Martin O'Malley, *Governor*
Anthony G. Brown, *Lt. Governor*

State Highway Administration
Maryland Department of Transportation

John D. Porcari, *Secretary*
Neil J. Pedersen, *Administrator*

STATE HIGHWAY ADMINISTRATION

RESEARCH REPORT

CONCURRENT FLOW LANES – PHASE I

PRINCIPAL INVESTIGATOR
ELISE MILLER-HOOKS

RESEARCH TEAM MEMBERS
XIAOHAN CHEN
CHIH-SHENG (JASON) CHOU
PHILLIP TARNOFF

UNIVERSITY OF MARYLAND

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The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Maryland State Highway Administration. This report does not constitute a standard, specification, or regulation.

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16. Abstract

This report provides the findings from an effort to gain a comprehensive understanding of the state-of-the-practice and state-of-the-art in modeling of nonbarrier separated electronic/high occupancy toll (HOT) lane and other concurrent flow lane operations.

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EXECUTIVE SUMMARY

This report provides the findings from an effort to gain a comprehensive understanding of the state-of-the-practice and state-of-the-art in modeling of nonbarrier separated electronic/high occupancy toll (HOT) lane and other concurrent flow lane operations. The report articulates information gathered from interviews conducted with project managers of existing and proposed HOT lane facilities, modelers and other domain experts and reviews related reports and literature.

The report includes details of: models employed, and analytical tools used, to evaluate the impact of proposed HOT lanes on traffic operations and potential revenue; supplemental analysis tools; lane configurations; tolling strategies; High Occupancy Vehicle (HOV) restrictions; types of separation; how weaving is addressed; and design alternatives for ingress and egress between the HOT and general purpose lanes. The findings also address alternate merging solutions reported by other states that have been modeled, analyzed and/or implemented with potential applicability to freeways in the Washington, D.C. region. Knowledge gained through the interview and literature review processes pertaining to model calibration and validation is also reported. A conceptual framework is described for future activities to be undertaken in subsequent phases of this research effort. Potential data sources for calibrating and validating developed models are also identified.

It appears that there are seven existing or currently proposed nonbarrier separated HOT lane facilities in the United States: I-394 in Minnesota; I-15 in Utah; SR-167 and I-405 in Washington State; and I-85/US-101, I-580, and I-680 in California. For nearly all of the studies for which modeling efforts have been undertaken, the VISSIM simulation platform was employed in modeling the impact of proposed HOT lane facilities on traffic operations; although, such models were predominantly developed for use as a tool to provide necessary input for a proprietary revenue forecasting technique developed at Wilbur Smith and Associates. In all such models, only one model (developed at the Washington Department of Transportation to study I-405) treated the HOT lane as a separate lane. In all other models, the HOT lane(s) was treated as a separated facility. In all models, violations were not permitted. That is, all models treated the HOT lane(s) as barrier separated facilities.

In addition to reducing revenue, violations are expected to lead to dangerous weaving maneuvers between the HOT and general purpose lanes. Thus, it is important that such violations be considered. Since there is no obvious way to model violations in existing simulation software products, a proof-of-concept was developed to illustrate how such details can be handled in the selected modeling framework, the VISSIM simulation platform, proposed for use in subsequent phases of this research effort.

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CHAPTER 1.

Introduction

As has been demonstrated in various regions within the United States, the use of Express Toll Lanes (ETLs) or similarly functioning High Occupancy Toll (HOT) lanes can lead to more effective use of existing roadway capacity, improved traffic flow along general purpose lanes and additional revenue to support much needed transportation improvements. This first phase of research has sought to develop a comprehensive understanding of the state-of-the-practice and state-of-the-art in modeling of nonbarrier separated electronic/high occupancy toll lane and other concurrent flow lane operations. This report provides findings from interviews conducted with project managers of existing and proposed HOT lane facilities, modelers and other domain experts and review of related reports and literature.

Findings from this research effort include details of: models employed, and analytical tools used, to evaluate the impact of proposed HOT lanes on traffic operations and potential revenue; supplemental analysis tools; lane configurations; tolling strategies; High Occupancy Vehicle (HOV) restrictions; types of separation; how weaving is addressed; and design alternatives for ingress and egress between the HOT and general purpose lanes. The findings also address alternate merging solutions reported by other states that have been modeled, analyzed and/or implemented with potential applicability to freeways in the Washington, D.C. region. Knowledge gained through the interview and literature review processes pertaining to model calibration and validation is also reported.

In addition to providing a picture of the state-of-the-art in concurrent flow lane modeling and analysis, this report defines the set of future activities, including cost and schedule estimates, for subsequent project phases. This presentation describes a proof-of-concept developed to illustrate how one can model details, such as violations across the buffer between nonbarrier separated HOT lanes and the general purpose lanes, in the selected modeling framework proposed for use in following phases of this research effort. Potential data sources

for calibrating and validating developed models are also identified

In Chapter 2, background concerning HOT lane separation methods, methods of access, strategies for tolling and technologies used for enforcement is given. Information gathered on existing and proposed HOT lane facilities in the United States is presented. Modeling and related analysis tools employed to study proposed HOT lane facilities in the United States are described in Chapter 3. Since the main tool employed in practice for this purpose is the VISSIM microsimulation software package, relevant details of this software are presented. In Chapter 4, steps required for calibration and validation of such simulation models are presented and a review of related efforts undertaken in the analysis of HOT lane facilities in the United States is provided. In Chapter 5, a proposed work plan defining the next steps is given. Details of a proof-of-concept developed to illustrate the feasibility of modeling a nonbarrier separated HOT lane as an adjacent lane, as opposed to a separate facility, with violators are given. Finally, potential data sources required in subsequent modeling efforts are identified in Chapter 6. A comprehensive listing of reports and other citations reviewed in the development of this report and a listing of the persons interviewed are provided in separate documents.

CHAPTER 2.

State-of-the-Art Review

In this chapter, a brief overview of existing and proposed nonbarrier separated HOT lane facilities in the United States is presented. Additional incidental information obtained on barrier separated HOT lane facilities in the United States is also provided. Basic background on methods of separation, access types, tolling plans and enforcement methods and technologies is given, along with the relationship of these methods to existing and proposed facilities.

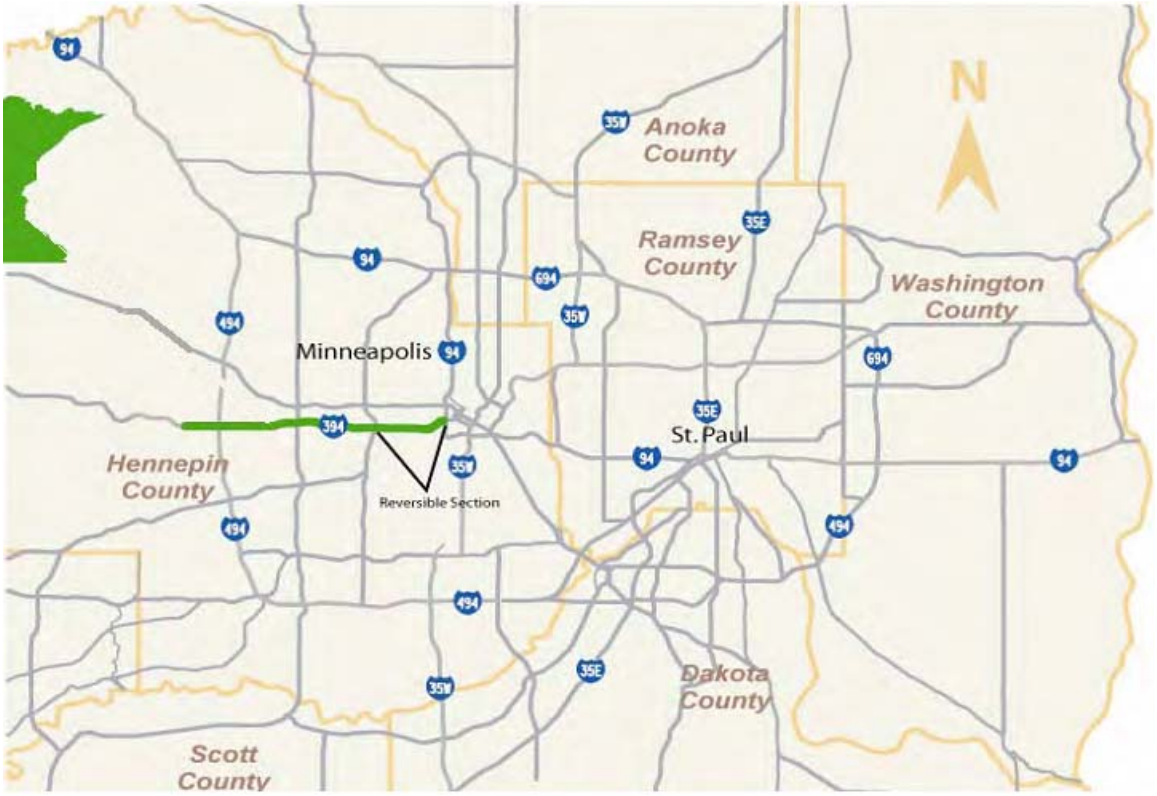
2.1 HOT Lane Facilities in the United States

2.1.1 Nonbarrier Separated Facilities

2.1.1.1 Minnesota

Continuous access HOV lanes, the I-394 MnPASS Express Lanes, re-opened in May 2005 as Minnesota's first HOT lane facility. The facility is 11 miles long, as shown in Figure 1, including a three-mile barrier separated, two reversible lane stretch from downtown Minneapolis to Highway 100 and an eight-mile, single lane buffer separated (with double white stripe) stretch from Highway 100 outbound (or to Highway 100 and inbound). In the buffer separated portion in the eastbound direction, there are five access points. Ingress and egress are at grade and are accomplished by a dashed line with minimum length of 0.25 miles and maximum length of 0.5 miles. The nonbarrier separated section operates from 6:00 a.m. to 10:00 a.m. eastbound and 2:00 p.m. to 7:00 p.m. westbound.

Figure 1 – Existing I-394 MnPASS Express Lanes



Source: Minnesota Department of Transportation.

2.1.1.2 Washington State

SR-167

HOT lanes on SR 167 are currently under construction. The facility will be the first HOT lane facility in Washington State. In January 2003, after evaluating the benefits of converting HOV lanes to HOT lanes, the Washington Department of Transportation proposed such conversion along SR 167.

SR 167 will contain one HOT lane along a 9-mile stretch, as shown in Figure 2. SOVs (Single or Solo Occupancy Vehicles) will be permitted to use the existing capacity in the HOV lane by paying a toll using an Electronic Toll Collection (ETC) system. Toll prices will vary depending on traffic volumes as a means of maintaining an acceptable level of speed and reliability along the HOT lanes. Access into the HOT lanes will remain free for transit, carpools and vanpools. Motorists will move into and out of the HOT lanes at access points and the HOT lane will be buffer separated from the general purpose lane. The access

openings will be 1,000 – 1,500 feet in length. Four access points have been selected for the northbound direction and three for the southbound direction.

Figure 2 – Proposed SR-167 HOT Lane

Source: http://www.wsdot.wa.gov/Projects/SR167/HOTLanes/Map.htm

I-405

To relieve congestion and improve mobility for motorists, transit and freight

users along the freeway's 30-mile length (shown in Figure 3), a non-barrier separated and direct access combination HOT lane, converted from an existing HOV lane, has been proposed. An additional general purpose lane will be added. A congestion-based pricing strategy is likely to be used. The toll will be collected at gantry toll plazas. The I-405 HOT lane project is awaiting legislation before construction can begin.

Figure 3 – I-405 Proposed HOT Lane

Source: Washington State Department of Transportation, 2007

2.1.1.3 California

A number of nonbarrier separated HOT lane facilities have recently been proposed in the San Francisco Bay Area of California: I-680, I-580, I-880 and I-85/ US-101. A map of the San Francisco Bay Area HOT lane network is provided in Figure 4. All of the proposed facilities involve non-barrier separated two- to four-foot buffers with painted double stripes. Ingress and egress are limited to designate at grade access points. HOT lane users are expected to carry FasTrak transponders for toll payment.

I-880, Alameda County

The possibility of allowing light duty trucks to pay for the use of existing HOV lanes, or of converting HOV-2 to HOV-3 lanes to allow additional capacity for sport utility vehicles and HOV-2 users to pay for the use of the existing HOV lanes, was considered with the goal of supporting the local economy. These options will not be furthered considered in the near-term.

I-680, Alameda County

I-680 HOT lanes are scheduled to open over the Sunol Grade in 2010. Existing HOV lanes along a 14 mile stretch of I-680 have been designated for conversion to HOT lanes. The HOV lanes were constructed as interim lanes and, thus, were not built to standards. To move forward with the HOV to HOT lane conversion, construction along the HOV lanes retaining walls) must first be completed so that the lanes will meet existing standards. Once this construction is complete, the lanes will be converted to HOT lanes and the facility will open. 24 hours per day, seven days per week operations are anticipated.

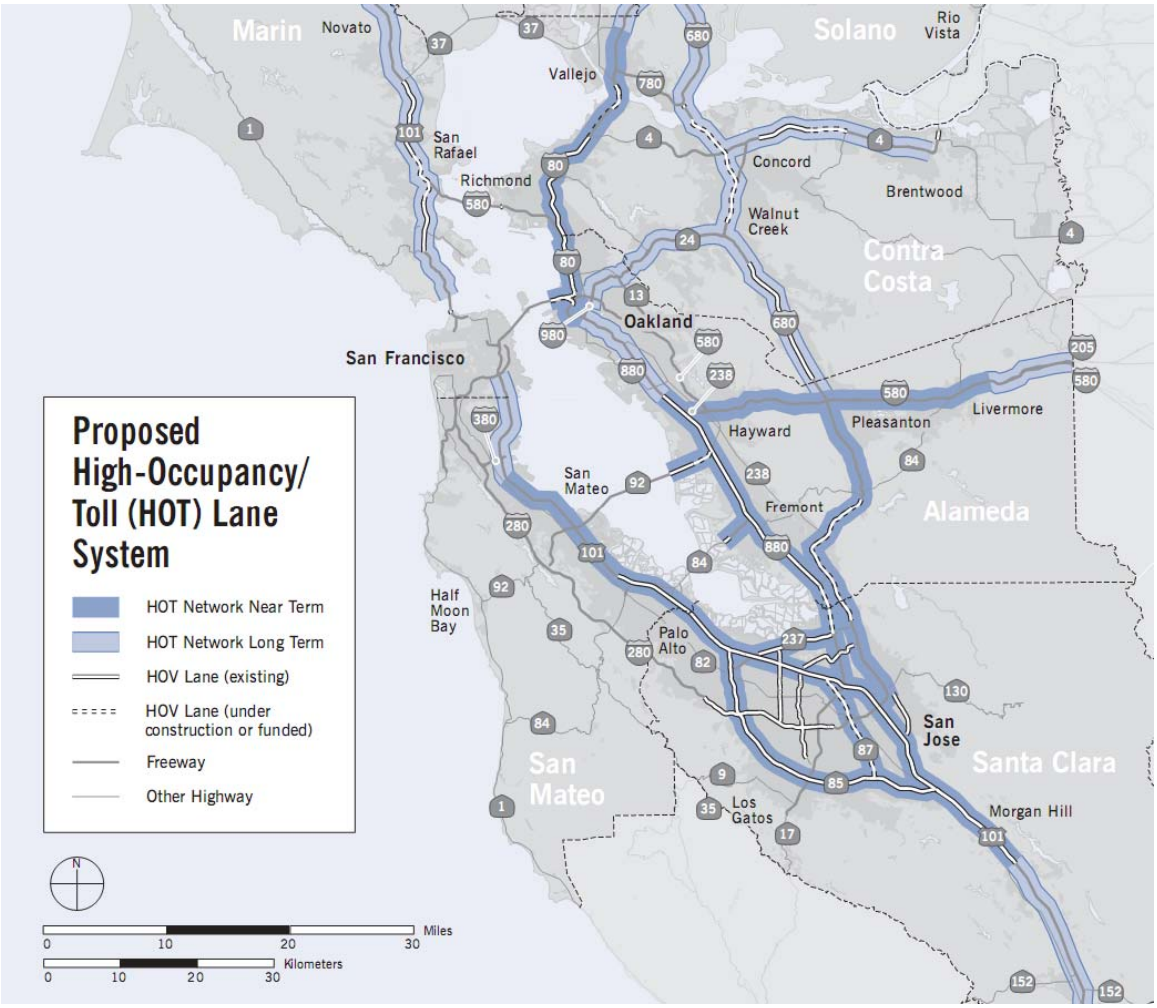
I-580, Alameda County

HOT lanes have been proposed along I-580. The design process of both I-580 and I-680 HOT lane facilities is similar and nearly identical strategies for pricing and designing the facilities will be employed. No HOV lanes exist currently along I-580. Thus, a single HOV lane must first be constructed in each direction. Once constructed, these HOV lanes will officially be converted to HOT lanes before the facility is opened. Buffers along I-580 between the general purpose and HOT lanes will be more consistent at 4 feet than will the buffers of I-680 as a consequence of the new construction of the facility. 24 hours per day, seven days per week operations are anticipated. The I-580 HOT lane facility is now in the technical study stage. It is hoped that it will open in 2011.

I-85/US-101, Santa Clara County

A large network of HOT lanes in Santa Clara County (the San Jose region) is envisioned. Two contiguous roadway segments have thus far been proposed along which HOT lanes would be constructed: a 40 mile stretch of I-85 and a 26-27 mile stretch of US-101. These roadways connect to form a nearly circular route. The HOT lanes will be constructed with at grade access and are likely to be buffer separated.

Figure 4 – Proposed High-Occupancy/Toll (HOT) Lane System in San Francisco Bay Area in 2030



Source: http://www.bicycling.511.org/pdf/hot_lanes.pdf

2.1.1.4 Utah

Utah's Express Lanes are located along 38 miles of I-15 from 600 North in Salt Lake City to University Parkway in Orem (Figure 5). HOV-2s, vanpools, buses, motorcycles, alternative fuel vehicles (AFVs) and emergency vehicles are eligible to use the HOT lanes without paying a toll. However, SOVs who choose to pay for a decal can also use the lane. No trucks or trailers are permitted. In 2009, the system will be electronically tolled and tolls will be charged by use. The HOT lanes will be expanded north to a length of 60 miles. At grade access will be provided at fixed locations. While buffer separation is anticipated, flexible

candlesticks (a form of pylon separation) may be employed. The HOT lanes operate 24 hours per day, seven days per week. Since in operation, travel time studies were conducted employing actual vehicles on the roadway. It was observed that the HOT lane speeds decreased as the general purpose lane speeds decreased.

Figure 5 – Proposed I-15 Express Lane

Source: Utah Department of Transportation

2.1.2 Barrier and Pylon Separated Facilities

While the goal of this report is to provide an understanding of the state-of-the-art in modeling nonbarrier separated concurrent flow lanes within the United States, limited incidental information gathered through interviews related to barrier separated (including lanes that are pylon separated) facilities is provided herein. Specifically, information about existing and proposed HOT lanes along I-15 in San Diego, California and SR 91 in Orange County, California are provided. Barrier separated HOT lanes have been proposed or are in use in other states, as well, including Colorado, Florida, Virginia, Maryland, Oregon and Texas.

San Diego (I-15)

Eight miles of HOT lanes are currently in operation along I-15 in San Diego, California. An additional stretch is under construction. The facility is currently barrier separated and once construction is complete, there will be four HOT lanes in total for both directions with movable barriers, allowing configurations with three HOT lanes in one direction and one in the other or two HOT lanes in each direction.

San Diego (I-5)

HOT lanes have been proposed along I-5. It is likely that these lanes will be barrier separated. There is currently discussion of including two managed lanes and four general purpose lanes in each direction. This project is in its infancy. Only preliminary studies have been conducted.

Orange County (SR-91)

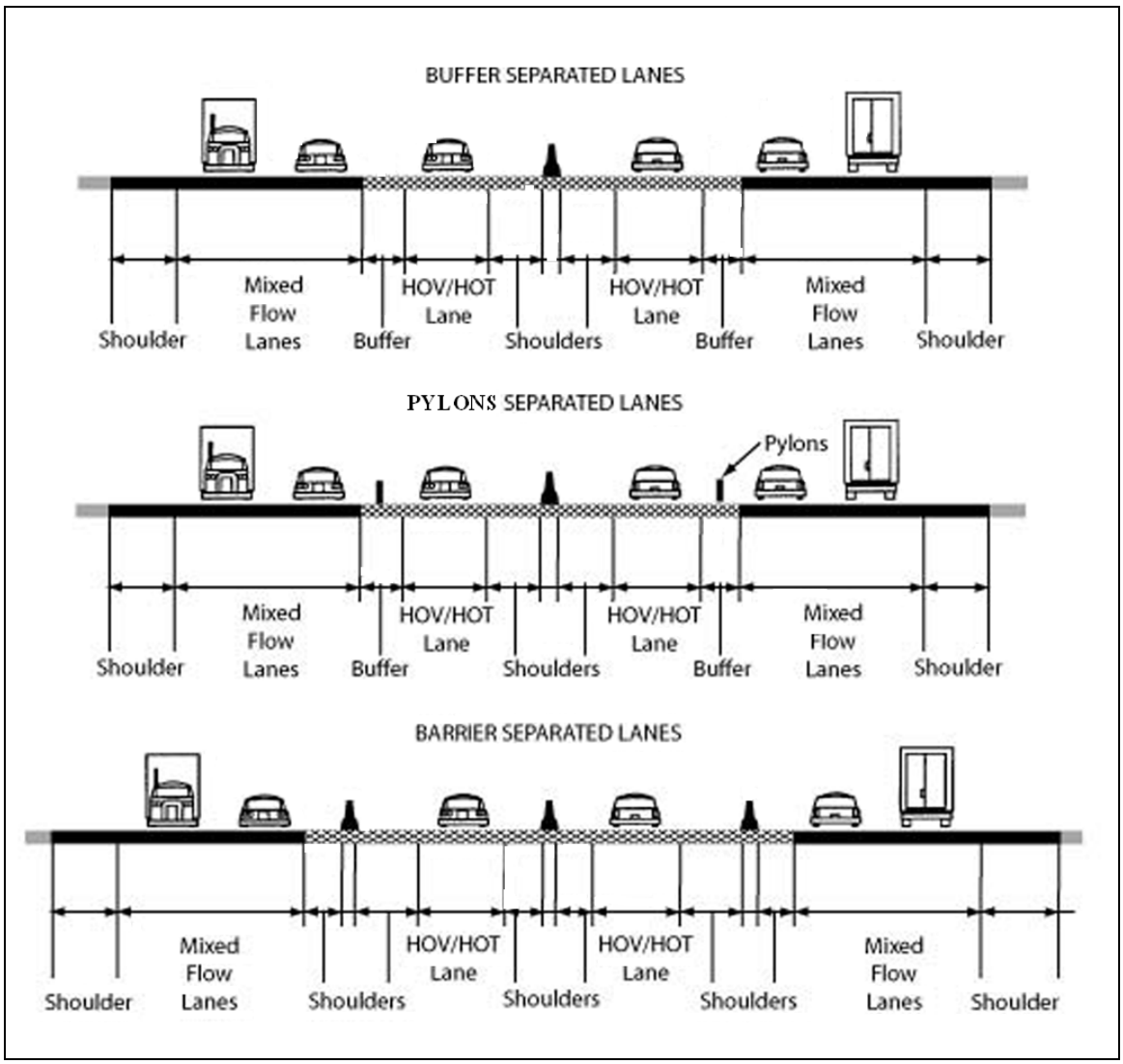
In 1995, toll lanes were opened on SR-91 in Orange County, California. These lanes were privately owned and operated by California Private Transportation Company (CPTC). In 2003, Orange County Transportation Authority (OCTA) purchased the lanes from CPTC for $207,000,000. In refinancing the project in 2003, OCTA did a traffic and revenue study. The lanes are now operated as HOT lanes, with two HOT lanes in each direction. The entire facility is channelized with three-foot tall pylon separation.

2.1.3 Category of Separation

Three primary techniques to separate HOT lanes from general purpose lanes include buffer separation, barrier separation, and separation by striping.

This discussion relies heavily on the information provided by Parsons Brinckerhoff, Texas Transportation Institute, and FHWA. Figure 1 illustrates how HOT lanes are separated from general purpose lanes using barriers, pylons, and buffers (Santa Clara Valley Transportation Authority, 2005).

Figure 6 – Types of HOT Lane Separations (Adapted from Santa Clara Valley Transportation Authority, 2005)



2.1.4 Barrier Separation

Physical barriers, such as concrete barriers, are used to separate the HOT and general purpose lanes. Barrier separation is typically costly in terms of both construction and maintenance; however, such physical separation reduces

enforcement costs by reducing violation rates. There are two types of barrier separation: fixed barrier and moveable barrier. Fixed barrier separation permanently separates the HOT and general purpose lanes. I-470 HOT lanes in Denver, Colorado have been designed with concrete barrier separation. Moveable barriers, on the other hand, are typically used where contra-flow operations are permitted during peak hours. The reconfiguration of the barriers for this purpose can be time consuming and costly and will require the temporary closure of the HOT lanes to traffic. Such moveable barriers are employed along I-15 in San Diego, where four reversible lanes have been designed for use in both directions. Additional reversible HOT lanes have been designed, are under construction, or are in operation in Texas (e.g. Katy QuickRide along I-10/US-290 in Houston), Virginia (I-95/I-395) and Florida (I-95/I-595 in Miami).

2.1.5 Pylon Separation

Separation of the HOT lane from adjacent general purpose lanes can be achieved through the implementation of permanently mounted traffic pylons. Typically, the pylons are mounted within a buffer area of four-foot width. Such pylon separation can, therefore, be viewed as a combination of barrier and buffer separation. The cost of implementation and maintenance can be significantly lower than barrier separation methods. The SR 91 Express Lanes in Orange County operate with this lane separation technique (Santa Clara Valley Transportation Authority, 2005). Four travel lanes (two in each direction) were constructed in the median of an existing 8-lane highway. The four lanes are physically separated from the general purpose lanes by double solid yellow lines and pylons. Throughout the remainder of this document, pylon separated HOT lanes are considered under the category of barrier separated lanes.

2.1.6 Buffer Separation

Separation of the HOT lane(s) from adjacent general purpose lanes can also be achieved without a physical barrier. Typically, a buffer (created through striping) of two to four feet is placed between these lanes. I-394 in Minnesota (8 of 11 miles are buffer separated); SR-167 and I-405 in Washington; I-680 and I-580 in Alameda County, California; I-85/US-101 in Santa Clara County, California; I-15 in Utah (although, there is some discussion of the use of flexible candlesticks as a means of separation) all employ (or include design of) buffers of between two and

four feet as the separation means.

2.1.7 Comparison of Separation Methods

The following table compares the three types of separation used in HOT lane projects in terms of enforcement, space requirements, implementation cost, maintenance, safety, operation and right-of-way requirements.

Table 1 – Comparison of HOT Lane Separation Methods

	Barrier Separation	Pylon Separation	Buffer Separation
Advantages	• Low enforcement costs • Protection from vehicle movements in general purpose lanes	• Requires little right-of-way if buffer is small	• Low implementation and maintenance costs • Required right-of-way depends on buffer size
Disadvantages	• Low flexibility • High implementation and maintenance costs	• High implementation and maintenance costs • Not suitable for extreme weather	• Potential safety ramifications due to violations and speed differences between adjacent lanes • High number of violations and resulting high enforcement cost

2.2 Access Types for Nonbarrier Separation

Access to nonbarrier separated HOT lanes can be categorized as either at-grade or direct, the latter of which is more costly. A combination of direct and at-grade access is employed in the design of I-405 in Washington. Access provided at-grade can be further classified as single entry/exit point, multiple entry/exit points, and continuous access points. In single entry/exit access, entry and exit are permitted only at the termination points of the HOT lane(s). For example, such single entry/exit access is employed along the barrier separated

portion of I-394 in Minnesota. Multiple entry/exit access is employed or designed along the nonbarrier separated portion of I-394, I-680, I-580, and I-85/US-101 in California, I-15 in Utah and SR-167 and I-405 in Washington, as well as along barrier-separated HOT lanes of I-15 in San Diego County. In continuous at-grade access, a broken line separates the concurrent flow lanes from the general purpose lanes. Traffic is, therefore, permitted to freely enter and exit the lanes throughout the length of the facility. With the exception of I-15 in Utah (where decals are in use until ETC is installed), there are currently no existing or planned HOT lanes in the United States that allow continuous access; however, such continuous access is often used to separate HOV lanes from general purpose lanes.

It is worth noting that the complexity of tolling and enforcement increases with the number of access points. Additional information about the benefits and detriments of each of these designs can be found in (Orange County Transportation Authority, 2002).

In the case of multiple entry/exit access, ingress and egress to and from the HOT lanes can be simultaneous (where a minimum of one-quarter mile of broken striping is used) or separated. Such simultaneous access is employed along I-394 in Minnesota. In the latter case, a merging lane is typically designed to allow vehicles entering and exiting the HOT lanes to change their speeds before merging into the HOT or general purpose lanes. Two such merging lane access point designs are considered for the at-grade portions of the proposed I-405 HOT lanes, the first of which employs an additional merging lane between the general purpose and HOT lane(s) and the second of which employs a portion of the buffered area to create short merging lanes for ingress and egress. Orange County Transportation Authority, 2002 provides additional detail concerning access point design. I-680, I-580, and I-85/US-101 in California and I-15 in Utah plan for multiple points of access.

2.3 Tolling

2.3.1 Pricing Plan

There are a number of tolling strategies along HOT lanes in use today. These range from monthly charges for decals to congestion-based and distance-based pricing. In between are: single fixed rate pricing strategies, where

a flat fee is charged for use of any portion of the HOT lane facility over any part of the day in which the HOT lanes operate; fixed rate pricing strategies, prorated by distance; strategies with preset variable rates, where tolls vary in a known way by distance traveled, time-of-day, day-of-week, and direction according to a schedule; and distance and congestion-based strategies (sometimes referred to as dynamic pricing strategies) that rely on detected levels of service.

Congestion-based pricing strategies can purposefully impact the facility's performance by adjusting price levels in response to varying traffic conditions and affecting the attractiveness of the facility to the users. Most plans for future HOT lane facilities include congestion-based pricing strategies. Such strategies are employed along I-394 in Minnesota, where prices range from $0.50 to $8 for use of the entire roadway segment. Also, along barrier-separated I-15 in San Diego County, California, congestion-based pricing is employed, with tolls ranging from $0.25 to $8 ($3.50 average per trip). The strategy for I-15 seeks to maintain a level of service "C." For example, congestion-based pricing is planned for use in the San Francisco Bay area. Plans for I-85/US-101 in Santa Clara County include a pricing plan with tolls that range from $2 to $7. Tolls ranging from $1 to $6 in the peak hours for use of planned HOT lane facilities along I-580 and I-680 in Alameda County are being discussed. In the plans for I-405 in Washington, HOT lane users will pay a single fixed rate; although, there are plans for introducing segment-based prices.

In some parts of the country, HOV users are also expected to pay a fee for use of the HOT lanes. For example, along SR-91, HOV-3 vehicles can use the facility for free during off-peak hours. In the peak hours, eastbound HOV-3 vehicles pay 50% of the toll.

2.3.2 Electronic Tolling System

Dynamic or congestion-based pricing schemes for HOT lane facilities are facilitated by Electronic Toll Collection (ETC) systems and technologies. In such systems, tolls are electronically collected at specified locations along the roadway segment. Vehicles carry transponders. Information is collected and recorded from the transponders roadside or as the vehicle passes under gantries or other overhead devices. HOV users do not require transponders and can prevent collection from on-board transponders if needed.

ETC systems with collection at gantries are widely used for the purpose of toll collection along existing HOT lane facilities. For example, FasTrak and MnPASS transponders are employed in toll collection along roadways in Southern California (e.g. in San Diego and Orange County) and Minnesota, respectively. Other proposed HOT lane facilities in the United States include plans for use of ETC systems (e.g. I-15 in Utah, SR-167 and I-405 in Washington, I-580, I-680 and I-85/US-101 in the San Francisco Bay Area).

2.4 Enforcement

There are several types of violations that may be incurred related to the use of HOT lanes. For both barrier and nonbarrier separated HOT lanes, violations may occur if a vehicle operates as if it is a valid HOV user when in fact it is not. This may arise when a SOV uses the HOT lane, but does not provide the necessary transponder or other form of payment at required locations. This may also arise when HOV-3 is required and an HOV-2 vehicle uses the lane without appropriate payment. Another form of violation is where a transponder is employed, but the user is not in good standing. In nonbarrier separated HOT lanes, additional forms of violation may arise. For example, a vehicle may cross into or out of the HOT lane from or to the general purpose lanes at points where access is denied. To minimize these forms of violation, which not only impact revenue, but also may lead to dangerous traffic maneuvers, enforcement is required.

Compliance in terms of appropriate payment for vehicle class can be addressed through visual inspection by officers with and without the aid of video cameras. Video cameras used for this purpose are often placed at the toll collection gantries. Video enforcement may also be used to detect vehicles with invalid transponders through a comparison of license plate numbers against a database of users whose transponders are in good standing. Video enforcement is employed along the express lanes of SR 91 in Orange County, California. Similar video surveillance techniques are proposed by the Utah Department of Transportation for use along the HOT lanes of I-15 once conversion to ETC systems is complete. An alternative technology uses a mobile reader or antennae to determine whether vehicles are equipped with a transponder that is in good standing.

Visual enforcement may also be useful in detecting access violations, where vehicles cross over the buffer or solid line into and out of the HOT lanes for convenience or to avoid payment.

Visual enforcement through surveillance and response by police officers necessitates a physical location at which the officers can wait and can pull over vehicles for violations. These locations may be in the median or on the shoulder. In Minnesota, for example, in addition to local enforcement, off-duty state police are paid to patrol the HOT lane corridor. With constant enforcement and high violation fees, the violation rate has dropped from approximately 24% to a rate of 5 or 6%. Similar visual inspection enforcement plans are employed along I-15 in San Diego County, California, where enforcement is performed by California Highway Patrol, and SR-167 in Washington. Along SR-167, if a valid toll transaction is not observed, a state patrol officer will assess the vehicle's occupancy. If the vehicle's occupancy does not meet the minimum required vehicle occupancy for HOV's, the officer will stop the vehicle, or radio a downstream officer for enforcement. Visual inspection is also planned for the proposed HOT lanes along I-580 and I-680 in Alameda County, California. While new technologies have been proposed, no fully-tested technology exists that has been accepted in practice for the purpose of aiding officers in electronically verifying vehicle occupancy. Reports indicate that deployment of such technologies may be coming in the next two or three years (Santa Clara Valley Transportation Authority, 2005). Consequently, visual verification is likely to be necessary at least in the near-term.

Table 2 – HOT Lanes with Non-physical Separation

HOT Lanes	Status	Length (Mile)	Operation Hour	Separation	Access	Tolling
I-394 MN	In Operation	8 mile buffer separated, 3 mile barrier separated	Buffer separated section opens: Eastbound, Mon. to Fri., 6 a.m. to 10 a.m. Westbound, Mon. to Fri., 2 p.m. to 7 p.m.	Buffer /barrier	At-grade limited access	ETC, congestion-based pricing strategies
SR-167 WA	Under construction	9	Unknown	Buffer	At-grade limited Access	ETC, congestion-based pricing strategies
I-405 WA	In proposal stage	30	To be determined	Buffer	At-grade/ direct limited access	ETC, congestion-based pricing strategies
SR-85/ US-101 CA	In preliminary stage	66-67	To be determined	Buffer	At-grade limited access	ETC, congestion-based pricing strategies, FasTrak
I-680 CA	Approved for construction	14	24/7*	Buffer	At-grade limited access	ETC, congestion-based pricing strategies, FasTrak

HOT Lanes	Status	Length (Mile)	Operation Hour	Separation	Access	Tolling
I-580 CA	Approved for construction	Unknown	24/7	Buffer	At-grade limited access	ETC, congestion-based pricing strategies, FasTrak
I-880 CA	Tabled	To be determined	To be determined	Buffer	To be determined	To be determined
I-15 UT	Extension under construction	38	24/7	Buffer (possible flexible candlesticks)	At-grade limited access	Decal is in use ETC, congestion-based pricing strategies

*24 hour per day, 7 days per week.

CHAPTER 3.

Operational Modeling Approaches

In this chapter, techniques used in practice in the United States to model HOT lane facilities and adjacent general purpose lanes are discussed. Such models are used to evaluate design alternatives, assess the impact of related weaving maneuvers on general traffic characteristics, forecast throughput and travel time along the HOT and general purpose lanes, and predict expected revenue. In Section 3.1, details of these approaches are provided for models developed to evaluate roadway segments containing nonbarrier separated HOT lane facilities in the United States. As the use of VISSIM simulation software for this purpose is prevalent (it has been successfully demonstrated as a tool for modeling HOV and HOT lanes in several states, including, for example, Texas, Utah and Washington), and because the use of this software is suggested for subsequent phases of this project, an overview of the VISSIM simulation software from the perspective of HOT lane facility modeling is given.

3.1 State-of-the-Practice in Modeling Techniques

3.1.1 Minnesota

The Minnesota Department of Transportation (MnDOT) partnered with Wilbur Smith and Associates to study the impact of what were then proposed HOT lanes on traffic characteristics, including weaving, lane capacities and general performance. The modelling work was completed by Wilbur Smith and Associates that has extended TRANPLAN to assess the potential demand for HOT lanes under various pricing strategies and levels. The model was not validated and its details are proprietary.

In addition to the study conducted by Wilbur Smith and Associates, an academic paper has been published related to the operation of the I-394 HOT lanes (Kwon et al., 2000). The paper proposes a two-layer hierarchical procedure for evaluating the impact of the HOT lanes on traffic patterns. In the upper layer,

the proposed approach uses an analytical dynamic traffic assignment model, which estimates network-wide impacts of HOT lane operations on flow patterns and identifies sub-networks including potential bottlenecks. The detailed operational impacts of toll lanes on sub-network flow patterns are then estimated by a microscopic simulation-assignment model. Several dynamic microscopic simulation modeling tools, including INTEGRATION, DYNASMART, AIMSUN2, THOREAU, and PARAMICS, were reviewed. PARAMICS was selected for use in their work, because it adopts a link cost function that reflects a fixed-toll for each link. The resulting model was applied to study I-394, where barrier separation was assumed.

3.1.2 Utah

Two VISSIM models of a 21-mile segment of I-15 in which HOT lanes are operated were developed at the Utah Department of Transportation. The first model includes only HOV lanes and the second model assumes that the HOV lanes have been converted to HOT lanes. The model involving the HOV lanes assumed continuous access between the HOV and general purpose lanes. In the model involving HOT lanes, two vehicle classes were developed (HOV and HOT) that could have access to the HOT lanes and the HOT lanes are modeled as separate facilities.

Results of an origin-destination study with 98.5% vehicle capture were employed. License plates were read upon entry and exit from the freeway during a couple of hours of the peak period on a given day. The results were used to develop the existing peak hour conditions model of demand and for the purpose of calibration (discussed in Chapter 4). This information was supplied by Eric Rasband of the Utah Department of Transportation. He also supplied the VISSIM files for the first (HOV lane) model. He can no longer locate the VISSIM files for the second (HOT lane) model.

Professor Peter Martin and associates at the University of Utah have created a 35-mile VISSIM model of I-15. The model has huge computational demands. Running on 20 personal computers, it requires no less than real-time. The nonbarrier separated HOT lanes of I-15 will be modeled as a separate facility.

3.1.3 Washington

SR-167

Washington Department of Transportation contracted Wilbur Smith and Associates to develop a VISSIM traffic simulation model for SR-167, including proposed HOT lanes, and to employ their proprietary TRANPLAN extension for revenue forecasting. The primary goal of the VISSIM model is to inform the revenue projection model. Results of the VISSIM model provide delay and travel time savings. The HOT lanes were modeled as separate facilities. Violations were ignored.

Additional modelling results are reported in (Washington State Department of Transportation, 2003), where it is stated that a significant bottleneck at the SR-167/I-405 interchange as vehicles from the HOT lane merge into I-405 was identified. To improve merging operations at this interchange, subsequent modelling efforts included minor changes to the ramp that significantly improved the operations of the overall HOT lane facility.

I-405

Wilbur Smith and Associates was contracted to complete the tolling analysis for proposed HOT lanes along I-405. A VISSIM model was created at the Washington Department of Transportation. The model was developed to capture traffic operations and feed the lane performance measures to the proprietary revenue forecasting model of Wilbur Smith and Associates, as described for efforts related to modeling the HOT lanes of I-167. In the VISSIM model developed for I-405, the HOT lane in each direction is modeled as a separate lane (as opposed to a separate facility). Violations were not modeled. Two variants of ingress and egress were considered, including a merging lane with on- and off-ramps to and from the HOT lanes from and to the general purpose lanes and use of a portion of the buffer to provide space for merging. The model included on- and off-ramps to the roadway segment and details of adjacent freeways. Runs require the simultaneous use of several high-end computers, taking greater than real-time. An extensive calibration effort was employed as discussed in Chapter 4.

3.1.4 California

I-85/US-101 (Santa Clara County)

A feasibility study has been conducted. The initial document required to obtain federal funding for the project is being developed. Travel demand forecasts have been completed. A consortium of three companies is developing the models necessary to study the proposed HOT lane facility: URS, Wilbur Smith and Associates and a local firm called Grey Bowin and Associates (or something similar). There are two phases to the modeling work. In the first phase (the current phase), a long range plan is to be developed. A geometric assessment has already been conducted to consider the potential impact on right-of-way. The universe of alternatives will be considered in this phase. URS is working with FREQ, a macroscopic simulation tool developed at UC-Berkeley for traffic modeling. Results from this model will be fed into the revenue forecasting model of Wilbur Smith and Associates. The primary goal of this phase is to determine a set of good alternatives. In the next phase to begin in 2008, a microscopic simulation model will be developed to provide the necessary input for the Wilbur Smith and Associates' revenue forecasting model. The ultimate goal is to develop a network of HOT lanes. If approved, this project will be a first step in that direction.

I-580, I-680 and I-880 (Alameda County)

The introduction of HOT lane facilities along three roadways in Alameda County have been discussed: I-580, I-680 and I-880. I-880 HOT lanes discussions have been tabled for the time being. No relevant modeling work had been conducted. The California Department of Transportation (Caltrans) works with the Alameda County Congestion Management Agency, a joint powers authority of which a number of agencies are members. This agency is responsible for the operation and implementation of the HOT lane projects on both I-580 and I-680. To receive federal funds for the development of HOT lanes along I-680, a SEMP (System Engineering Management Plan) was developed. This plan includes, for example, plans for enforcement, quality management, data security, and concept of operation. In addition to the SEMP, feasibility and pricing studies were conducted. The modeling work was completed in approximately 2004. Parson's Brinckerhoff was the prime on this project. They also involved ECONorthwest of Portland, Oregon. These companies conducted an operational

analysis and a report was ultimately produced by URS. The work included the development of a VISSIM model (possibly by URS).

For I-580, Wilber Smith and Associates took the lead. A travel demand modeling analysis using Cube Voyager was conducted. URS conducted the operations modeling using the VISSIM software package. The HOT lanes are modeled as if they are barrier separated. It is also assumed that 20% of eligible users will not use the HOT lanes.

The following overall process was followed.

Step 1: Conduct travel demand forecasting via Cube Voyager. Feed demand numbers into the VISSIM model in Step 2.
Step 2: Employ VISSIM model of operations. Iterate Steps 1 and 2. Feed the output of Step 2 into Step 3.
Step 3: Forecast revenue via proprietary TRANPLAN extension.

Note that one might want to iterate between Steps 2 and 3. They did not do this.

Table 3 – Models Adopted by Current HOT/HOV Lanes

HOT Lanes	Producer	Modelling Tool	Model Capability	Model Type	Reference
I-394 MN	Wilbur Smith and Associates	TRANPLAN extension	• Assess the potential demand for the HOT lanes under various pricing strategies and levels • The model has not been validated and • Details are proprietary	Pricing	Interview
	University of Minnesota and University of Wisconsin	DTA and PARAMICS	• Evaluate the impact of the HOT lanes on traffic patterns • Two-layer Hierarchical Procedure	Pricing/ Simulation	Kwon et al., 2000
I-15 UT	Utah Department of Transportation	VISSIM	• Only HOV lanes • Assumed continuous access • Results of an origin-destination study are used to develop the existing peak hour conditions model of demand and for the purpose of calibration	Simulation	Interview
	Utah Department of Transportation	VISSIM	• Assumes that the HOV lanes have been converted to HOT lanes • Two vehicle classes were developed (HOV and HOT) that could have access to the HOT lanes • The HOT lanes are modeled as separate facilities	Simulation	Interview

HOT Lanes	Producer	Modelling Tool	Model Capability	Model Type	Reference
	University of Utah	VISSIM	• The nonbarrier separated HOT lanes of I-15 will be modeled as a separate facility • 35-mile HOT lane is modeled	Simulation	Interview
SR-167 WA	Wilbur Smith and Associates	VISSIM	• Proposed HOT lanes are modeled • The primary goal of the VISSIM model is to inform the revenue projection model • Results of the VISSIM model provide delay and travel time savings • The HOT lanes were modeled as separate facilities • Violations were ignored	Simulation	Interview
	Wilbur Smith and Associates	TRANPLAN extension	• Revenue forecasting	Pricing	Interview
	Washington State Department of Transportation	VISSIM	• Bottleneck at SR-167/I-405 interchange	Simulation	Washington State Department of Transportation, 2003
I-405 WA	Wilbur Smith and Associates	TRANPLAN extension	• Tolling analysis	Pricing	Interview

HOT Lanes	Producer	Modelling Tool	Model Capability	Model Type	Reference
	Washington Department of Transportation	VISSIM	• The HOT lanes were modeled as separate facilities • Violations were not modeled • Two variants of ingress and egress were considered	Simulation	Interview
SR-85/ US-101 CA	Three companies	Unknown	• a simulation model is to be developed in 2008	Demand forecasting only	Interview
I-680 CA	A joint powers authority	VISSIM	• VISSIM model (possibly developed by URS)	Simulation	Interview
I-580 CA	Wilber Smith and Associates	Cube Voyager	• Predict the travel demand for I-580	Travel Demand	Interview
	URS	VISSIM	• Model the HOT lanes as barrier separated lanes • Assumed that 20% of eligible users will not use the HOT lanes	Simulation	Interview
I-880 CA	--	--	• No relevant modeling work had been conducted	--	Interview

3.2 The VISSIM Simulator

The VISSIM software package, like many others, implements accepted car-following and lane-changing models to capture the detailed interaction between vehicles. Application Programming Interface (API) and Component Object Model (COM) interfaces are provided to permit the interface with external driving behavior models and other control algorithms. Dynamic traffic assignment is permitted through a route choice model. In following subsections, additional detail is presented pertaining to the embedded car-following and lane-changing models, relevant model parameters, and key network elements employed in constructing a simulation model.

3.2.1 Car-Following Model

Car-following models define the interaction between leading and lagging vehicles. There are a variety of existing car-following models, some of which focus on the acceleration function of the lagging vehicle and consider such measures as gap distance, vehicle speed, and speed difference between two cars. Other models focus on safety distance, where it is assumed that the following vehicle will maintain an appropriate safety distance. Remaining models are classified as psycho-physical models. Such models apply a minimum speed difference threshold for following and leading vehicles. The model adopted in VISSIM is a psycho-physical car following model of longitudinal vehicle movement developed by Wiedemann (Olstam and Tapani, 2004). A rule-based algorithm is employed for lateral movements. Briefly, drivers of vehicles are classified into types: free driving, approaching, following, and braking. Two model options are available: “Wiedemann 74” and “Wiedemann 99.” The former model is most appropriate for modeling urban traffic; whereas, the latter model was developed for interurban and freeway traffic modeling. Parameters that must be set in these models are provided in Table 4.

Table 4 – List of VISSIM Car-following Parameters

Car-Following Model Parameters		
Common Parameter	**Wiedemann 74**	**Wiedemann 99**
■ Look ahead distance ■ Number of observed vehicles ■ Temporary lack of attention	■ Average standstill distance ■ Additive part of safety distance ■ Multiplicative part of safety distance	■ Standstill distance ■ Headway time ■ Following variation ■ Threshold for entering 'following' ■ 'following' thresholds ■ Speed dependency of oscillation ■ Oscillation acceleration ■ Standstill acceleration ■ Acceleration at 80 km/h

3.2.2 Lane-Changing Model

Lane-changing maneuvers on the main lanes of the freeway or at ramp interchanges can be classified as either weaving or merging maneuvers. The VISSIM software provides two options for lane-changing maneuvers: "free lane selection" and "right side rule". The former option allows vehicles to overtake one-another in any lane, while the latter allows overtaking only by vehicles in the fast lane given some threshold value. Parameters of both models for modeling lane-changing behavior that must be set are listed in Table 5. An additional parameter related to collision time must be set if the right side rule is employed.

Table 5 – List of VISSIM Lane Changing Parameters

Lane Changing Model Parameters
■ Maximum deceleration ■ -1 ft/s^2 per distance ■ Accepted deceleration ■ Waiting time before diffusion ■ Minimum headway ■ Safety distance reduction factor ■ Maximum deceleration for cooperative breaking

3.2.3 Additional Features

Additional functionality in terms of driver behavior and signal control reaction is built into the VISSIM software. For example, additional models of lateral behavior, such as where a vehicle might decide to overtake a bicyclist, are employed. Models of decisions related to the amber dilemma are also included.

3.2.4 Network Elements for Model Construction

The traffic network and vehicles that traverse the network are constructed in the VISSIM software through the use of several network elements (the simulation entities). These include:

1. **Links**: The VISSIM input network is constructed by joining consecutive links. An intersection can be formed at the location at which two links cross one another.
2. **Routes**: A route is developed from a sequence of links. Routes are used to define paths along which vehicles travel. The user can define the volume split for each route.
3. **Vehicles**: The traffic volume traversing the links of the network is based on vehicle input. Users must define the volume and traffic composition for the desired traffic stream. Vehicles are generated at the beginning of chosen links and can enter the traffic network over time.
4. **Desired speed change**: A “design speed change” entity is employed at locations in the network, where the design speeds change. For example, the design speed can vary from one lane to the next. Two types of design speed change entities can be applied: “desired speed decisions” and “reduced speed area.” These are used for permanent and temporary speed changes, respectively.

Additional network elements may be defined, including priority rules (employed at interchanges and intersections), traffic signal deployment, detectors, transit vehicles, and data collection points. Detail concerning these and other settings can be found in the VISSIM user manual (PTV, 2007).

Attributes of the entities are often set when creating the simulation model.

For example, one can select acceleration and deceleration functions, desired speed, vehicle weight distribution, traffic composition in terms of vehicle class, and vehicle brand distributions. Selection of signal controller type at a signalized intersection and related settings are also needed.

CHAPTER 4.

Calibration and Validation: Background and State-of-the-Practice

As discussed in Chapter 3, simulation modeling has been widely used in practice to assess the potential impact of the introduction of HOT lanes on traffic flow characteristics and to forecast probable revenue. The use of simulation for this purpose is proposed in Chapter 5 for the study in subsequent phases of proposed HOT lane facility designs for I-495 in Maryland. Measures produced by simulation are sensitive to the parameter settings embedded in the simulator. For example, parameters associated with car-following and lane changing behaviors employed within the simulation platform. Such parameters are described in Chapter 3 in the context of the VISSIM simulation software package.

In the absence of information to guide the setting of the parameters, default settings chosen by the software company can be used. However, the resulting driving behavior and other characteristics replicated in the simulation may not be consistent with reality for the chosen study area. Thus, an uncalibrated simulation model can lead to misleading or erroneous findings and conclusions. It is preferable that the model be appropriately calibrated and validated to yield a set of parameters that fit the local traffic environment. Such calibration and validation efforts will yield a tool with greater fidelity and credibility.

As ascertained through interviews with project managers, modelers and other experts, such calibration efforts were undertaken in studies of proposed HOT lane facilities in Washington, Utah, and California, where simulation was employed. This chapter presents background and related information on state-of-the-practice on calibration and validation processes.

4.1 Background

Calibration of a micro-simulation tool for traffic modeling is the process of selecting appropriate settings for model parameters such that the behavior and

general characteristics of the entities replicated within the model are consistent with reality. Thus, field data is often employed in this process. As the results in terms of measures of effectiveness that are produced by the simulation model are sensitive to the parameter settings, it is crucial that the sample field data used in the calibration process be representative of the conditions under which the system will be evaluated. Thus, it is necessary to consider such characteristics of the sample data as season, day-of-week, time-of-day, occurrence of incidents, construction, weather and other special circumstances.

Typically, the calibration process seeks a match of the simulation output with the real-world in terms of one or more measures of effectiveness. In the calibration process for the VISSIM model of I-405, a parameter related to the headway between vehicles was adjusted until a capacity of 2,250 vehicles per hour per lane was achieved.

More typically, multiple parameters must be simultaneously calibrated. If one were to test every combination of parameter settings, an enormous number of runs would be required. For example, in the case where eight parameters must be adjusted, each with five potential values, 5^8 (390,625) runs would be required to assess each combination of parameter settings. Thus, sampling techniques, e.g. Latin Hypercube (which ensures that the entire range of each parameter is sampled), can be used to select a subset of runs. Park and Qi (2005) and Park and Schneeberger (2003) employ such a method for calibrating a VISSIM traffic simulation model of intersections.

Park and Qi developed a linear regression model from results of the simulation runs for each of the parameter combinations selected via the Latin Hypercube sampling technique. The resulting regression model can be used to select parameter settings to achieve a given level of output.

Park and Schneeberger proposed a genetic algorithm (GA) that seeks the best combination of parameter settings to achieve a given travel time value obtained from field data. The Latin Hypercube sampling technique is employed in selection of the initial population. The fitness value of each solution generated in the GA is taken as the difference between the simulated estimate of travel time and the actual travel time. Animation from the simulation is reviewed to ensure that the general traffic characteristics for a given set of parameter settings are similar to those of reality.

Details of calibration efforts employed in studies of HOT lane facilities in the United States are given in Section 4.2.

Once the model is calibrated, one can validate the model in two ways. First, one can assess how close the calibrated model matches the real-world data in terms of measures, such as volume, speed, and travel time (by lane type). Second, one can assess such consistency between model performance and reality with tests at various locations or for different time periods over the same location. In this second approach, the model can be recalibrated for each run. Alternatively, validation may consist of comparing results of the calibrated model on a similar, but different, data set. For example, one might calibrate the model based on data for a given date and time and then compare the model results to real-world data for a similar day-of-week and time-of-day under similar conditions. If the model results match reality in both scenarios given that it was calibrated only for the first, one might say the model has been validated. While extensive calibration efforts have been conducted related to simulation modeling of HOT lanes in some states, it appears that the first method of validation (i.e. where a model is considered to be validated if it can be calibrated such that it results in output that matches reality closely) has sufficed in all such studies.

4.2 Calibration and Validation Efforts in HOT Lane Facility Modeling

Calibration of traffic simulation models of HOT lane facilities in the United States have been undertaken in studies of I-405 in Washington, I-15 in Utah and I-580 and I-680 in California. Where Wilbur Smith and Associates has been employed to develop the traffic and revenue models, no validation studies were conducted and no information about calibration efforts could be obtained. No additional information about calibration and validation efforts has been obtained from other locations either due to lack of information or lack of such efforts.

4.2.1 Washington

VISSIM, CORSIM and SYNCHRO software products were employed in the modeling and calibration efforts of the HOT lane facility along I-405. The VISSIM

software was employed to model the main freeway lanes, on- and off-ramps, interchanges and freeway connections. SYNCHRO was used to optimize the signal timing at intersections of adjacent arterials contained in the network model of I-405 and nearby roadways. CORSIM was used to model the arterial intersections, due to the computational demands of the VISSIM platform for modeling traffic signals (Westby, 2005).

Occupancy, speed, and volume data were supplied from loop detectors at several locations. A scenario depicting the peak hour traffic for a typical day was developed using ramp volume data at 15 minute increments for six-hour morning and six-hour evening peak periods. A parameter (the “CC1” parameter in Wiedemann 99 car-following model that is embedded in VISSIM) related to the headway required to maintain a desired speed was calibrated such that capacity (given in terms of vehicles per hour per lane) generated in the simulation model matched that of reality for the same time period (Westby (2005) and interview with Westby). The calibrated model has been applied over many scenarios; ultimately, suggesting that no additional validation is required (according to the modeller).

4.2.2 Utah

A genetic algorithm was developed for calibrating a large-scale VISSIM model of a 35-mile segment of I-15 in Utah (http://www.humis.utah.edu/). An extensive data collection effort was undertaken, where license plates were read upon entry and exit from the freeway during a couple of hours of the peak period on a given day. This data was used for calibration purposes and to build an existing conditions model. Journal articles are expected to be published.

4.2.3 California

I-580 (Alameda County)

The VISSIM model developed by URS for modeling I-580 and its proposed HOT lane facility was calibrated on existing conditions. Vehicle counts at select screen lines were employed and the model was calibrated based on data from these locations. A travel demand model for 2007 was employed in this calibration effort. No additional validation efforts were made.

I-680 (Alameda County)

A related study of ramp metering strategies for I-680 was conducted. Significant effort is described related to the calibration and validation of a PARAMICS based model of the ramp metering operations. The MOEs of travel time, speed and flow were chosen for model validation (May et al., 2003). The study also addressed the modeling of a continuous access HOV lane along I-680 and illustrated how the use of a new API supplied by Quadstone could allow them to model I-680 with an HOV lane facility.

CHAPTER 5.

Next Steps: Recommended Tools for Conducting Operational Analyses of Potential I-495 HOT Lanes

The VISSIM simulation software is widely used in the United States as a tool for assessing the operational impacts of the introduction of HOT lanes to existing roadway facilities, including the impacts resulting from selection of particular toll collection and access point locations. It has also been used to provide necessary input in terms of travel times for revenue forecasting. While VISSIM has been employed to model the HOT lane facilities, in only one location in the United States of which we are aware, the HOT lane is treated as a separate lane rather than as a separate facility. In this particular case, no violations in terms of crossing into (out of) the HOT lanes from (to) the general purpose lanes at locations other than designated access points are modeled. This chapter describes the methods that we propose to use in subsequent phases of this project to model proposed HOT lanes as nonbarrier separated lanes (as opposed to separate facilities), where violations involving access to and from the HOT lanes at undesignated locations are modeled.

In Section 5.1, key traffic maneuvers associated with HOT lane operations that may be modeled in the VISSIM simulation model are described. A demonstration of relevant VISSIM software capabilities related to traffic movements along the main freeway lanes, including HOT or HOV lanes, at the on- and off-ramps, and at access points to the HOT lanes is provided in Section 5.2. In Section 5.3, the steps required to develop the VISSIM simulation model for a portion of I-495 in Maryland for use in future analyses are described. Such analyses will be conducted to assess design alternatives and the impact of these alternatives on traffic performance.

5.1 Modeling Characteristics Specific to Nonbarrier Separated HOT Lanes

As mentioned in Chapter 3, the VISSIM simulation platform can be employed to model traffic operations along traffic facilities, including both freeways and arterials. Measures, such as average speeds, travel times, and throughput are commonly studied to assess the impact of potential facility designs. The VISSIM software is proposed herein for use in modeling the impact of the introduction of one or more nonbarrier separated HOT lanes along a segment of I-495 in Maryland. The model will be used to study the impact of traffic violations across the HOT lane-general purpose lane boundary, weaving maneuvers required for accessing the lanes at predetermined ingress and egress locations, and general performance in terms of traffic flow of both the HOT lanes and general purpose lanes for given traffic levels and splits under various design scenarios. In addition to studying the impact on mobility, potential safety implications will be considered.

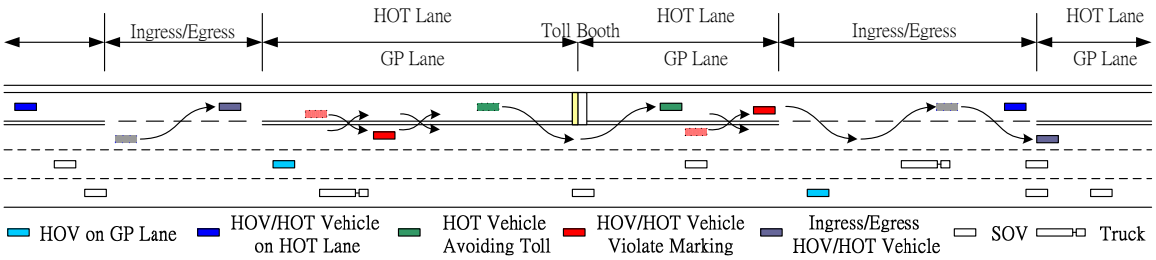
Figure 2 illustrates the potential traffic maneuvers that can be modeled along a nonbarrier (buffer) separated concurrent flow lane facility of a freeway within the VISSIM simulation platform. Five classes of vehicles are modeled in this example: SOVs (without the necessary equipment to use the HOT lane), HOVs, HOT lane vehicles (HOTs), and trucks (which are not permitted to use the HOT lanes). One could further distinguish HOV-2 from HOV-3 and could include other user classes, such as buses and fuel efficient vehicles.

SOVs and trucks are modeled as background traffic. These user classes are restricted to the general purpose lanes. Only change of lane between the general purpose lanes and ingress and egress to and from the freeway through on- and off-ramps are permitted. HOVs are permitted to use the general purpose and HOT lanes without paying a fee, while HOTs are similarly permitted to use either lane type, but must pay a fee at designated tolling locations. HOVs are, therefore, not likely to avoid the tolling location by crossing the buffer immediately prior to the tolling facility. HOVs and HOTs alike, however, may choose to cross the buffer in violation of the law along the entire stretch for convenience. Thus, HOVs and HOTs are permitted in the model to switch between the general purpose lanes and the HOT lane. Violators of HOV or HOT lane restrictions,

referred to as HOT-violators (e.g. an SOV with no transponder), can be modeled, where such vehicles are likely to cross the buffer immediately prior to the tolling location.

Figure 2 illustrates a number of different maneuvers, including the movement of vehicles into and out of the HOT lane at permissible locations (access points), shown by a dashed line. A vehicle whose driver avoids toll payment by switching between the HOT lane and the adjacent general purpose lane immediately prior to the tolling location is shown (in green). Two vehicles whose drivers violate the law by crossing the buffer either from the general purpose lane into the HOT lane or from the HOT lane into the general purpose lane are also shown (in red). Note that violations are not confined to the HOVs/HOTs. Some SOVs or trucks might also show the same violation behavior.

Figure 7 – Example of Driving Maneuver



5.2 Modeling Roadway Components in the VISSIM Simulation Platform

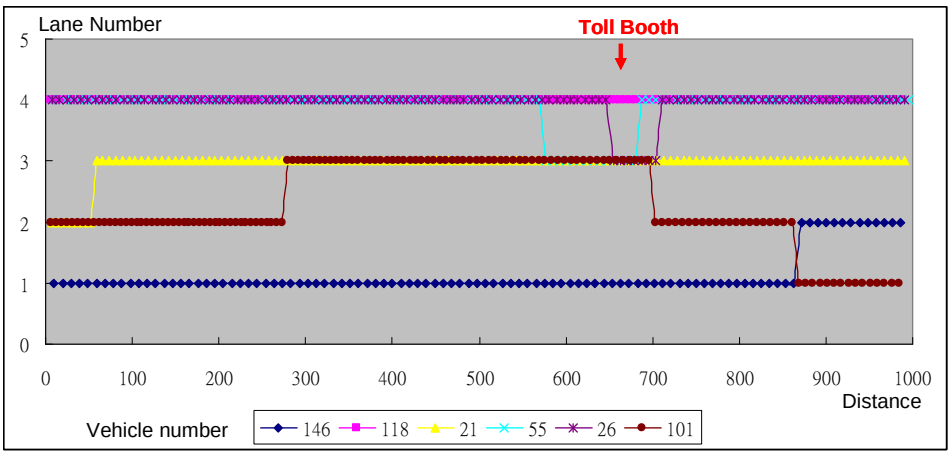
This section demonstrates the use of the VISSIM simulation software in modeling the mainline freeway, on- and off-ramps to and from the freeway and ingress and egress points to and from a HOT lane facility at designated locations. Access violations to the HOT lane facility are also demonstrated.

A small segment of a freeway (one direction only) with a single nonbarrier separated HOT lane (modeled as a separate lane as opposed to a separate facility) was modeled. In forthcoming subsections, the methods used to model this roadway segment, various components thereof, or variants are described and sample vehicle trajectories from the model output are shown.

5.2.1 Modeling Mainline Freeway Links

Three vehicle classes are considered in the model of the freeway segment's mainline: SOVs, HOVs, HOTs, (referred to here simultaneously as HOV/HOTs) and HOT-violators. Lanes 1 through 3 are general purpose lanes and lane 4 is classified as a HOT lane. Figure 3 shows the vehicle trajectories (developed from output from the VISSIM simulation platform) of different vehicle types traveling along the mainline freeway. Vehicles 110 and 21 are SOVs. These vehicles only use the general purpose lanes. Vehicles 118 and 146 are HOV/HOTs. Over the course of the simulation as shown in the figure, vehicle 118 employed the HOT lane, never crossing into the general purpose lanes, while vehicle 146 employed only the general purpose lanes. Vehicles 55 and 26 are HOT-violators. These two vehicles employed the HOT lane up to the location of the toll booth shown in the figure. Both vehicles violated the law and crossed over the buffer into the general purpose lane immediately prior to the tolling location to avoid paying the toll. Immediately after the toll booth, both vehicles crossed illegally back into the HOT lane. Such HOT-violators can be given traits that make it more or less likely to take violation decisions. This example illustrates that the user can model such violations within VISSIM to assess their impact on traffic flow characteristics (and safety) within both the HOT and general purpose lanes.

Figure 8 – Vehicle Trajectories along Mainline Freeway



5.2.2 Modeling of On- and Off-Ramps

Two models were developed to demonstrate how on- and off-ramps are modeled in the VISSIM platform. Such modeling is important to any HOT lane study, because weaving maneuvers between the HOT lanes and the general purpose lanes will be impacted by the location of the HOT lane access points and the on- and off-ramps to the mainline freeway. A study of the optimal distance between the HOT lane access points and on- and off-ramps was conducted for I-10 (Katy freeway) in Texas (Fitzpatrick et al., 2006).

Figure 4 shows the vehicle trajectories of two vehicles (vehicles 60 and 174) that maneuver between the on-ramp and the HOT lane. Vehicle 11 is a HOT lane user that violates the law and avoids paying the toll. Figure 5 shows the vehicle trajectories of two vehicles (118 and 145) that maneuver between the HOT lane and the off-ramp and of two vehicles (46 and 145) that violate the law and avoid paying the toll. In both the on-ramp and off-ramp scenarios, one can see that it is possible to observe the impact of such weaving maneuvers on the HOT and general purpose lane traffic.

Figure 9 – On-Ramp Vehicle Trajectories

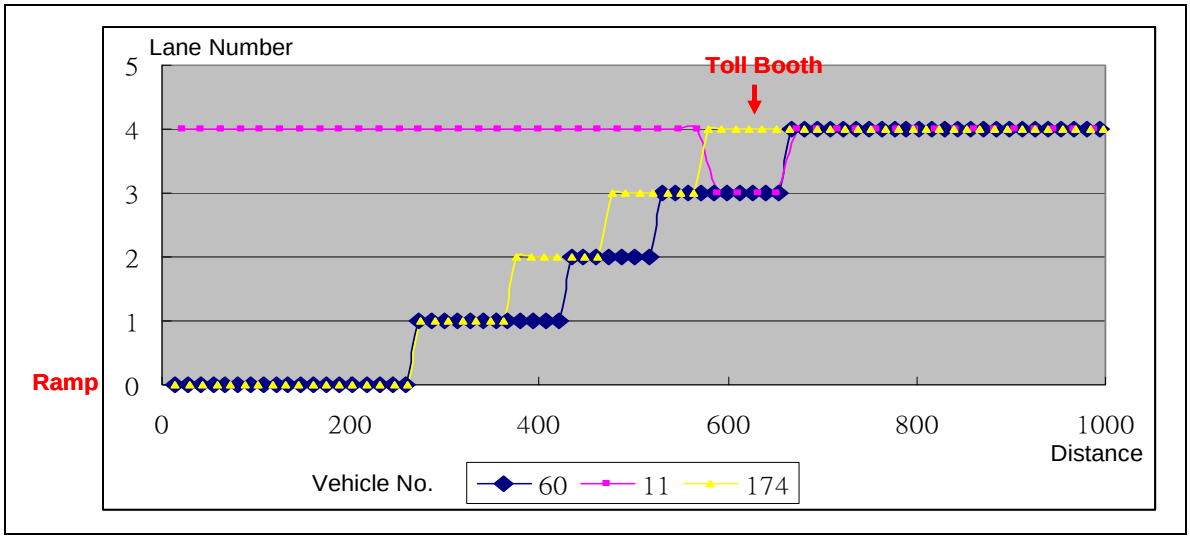
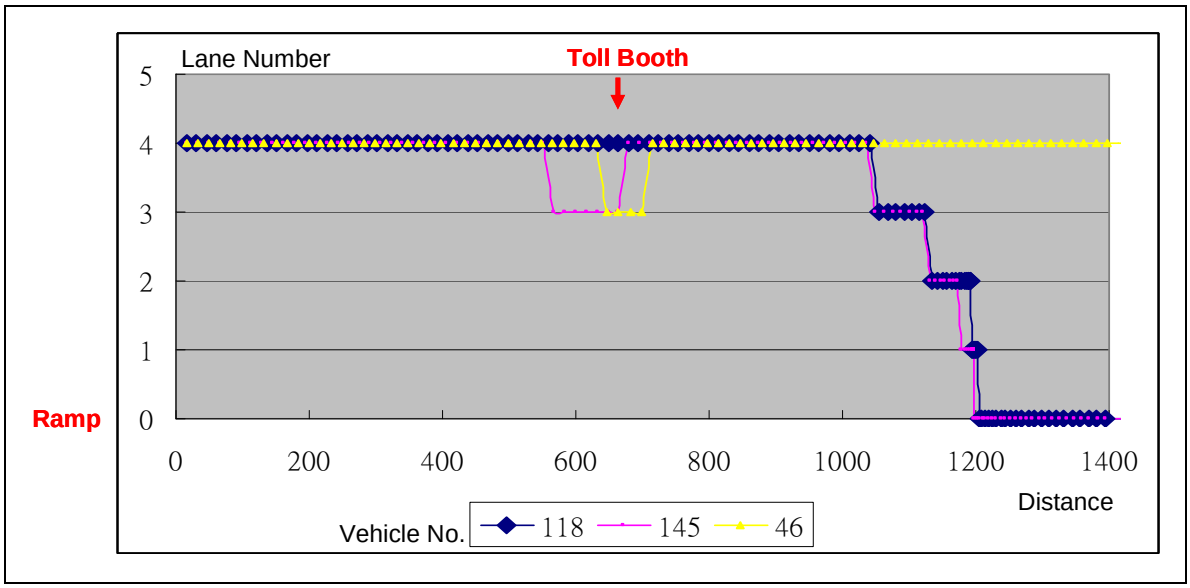


Figure 10 – On-Ramp Vehicle Trajectories

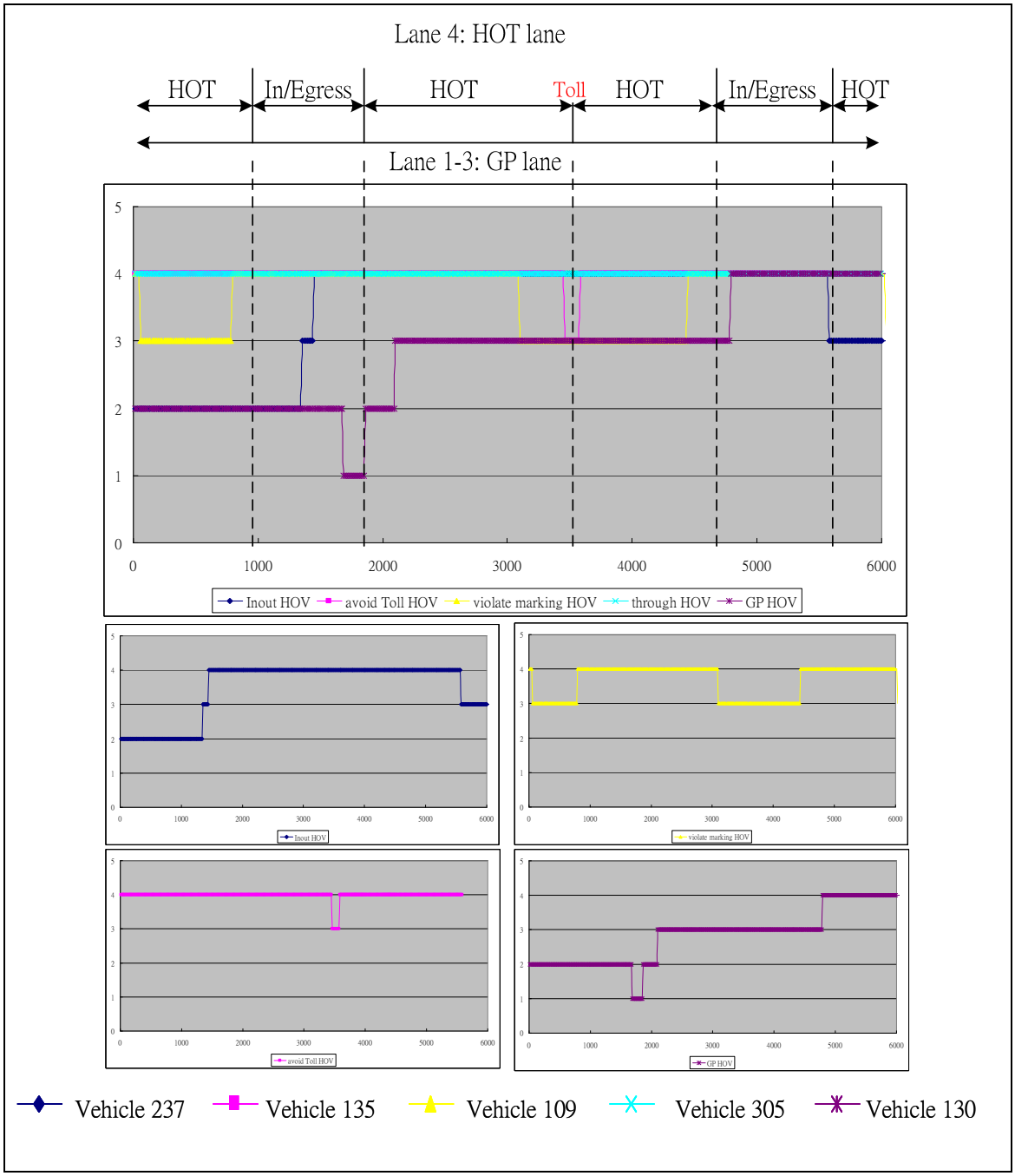


5.2.3 Modeling Ingress and Egress

In this subsection, how ingress and egress to and from a HOT lane can be modeled within the VISSIM platform is demonstrated. The segment is composed of four lanes, one of which (lane 4) is a HOT lane. The remaining three lanes (lanes 1 through 3) are general purpose lanes. There are two access points to the HOT lane for both ingress and egress and a single toll plaza for toll collection. This configuration is shown in Figure 6 and is identical to that given in Figure 2. Vehicles of the class of HOT-violators were created. Within this class, two types of HOT-violators were developed: those that cross the buffer to and from the HOT lane at points that are not permitted (vehicle 109, shown in pink in the figure) and those that cross from the HOT lane into the general purpose lane across the buffer immediately before the toll plaza and return to the HOT lane immediately after (vehicle 135, shown in yellow in the figure). The former maneuver may be undertaken to achieve improved service levels or for convenience of the driver. The latter requires two consecutive traffic maneuvers and has the goal of avoiding toll payment. All other HOVs and HOTs will access the HOT lane only at designated access points (vehicle 237 enters the HOT lane at the first access point and exits at the second, shown in dark blue in the figure; vehicle 130 enters at the second access point, shown in magenta; and vehicle 305 enters at an earlier roadway segment and does not exit within the modeled roadway segment, shown in light blue).

This VISSIM model illustrates that it is possible to treat the HOT lane as a lane instead of a separate facility, where SOVs, trucks and other non-HOT lane users are restricted from using the HOT lane, access is limited only to designated locations, and various types of violations are modeled and controlled.

Figure 11 – Ingress and Egress Vehicle Trajectories

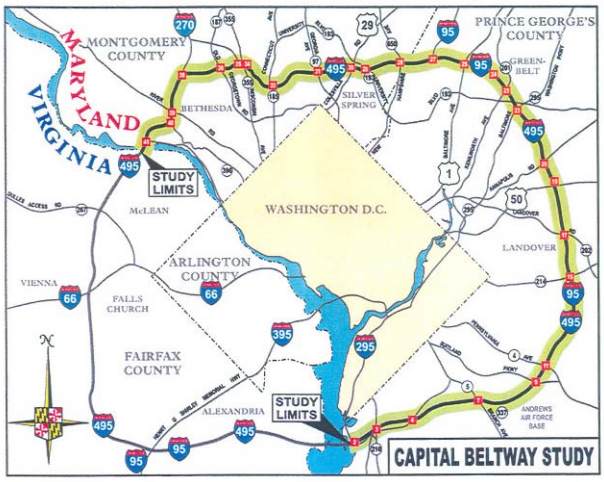


Various configurations of the access points and various access point locations can be modeled and evaluated in terms of traffic flow characteristics. In this example, access points are modeled such that both ingress and egress are simultaneously permitted (e.g. dashed striping in place of solid striping for a short portion of the roadway). Several proposed HOT lane facilities in the country employ an approach in their design, where merging lanes are included to allow vehicles to merge smoothly into the HOT lane and into the general purpose lanes. Such designs, where ingress and egress are separated, can also be modeled. Additionally, the impact of violations on traffic flow can be investigated by considering various types of violators and the impact of violations made in specific locations.

5.3 Application to I-495, the Capital Beltway

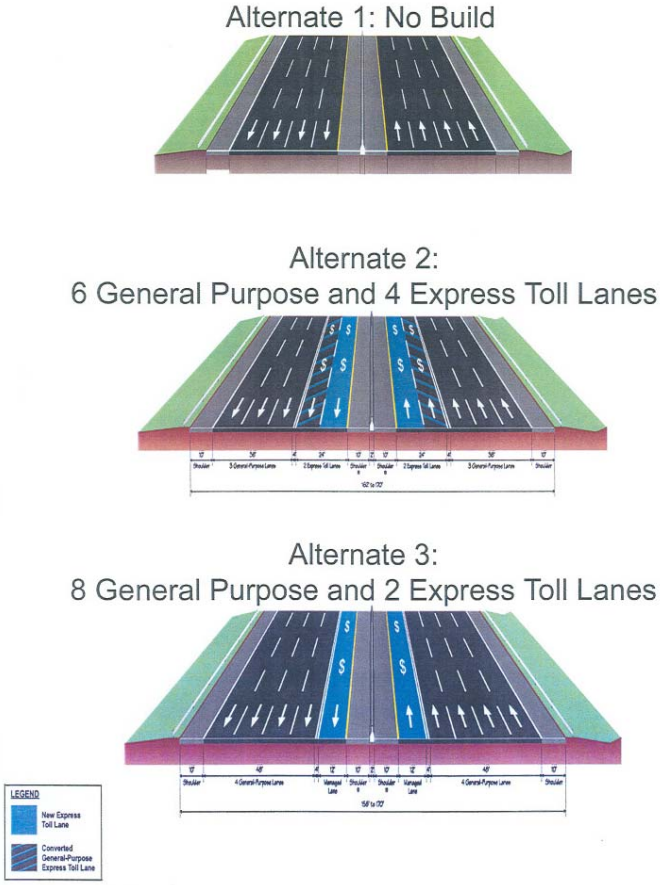
The Capital Beltway (I-495) depicted in Figure 7, provides an essential highway link serving local, regional and interstate trips. As congestion continues to worsen in the region and on the Capital Beltway, the number of freeway segments or ramp junctions currently experiencing level-of-service (LOS) F during peak hours and the duration of each peak hour are expected to increase if no improvements are made. Managing traffic during these peak periods is critical to the efficient operation of the Capital Beltway and other similarly congested highways in Maryland. While non-tolled roadways are experiencing more and more congestion, toll roads have prospered and, with the addition of electronic tolling, some have become more efficient and cost effective.

Figure 12- Capital Beltway Study Map



Subsequent phases of this research effort will seek to quantify the potential benefits in terms of level-of-service along the HOT and general purpose lanes under variable or congestion-based pricing solutions along the Capital Beltway (I-495) within the State of Maryland (see Figure 7). Various configurations involving the general purpose lanes, proposed HOT lane(s), location of access points to and from the HOT lane(s), and location of tolling plazas will be considered along the chosen segment. Two alternatives configurations under varying access type options and various options for setting the frequency and specific locations for toll collection that have been discussed are shown in Figure 8. The VISSIM simulation software is proposed for use in modeling the operations along the study segment and, thus, quantifying the potential effects of access type and toll collection plaza location, as well as frequency, on transitioning vehicles in and out of the managed lanes, the resulting cross-highway weaving, and erratic traffic maneuvers that may result in an effort to avoid the toll collection plazas (or gantries).

Figure 13 – Proposed Alternative Configurations



In this section, a description of the some of the main components of steps that will be taken to create, calibrate and validate the VISSIM simulation model of the chosen Capital Beltway segment will be provided. In addition, features of the scenarios that will be tested with the simulation model will be delineated. In Chapter 6, potential data sources that could be employed for model calibration and validation are described.

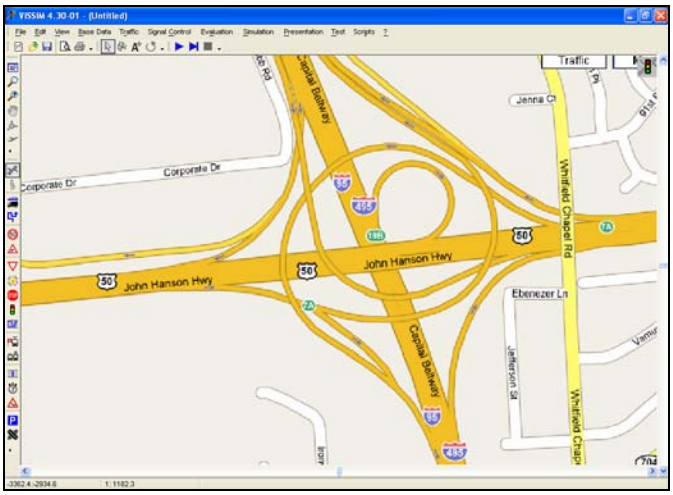
5.3.1 Model Construction, Calibration and Validation

5.3.1.1 Model Construction

A VISSIM simulation model will be created for a segment of the Capital Beltway in Maryland. Data on geometric characteristics of the roadway and proposed design alternatives are required. Ideally, demand for use of the roadway segment will be estimated and provided in the form of a time-of-day based (e.g. morning peak, evening peak and non-peak hours) origin-destination table. Estimates of the fraction of vehicles that are eligible to use the HOT lane(s) as an HOV and fraction of vehicles in each user class, e.g. truck, bus, passenger vehicle, that will employ the roadway segment during the study period are needed. Such estimates can be derived from a study of the segment over a short study period, where passenger occupancy and vehicle class data can be collected.

The resulting model will be displayed in the VISSIM software through a graphical user interface (GUI) as illustrated for one of the interchanges along the Capital Beltway in Maryland in Figure 9.

Figure 14 – Example of VISSIM GUI for network construction



While such models can include intersecting roadways, in the next phase, it is expected that only the on- and off-ramps to and from these adjacent facilities will be modeled.

5.3.1.2 Model Calibration

Once the model is constructed, its parameters must be calibrated with real-world data. That is, the parameters are set such that the outcome of the model, in terms of such measures as travel speed, traffic volume and travel time, match the actual experienced conditions. For this purpose, field data related to such mentioned measures must be collected and comparisons with measures produced by the model are made. Parameters are tuned until the measures produced by the model are comparable to those of reality. For example, it is necessary to tune the parameters associated with driving behavior. How such parameters are set depends on characteristics of the local area. An initial list of parameters that may be considered for tuning is provided in Chapter 3.

5.3.1.3 Model Validation

In existing and recent HOT lane projects around the United States, calibration efforts resulting in a close match between simulated traffic flows and reality for a given study period served as validation of the model. One might further validate such a model by applying the calibrated version of the model to a new study location to assess how well the model replicates reality with or without further parameter tuning. In subsequent phases of this effort, if the study area is to be extended in length to answer additional questions about proposed HOT lane facility alternatives, one might wish to conduct such additional validation studies before applying the model to the more extensive study area.

5.3.2 Features of Scenarios for Experiments

The simulation model, once developed, can be employed to assess a series of what-if scenarios. The following features of the scenarios will be considered in scenario development in subsequent phases of this effort.

1. Configuration of the general purpose and HOT lanes, including:
    a. Number and width of HOT lanes;
    b. Separation technique (e.g. buffer size);

c. Access point locations;
d. Access point design, in terms of whether or not the ingress and egress to and from the HOT lanes are at shared locations or are separated with on- and off-ramps and other geometric characteristics, including length of on- and off-ramps to permit merging if applicable;
e. Location of tolling plazas and related technologies; and
f. Location of points of termination of the HOT lanes if in the study area.

2. Hours of operation of the HOT lanes (e.g. directional peak period on weekdays only, 24 hours per day, 7 days per week,…).
3. Violation rates for varying types of violations pertaining to the chosen design and enforcement strategies.
4. Level of potential use of HOT lanes as a function of split and percentage of vehicles assumed to be equipped to use the HOT lane(s), where splits are based on tolls and are assumed given.
5. Time-of-day, e.g. morning peak, evening peak, non-peak hour.
6. Occurrence of incidents.

The study area and select set of relevant scenarios will be designed in conjunction with the State Highway Administration based on varying choices related to these features. Once chosen, required data must be collected and the VISSIM model must be adjusted or reconfigured to allow the testing of the chosen scenarios.

5.3.3 Proposed Procedure for Subsequent Phases of the Study

The VISSIM model described in Section 5.3.1 can be employed as part of a larger HOT lane facility analysis tool. Information gathered in interviews with project managers, modelers and other experts on HOT lanes in the United States has led to the following general approach to assessing traffic impacts and expected revenue generated by the introduction of a HOT lane facility, also depicted in Figure 10.

Step 0: k=0 and n=0.

Step 1: Forecast demand in study area for study period. k=k+1.

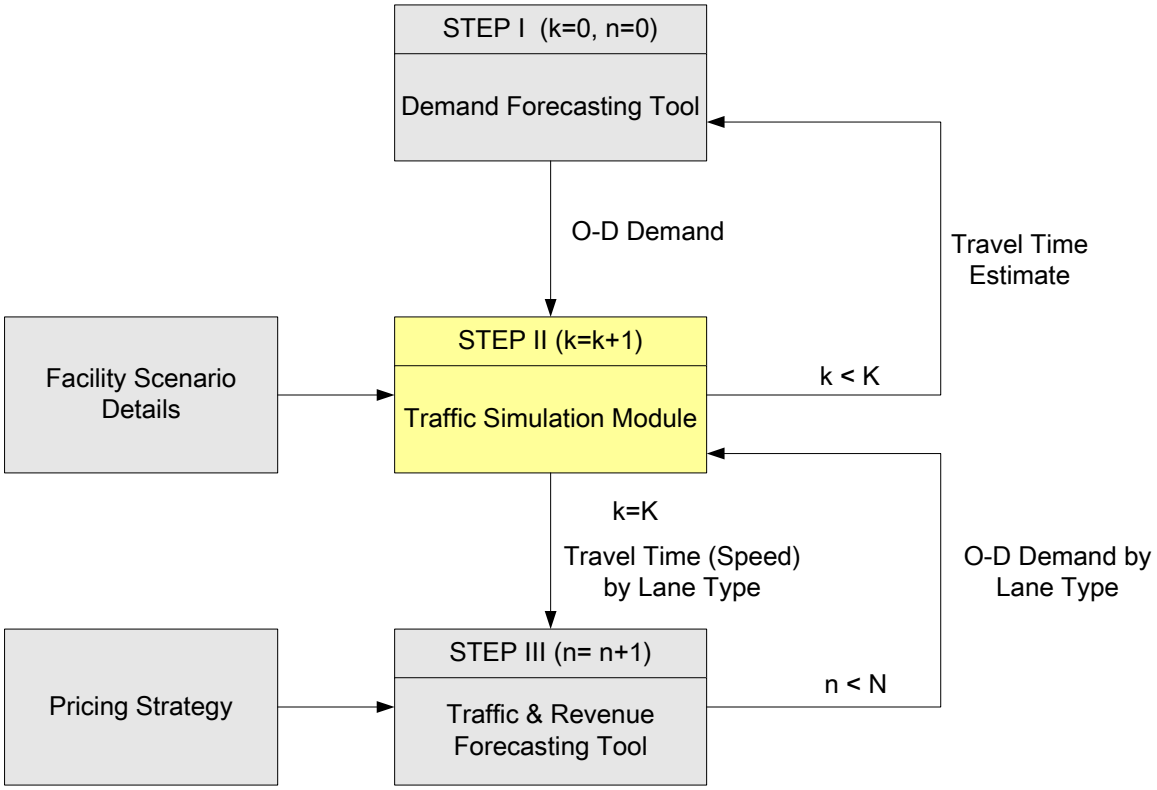
Step 2: Employ microsimulation of traffic to estimate travel times in the general purpose and HOT lanes. Return to Step 1 if k < K. If k=K, n=n+1 and continue to Step 3.

Step 3: Based on travel time estimates from step 2, employ technique to forecast lane usage by vehicle for given pricing structure. Return to Step 2 if n<N; otherwise, stop.

This technique terminates with estimates of traffic flow by lane and revenue forecasts.

The majority of modeling efforts conducted under the various HOT lane projects in the United States perform a variant of one or more steps of this procedure. A similar procedure is recommended for use in subsequent phases of this study. Studies of I-580 and I-680 in California employ a similar procedure; although, no iteration between Steps 2 and 3 was considered. In their particular approach, they employed Cube Voyager to forecast demand in Step 1, the VISSIM software to model traffic in Step 2, and a proprietary technique built on TRANPLAN developed at Wilbur Smith and Associates for Step 3. A similar approach was employed in the study of I-405 in Washington, where a regional model was employed in Step 1. Iterations between Steps 2 and 3 were taken; although, no iterations between Steps 1 and 2 were indicated.

Figure 15 – Three Step Procedure for HOT Lane Facility Analysis



CHAPTER 6.

Data Resources for Calibration and Validation of Operational Analysis Tools

A procedure and necessary data for developing the simulation model required for conducting analysis of HOT lane facilities, including traffic simulation model construction, calibration and validation, are described in Chapter 5. In this chapter, potential sources of relevant data required for model construction pertaining to a study area along I-495 in Maryland, and subsequent calibration and validation are provided.

6.1 Geometric Network

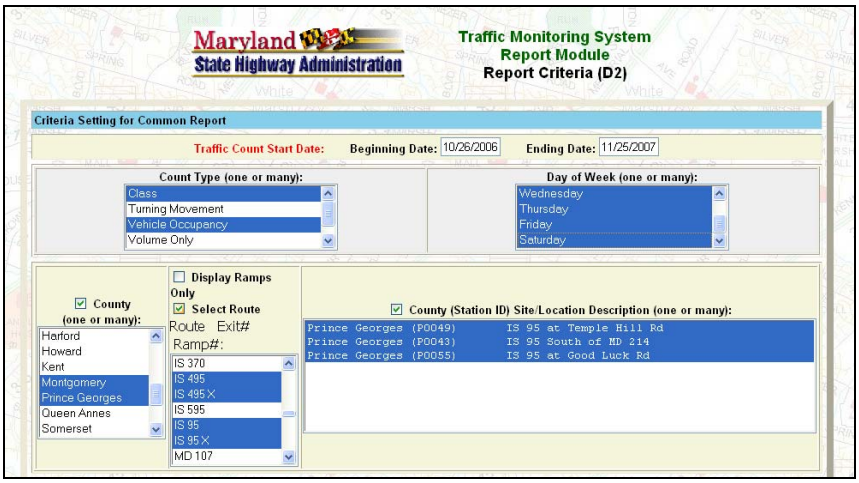
The Maryland portion of the Capital Beltway is approximately 40 miles in length and includes 30 interchanges. A VISSIM model of approximately 8 miles in the northern portion (between I-95 to Connecticut Avenue interchanges) was created in 2006 (RK&K and PB, 2006) by employees of Rummel, Klepper and Kahl, LLP (RK&K) for a project with the State Highway Administration of Maryland. If the study area is selected such that it does not overlap this northern portion of I-495, data pertaining to the roadway geometry, including interchange design, necessary to create a similar model for the chosen roadway segment will be required. The Maryland State Highway Administration may have access to additional simulation models of this roadway that may be in other formats, e.g. it may be the case that a CORSIM model of this roadway has already been developed for other studies. However, it is difficult and time-consuming to extract the necessary information from such a model. A preferable method would be to load a map in a format such as dwg, bmp, gif, and jpg into the VISSIM software and employ drawing tools to construct the model.

6.2 Traffic Data

Two potential data resources have been identified for obtaining information on traffic characteristics, such as volume, speed, passenger occupancy and vehicle class: the Maryland State Highway Administration's website[1] and the Center for Advanced Transportation Technologies (CATT) at the University of Maryland[2].

Vehicle class survey and passenger occupancy data are available from the State Highway Administration's website on "Traffic Monitoring System Report Module." Figure 11 shows a screenshot of the GUI of this website. A total of 13 vehicle classes (e.g. motorcycles, passenger cars, and light trucks) are included in the vehicle class survey data. Results from queries in the vehicle class and passenger occupancy survey data resources are given in Tables 6 and 7, respectively. It must be noted, however, that this resource is limited in scope. In queries conducted to ascertain the utility of these resources for the purpose of this study, very limited data could be found. For example, in querying the passenger occupancy data resource in the one-year period beginning October 1, 2006, only one detector provided data along I-270. No detectors reported information along I-495. In querying the vehicle class data resource for the same period, five detectors (Persimmon Tree Rd, MD 650, MD 214, Temple Hill Rd and Good Luck Rd stations) along I-495 provided data.

Figure 16 – SHA Website GUI for Traffic Data Query



[1] http://www.sha.state.md.us/tmsreports/
[2] http://www.ritis.org/index.php

Table 6 – Example of Traffic Data Query – Vehicle Class

State Highway Administration
Highway Information Services Division

Program Classified Count Detail Report

Station ID : P0043
Location : IS 95 South of MD 214
Date : 01/01/2007 To 01/01/2007
County : Prince Georges
Compiled By : SHATMS

01/01/2007 **Direction: North**

					Single-Unit Trucks		Single-Trailer Trucks			Multi-Trailer Trucks				
	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10	Class 11	Class 12	Class 13	
Beginning Hour	Motorcycles	Passenger Cars	Light Trucks	Buses	2 Axle 6 Tire	3 Axle	>=4 Axle	>=4 Axle	5 Axle	>=6 Axle	>=5 Axle	6 Axle	>=7 Axle	Total
0 : 00	0	2201	47	3	6	7	0	4	20	1	0	0	0	2,289
1 : 00	0	2835	58	0	5	0	0	4	17	0	0	0	0	2,919
2 : 00	0	1853	52	2	6	0	0	4	11	0	1	1	0	1,930
3 : 00	0	1352	35	2	6	1	0	3	19	0	0	0	0	1,418
4 : 00	0	885	31	0	3	3	0	3	13	0	0	0	0	938
5 : 00	0	773	38	0	10	4	0	0	22	0	0	0	0	847
6 : 00	1	805	41	1	3	4	1	6	9	0	1	0	0	872
7 : 00	0	925	55	1	7	4	0	7	21	0	0	0	0	1,020
8 : 00	0	1116	70	1	8	3	0	10	16	0	0	0	0	1,224
9 : 00	4	1563	106	1	13	10	0	9	26	0	0	0	0	1,732
10 : 00	2	2163	110	3	16	14	0	11	39	0	0	0	0	2,358
11 : 00	3	2820	160	3	15	7	0	11	56	2	0	1	0	3,078
12 : 00	4	3524	169	1	17	9	0	10	52	0	0	0	0	3,786
13 : 00	1	4058	175	5	18	6	0	21	62	0	0	0	0	4,346
14 : 00	1	4281	190	7	16	19	0	33	70	0	0	0	0	4,617
15 : 00	1	4614	209	9	13	9	0	19	57	0	1	0	0	4,932
16 : 00	1	4640	184	4	14	10	0	25	72	0	2	0	0	4,952
17 : 00	0	4110	184	1	15	10	0	5	70	0	0	0	1	4,396
18 : 00	1	4036	159	4	14	16	0	18	81	1	2	0	0	4,332
19 : 00	2	3572	144	3	16	10	0	17	77	0	0	0	0	3,841
20 : 00	2	3262	123	3	13	12	0	25	95	0	1	0	0	3,536
21 : 00	2	2672	102	3	10	14	0	27	108	0	0	1	0	2,939
22 : 00	1	2284	72	4	10	9	0	29	114	0	1	0	0	2,524
23 : 00	2	1619	56	1	17	21	0	19	97	0	0	1	0	1,833
Total :	28	61963	2570	62	271	202	1	320	1224	4	9	4	1	66,659
Percentage :	0.04%	92.96%	3.86%	0.09%	0.41%	0.30%	0.00%	0.48%	1.84%	0.01%	0.01%	0.01%	0.00%	

Total of Class 1-4 : 64,623 **Percent of Class 1-4 :** 96.95% **Total of Class 5-13 :** 2,036 **Percent of Class 5-13 :** 3.05% 139064

11/25/2007 ClassDetailrpt Page 1 of 3

Table 7 – Example of Traffic Data Query – Passenger Occupancy

Maryland Department of Transportation
State Highway Administration
Highway Information Services Division

Vehicle Occupancy Count Report

Station ID : S1997150042
Location : IS 270 SOUTH OF SHADY GROVE RD
Date : 06/06/2007
Comments: Lane 7 - HOV(NB) ; Lane 8 - HOV(SB)
Count NO : 665238
Compiled By : SHATMS

Lane 8 South **Occupants**

Beginning Time	1	2	3	COUNT.COUNT_COMMENTS (String)				Truck	Total
06:00	382	152	16	4	0	1	2	0	557
06:15	146	213	3	2	0	4	5	0	373
06:30	7	218	5	7	0	7	5	0	249
06:45	4	257	5	1	0	2	8	0	277
07:00	14	228	7	3	0	3	10	0	265
07:15	41	259	5	4	0	0	7	0	316
07:30	26	235	7	1	0	1	11	0	281
07:45	22	215	3	3	0	2	8	0	253
08:00	53	233	5	2	0	3	7	0	303
08:15	35	240	1	2	1	2	10	1	292
08:30	81	241	5	0	0	2	7	4	340
08:45	126	130	7	0	0	0	3	2	268
09:00	287	59	2	0	0	1	1	0	350
09:15	346	55	0	1	0	2	2	1	407
09:30	273	32	0	0	0	1	5	0	311
09:45	299	23	0	0	0	1	5	1	327
Total :	2142	2790	71	30	1	32	94	9	2169

Reports from detectors in Maryland and Virginia with information on volume, speed and detector occupancy can be obtained from resources at the CATT Laboratory of the CATT at the University of Maryland. Traffic data is reported every five minutes. Figure 12 shows a screenshot of the GUI for data query from this data resource. In addition, one can see the location of the detectors in the Washington, D. C. Metropolitan area. Table 8 shows the output

from conducting a traffic data query for a particular detector over a given time period.

In portions of the region, detector density is high and it could be possible to collect much of the required traffic data needed to create a detailed traffic evolution profile for subsequent phases of the study. However, the majority of the detectors can be found on the radial roadways emanating from the Capital Beltway. That is, the Maryland portion of I-495 is equipped with very few detectors. It is possible that additional detectors will be deployed along I-495 in Maryland in the near future. Additional information about such deployment is required.

Figure 17 – CATT Website GUI for Traffic Data Query

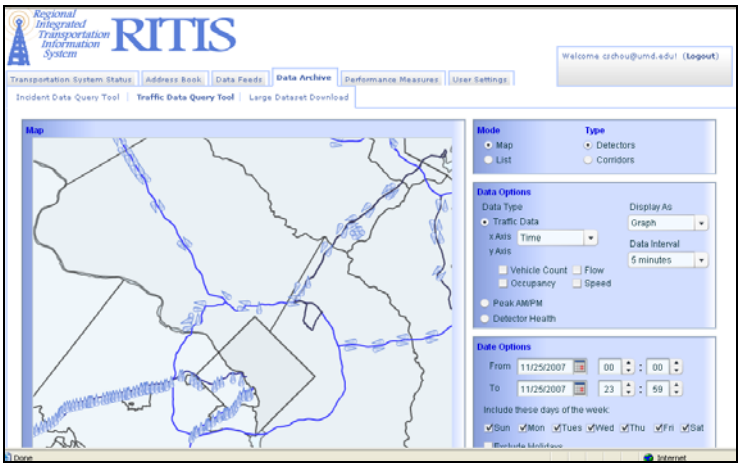


Table 8 – An Example of Traffic Data from CATT – Detector Output

UMD CATT Lab Traffic Data						
TIME	DIRECTION	LOCATION	OCCUPANCY	SPEED	COUNT	VEHICLES/HOUR
10/29/2007 14:02:48	Unknown	I-495 between Md 97 & US 29	7.2	65.9	492	5904
10/29/2007 14:07:48	Unknown	I-495 between Md 97 & US 29	6	66.8	444	5328
10/29/2007 14:12:48	Unknown	I-495 between Md 97 & US 29	8	66.7	553	6636
10/29/2007 14:17:48	Unknown	I-495 between Md 97 & US 29	7.5	65	511	6132
10/29/2007 14:22:48	Unknown	I-495 between Md 97 & US 29	7.7	65.7	540	6480
10/29/2007 14:27:48	Unknown	I-495 between Md 97 & US 29	8.7	62.6	562	6744
10/29/2007 14:32:48	Unknown	I-495 between Md 97 & US 29	7.7	64	541	6492
10/29/2007 14:37:48	Unknown	I-495 between Md 97 & US 29	7	66.2	535	6420
10/29/2007 14:42:48	Unknown	I-495 between Md 97 & US 29	7	64.5	523	6276
10/29/2007 14:47:48	Unknown	I-495 between Md 97 & US 29	7	66.2	525	6300
10/29/2007 14:52:48	Unknown	I-495 between Md 97 & US 29	8.5	64.8	573	6876
10/29/2007 14:57:48	Unknown	I-495 between Md 97 & US 29	7.2	68.2	570	6840
10/29/2007 15:02:48	Unknown	I-495 between Md 97 & US 29	8.2	65.1	543	6516
10/29/2007 15:07:48	Unknown	I-495 between Md 97 & US 29	6.2	68.7	477	5724
10/29/2007 15:12:48	Unknown	I-495 between Md 97 & US 29	7.5	65.1	541	6492
10/29/2007 15:17:48	Unknown	I-495 between Md 97 & US 29	8.2	67.9	541	6492
10/29/2007 15:22:48	Unknown	I-495 between Md 97 & US 29	7	66.7	535	6420
10/29/2007 15:27:48	Unknown	I-495 between Md 97 & US 29	7	65.3	529	6348

To calibrate and validate the simulation model that will be developed in subsequent phases of this study, it will be necessary to obtain travel time information for the study segment. While it is possible to gather data on travel speed and traffic density, no technology that we are aware of has been deployed for directly estimating travel time along I-495 or nearby roadways. One possibility might be to collect travel times using “tach run” survey data or through extraction from Closed-Circuit Television (CCTV) along the study segment.

6.3 Traffic Maneuvers

To validate (and possibly calibrate) the model in terms of traffic maneuvers (e.g. lane changing behavior near on- and off-ramps along I-495), observations from CCTV images can be used. A related study of lane changing maneuvers at an access point to a barrier separated HOT lane facility in Texas has been conducted (Venglar and Fenno, 2003). In this study, the CCTV image focused on the access point. Information from adjacent general purpose lanes was not obtained.

CCTV is available in locations along I-270 and I-495 in Maryland. 10 such units exist along I-270, at locations depicted in Figure 13. Sample images from two of these 10 CCTV units are provided in Figure 14. Note that the left most lane is an HOV lane with continuous access. Likewise, Figure 15 shows the location of 19 CCTV units along I-495 in Maryland.

Figure 18 – CCTV along I-270 and Example Images

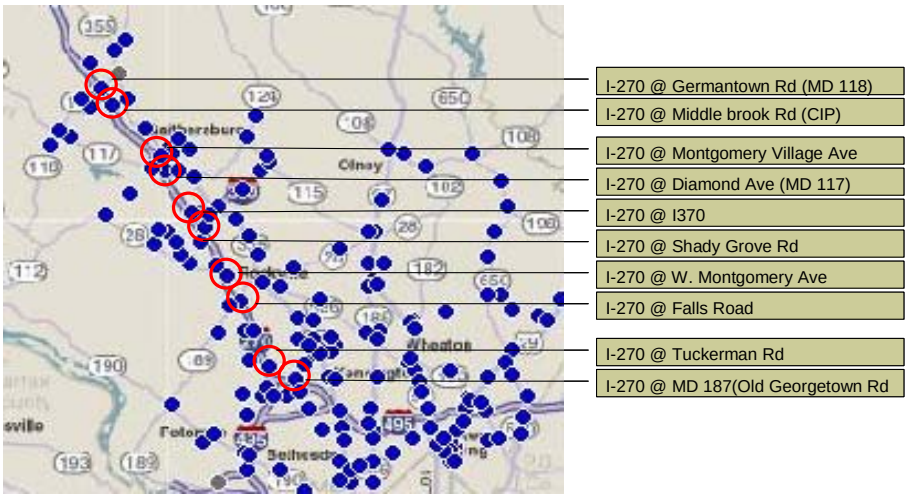
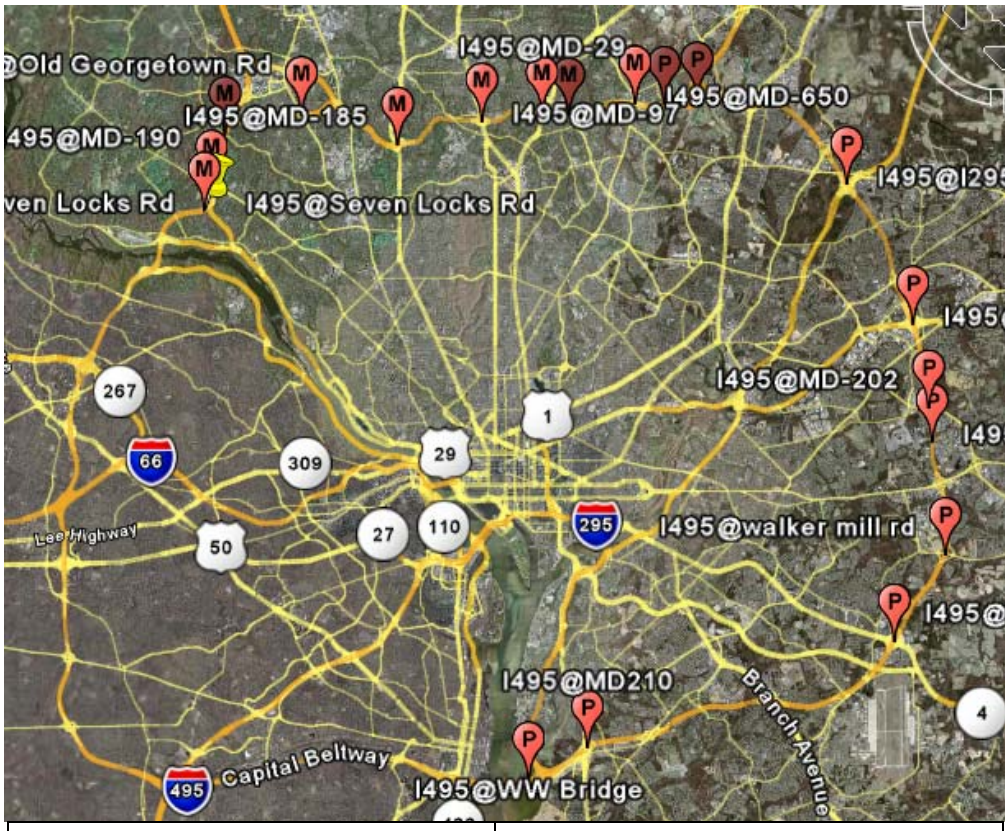


Figure 19 – Sample Images from CCTV along I-270

I-270 and Middlebrook Rd (CIP)
Traffic closest to camera travelling North

I-270 and Montgomery Village Ave MD 124
Traffic closest to camera travelling North

Figure 20 – CCTV Location Map and List along I-495/I95



Montgomery County	PG County
■ I-495 @ Seven Locks Rd	■ I-95 @ MD-212
■ I-495 @ MD190 (River Rd)	■ I-95 @ I-495
■ I-495 @ Bradley Blvd	■ I-95/495 @ I-295
■ I-495 @ Old Georgetown Rd	■ I-95/495 S. OF US 50
■ I-495 @ MD185 (Connecticut Ave)	■ I-95/495 @ MD 202

■ **I-495 @ 97 (Georgia Ave)** ■ **I-495 @ MD29 (Colesville Rd)** ■ **I-495 @ MD193** ■ **I-495 @ MD650**	■ **I-95/495 @ ARENA DR** ■ **I-95/495 @ EXIT 13 (Walker Mill Rd)** ■ **I-95/495 @ MD 4** ■ **I-95/495 N of MD 210** ■ **I-95/495 W.W. Bridge**

A single nonbarrier separated HOV lane with unlimited (i.e. continuous) access exists in each direction along a portion of I-270 in Maryland. Access to and from the HOV lane is limited for only a small portion near the junction with I-495. Thus, CCTV units can capture only a small portion of maneuvers between the general purpose and HOV lanes. Moreover, the character of maneuvers between these lanes given that there is continuous access to the HOV lane along its remainder will differ significantly from maneuvers between such lanes where access is limited to select locations.

Images that can be obtained from CCTV units along I-495 are limited in their utility for this study. This is because no facility similar to an HOT lane facility exists along this roadway for which access maneuvers can be studied. Such CCTV units would be useful in studying the performance of such a facility once constructed.

REFERENCES

1. Dahlgren, J., *"High Occupancy Vehicle/ Toll Lanes: How Do They Operate and Where Do They Make Sense?"* 2000.
2. Fitzpatrick, K., Brewer, M. and Park, E., *"Intermediate Access to Buffer-Separated Managed Lanes,"* Texas Transportation Institute, Report No. FHWA/TX-07/0-5547-1, 2006.
3. Gardes, Y., Kim, A. and May, D., *"Bay Area Simulation and Ramp Metering Study - Year 2 Report,"* University of California, Berkeley: Journal of PATH Research Report, No. 27206, 2003.
4. Halvorson, R., Nookala, M. and Buckeye, K., *"High Occupancy Toll Lane Innovations: I-394 MnPASS,"* Public Works Management Policy 10, pp. 242-255, 2006.
5. Kwon, E., Kelen, C., Ran, B. and He, R., *"Hierarchical Evaluation of HOT Lane Operation using Dynamic Network Models,"* 79th Transportation Research Board Meeting CD, 2000.
6. Lari, A. and Buckeye, K., *"High Occupancy Toll Lane System—A Concept Plan for the Twin Cities,"* Transportation Research Record, No. 1659, pp. 111-118, 1998.
7. May, A., Gardes, Y. and Kim, A., *"Bay Area simulation and Ramp Metering study Year 2 Report,"* University of California, Berkeley, 2003.
8. Metropolitan Transportation Commission with CALTRANS, *"Bay Area High-Occupancy/Toll (HOT) Network Study,"* 2007.
9. Metropolitan Transportation Commission with CALTRANS, *"Bay Area*

High-Occupancy/Toll (HOT) Network Study," 2007.

10. Minnesota Department of Transportation, *"Phase II Planning Study, Optimizing Corridor Performance"*.
11. Munnich, L. and Buckeye, K., *"MnPASS High-Occupancy Toll Lanes: Planning and Operational Issues and Outcomes, Lessons Learned in Year One,"* Transportation Research Record, No.1996 pp. 49-57, 2007.
12. Olstam, J. and Tapani, A., "*Comparison of Car-following Models,"* Swedish National Road and Transport Research Institute, 2004.
13. Orange County Transportation Authority, *"Orange County HOV Lane Operations Policy Study,"* 2002.
14. Park, B. and Qi, H., *"Development and Evaluation of a Procedure for the Calibration of Simulation Models,"* Transportation Research Record: Journal of the Transportation Research Board, No. 1934, pp. 208-217, 2005.
15. Park, B. and Schneeberger, J., *"Microscopic Simulation Model Calibration and Validation: Case study of VISSIM Simulation Model for a Coordinated Actuated Signal System,"* Transportation Research Record, No. 1856, pp. 185-192, 2003.
16. Parsons Brinckerhoff, Texas Transportation Institute, and FHWA, *"A Guide for HOT Lane Development,"* Publication No. FHWA-OP-03-009.

17. PB Americas, Inc. with ECONorthwest, *"Regional HOT Lanes Network Feasibility Study—Task 4 Policy and Operation Considerations for a Regionwide Bay Area HOT Lane Network,"* 2006.

18. RK&K/PB Joint Venture, "*Capital Beltway Study*," 2006.

19. Santa Clara Valley Transportation Authority, *"Santa Clara County HOT Lane Feasibility Study,"* 2005.

20. Venglar, S. and Fenno, D., *"Weaving Recommendations for Managed Lanes,"* 82nd Transportation Research Board Annual Meeting CD, 2003.

21. *"VISSIM Version 4.3 User Manual,"* Innovative Transportation Concepts. PTV Planung Transport Verkehr AG, Karlsruhe, Germany, 2007.

22. Washington State Department of Transportation, *"Managed Lanes White Paper: I-405 Congestion Relief and Bus Rapid Transit Projects,"* 2007.

23. Washington State Department of Transportation, *"SR 167 HOT Lane Pilot Project Analysis,"* 2003.

24. Westby, K. *"Memorandum for Congestion Relief and Bus Rapid Transit Projects I-405 Team"*, Washington State, 2005.