, of course, result in the lowest peak revenue. Conversely, charging HOV the same toll as SOV results in the highest revenue. The second greatest peak hour revenue in each subset is attained by charging the HOV2 the same as the SOV and the HOV3+ half as much as the SOV. Naturally, as the scenarios become more preferential towards the HOV2 and HOV3+, toll revenues decrease.

5.3.2 Policy Scenarios 19 to 24

Policy scenarios 19 to 24, with tolls as low as $0.02/mile and as much as $0.03/mile, are aimed at maintaining the ML speed at 65 mph. These scenarios result in the same GPL speed at 62 mph. They show little difference in VOC emission, and no change is observed for other emissions. Scenario 19 results in the highest ML volume of 3,757 vph. Scenario 20, with the maximum HOV preferential treatment, yields the lowest toll revenue of $289. Scenario 24 which charges SOV and HOV2 at $0.03/mile and HOV3+ at half price yields a maximum revenue of $445.

Table 5.6 Impact estimates using the TPM-4.3 (Appendix A)

Scenario	Toll Amount ($/mile)			Peak Hr. Volume (vph)		Peak Hr. Avg. Speed (mph)		Peak Hr. Emissions (Kilograms/mile)					Peak Hr. Corridor Revenue ($/peak hr)
	SOV	HOV2	HOV3+	ML	GPL	ML	GPL	CO	VOC	NOx	CO_2	SO_2	
1	$0.10	SOV	SOV	3344	7656	69	58	114.4	0.983	4.77	1,987	0.084	$1,634
2	$0.10	Free	Free	3472	7528	67	60	117.2	0.983	4.80	1,977	0.084	$832
3	$0.10	0.5xSOV	0.5xSOV	3381	7619	68	59	115.7	0.983	4.79	1,982	0.084	$1,478
4	$0.10	0.5xSOV	Free	3404	7596	68	59	115.8	0.985	4.79	1,982	0.084	$1,224
5	$0.10	SOV	0.5xSOV	3357	7642	69	58	114.4	0.984	4.77	1,987	0.084	$1,562
6	$0.10	SOV	Free	3380	7620	68	59	115.7	0.984	4.79	1,982	0.084	$1,308
7	$0.25	SOV	SOV	2622	8378	73	40	88.0	0.972	4.44	2,199	0.084	$3,182
8	$0.25	Free	Free	2959	8041	71	52	104.6	0.970	4.64	2,034	0.084	$1,438
9	$0.25	0.5xSOV	0.5xSOV	2714	8286	73	41	89.5	0.972	4.46	2,178	0.084	$2,925
10	$0.25	0.5xSOV	Free	2791	8209	72	43	91.8	0.968	4.48	2,144	0.084	$2,327
11	$0.25	SOV	0.5xSOV	2660	8340	73	40	88.1	0.973	4.44	2,198	0.084	$3,062
12	$0.25	SOV	Free	2739	8261	73	42	90.8	0.970	4.48	2,160	0.084	$2,469
13	$0.50	SOV	SOV	1723	9278	77	30	76.9	1.016	4.34	2,503	0.084	$4,115
14	$0.50	Free	Free	2179	8821	75	35	82.1	0.986	4.38	2,322	0.084	$925
15	$0.50	0.5xSOV	0.5xSOV	1853	9147	77	31	78.1	1.012	4.35	2,459	0.084	$3,772
16	$0.50	0.5xSOV	Free	2014	8986	76	33	80.1	0.997	4.36	2,385	0.084	$2,770
17	$0.50	SOV	0.5xSOV	1779	9221	77	31	77.9	1.010	4.34	2,463	0.084	$3,959
18	$0.50	SOV	Free	1936	9064	76	32	78.9	1.004	4.35	2,420	0.084	$2,930
19	**$0.02**	SOV	SOV	3757	7243	**65**	62	120.0	0.982	4.83	1,970	0.084	$368
20	**$0.03**	Free	Free	3733	7267	**65**	62	120.0	0.981	4.83	1,970	0.084	$289
21	**$0.02**	0.5xSOV	0.5xSOV	3751	7249	**65**	62	120.0	0.983	4.83	1,970	0.084	$330
22	**$0.03**	0.5xSOV	Free	3733	7267	**65**	62	120.0	0.982	4.83	1,970	0.084	$406
23	**$0.02**	SOV	0.5xSOV	3750	7250	**65**	62	120.0	0.983	4.83	1,970	0.084	$350
24	**$0.03**	SOV	Free	3733	7267	**65**	62	120.0	0.982	4.83	1,970	0.084	$445

5.4 Sensitivity Analysis

The impact estimates of the proposed scenarios are presented in the previous section. In this section, sensitivity analysis is performed and the results are graphically presented to better explain the relationship between various operational outcomes and toll rate as well as demand level.

5.4.1 Toll Rate Sensitivity

Figures 5.3 through 5.8 illustrate the toll sensitivity curves under various toll policies. The figures show the effects that toll rates have on average speed on both managed lanes (ML) and general purpose lanes (GPL), revenue and emissions. Graph (a) in each figure presents the average operating speeds on ML and GPL. As seen, the speeds between ML and GPL slightly differ at low toll rate (< \$0.10) and the difference increases when toll is increased. This also shows that increasing the average operating speed on the ML can be achieved by implementing a higher toll rate.

Graph (b) in each figure shows the estimated revenue collected from the proposed managed lane facility. As toll increases, revenue also increases to a point where the maximum revenue is reached (Figure 5.4) or the curve slope starts decreasing.

Graphs (c) through (f) in each figure show the relationship between toll rate and emissions. As seen, CO (graphs (c)) and NOx (graph (e)) decrease when toll increases. In contrast, CO_2 (graphs (f)) increases as toll increases. An increase in CO_2 is associated with a reduction in CO and NOx. Interestingly, as toll increases, VOC (graphs (d)) drops to the minimum level at toll rate between \$0.20 and \$0.25.

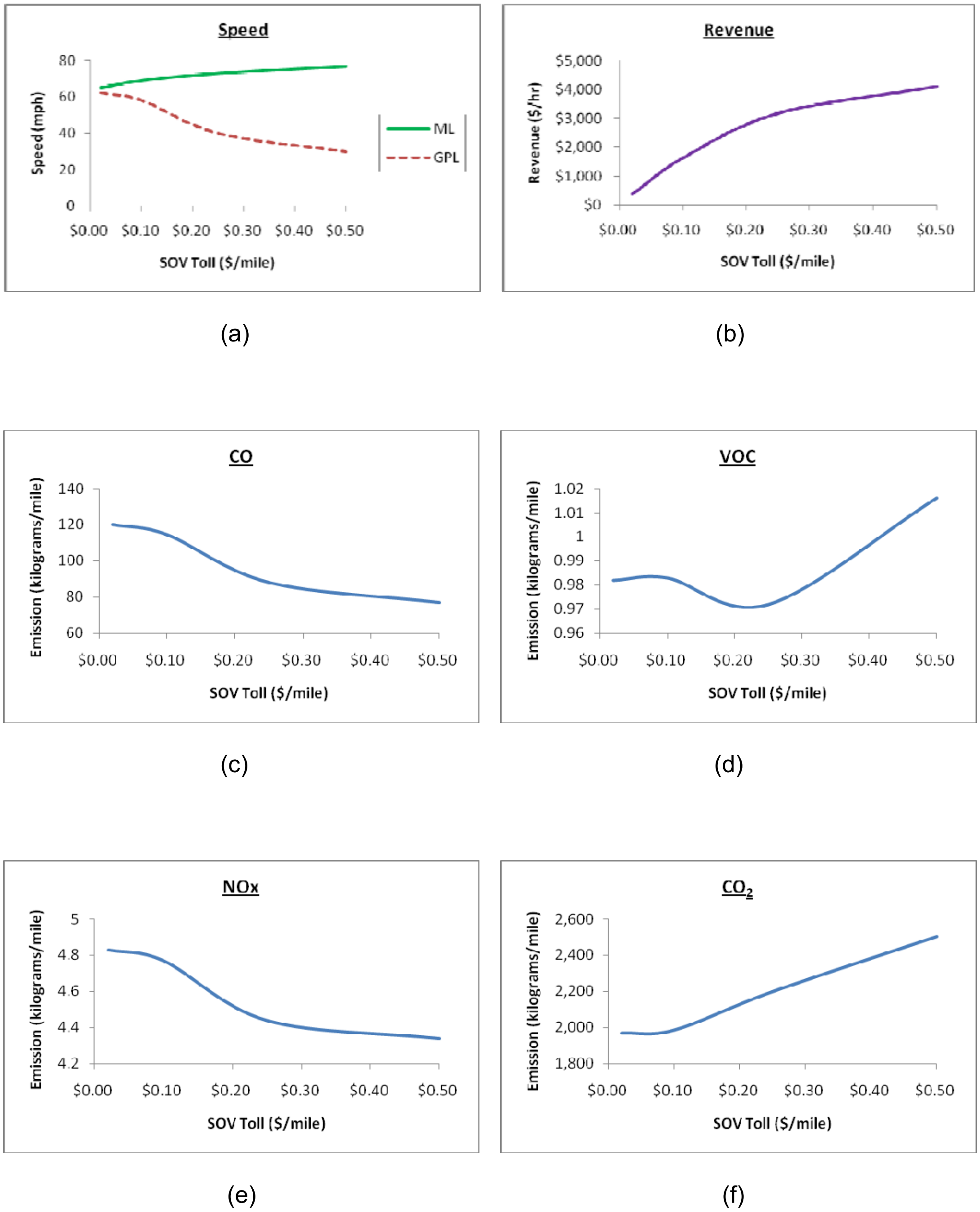


Figure 5.3 Operational outcomes for policy: HOV2 toll = SOV and HOV3+ = SOV; (a) Speed, (b) Revenue, (c) CO, (d) VOC, (e) NOx, (f) CO_2.

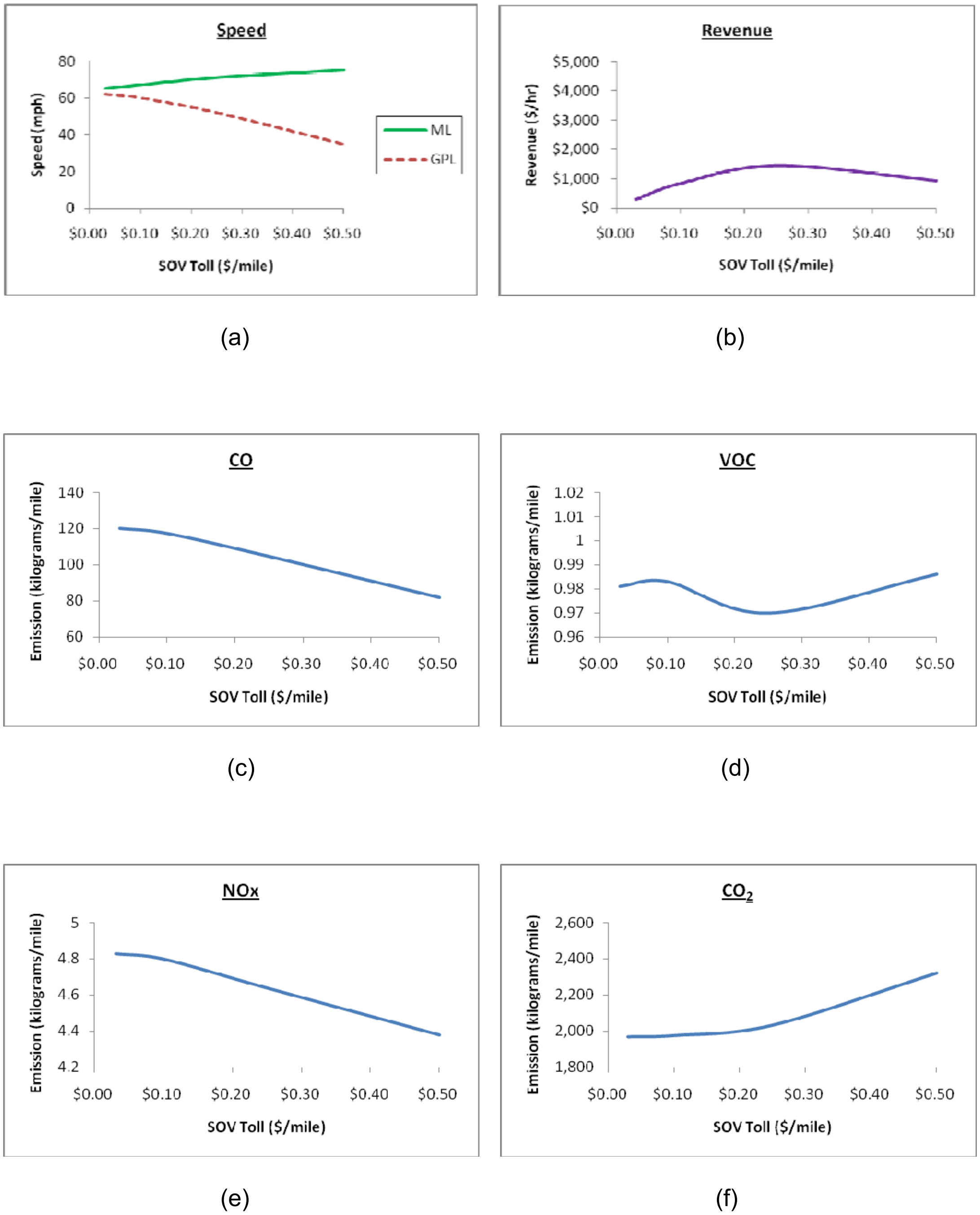
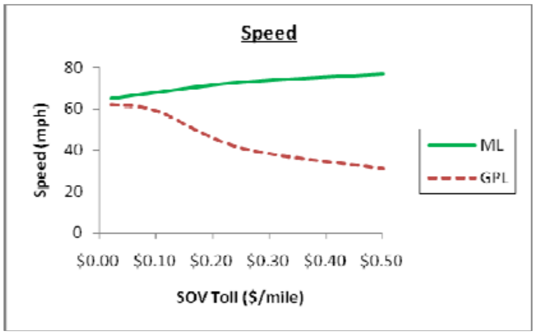
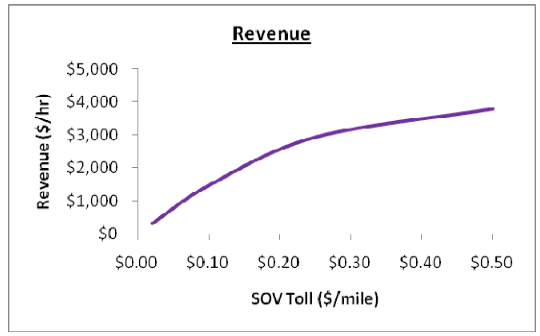


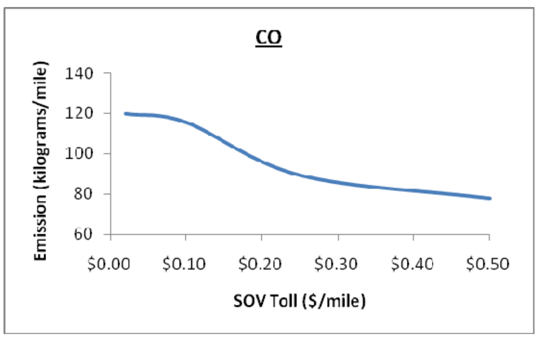
Figure 5.4 Operational outcomes for policy: HOV2 toll = Free and HOV3+ = Free; (a) Speed, (b) Revenue, (c) CO, (d) VOC, (e) NOx, (f) CO_2.



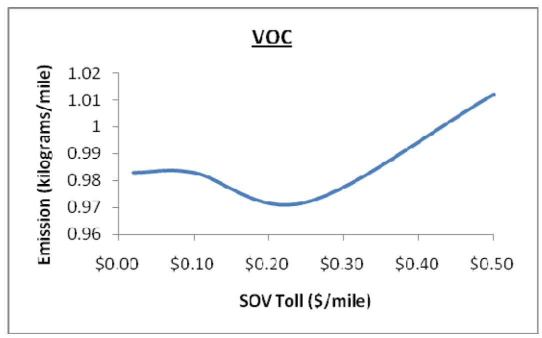
(a)



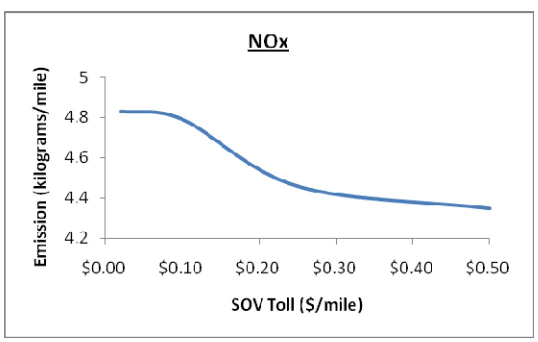
(b)



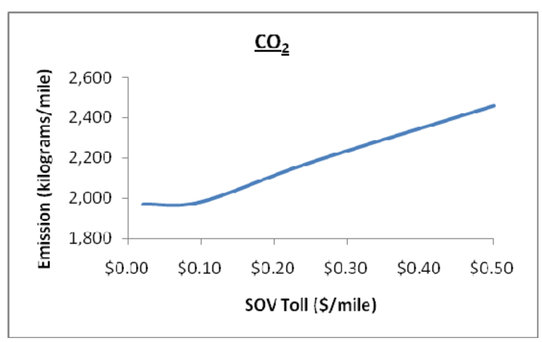
(c)



(d)

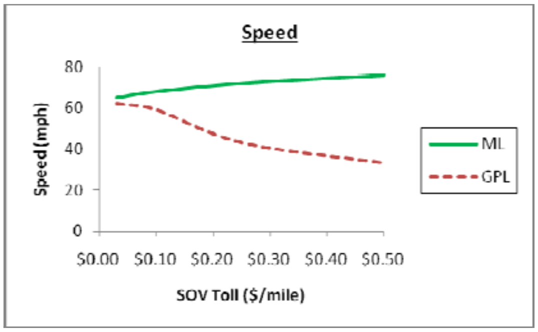


(e)

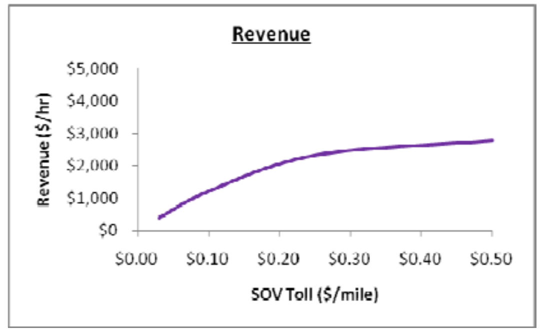


(f)

Figure 5.5 Operational outcomes for policy: HOV2 toll = 50%SOV and HOV3+ = 50%SOV; (a) Speed, (b) Revenue, (c) CO, (d) VOC, (e) NOx, (f) CO_2.



(a)



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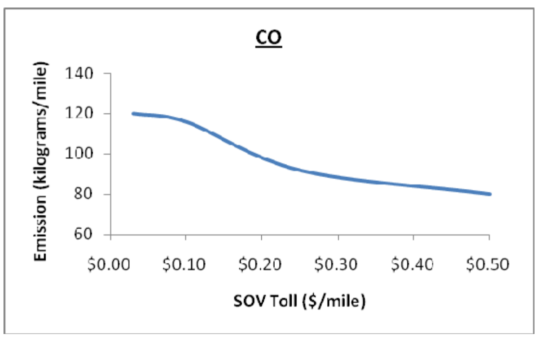

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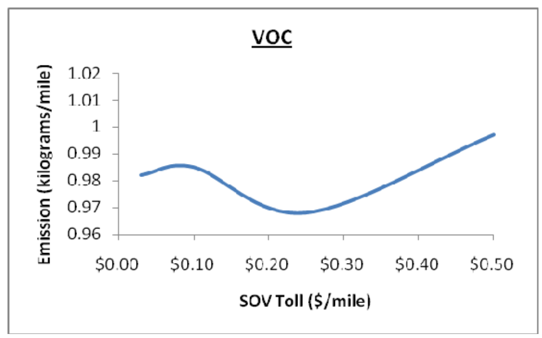
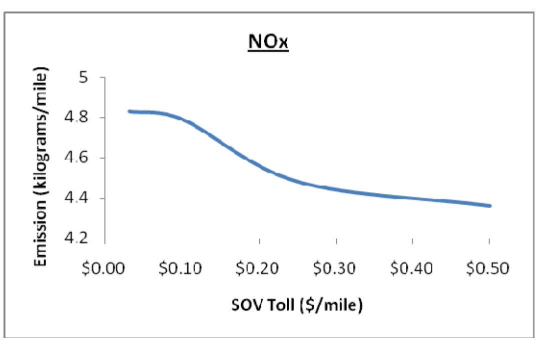


(d)



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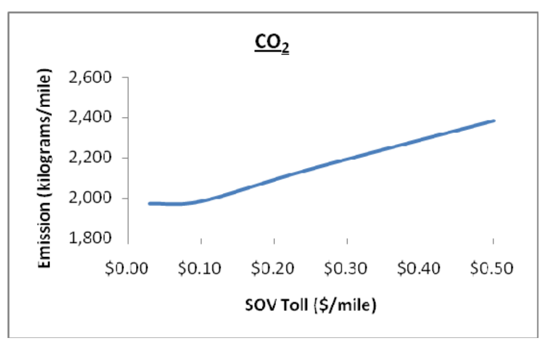
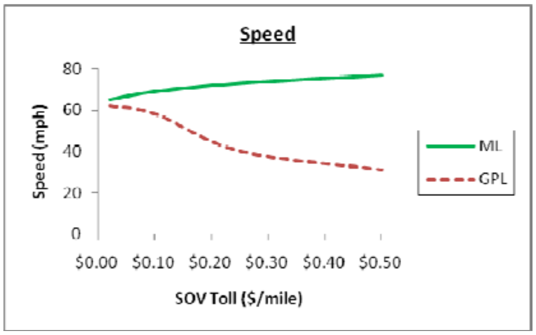
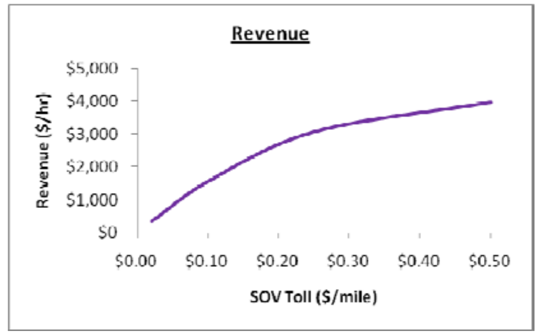


(f)

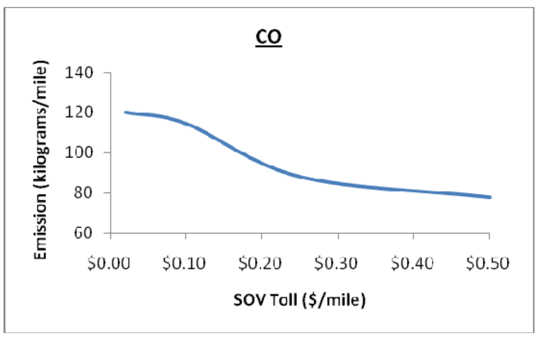
Figure 5.6 Operational outcomes for policy: HOV2 toll = 50%SOV and HOV3+ = Free; (a) Speed, (b) Revenue, (c) CO, (d) VOC, (e) NOx, (f) CO_2.



(a)



(b)



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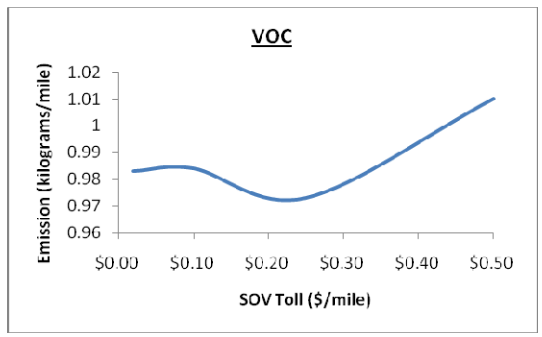
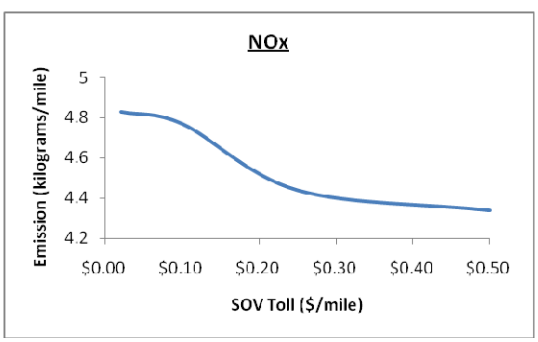


(d)



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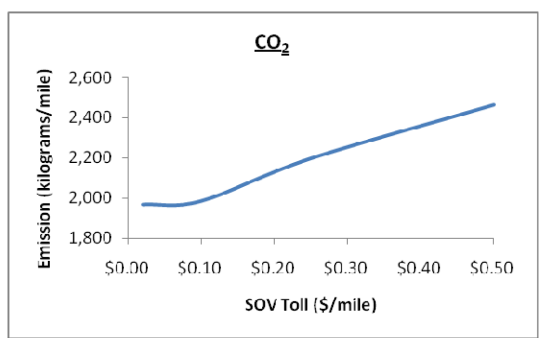
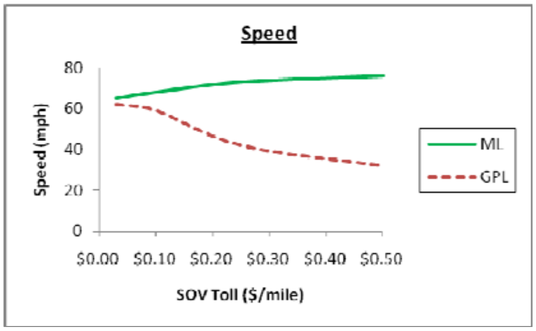
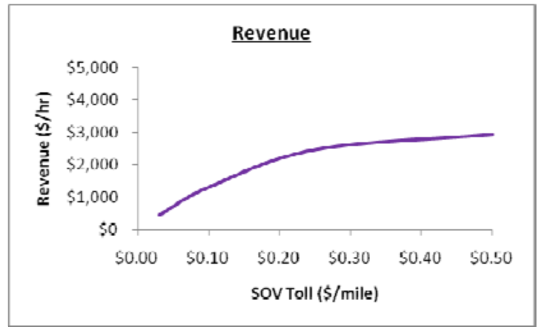


(f)

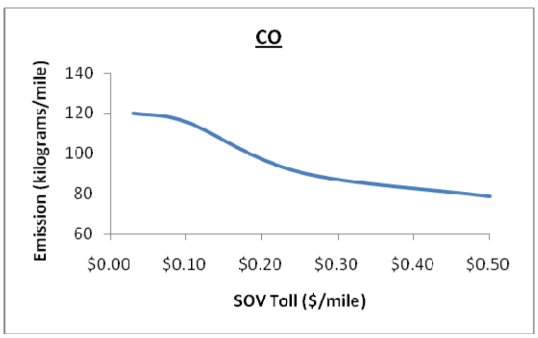
Figure 5.7 Operational outcomes for policy: HOV2 toll = SOV and HOV3+ = 50%SOV; (a) Speed, (b) Revenue, (c) CO, (d) VOC, (e) NOx, (f) CO_2.

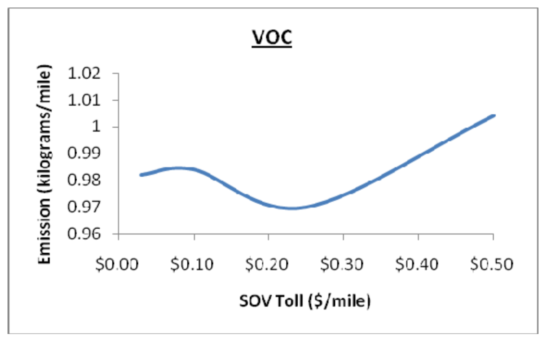




(a)

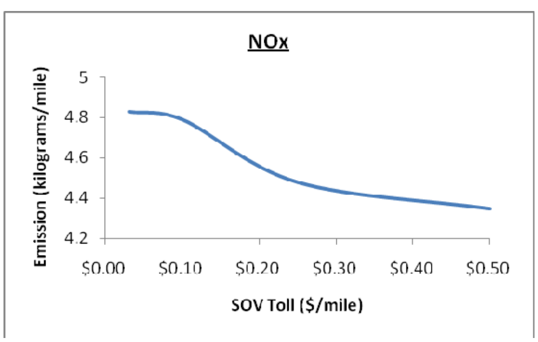
(b)

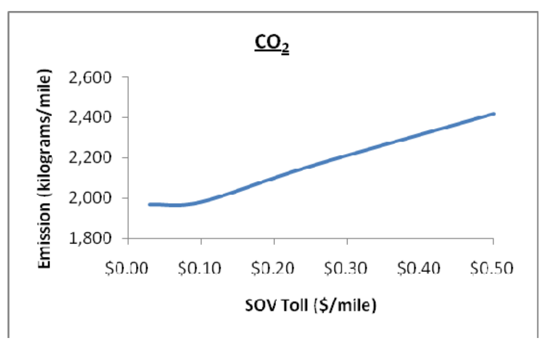




(c)

(d)





(e)

(f)

Figure 5.8 Operational outcomes for policy: HOV2 toll = SOV and HOV3+ = Free;
(a) Speed, (b) Revenue, (c) CO, (d) VOC, (e) NOx, (f) CO_2.

5.4.2 Demand Sensitivity

Figure 5.9 shows the demand sensitivity curves based on the policy of SOV toll = $0.25, HOV2 toll = $0.125 and HOV3+ = Free. Graphs (a), (b), (c) and (d) illustrate the relationship between demand level (v/c) and amount of CO, VOC, NOx and CO_2, respectively. As seen, the amount of all emissions increases as demand increases, except for CO. In general, lesser speed emits lower CO. When demand is greater than 75% of capacity, speeds on both GPL and ML drop. This results in reduction in CO.

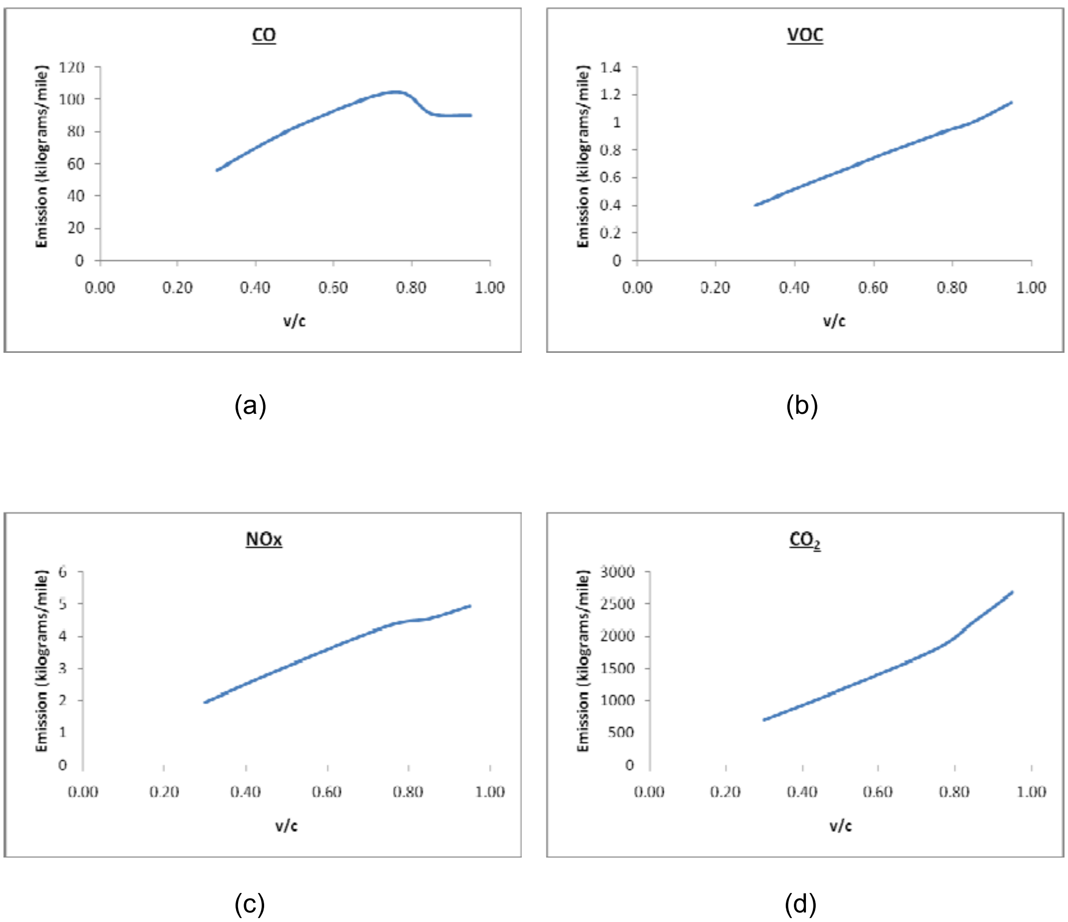


Figure 5.9 Emissions emitted at different demand levels (v/c) based on the policy of SOV toll = $0.25, HOV2 toll = $0.125 and HOV3+ = Free;
(a) CO, (d) VOC, (e) NOx, (f) CO_2.

5.5 Impact Summary

Based on the results, impacts on system performance, emissions and revenue can be summarized as follows:

5.5.1 System Performance Impacts

Based on the stated-preference price sensitivities derived from previous studies for Texas drivers, tolls below the level of \$0.10/mile tend to spread out vehicles in both the GPL and ML. As a result, there would be no significant difference in speeds between the GPL and ML. Charging a toll of \$0.25/mile or higher would increase system performance on the ML and reduce system performance on the GPL. In each subset, HOV preferential treatments have little impact on overall system performance. However, lower HOV preferential treatment (higher tolls) would increase system performance on the ML.

Maintaining a speed of 65 mph on the ML requires a tradeoff between toll rate and HOV preferential treatment, namely, either a SOV toll rate of \$0.02/mile with no HOV preferential treatment, or a toll rate of \$0.03/mile with free HOV access, or some combination of these pricing policies.

5.5.2 Emissions Impacts

As seen, the most preferential treatment scenario generates the most CO and NOx emissions. Regardless of the toll policy, no change in the amount of peak hour SO_2 emissions is observed. Trucks are by policy not allowed on the ML. Scenarios 13 to 18 have the greatest CO_2 emissions followed by scenarios 7 to 12. The greatest reduction in CO and NOx emissions occurs in scenarios at the toll level of \$0.50/mile. Among all scenarios, the policy with a toll rate of \$0.50/mile and no HOV preferential treatment results in the least CO and NOx emissions. It is observed that a reduction in NOx is generally associated with an increase in VOC.

5.5.3 Revenue Impacts

Although HOV preferential treatments do not significantly affect peak hour system performance, they do negatively impact the peak hour revenue. In general, lower HOV preferential treatment (higher tolls) results in an increase in overall toll revenues. In scenarios where HOV has free access to ML, revenue is observed at the minimum for every subset. The maximum revenue of $4,115 is obtained in scenario 13 at a toll of $0.50 with the least preferential treatment for HOV, followed by $3,959 and $3,772 for scenarios 17 and 15, respectively.

Overall, except for the highest preferential treatment scenarios for HOV, higher toll rates tend to generate higher toll revenues, reduce overall CO and NOx emissions, and shift travel demand to GPL. HOV preferential treatments at any given toll level tend to reduce toll revenue, either have no impact or reduce system performance on ML, and increase CO and NOx emissions.

5.6 Summary

In this chapter, the model estimates are compared with the estimates from the previous studies (WSA 2007; MnDOT 2006) to validate the proposed toll pricing model. This chapter also examines the case study by using the TPM-4.3 to predict the potential users on managed lanes and estimate the system performances, revenue and emissions. In addition, several sensitivity analyses are performed and recommended toll rates are presented for each policy. Finally, the impact estimates from the case study are discussed and summarized. In the next chapter, conclusions and recommendations related to the TPM-4.3 and future directions are presented.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

This research developed and implemented the Toll Pricing Modeler version 4.3 (TPM-4.3) for a dynamic toll pricing study for multiple vehicle classes based on a new paradigm in user equilibrium. The TPM-4.3 was utilized to estimate impacts of toll pricing scenarios on system performance, toll revenue and emissions on the proposed I-30 managed lane facility by using value of time (VOT) distributions derived from Dallas-Fort Worth area. For each vehicle class, different VOT distributions were used to estimate the impact on user equilibrium assignment. This chapter provides conclusions and a summary of contributions along with a discussion of future directions.

6.1 Conclusions

The impact analysis results indicate that various toll pricing policies could have substantial impacts on the volume assignment, system performance, total revenue and emissions. A number of key conclusions can be drawn from this analysis:

1. In the low volume conditions, the managed lanes (ML) become less-attractive to single occupancy vehicles (SOV) if the ML travel times do not differ or are only slightly lower than the general purpose lane (GPL) travel times and travelers are likely to continue using the GPLs. As the volume increases to the point where volumes can greatly increase the travel time on the GPLs, the probability of using MLs will also increase.

2. Based on the stated-preference price sensitivities for Dallas-Fort Worth drivers, tolls below $0.10/mile tend to spread vehicles across the GPLs and MLs in such a way to generate significant ML travel time improvements. At this toll rate, more than 30% of travelers on the corridor would pay a toll to use managed lanes.

3. In the scenarios where SOVs and high occupancy vehicles (HOV) are charged the same price, the predicted ML shares are different because characteristics of the VOT distribution of the SOVs differ from those of the HOVs.

4. HOV preferential treatments (lower HOV tolls) have little impact on system performance. However, lower HOV preferential treatment (higher HOV tolls) would increase system performance on the ML.

5. A tradeoff between SOV toll rate and HOV preferential treatment can be used to maintain a speed on the ML at or above a threshold value.

6. The HOV preferential treatment (lower HOV tolls) on the managed lanes increases the level of CO and NOx emissions.

7. There is no difference in the amount of peak hour SO_2 emissions across the various policies since SO_2 does not depend on the speed. In general, SO_2 is emitted by trucks using diesel fuel and trucks are not allowed on ML under any of the policies examined.

8. The greatest reduction in CO and NOx emissions occurs at a high toll rate. A policy with a high toll rate and no HOV preferential treatment results in the least CO and NOx emissions. Also, a reduction in NOx is generally associated with an increase in VOC and CO_2.

9. HOV preferential treatments do not significantly affect peak hour system performance but they do negatively impact the peak hour revenue. In general, lower HOV preferential treatment and higher toll rate result in an increase in toll revenues.

6.2 Summary of Contributions

The ultimate motivation behind this study was to develop a simulation model for volume assignment on the managed lane facilities and to incorporate VOT distributions for various vehicle classes to assess the impact of a dynamic toll pricing policy. As a result, the Toll Pricing Modeler version 4.3 (TPM-4.3) was developed based on a new user equilibrium. The contributions of this research include introduction of a new paradigm in user equilibrium on the basis of values of time versus tolls per unit time of savings. In addition, the use of value of time for various classes of users and testing the predictive ability of the TPM-4.3 using field data are among other key contributions of this study.

6.2.1 A New Paradigm in User Equilibrium

In managed lane networks, conventional equilibrium concepts cannot be applied to determine the equilibrium state. This is because managed lanes are designed to provide a lower travel time when compared to general purpose lanes. Due to this reason, a proposed new paradigm in user equilibrium is introduced and incorporated into the model to predict the potential managed lane users and their overall impact on system performance, total revenues and emissions. Based on the proposed concept, a managed lane facility that operates with a dynamic tolling strategy and also multiple vehicle classes can be analyzed to examine system performance.

6.2.2 Value of Time

Average values of time have been used in previous travel demand models to forecast volume assignments. While this seems to be a preferable option due to its simplicity and ease of data collection, it could lead to large estimation errors because a linear relationship is assumed for the toll users' sensitivity. Also, the assumption that all vehicle classes have the same value of time distribution will limit the ability to predict potential managed lane users among various vehicle classes. Therefore, a single average VOT, as used previously, is not an effective representation for predicting ML demands. In this study, several VOT distributions presented in chapter three can represent the willingness to pay of the different user types in Dallas-Fort Worth. As a result, various tolling policies can be effectively analyzed for the proposed I-30 managed lane facility that will operate with multiple vehicle classes and toll rates.

6.2.3 The TPM-4.3

Various TPM-4.3 input modules are described in detail, including the facility information, user information, VOT and facility objectives. This allows the transportation analysts to model their proposed managed facility toll policies and study the impacts on the network. A key feature of this software is its capability to incorporate VOTs for multiple vehicle classes and to combine several toll operating policies to estimate impacts. Transportation analysts can use one of the two built-in objectives to predict the volume assignments on their facility. This software can estimate the demands on the MLs and GPLs, among other outcomes such as speeds, revenues and emissions.

6.3 Future Directions

A key future research topic could be a better determination of VOT distributions through revealed preferences as well as an expansion of the VOT distribution to other potential vehicle classes such as trucks and motorcycles. In fact, other important factors influencing VOT, such as trip purpose, time of day, income, race, gender and payment modes (e.g., cash, prepaid tags, credit card charge, etc.), can be included in the price sensitivity analysis to derive the VOT distributions. Also, recognition that the price sensitivity could vary from region to region should be taken into account.

In this version, the software does not include a conversion between modes. If HOV preferential treatments (lower HOV tolls or free) are implemented on the ML to encourage carpooling, a SOV may become a HOV. In this case, mode change can happen but it cannot be captured in the software. Also, when the managed lane concept is implemented on the corridor, travelers may change their commute route. A possibility of route change (increase or decrease in demand) does not exist in the TPM-4.3 model. A future version should include the functions to capture potential mode and route changes.

Based on the previous study by Nepal (2008), the Drake model (Drake et al. 1967) is recommended to characterize the relationship between flow, concentration and speed (q-k-u) on the freeways in Dallas-Fort Worth. However, if managed lanes are proposed in other regions, the q-k-u model should be estimated from the detector data collected in that region or on the proposed managed lane corridor. This allows more accurate predictions for the study corridor since its characteristics such as free-flow speed are obtained and used for the analysis input. Other improvements can be the use of more accurate link performance functions such as travel time function in terms of lane volume and capacity. Also, a Monte-Carlo simulation approach may be an interesting strategy for assigning vehicles in equilibrium reaching process.

In the TPM-4.3, emission estimates, except for the SO_2 emission, are based on a number of regression equations which use the average speed as the predictor variable (Yerramalla, 2007). The SO_2 emission rates are obtained from the information provided by vehicle manufacturers and built into MOBILE6.2. These emission estimates can be improved by updating emission models using Motor Vehicle Emission Simulator (MOVES) (USEPA 2009). This program provides more accurate results and will replace MOBILE6 for all official analyses.

As mentioned previously, the TPM-4.3 has potential application to analysis of alternative toll versus free highway that has a same origin-destination pair with different length. However, further validation of this analysis type should be performed to ensure the model applicability. Additionally, the model validation using I-30 or Katy freeway data is needed when it is available because various components in the TPM-4.3 are based on the results from the previous studies using Texas data. Therefore, the TPM-4.3 is expected to effectively perform on the toll facilities in Texas.

During the model validation process, the TPM-4.3 predicts no toll users on the ML while a previous study (WSA 2007) shows potential toll users on the facility. This happens in the low volume conditions where travel times on MLs and GPLs only slightly differ. From the economic standpoint, it is not worth paying a toll for very little or no time savings. This can be because there is a group of motorists who are not sensitive to the price and will pay any toll rates for their trips. The reasons may be because they have a high VOT, their trips are highly important or they have other reasons such as safety considerations. Therefore, the study should be conducted to capture this behavior and incorporate it into future models.

Finally, in the TPM-4.3, the last VOT range for the VOT input is assumed to have a same interval as previous range. This assumption may lead to prediction errors. This group of motorists (high VOT) has an important role on the ML utilization since they will influence the toll charge when available capacity for SOV is low. In order to improve a result, actual characteristic of VOT distributions at upper limit must be clearly known. Thus, a future study should be able to explain this characteristic and include this additional element in the models.

APPENDIX A

TPM-4.3 OUTPUTS

A.1 Scenario 1

Objective 1: SOV toll value per mile: $0.10
Speed-flow model: Drake
Number of Managed Lanes: 2 lanes
Number of General Purpose Lanes: 4 lanes
Length of Managed Lane corridor: 5 miles
Corridor Demand: 11000 vph

VOLUME AND TOLL SUMMARY:

Vehicle Class	VolML(vph)	VolGPL(vph)	MLShare(%)	Toll($/mile)	Revenue($/hr)
SOV	2898	5506	34.5	0.1	1449
HOV2	213	887	19.4	0.1	106.5
HOV3+	116	434	21.1	0.1	58
Vanpool	39	126	23.6	0.1	19.5
Para-Transit	55	0	100	Free	0
Bus	22	0	100	Free	0
Motorcycle	0	0	0	N/A	0
Light Freight	0	88	0	N/A	0
Single Trailer	0	572	0	N/A	0
Double Trailer	0	44	0	N/A	0
Total	3343	7657	30.4	-	1633

	ML	GPL
Total Volume (pc/hr)	3383	8385
Avg. Speed (Mile/hr)	69	58

EMMISIONS SUMMARY: (grams/mile)

Vehicle Class	COML	COGPL	VOCML	VOCGPL	NOML	NOGPL	CO2ML	CO2GPL	SO2ML	SO2GPL
SOV	17869	27879	281	467	974	1649	451644	889316	19.6	37.2
HOV2	1313	4491	21	75	72	266	33195	143266	1.4	6
HOV3+	715	2198	11	37	39	130	18078	70099	0.8	2.9
Vanpool	268	711	5	13	15	43	7844	26235	0.3	1.1
Para-Transit	331	0	7	0	21	0	11062	0	0.4	0
Bus	5014	0	2	0	134	0	13084	0	0.6	0
Motorcycle	0	0	0	0	0	0	0	0	0	0
Light Freight	0	394	0	11	0	49	0	24074	0	1
Single Trailer	0	48472	0	46	0	1183	0	275119	0	11.5
Double Trailer	0	4719	0	7	0	195	0	24412	0	1
Total	25510	88864	327	656	1255	3515	534907	1452521	23.1	60.7

A.2 Scenario 2

Objective 1: SOV toll value per mile: $0.10
Speed-flow model: Drake
Number of Managed Lanes: 2 lanes
Number of General Purpose Lanes: 4 lanes
Length of Managed Lane corridor: 5.0 miles
Corridor Demand: 11000 vph

VOLUME AND TOLL SUMMARY:

Vehicle Class	VolML(vph)	VolGPL(vph)	MLShare(%)	Toll($/mile)	Revenue($/hr)
SOV	1663	6741	19.8	0.1	831.5
HOV2	1045	55	95	Free	0
HOV3+	522	28	94.9	Free	0
Vanpool	165	0	100	Free	0
Para-Transit	55	0	100	Free	0
Bus	22	0	100	Free	0
Motorcycle	0	0	0	N/A	0
Light Freight	0	88	0	N/A	0
Single Trailer	0	572	0	N/A	0
Double Trailer	0	44	0	N/A	0
Total	3472	7528	31.6	-	831.5

	ML	GPL
Total Volume (pc/hr)	3537	8231
Avg. Speed (Mile/hr)	67	60

EMMISIONS SUMMARY: (grams/mile)

Vehicle Class	COML	COGPL	VOCML	VOCGPL	NOML	NOGPL	CO2ML	CO2GPL	SO2ML	SO2GPL
SOV	9892	35366	157	584	547	2059	260432	1079814	11.2	45.5
HOV2	6216	289	99	5	344	17	163651	8810	7.1	0.4
HOV3+	3105	147	49	2	172	9	81747	4485	3.5	0.2
Vanpool	1094	0	20	0	63	0	33340	0	1.5	0
Para-Transit	316	0	7	0	21	0	11113	0	0.4	0
Bus	4817	0	3	0	133	0	13148	0	0.6	0
Motorcycle	0	0	0	0	0	0	0	0	0	0
Light Freight	0	408	0	11	0	50	0	23875	0	1
Single Trailer	0	50588	0	40	0	1190	0	272845	0	11.5
Double Trailer	0	4925	0	6	0	196	0	24211	0	1
Total	25440	91723	335	648	1280	3521	563431	1414040	24.3	59.6

A.3 Scenario 3

Objective 1: SOV toll value per mile: $0.10
Speed-flow model: Drake
Number of Managed Lanes: 2 lanes
Number of General Purpose Lanes: 4 lanes
Length of Managed Lane corridor: 5.0 miles
Corridor Demand: 11000 vph

VOLUME AND TOLL SUMMARY:

Vehicle Class	VolML(vph)	VolGPL(vph)	MLShare(%)	Toll($/mile)	Revenue($/hr)
SOV	2605	5799	31	0.1	1302.5
HOV2	397	703	36.1	0.05	99.25
HOV3+	232	318	42.2	0.05	58
Vanpool	70	95	42.4	0.05	17.5
Para-Transit	55	0	100	Free	0
Bus	22	0	100	Free	0
Motorcycle	0	0	0	N/A	0
Light Freight	0	88	0	N/A	0
Single Trailer	0	572	0	N/A	0
Double Trailer	0	44	0	N/A	0
Total	3381	7619	30.7	-	1477

	ML	GPL
Total Volume (pc/hr)	3427	8341
Avg. Speed (Mile/hr)	68	59

EMMISIONS SUMMARY: (grams/mile)

Vehicle Class	COML	COGPL	VOCML	VOCGPL	NOML	NOGPL	CO2ML	CO2GPL	SO2ML	SO2GPL
SOV	15776	29887	250	497	866	1754	406932	932669	17.6	39.1
HOV2	2404	3623	38	60	132	213	62016	113065	2.7	4.7
HOV3+	1405	1639	22	27	77	96	36241	51145	1.6	2.1
Vanpool	473	546	8	10	27	33	14110	19699	0.6	0.8
Para-Transit	323	0	7	0	21	0	11086	0	0.4	0
Bus	4915	0	3	0	134	0	13115	0	0.6	0
Motorcycle	0	0	0	0	0	0	0	0	0	0
Light Freight	0	401	0	11	0	50	0	23972	0	1
Single Trailer	0	49521	0	43	0	1186	0	273950	0	11.5
Double Trailer	0	4821	0	7	0	196	0	24308	0	1
Total	25296	90438	328	655	1257	3528	543500	1438808	23.5	60.2

A.4 Scenario 4

Objective 1: SOV toll value per mile: $0.10
Speed-flow model: Drake
Number of Managed Lanes: 2 lanes
Number of General Purpose Lanes: 4 lanes
Length of Managed Lane corridor: 5.0 miles
Corridor Demand: 11000 vph

VOLUME AND TOLL SUMMARY:

Vehicle Class	VolML(vph)	VolGPL(vph)	MLShare(%)	Toll($/mile)	Revenue($/hr)
SOV	2256	6148	26.8	0.1	1128
HOV2	384	716	34.9	0.05	96
HOV3+	522	28	94.9	Free	0
Vanpool	165	0	100	Free	0
Para-Transit	55	0	100	Free	0
Bus	22	0	100	Free	0
Motorcycle	0	0	0	N/A	0
Light Freight	0	88	0	N/A	0
Single Trailer	0	572	0	N/A	0
Double Trailer	0	44	0	N/A	0
Total	3404	7596	30.9	-	1224

	ML	GPL
Total Volume (pc/hr)	3469	8299
Avg. Speed (Mile/hr)	68	59

EMMISIONS SUMMARY: (grams/mile)

Vehicle Class	COML	COGPL	VOCML	VOCGPL	NOML	NOGPL	CO2ML	CO2GPL	SO2ML	SO2GPL
SOV	13663	31686	216	527	750	1859	352414	988799	15.2	41.5
HOV2	2326	3690	37	61	128	217	59985	115156	2.6	4.8
HOV3+	3161	144	50	2	174	8	81543	4503	3.5	0.2
Vanpool	1114	0	20	0	64	0	33259	0	1.5	0
Para-Transit	323	0	7	0	21	0	11086	0	0.4	0
Bus	4915	0	3	0	134	0	13115	0	0.6	0
Motorcycle	0	0	0	0	0	0	0	0	0	0
Light Freight	0	401	0	11	0	50	0	23972	0	1
Single Trailer	0	49521	0	43	0	1186	0	273950	0	11.5
Double Trailer	0	4821	0	7	0	196	0	24308	0	1
Total	25502	90263	333	651	1271	3516	551402	1430688	23.8	60

A.5 Scenario 5

Objective 1: SOV toll value per mile: $0.10
Speed-flow model: Drake
Number of Managed Lanes: 2 lanes
Number of General Purpose Lanes: 4 lanes
Length of Managed Lane corridor: 5.0 miles
Corridor Demand: 11000 vph

VOLUME AND TOLL SUMMARY:

Vehicle Class	VolML(vph)	VolGPL(vph)	MLShare(%)	Toll($/mile)	Revenue($/hr)
SOV	2767	5637	32.9	0.1	1383.5
HOV2	199	901	18.1	0.1	99.5
HOV3+	241	309	43.8	0.05	60.25
Vanpool	73	92	44.2	0.05	18.25
Para-Transit	55	0	100	Free	0
Bus	22	0	100	Free	0
Motorcycle	0	0	0	N/A	0
Light Freight	0	88	0	N/A	0
Single Trailer	0	572	0	N/A	0
Double Trailer	0	44	0	N/A	0
Total	3357	7643	30.5	-	1561.5

	ML	GPL
Total Volume (pc/hr)	3404	8364
Avg. Speed (Mile/hr)	69	58

EMMISIONS SUMMARY: (grams/mile)

Vehicle Class	COML	COGPL	VOCML	VOCGPL	NOML	NOGPL	CO2ML	CO2GPL	SO2ML	SO2GPL
SOV	17061	28543	269	478	930	1688	431228	910475	18.7	38
HOV2	1227	4562	19	76	67	270	31014	145527	1.3	6.1
HOV3+	1486	1565	23	26	81	93	37559	49909	1.6	2.1
Vanpool	502	519	9	10	28	32	14682	19156	0.6	0.8
Para-Transit	331	0	7	0	21	0	11062	0	0.4	0
Bus	5014	0	2	0	134	0	13084	0	0.6	0
Motorcycle	0	0	0	0	0	0	0	0	0	0
Light Freight	0	394	0	11	0	49	0	24074	0	1
Single Trailer	0	48472	0	46	0	1183	0	275119	0	11.5
Double Trailer	0	4719	0	7	0	195	0	24412	0	1
Total	25621	88774	329	654	1261	3510	538629	1448672	23.2	60.5

A.6 Scenario 6

Objective 1: SOV toll value per mile: $0.10
Speed-flow model: Drake
Number of Managed Lanes: 2 lanes
Number of General Purpose Lanes: 4 lanes
Length of Managed Lane corridor: 5.0 miles
Corridor Demand: 11000 vph

VOLUME AND TOLL SUMMARY:

Vehicle Class	VolML(vph)	VolGPL(vph)	MLShare(%)	Toll($/mile)	Revenue($/hr)
SOV	2439	5965	29	0.1	1219.5
HOV2	177	923	16.1	0.1	88.5
HOV3+	522	28	94.9	Free	0
Vanpool	165	0	100	Free	0
Para-Transit	55	0	100	Free	0
Bus	22	0	100	Free	0
Motorcycle	0	0	0	N/A	0
Light Freight	0	88	0	N/A	0
Single Trailer	0	572	0	N/A	0
Double Trailer	0	44	0	N/A	0
Total	3380	7620	30.7	-	1308

	ML	GPL
Total Volume (pc/hr)	3445	8323
Avg. Speed (Mile/hr)	68	59

EMMISIONS SUMMARY: (grams/mile)

Vehicle Class	COML	COGPL	VOCML	VOCGPL	NOML	NOGPL	CO2ML	CO2GPL	SO2ML	SO2GPL
SOV	14771	30743	234	511	811	1804	381001	959367	16.5	40.3
HOV2	1072	4757	17	79	59	279	27650	148449	1.2	6.2
HOV3+	3161	144	50	2	174	8	81543	4503	3.5	0.2
Vanpool	1114	0	20	0	64	0	33259	0	1.5	0
Para-Transit	323	0	7	0	21	0	11086	0	0.4	0
Bus	4915	0	3	0	134	0	13115	0	0.6	0
Motorcycle	0	0	0	0	0	0	0	0	0	0
Light Freight	0	401	0	11	0	50	0	23972	0	1
Single Trailer	0	49521	0	43	0	1186	0	273950	0	11.5
Double Trailer	0	4821	0	7	0	196	0	24308	0	1
Total	25356	90387	331	653	1263	3523	547654	1434549	23.7	60.2

A.7 Scenario 7

Objective 1: SOV toll value per mile: $0.25
Speed-flow model: Drake
Number of Managed Lanes: 2 lanes
Number of General Purpose Lanes: 4 lanes
Length of Managed Lane corridor: 5 miles
Corridor Demand: 11000 vph

VOLUME AND TOLL SUMMARY:

Vehicle Class	VolML(vph)	VolGPL(vph)	MLShare(%)	Toll($/mile)	Revenue($/hr)
SOV	2266	6138	27	0.25	2832.5
HOV2	164	936	14.9	0.25	205
HOV3+	88	462	16	0.25	110
Vanpool	27	138	16.4	0.25	33.75
Para-Transit	55	0	100	Free	0
Bus	22	0	100	Free	0
Motorcycle	0	0	0	N/A	0
Light Freight	0	88	0	N/A	0
Single Trailer	0	572	0	N/A	0
Double Trailer	0	44	0	N/A	0
Total	2622	8378	23.8	-	3181.25

	ML	GPL
Total Volume (pc/hr)	2659	9109
Avg. Speed (Mile/hr)	73	40

EMMISIONS SUMMARY: (grams/mile)

Vehicle Class	COML	COGPL	VOCML	VOCGPL	NOML	NOGPL	CO2ML	CO2GPL	SO2ML	SO2GPL
SOV	15010	23326	232	455	797	1612	350405	1124426	15.3	41.4
HOV2	1086	3557	17	69	58	246	25360	171467	1.1	6.3
HOV3+	583	1756	9	34	31	121	13608	84634	0.6	3.1
Vanpool	199	581	3	13	11	40	5390	32520	0.2	1.2
Para-Transit	361	0	7	0	23	0	10980	0	0.4	0
Bus	5426	0	0	0	136	0	12982	0	0.6	0
Motorcycle	0	0	0	0	0	0	0	0	0	0
Light Freight	0	294	0	9	0	43	0	27305	0	1
Single Trailer	0	32655	0	106	0	1131	0	312094	0	11.5
Double Trailer	0	3179	0	16	0	187	0	27691	0	1
Total	22665	65348	268	702	1056	3380	418725	1780137	18.2	65.5

A.8 Scenario 8

Objective 1: SOV toll value per mile: $0.25
Speed-flow model: Drake
Number of Managed Lanes: 2 lanes
Number of General Purpose Lanes: 4 lanes
Length of Managed Lane corridor: 5.0 miles
Corridor Demand: 11000 vph

VOLUME AND TOLL SUMMARY:

Vehicle Class	VolML(vph)	VolGPL(vph)	MLShare(%)	Toll($/mile)	Revenue($/hr)
SOV	1150	7254	13.7	0.25	1437.5
HOV2	1045	55	95	Free	0
HOV3+	522	28	94.9	Free	0
Vanpool	165	0	100	Free	0
Para-Transit	55	0	100	Free	0
Bus	22	0	100	Free	0
Motorcycle	0	0	0	N/A	0
Light Freight	0	88	0	N/A	0
Single Trailer	0	572	0	N/A	0
Double Trailer	0	44	0	N/A	0
Total	2959	8041	26.9	-	1437.5

	ML	GPL
Total Volume (pc/hr)	3024	8744
Avg. Speed (Mile/hr)	71	52

EMMISIONS SUMMARY: (grams/mile)

Vehicle Class	COML	COGPL	VOCML	VOCGPL	NOML	NOGPL	CO2ML	CO2GPL	SO2ML	SO2GPL
SOV	7350	33103	115	578	395	2058	178472	1208044	7.8	49
HOV2	6679	251	104	4	359	16	162177	9159	7.1	0.4
HOV3+	3336	128	52	2	180	8	81011	4663	3.5	0.2
Vanpool	1176	0	21	0	66	0	33052	0	1.5	0
Para-Transit	346	0	7	0	22	0	11017	0	0.4	0
Bus	5217	0	1	0	135	0	13029	0	0.6	0
Motorcycle	0	0	0	0	0	0	0	0	0	0
Light Freight	0	355	0	10	0	47	0	24822	0	1
Single Trailer	0	42555	0	66	0	1164	0	283685	0	11.5
Double Trailer	0	4143	0	10	0	192	0	25172	0	1
Total	24104	80535	300	670	1157	3485	478758	1555545	20.9	63.1

A.9 Scenario 9

Objective 1: SOV toll value per mile: $0.25
Speed-flow model: Drake
Number of Managed Lanes: 2 lanes
Number of General Purpose Lanes: 4 lanes
Length of Managed Lane corridor: 5.0 miles
Corridor Demand: 11000 vph

VOLUME AND TOLL SUMMARY:

Vehicle Class	VolML(vph)	VolGPL(vph)	MLShare(%)	Toll($/mile)	Revenue($/hr)
SOV	2017	6387	24	0.25	2521.25
HOV2	354	746	32.2	0.13	230.1
HOV3+	204	346	37.1	0.13	132.6
Vanpool	62	103	37.6	0.13	40.3
Para-Transit	55	0	100	Free	0
Bus	22	0	100	Free	0
Motorcycle	0	0	0	N/A	0
Light Freight	0	88	0	N/A	0
Single Trailer	0	572	0	N/A	0
Double Trailer	0	44	0	N/A	0
Total	2714	8286	24.7	-	2924.25

	ML	GPL
Total Volume (pc/hr)	2758	9010
Avg. Speed (Mile/hr)	73	41

EMMISIONS SUMMARY: (grams/mile)

Vehicle Class	COML	COGPL	VOCML	VOCGPL	NOML	NOGPL	CO2ML	CO2GPL	SO2ML	SO2GPL
SOV	13360	24594	207	475	710	1685	311900	1158205	13.6	43.1
HOV2	2345	2873	36	55	125	197	54741	135278	2.4	5
HOV3+	1351	1332	21	26	72	91	31546	62743	1.4	2.3
Vanpool	458	440	8	10	25	30	12377	24030	0.5	0.9
Para-Transit	361	0	7	0	23	0	10980	0	0.4	0
Bus	5426	0	0	0	136	0	12982	0	0.6	0
Motorcycle	0	0	0	0	0	0	0	0	0	0
Light Freight	0	298	0	9	0	44	0	27029	0	1
Single Trailer	0	33381	0	102	0	1134	0	308934	0	11.5
Double Trailer	0	3250	0	16	0	187	0	27411	0	1
Total	23301	66168	279	693	1091	3368	434526	1743630	18.9	64.8

A.10 Scenario 10

Objective 1: SOV toll value per mile: $0.25
Speed-flow model: Drake
Number of Managed Lanes: 2 lanes
Number of General Purpose Lanes: 4 lanes
Length of Managed Lane corridor: 5.0 miles
Corridor Demand: 11000 vph

VOLUME AND TOLL SUMMARY:

Vehicle Class	VolML(vph)	VolGPL(vph)	MLShare(%)	Toll($/mile)	Revenue($/hr)
SOV	1681	6723	20	0.25	2101.25
HOV2	346	754	31.5	0.13	224.9
HOV3+	522	28	94.9	Free	0
Vanpool	165	0	100	Free	0
Para-Transit	55	0	100	Free	0
Bus	22	0	100	Free	0
Motorcycle	0	0	0	N/A	0
Light Freight	0	88	0	N/A	0
Single Trailer	0	572	0	N/A	0
Double Trailer	0	44	0	N/A	0
Total	2791	8209	25.4	-	2326.15

	ML	GPL
Total Volume (pc/hr)	2856	8912
Avg. Speed (Mile/hr)	72	43

EMMISIONS SUMMARY: (grams/mile)

Vehicle Class	COML	COGPL	VOCML	VOCGPL	NOML	NOGPL	CO2ML	CO2GPL	SO2ML	SO2GPL
SOV	10938	26617	170	504	585	1791	260391	1196257	11.3	45.4
HOV2	2251	2985	35	56	120	201	53596	134163	2.3	5.1
HOV3+	3396	111	53	2	182	7	80859	4982	3.5	0.2
Vanpool	1197	0	21	0	67	0	32993	0	1.5	0
Para-Transit	353	0	7	0	22	0	10998	0	0.4	0
Bus	5321	0	1	0	135	0	13005	0	0.6	0
Motorcycle	0	0	0	0	0	0	0	0	0	0
Light Freight	0	307	0	9	0	44	0	26522	0	1
Single Trailer	0	34888	0	95	0	1139	0	303132	0	11.5
Double Trailer	0	3397	0	15	0	188	0	26896	0	1
Total	23456	68305	287	681	1111	3370	451842	1691952	19.6	64.2

A.11 Scenario 11

Objective 1: SOV toll value per mile: $0.25
Speed-flow model: Drake
Number of Managed Lanes: 2 lanes
Number of General Purpose Lanes: 4 lanes
Length of Managed Lane corridor: 5.0 miles
Corridor Demand: 11000 vph

VOLUME AND TOLL SUMMARY:

Vehicle Class	VolML(vph)	VolGPL(vph)	MLShare(%)	Toll($/mile)	Revenue($/hr)
SOV	2148	6256	25.6	0.25	2685
HOV2	148	952	13.5	0.25	185
HOV3+	219	331	39.8	0.13	142.35
Vanpool	68	97	41.2	0.13	44.2
Para-Transit	55	0	100	Free	0
Bus	22	0	100	Free	0
Motorcycle	0	0	0	N/A	0
Light Freight	0	88	0	N/A	0
Single Trailer	0	572	0	N/A	0
Double Trailer	0	44	0	N/A	0
Total	2660	8340	24.2	-	3356.55

	ML	GP
Total Volume (pc/hr)	2706	9062
Avg. Speed (Mile/hr)	73	40

EMMISIONS SUMMARY: (grams/mile)

Vehicle Class	COML	COGPL	VOCML	VOCGPL	NOML	NOGPL	CO2ML	CO2GPL	SO2ML	SO2GPL
SOV	14228	23774	220	464	756	1643	332158	1146043	14.5	42.2
HOV2	980	3618	15	71	52	250	22886	174398	1	6.4
HOV3+	1451	1258	22	25	77	87	33865	60636	1.5	2.2
Vanpool	502	409	9	9	28	28	13575	22858	0.6	0.9
Para-Transit	361	0	7	0	23	0	10980	0	0.4	0
Bus	5426	0	0	0	136	0	12982	0	0.6	0
Motorcycle	0	0	0	0	0	0	0	0	0	0
Light Freight	0	294	0	9	0	43	0	27305	0	1
Single Trailer	0	32655	0	106	0	1131	0	312094	0	11.5
Double Trailer	0	3179	0	16	0	187	0	27691	0	1
Total	22948	65187	273	700	1072	3369	426446	1771025	18.6	65.2

A.12 Scenario 12

Objective 1: SOV toll value per mile: $0.25
Speed-flow model: Drake
Number of Managed Lanes: 2 lanes
Number of General Purpose Lanes: 4 lanes
Length of Managed Lane corridor: 5.0 miles
Corridor Demand: 11000 vph

VOLUME AND TOLL SUMMARY:

Vehicle Class	VolML(vph)	VolGPL(vph)	MLShare(%)	Toll($/mile)	Revenue($/hr)
SOV	1845	6559	22	0.25	2306.25
HOV2	130	970	11.8	0.25	162.5
HOV3+	522	28	94.9	Free	0
Vanpool	165	0	100	Free	0
Para-Transit	55	0	100	Free	0
Bus	22	0	100	Free	0
Motorcycle	0	0	0	N/A	0
Light Freight	0	88	0	N/A	0
Single Trailer	0	572	0	N/A	0
Double Trailer	0	44	0	N/A	0
Total	2739	8261	24.9	-	2468.75

	ML	GPL
Total Volume (pc/hr)	2804	8964
Avg. Speed (Mile/hr)	73	42

EMMISIONS SUMMARY: (grams/mile)

Vehicle Class	COML	COGPL	VOCML	VOCGPL	NOML	NOGPL	CO2ML	CO2GPL	SO2ML	SO2GPL
SOV	12221	25604	189	489	649	1739	285303	1177918	12.5	44.3
HOV2	861	3786	13	72	46	257	20103	174200	0.9	6.5
HOV3+	3458	109	54	2	184	7	80720	5028	3.5	0.2
Vanpool	1219	0	21	0	68	0	32939	0	1.5	0
Para-Transit	361	0	7	0	23	0	10980	0	0.4	0
Bus	5426	0	0	0	136	0	12982	0	0.6	0
Motorcycle	0	0	0	0	0	0	0	0	0	0
Light Freight	0	303	0	9	0	44	0	26768	0	1
Single Trailer	0	34126	0	99	0	1136	0	305951	0	11.5
Double Trailer	0	3322	0	15	0	187	0	27146	0	1
Total	23546	67250	284	686	1106	3370	443027	1717011	19.4	64.5

<u>A.13 Scenario 13</u>

Objective 1: SOV toll value per mile: $0.50
Speed-flow model: Drake
Number of Managed Lanes: 2 lanes
Number of General Purpose Lanes: 4 lanes
Length of Managed Lane corridor: 5 miles
Corridor Demand: 11000 vph

VOLUME AND TOLL SUMMARY:

Vehicle Class	VolML(vph)	VolGPL(vph)	MLShare(%)	Toll($/mile)	Revenue($/hr)
SOV	1477	6927	17.6	0.5	3692.5
HOV2	102	998	9.3	0.5	255
HOV3+	49	501	8.9	0.5	122.5
Vanpool	18	148	10.8	0.5	45
Para-Transit	55	0	100	Free	0
Bus	22	0	100	Free	0
Motorcycle	0	0	0	N/A	0
Light Freight	0	88	0	N/A	0
Single Trailer	0	572	0	N/A	0
Double Trailer	0	44	0	N/A	0
Total	1723	9278	15.7	-	4115

	ML	GPL
Total Volume (pc/hr)	1758	10010
Avg. Speed (Mile/hr)	77	30

EMMISIONS SUMMARY: (grams/mile)

Vehicle Class	COML	COGPL	VOCML	VOCGPL	NOML	NOGPL	CO2ML	CO2GPL	SO2ML	SO2GPL
SOV	10504	23946	160	528	545	1800	227144	1451733	10	46.8
HOV2	725	3450	11	76	38	259	15686	209157	0.7	6.7
HOV3+	348	1732	5	38	18	130	7536	104998	0.3	3.4
Vanpool	143	563	2	15	8	42	3575	39840	0.2	1.3
Para-Transit	394	0	7	0	24	0	10923	0	0.4	0
Bus	5862	0	-2	0	138	0	12911	0	0.6	0
Motorcycle	0	0	0	0	0	0	0	0	0	0
Light Freight	0	266	0	9	0	42	0	31238	0	1
Single Trailer	0	26374	0	145	0	1111	0	357069	0	11.5
Double Trailer	0	2568	0	22	0	183	0	31681	0	1
Total	17976	58899	183	833	771	3567	277775	2225716	12.2	71.7

A.14 Scenario 14

Objective 1: SOV toll value per mile: $0.50
Speed-flow model: Drake
Number of Managed Lanes: 2 lanes
Number of General Purpose Lanes: 4 lanes
Length of Managed Lane corridor: 5.0 miles
Corridor Demand: 11000 vph

VOLUME AND TOLL SUMMARY:

Vehicle Class	VolML(vph)	VolGPL(vph)	MLShare(%)	Toll($/mile)	Revenue($/hr)
SOV	370	8034	4.4	0.5	925
HOV2	1045	55	95	Free	0
HOV3+	522	28	94.9	Free	0
Vanpool	165	0	100	Free	0
Para-Transit	55	0	100	Free	0
Bus	22	0	100	Free	0
Motorcycle	0	0	0	N/A	0
Light Freight	0	88	0	N/A	0
Single Trailer	0	572	0	N/A	0
Double Trailer	0	44	0	N/A	0
Total	2179	8821	19.8	-	925

	ML	GPL
Total Volume (pc/hr)	2244	9524
Avg. Speed (Mile/hr)	75	35

EMMISIONS SUMMARY: (grams/mile)

Vehicle Class	COML	COGPL	VOCML	VOCGPL	NOML	NOGPL	CO2ML	CO2GPL	SO2ML	SO2GPL
SOV	2540	28838	39	596	133	2082	57043	1561037	2.5	54.2
HOV2	7173	197	110	4	376	14	161107	10687	7.1	0.4
HOV3+	3583	101	55	2	188	7	80476	5441	3.5	0.2
Vanpool	1263	0	22	0	69	0	32845	0	1.5	0
Para-Transit	377	0	7	0	23	0	10948	0	0.4	0
Bus	5641	0	-1	0	137	0	12943	0	0.6	0
Motorcycle	0	0	0	0	0	0	0	0	0	0
Light Freight	0	277	0	9	0	43	0	28962	0	1
Single Trailer	0	29291	0	124	0	1120	0	331038	0	11.5
Double Trailer	0	2852	0	19	0	185	0	29372	0	1
Total	20577	61556	232	754	926	3451	355362	1966537	15.6	68.3

A.15 Scenario 15

Objective 1: SOV toll value per mile: $0.50
Speed-flow model: Drake
Number of Managed Lanes: 2 lanes
Number of General Purpose Lanes: 4 lanes
Length of Managed Lane corridor: 5.0 miles
Corridor Demand: 11000 vph

VOLUME AND TOLL SUMMARY:

Vehicle Class	VolML(vph)	VolGPL(vph)	MLShare(%)	Toll($/mile)	Revenue($/hr)
SOV	1241	7163	14.8	0.5	3102.5
HOV2	307	793	27.9	0.25	383.75
HOV3+	175	375	31.8	0.25	218.75
Vanpool	53	112	32.1	0.25	66.25
Para-Transit	55	0	100	Free	0
Bus	22	0	100	Free	0
Motorcycle	0	0	0	N/A	0
Light Freight	0	88	0	N/A	0
Single Trailer	0	572	0	N/A	0
Double Trailer	0	44	0	N/A	0
Total	1853	9147	16.8	-	3771.25

	ML	GPL
Total Volume (pc/hr)	1896	9872
Avg. Speed (Mile/hr)	77	31

EMMISIONS SUMMARY: (grams/mile)

Vehicle Class	COML	COGPL	VOCML	VOCGPL	NOML	NOGPL	CO2ML	CO2GPL	SO2ML	SO2GPL
SOV	8825	24901	134	542	458	1857	190850	1476260	8.4	48.4
HOV2	2183	2757	33	60	113	206	47213	163434	2.1	5.4
HOV3+	1245	1304	19	28	65	97	26913	77286	1.2	2.5
Vanpool	420	429	7	11	23	32	10526	29653	0.5	1
Para-Transit	394	0	7	0	24	0	10923	0	0.4	0
Bus	5862	0	-2	0	138	0	12911	0	0.6	0
Motorcycle	0	0	0	0	0	0	0	0	0	0
Light Freight	0	268	0	9	0	42	0	30719	0	1
Single Trailer	0	26922	0	141	0	1113	0	351136	0	11.5
Double Trailer	0	2621	0	22	0	184	0	31155	0	1
Total	18929	59202	198	813	821	3531	299336	2159643	13.2	70.8

A.16 Scenario 16

Objective 1: SOV toll value per mile: $0.50
Speed-flow model: Drake
Number of Managed Lanes: 2 lanes
Number of General Purpose Lanes: 4 lanes
Length of Managed Lane corridor: 5.0 miles
Corridor Demand: 11000 vph

VOLUME AND TOLL SUMMARY:

Vehicle Class	VolML(vph)	VolGPL(vph)	MLShare(%)	Toll($/mile)	Revenue($/hr)
SOV	966	7438	11.5	0.5	2415
HOV2	284	816	25.8	0.25	355
HOV3+	522	28	94.9	Free	0
Vanpool	165	0	100	Free	0
Para-Transit	55	0	100	Free	0
Bus	22	0	100	Free	0
Motorcycle	0	0	0	N/A	0
Light Freight	0	88	0	N/A	0
Single Trailer	0	572	0	N/A	0
Double Trailer	0	44	0	N/A	0
Total	2014	8986	18.3	-	2770

	ML	GPL
Total Volume (pc/hr)	2079	9689
Avg. Speed (Mile/hr)	76	33

EMMISIONS SUMMARY: (grams/mile)

Vehicle Class	COML	COGPL	VOCML	VOCGPL	NOML	NOGPL	CO2ML	CO2GPL	SO2ML	SO2GPL
SOV	6749	26228	103	556	352	1925	148733	1486194	6.5	50.2
HOV2	1984	2877	30	61	103	211	43727	163046	1.9	5.5
HOV3+	3647	99	56	2	190	7	80371	5595	3.5	0.2
Vanpool	1286	0	22	0	70	0	32805	0	1.5	0
Para-Transit	385	0	7	0	23	0	10935	0	0.4	0
Bus	5751	0	-1	0	137	0	12926	0	0.6	0
Motorcycle	0	0	0	0	0	0	0	0	0	0
Light Freight	0	272	0	9	0	43	0	29783	0	1
Single Trailer	0	28071	0	132	0	1117	0	340426	0	11.5
Double Trailer	0	2733	0	20	0	184	0	30204	0	1
Total	19802	60280	217	780	875	3487	329497	2055248	14.4	69.4

A.17 Scenario 17

Objective 1: SOV toll value per mile: $0.50
Speed-flow model: Drake
Number of Managed Lanes: 2 lanes
Number of General Purpose Lanes: 4 lanes
Length of Managed Lane corridor: 5.0 miles
Corridor Demand: 11000 vph

VOLUME AND TOLL SUMMARY:

Vehicle Class	VolML(vph)	VolGPL(vph)	MLShare(%)	Toll($/mile)	Revenue($/hr)
SOV	1371	7033	16.3	0.5	3427.5
HOV2	94	1006	8.5	0.5	235
HOV3+	180	370	32.7	0.25	225
Vanpool	57	108	34.5	0.25	71.25
Para-Transit	55	0	100	Free	0
Bus	22	0	100	Free	0
Motorcycle	0	0	0	N/A	0
Light Freight	0	88	0	N/A	0
Single Trailer	0	572	0	N/A	0
Double Trailer	0	44	0	N/A	0
Total	1779	9221	16.2	-	3958.75

	ML	GPL
Total Volume (pc/hr)	1822	9946
Avg. Speed (Mile/hr)	77	31

EMMISIONS SUMMARY: (grams/mile)

Vehicle Class	COML	COGPL	VOCML	VOCGPL	NOML	NOGPL	CO2ML	CO2GPL	SO2ML	SO2GPL
SOV	9750	24449	149	532	505	1823	210842	1449468	9.3	47.5
HOV2	668	3497	10	76	35	261	14456	207332	0.6	6.8
HOV3+	1280	1286	20	28	66	96	27682	76255	1.2	2.5
Vanpool	452	413	8	11	25	31	11320	28594	0.5	1
Para-Transit	394	0	7	0	24	0	10923	0	0.4	0
Bus	5862	0	-2	0	138	0	12911	0	0.6	0
Motorcycle	0	0	0	0	0	0	0	0	0	0
Light Freight	0	268	0	9	0	42	0	30719	0	1
Single Trailer	0	26922	0	141	0	1113	0	351136	0	11.5
Double Trailer	0	2621	0	22	0	184	0	31155	0	1
Total	18406	59456	192	819	793	3550	288134	2174659	12.6	71.3

A.18 Scenario 18

Objective 1: SOV toll value per mile: $0.50
Speed-flow model: Drake
Number of Managed Lanes: 2 lanes
Number of General Purpose Lanes: 4 lanes
Length of Managed Lane corridor: 5.0 miles
Corridor Demand: 11000 vph

VOLUME AND TOLL SUMMARY:

Vehicle Class	VolML(vph)	VolGPL(vph)	MLShare(%)	Toll($/mile)	Revenue($/hr)
SOV	1095	7309	13	0.5	2737.5
HOV2	77	1023	7	0.5	192.5
HOV3+	522	28	94.9	Free	0
Vanpool	165	0	100	Free	0
Para-Transit	55	0	100	Free	0
Bus	22	0	100	Free	0
Motorcycle	0	0	0	N/A	0
Light Freight	0	88	0	N/A	0
Single Trailer	0	572	0	N/A	0
Double Trailer	0	44	0	N/A	0
Total	1936	9064	17.6	-	2930

	ML	GPL
Total Volume (pc/hr)	2001	9767
Avg. Speed (Mile/hr)	76	32

EMMISIONS SUMMARY: (grams/mile)

Vehicle Class	COML	COGPL	VOCML	VOCGPL	NOML	NOGPL	CO2ML	CO2GPL	SO2ML	SO2GPL
SOV	7651	25578	117	549	399	1893	168595	1482610	7.4	49.3
HOV2	538	3580	8	77	28	265	11856	207513	0.5	6.9
HOV3+	3647	98	56	2	190	7	80371	5680	3.5	0.2
Vanpool	1286	0	22	0	70	0	32805	0	1.5	0
Para-Transit	385	0	7	0	23	0	10935	0	0.4	0
Bus	5751	0	-1	0	137	0	12926	0	0.6	0
Motorcycle	0	0	0	0	0	0	0	0	0	0
Light Freight	0	270	0	9	0	42	0	30235	0	1
Single Trailer	0	27487	0	137	0	1115	0	345600	0	11.5
Double Trailer	0	2676	0	21	0	184	0	30663	0	1
Total	19258	59689	209	795	847	3506	317488	2102301	13.9	69.9

A.19 Scenario 19

Objective 2: Min desired speed on ML: 65 mph
Speed-flow model: Drake
Number of Managed Lanes: 2 lanes
Number of General Purpose Lanes: 4 lanes
Length of Managed Lane corridor: 5.0 miles
Corridor Demand: 11000 vph

VOLUME AND TOLL SUMMARY:

Vehicle Class	VolML(vph)	VolGPL(vph)	MLShare(%)	Toll($/mile)	Revenue($/hr)
SOV	3261	5143	38.8	0.25	4076.25
HOV2	237	863	21.5	0.25	296.25
HOV3+	136	414	24.7	0.25	170
Vanpool	46	119	27.9	0.25	57.5
Para-Transit	55	0	100	Free	0
Bus	22	0	100	Free	0
Motorcycle	0	0	0	N/A	0
Light Freight	0	88	0	N/A	0
Single Trailer	0	572	0	N/A	0
Double Trailer	0	44	0	N/A	0
Total	3757	7243	34.2	-	4600

	ML	GPL
Total Volume (pc/hr)	3798	7970
Avg. Speed (Mile/hr)	65	62

EMMISIONS SUMMARY: (grams/mile)

Vehicle Class	COML	COGPL	VOCML	VOCGPL	NOML	NOGPL	CO2ML	CO2GPL	SO2ML	SO2GPL
SOV	18712	27963	301	457	1049	1603	513515	817741	22	34.7
HOV2	1360	4692	22	77	76	269	37321	137218	1.6	5.8
HOV3+	780	2251	13	37	44	129	21416	65826	0.9	2.8
Vanpool	294	721	5	13	17	43	9344	24401	0.4	1
Para-Transit	301	0	6	0	20	0	11173	0	0.4	0
Bus	4625	0	4	0	132	0	13221	0	0.6	0
Motorcycle	0	0	0	0	0	0	0	0	0	0
Light Freight	0	423	0	11	0	51	0	23699	0	1
Single Trailer	0	52775	0	33	0	1197	0	270819	0	11.5
Double Trailer	0	5138	0	5	0	197	0	24031	0	1
Total	26072	93963	351	633	1338	3489	605990	1363735	25.9	57.8

A.20 Scenario 20

Objective 2: Min desired speed on ML: 65 mph
Speed-flow model: Drake
Number of Managed Lanes: 2 lanes
Number of General Purpose Lanes: 4 lanes
Length of Managed Lane corridor: 5.0 miles
Corridor Demand: 11000 vph

VOLUME AND TOLL SUMMARY:

Vehicle Class	VolML(vph)	VolGPL(vph)	MLShare(%)	Toll($/mile)	Revenue($/hr)
SOV	1924	6480	22.9	0.25	2405
HOV2	1045	55	95	Free	0
HOV3+	522	28	94.9	Free	0
Vanpool	165	0	100	Free	0
Para-Transit	55	0	100	Free	0
Bus	22	0	100	Free	0
Motorcycle	0	0	0	N/A	0
Light Freight	0	88	0	N/A	0
Single Trailer	0	572	0	N/A	0
Double Trailer	0	44	0	N/A	0
Total	3733	7267	33.9	-	2405

	ML	GPL
Total Volume (pc/hr)	3798	7970
Avg. Speed (Mile/hr)	65	62

EMMISIONS SUMMARY: (grams/mile)

Vehicle Class	COML	COGPL	VOCML	VOCGPL	NOML	NOGPL	CO2ML	CO2GPL	SO2ML	SO2GPL
SOV	11040	35233	177	575	619	2020	302976	1030325	13	43.7
HOV2	5996	299	96	5	336	17	164558	8745	7.1	0.4
HOV3+	2995	152	48	2	168	9	82200	4452	3.5	0.2
Vanpool	1056	0	19	0	61	0	33518	0	1.5	0
Para-Transit	301	0	6	0	20	0	11173	0	0.4	0
Bus	4625	0	4	0	132	0	13221	0	0.6	0
Motorcycle	0	0	0	0	0	0	0	0	0	0
Light Freight	0	423	0	11	0	51	0	23699	0	1
Single Trailer	0	52775	0	33	0	1197	0	270819	0	11.5
Double Trailer	0	5138	0	5	0	197	0	24031	0	1
Total	26013	94020	350	631	1336	3491	607646	1362071	26.1	57.8

A.21 Scenario 21

Objective 2: Min desired speed on ML: 65 mph
Speed-flow model: Drake
Number of Managed Lanes: 2 lanes
Number of General Purpose Lanes: 4 lanes
Length of Managed Lane corridor: 5.0 miles
Corridor Demand: 11000 vph

VOLUME AND TOLL SUMMARY:

Vehicle Class	VolML(vph)	VolGPL(vph)	MLShare(%)	Toll($/mile)	Revenue($/hr)
SOV	2916	5488	34.7	0.25	3645
HOV2	425	675	38.6	0.13	276.25
HOV3+	257	293	46.7	0.13	167.05
Vanpool	76	89	46.1	0.13	49.4
Para-Transit	55	0	100	Free	0
Bus	22	0	100	Free	0
Motorcycle	0	0	0	N/A	0
Light Freight	0	88	0	N/A	0
Single Trailer	0	572	0	N/A	0
Double Trailer	0	44	0	N/A	0
Total	3751	7249	34.1	-	4137.7

	ML	GPL
Total Volume (pc/hr)	3798	7970
Avg. Speed (Mile/hr)	65	62

EMMISIONS SUMMARY: (grams/mile)

Vehicle Class	COML	COGPL	VOCML	VOCGPL	NOML	NOGPL	CO2ML	CO2GPL	SO2ML	SO2GPL
SOV	16732	29839	269	487	938	1711	459188	872596	19.7	37
HOV2	2439	3670	39	60	137	210	66926	107325	2.9	4.6
HOV3+	1475	1593	24	26	83	91	40470	46587	1.7	2
Vanpool	486	539	9	10	28	32	15439	18250	0.7	0.8
Para-Transit	301	0	6	0	20	0	11173	0	0.4	0
Bus	4625	0	4	0	132	0	13221	0	0.6	0
Motorcycle	0	0	0	0	0	0	0	0	0	0
Light Freight	0	423	0	11	0	51	0	23699	0	1
Single Trailer	0	52775	0	33	0	1197	0	270819	0	11.5
Double Trailer	0	5138	0	5	0	197	0	24031	0	1
Total	26058	93977	351	632	1338	3489	606417	1363307	26	57.9

A.22 Scenario 22

Objective 2: Min desired speed on ML: 65 mph
Speed-flow model: Drake
Number of Managed Lanes: 2 lanes
Number of General Purpose Lanes: 4 lanes
Length of Managed Lane corridor: 5.0 miles
Corridor Demand: 11000 vph

VOLUME AND TOLL SUMMARY:

Vehicle Class	VolML(vph)	VolGPL(vph)	MLShare(%)	Toll($/mile)	Revenue($/hr)
SOV	2572	5832	30.6	0.25	3215
HOV2	397	703	36.1	0.13	258.05
HOV3+	522	28	94.9	Free	0
Vanpool	165	0	100	Free	0
Para-Transit	55	0	100	Free	0
Bus	22	0	100	Free	0
Motorcycle	0	0	0	N/A	0
Light Freight	0	88	0	N/A	0
Single Trailer	0	572	0	N/A	0
Double Trailer	0	44	0	N/A	0
Total	3733	7267	33.9	-	3473.05

	ML	GPL
Total Volume (pc/hr)	3798	7970
Avg. Speed (Mile/hr)	65	62

EMMISIONS SUMMARY: (grams/mile)

Vehicle Class	COML	COGPL	VOCML	VOCGPL	NOML	NOGPL	CO2ML	CO2GPL	SO2ML	SO2GPL
SOV	14758	31710	237	518	828	1818	405017	927292	17.4	39.4
HOV2	2278	3822	37	62	128	219	62516	111778	2.7	4.7
HOV3+	2995	152	48	2	168	9	82200	4452	3.5	0.2
Vanpool	1056	0	19	0	61	0	33518	0	1.5	0
Para-Transit	301	0	6	0	20	0	11173	0	0.4	0
Bus	4625	0	4	0	132	0	13221	0	0.6	0
Motorcycle	0	0	0	0	0	0	0	0	0	0
Light Freight	0	423	0	11	0	51	0	23699	0	1
Single Trailer	0	52775	0	33	0	1197	0	270819	0	11.5
Double Trailer	0	5138	0	5	0	197	0	24031	0	1
Total	26013	94020	351	631	1337	3491	607645	1362071	26.1	57.8

A.23 Scenario 23

Objective 2: Min desired speed on ML: 65 mph
Speed-flow model: Drake
Number of Managed Lanes: 2 lanes
Number of General Purpose Lanes: 4 lanes
Length of Managed Lane corridor: 5.0 miles
Corridor Demand: 11000 vph

VOLUME AND TOLL SUMMARY:

Vehicle Class	VolML(vph)	VolGPL(vph)	MLShare(%)	Toll($/mile)	Revenue($/hr)
SOV	3095	5309	36.8	0.25	3868.75
HOV2	237	863	21.5	0.25	296.25
HOV3+	262	288	47.6	0.13	170.3
Vanpool	79	86	47.9	0.13	51.35
Para-Transit	55	0	100	Free	0
Bus	22	0	100	Free	0
Motorcycle	0	0	0	N/A	0
Light Freight	0	88	0	N/A	0
Single Trailer	0	572	0	N/A	0
Double Trailer	0	44	0	N/A	0
Total	3750	7250	34.1	-	4386.65

	ML	GPL
Total Volume (pc/hr)	3798	7970
Avg. Speed (Mile/hr)	65	62

EMMISIONS SUMMARY: (grams/mile)

Vehicle Class	COML	COGPL	VOCML	VOCGPL	NOML	NOGPL	CO2ML	CO2GPL	SO2ML	SO2GPL
SOV	17759	28866	285	471	996	1655	487375	844135	20.9	35.8
HOV2	1360	4692	22	77	76	269	37321	137218	1.6	5.8
HOV3+	1503	1566	24	26	84	90	41258	45792	1.8	1.9
Vanpool	505	521	9	10	29	31	16048	17635	0.7	0.8
Para-Transit	301	0	6	0	20	0	11173	0	0.4	0
Bus	4625	0	4	0	132	0	13221	0	0.6	0
Motorcycle	0	0	0	0	0	0	0	0	0	0
Light Freight	0	423	0	11	0	51	0	23699	0	1
Single Trailer	0	52775	0	33	0	1197	0	270819	0	11.5
Double Trailer	0	5138	0	5	0	197	0	24031	0	1
Total	26053	93981	350	633	1337	3490	606396	1363329	26	57.8

A.24 Scenario 24

Objective 2: Min desired speed on ML: 65 mph
Speed-flow model: Drake
Number of Managed Lanes: 2 lanes
Number of General Purpose Lanes: 4 lanes
Length of Managed Lane corridor: 5.0 miles
Corridor Demand: 11000 vph

VOLUME AND TOLL SUMMARY:

Vehicle Class	VolML(vph)	VolGPL(vph)	MLShare(%)	Toll($/mile)	Revenue($/hr)
SOV	2771	5633	33	0.25	3463.75
HOV2	198	902	18	0.25	247.5
HOV3+	522	28	94.9	Free	0
Vanpool	165	0	100	Free	0
Para-Transit	55	0	100	Free	0
Bus	22	0	100	Free	0
Motorcycle	0	0	0	N/A	0
Light Freight	0	88	0	N/A	0
Single Trailer	0	572	0	N/A	0
Double Trailer	0	44	0	N/A	0
Total	3733	7267	33.9	-	3711.25

	ML	GPL
Total Volume (pc/hr)	3798	7970
Avg. Speed (Mile/hr)	65	62

EMMISIONS SUMMARY: (grams/mile)

Vehicle Class	COML	COGPL	VOCML	VOCGPL	NOML	NOGPL	CO2ML	CO2GPL	SO2ML	SO2GPL
SOV	15900	30628	255	500	892	1756	436354	895651	18.7	38
HOV2	1136	4904	18	80	64	281	31179	143419	1.3	6.1
HOV3+	2995	152	48	2	168	9	82200	4452	3.5	0.2
Vanpool	1056	0	19	0	61	0	33518	0	1.5	0
Para-Transit	301	0	6	0	20	0	11173	0	0.4	0
Bus	4625	0	4	0	132	0	13221	0	0.6	0
Motorcycle	0	0	0	0	0	0	0	0	0	0
Light Freight	0	423	0	11	0	51	0	23699	0	1
Single Trailer	0	52775	0	33	0	1197	0	270819	0	11.5
Double Trailer	0	5138	0	5	0	197	0	24031	0	1
Total	26013	94020	350	631	1337	3491	607645	1362071	26	57.8

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