Comprehensive analysis on the conversion of the existing HOV lanes into HOT lanes in Tennessee

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16. Abstract
This study analyzed the conversion of HOV Lanes to HOT Lanes in Tennessee. The research applied several approaches including microsimulations of HOV/HOT Lanes that employed data from Greater Nashville Regional Council (GNRC) travel demand model and field collected traffic counts. Microsimulation was conducted through VISUM and VISSIM software by importing TransCAD based GNRC traffic travel demand. Apart from the comprehensive literature review on HOT Lane effectiveness from other states, the study reviewed best practices from other cities and states on conversion of HOV Lanes to HOT Lanes, enforcement, violation and penalty structures, and policy initiatives. A total of four scenarios were evaluated including:(1) the base scenario with HOV Lanes without effective enforcement as it is currently operated (2) HOV Lanes converted to HOT Lanes with no intermediate access (3) HOT Lanes with one intermediate access point and (4) HOT Lanes with multiple access points along the current HOV Lane corridors. The study found that converting HOV Lanes to HOT Lanes without intermediate access performs better (meaning reduced travel time) when compared to HOT Lanes with additional intermediate entrance/exit points. With HOT Lanes, travel time for all traffic along major interstate highways in Tennessee will be reduced by an average of 23% from the current travel times. Travel time for the traffic that will be using the HOT Lanes along major interstate highways in Tennessee will be much reduced compared to other GP lanes from the current travel times. Key findings from the case studies of other regions and Cities with currently operating HOT Lanes view them as effective means to manage congestion. Given the proper commitment by TDOT, HOT Lanes have the potential to be a better and more efficient usage of resources to relieve congestion on highways than the construction of more general-purpose lanes. Study recommends TDOT convert the current HOV Lanes to HOT Lanes without intermediate access (entrance/exit). The entrance/exit points should be only at the beginning and end of the HOT Lanes. Study recommends a toll fee of 10 cents per mile and tolls should be collected electronically (static or dynamic tolls). Study recommends that separation of the HOT Lanes and GP lanes should be through pavement marking (not physical barriers). Only single occupant vehicles (SOV) will be required to pay tolls, and all HOVs (2+) using the HOT Lane will be exempted from toll payment. Dynamic Message Signs should be initially located 1 mile prior to the starting of the HOT Lane to provide travel alerts and incident information. Video cameras installed along HOT corridors must be used for violators' identification and incident detection.

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Executive Summary

This study analyzed the conversion of HOV Lanes to HOT Lanes in Tennessee. Research was performed to answer the following questions: (1) how have managed lanes been implemented in other cities/states; (2) What are the potential improvements in mobility measures as a result of implementing HOT Lanes in Tennessee; and (3) what lessons are learned from other cities of similar population or traffic size/volume. The study is a building block to a broader research knowledge that needs to be documented in Tennessee, as congestion pricing and managed lanes may become a new norm in the future of transportation. From literature, the findings show that HOT Lanes can substantially improve congestion. The study findings quantitatively and qualitatively show that the implementation of HOT Lanes in Tennessee could bring potential benefits to the state; including travel time savings, reduced vehicle hours traveled, revenue generation, enhanced corridor mobility, trip options, utilization of excess capacity, and a remedy for underperforming HOV Lanes in Tennessee, among others.

The research applied several approaches including microsimulation of HOV/HOT Lanes that employed data from Greater Nashville Regional Council (GNRC) travel demand model and field collected traffic counts. Microsimulation was conducted through VISUM and VISSIM software by importing TransCAD based GNRC traffic travel demand. TransCAD software was used for demand forecasting utilizing a built-in geographic information system (GIS) for transportation which incorporate HOV/HOT Lane operations. The study employed VISSIM microsimulation to HOV/HOT Lanes that provided better understanding on how effective the HOT Lanes can be and under what context in Tennessee. The study completed the following:

- A comprehensive literature review on HOT Lane operations effectiveness from other states.
- Reviewing best practices from other cities and states on conversion of HOV Lanes to HOT Lanes, enforcement, violation and penalty structures, and policy initiatives.
- Synthesized the findings and lessons learned on how other cities/states have implemented managed lanes, including the process involved with such implementation and/or conversion from prior HOV Lanes.
- Determined ridesharing projections along HOV/HOT conversion corridors in Tennessee.
- Through VISSIM microsimulation, the study:
  - *Evaluated the operational effectiveness of HOT Lanes compared to HOV Lanes in Tennessee.*
  - *Evaluated and developed HOT Lanes operational concepts in Tennessee.*
  - *Evaluated how the conversion of HOV Lanes to HOT Lanes decrease the travel time and improve people moving through the deployed corridors.*
  - *Evaluated whether the conversion of HOV Lanes to HOT will efficiently reduce congestion.*
  - *Evaluated the mechanism of HOT Lanes, including separation mechanism with inside lanes or outer lanes, openings, and connection to entrance and exit ramps.*
  - *Evaluated toll pricing for HOTs (toll rates) and incentive for carpooling.*
  - *Evaluated the use of dynamic message signs prior to the entrance of the facility.*

A total of four scenarios were evaluated including the base scenario (1) HOV Lanes without effective enforcement (2) HOV Lanes converted to HOT Lanes with no intermediate access (3)

HOT Lanes with one intermediate access point and (4) HOT Lanes with multiple access points along the current HOV Lane corridors.

Key Findings

With conversion of HOV Lanes to HOT Lanes and a static (predetermined) tolling of 10 cent/mile:

- Converting HOV Lanes to HOT Lanes without intermediate access (entrance/exit only at the beginning and end of HOT lanes) performs better (reduced travel time) compared to HOT Lanes with additional intermediate entrance/exit points.
- Travel time along major interstate highways in Tennessee will be reduced by an average of 24% from the current travel times for the traffic that will be using the HOT Lanes.
- Travel time along major interstate highways in Tennessee will be reduced by an average of 21% from the current travel times for the traffic that will be using the GP lanes.
- Travel speed along major interstate highways in Tennessee will be increased by an average of 15% from the current travel speeds for the traffic using the HOT Lanes.
- Travel speeds along major interstate highways in Tennessee will be increased by an average of 10% from the current travel speeds for the traffic using the GP lanes.
- The minimum decision distance for drivers to make decision whether to use HOT Lanes or remain in GP lanes should not be less than 3500 ft and can vary depending on the geometry of the facility at specific locations.
- The amount of revenue collected varies depending on the location of the entrance point. More revenue (toll) is collected with more intermediate access points to HOT Lane. The more access points into a HOT Lane, the more tolls are collected.

Key findings from the case studies of other regions about HOT Lanes and their viability for potential adoption in Tennessee:

- Cities with operating HOT Lanes view them as effective means to manage congestion.
- There are three different types of physical design for HOT Lanes, each requiring varying levels of commitment and resources in conversion:
    - The "Toronto" model of limited physical requirements.
    - The "Minneapolis" model requiring the painting of additional lineage and dashing, along with the implementation of sensors and beacons for payment detection.
    - The "Houston" model, with the development of dedicated HOT Lanes separated by hard barriers and the ability for adjustable flow direction.
- There is not a clear answer on which model is preferable, but there is evidence to show that all three functions in their given location.
- Establishment of a tolling system is one of the biggest challenges for a city or state's first HOT Lane development. For Tennessee, utilizing the EZ-Pass infrastructure that currently exists across most of the eastern United States would quickly connect potential HOT Lane users and provide a level of familiarity to users. Additionally, it would eliminate the need to establish a separate dedicated tolling agency.
- Fostering trust and public support is vital to having successful operation of HOT Lanes.
    - Dispelling commonly held myths is key to building belief in the system.
    - Educating the public on how HOT Lanes operate is necessary to drive ridership, particularly in the early stages of operation. This may be particularly important for regions that have no history of tolling or little usage of existing HOV Lanes.

- Support for HOT Lanes likely will increase after opening, once the public can observe the effects on congestion.

- Given the proper commitment by a DOT, HOT Lanes have the potential to be a better and more efficient usage of resources to relieve congestion on highways than the construction of more general-purpose lanes.

Key Recommendations

- Convert the current HOV Lanes to HOT Lanes without intermediate access (entrance/exit only at the beginning and end of HOT lanes). The entrance/exit points should be only at the beginning and end of the HOT Lanes. This alternative resulted in significant travel time reduction and travel speed increase compared to other scenarios evaluated.
- A toll fee of 10 cent per mile is recommended (alternatively, a dynamic tolling system which varies depending on the congestion level, travel time savings, and speed on the HOT Lane can also be adopted. The difference in travel time improvement using static and dynamic tolling is insignificant).
- Tolls should be collected electronically (static or dynamic tolls).
- Separation of the HOT Lanes and GP lanes should be through pavement markings (not physical barriers). A double solid line and the use of collapsible pylons/delineators is recommended.
- Only single occupant vehicles (SOV) will be required to pay a toll; all HOVs (2+) using the HOT Lane are exempted from toll payments.
- Other vehicles such as transit and emergency vehicles and motorcycles can be allowed to use the HOT Lane at no/reduced cost.
- Trucks should be restricted from using the HOT Lanes
- State troopers driving in the adjacent GP lane can be used to monitor vehicles in the HOT Lane. Vehicles should either have more than one occupant or a single occupant with toll tag on the windshield.
- Dynamic Message Signs should be initially located 1 mile prior to the starting of the HOT Lane to provide travel alerts and incident information.
- Video cameras installed along HOT corridors must be used for violators' identification and incident detection.
- Codifying a dynamic payment structure with cost limits is key to having a highly effective way to adjust control for traffic levels while also maintaining public support.
- Automated enforcement will be key to a successful HOT Lane system. Also, coordination with local law enforcement will be necessary for additional enforcement with a dedicated division to patrol the lanes. Law enforcement might also use beacons to determine compliance and to identify violators.

- Dispelling commonly held myths is key to building belief in the HOT system.
- Educating the public on how HOT Lanes operate is necessary to drive ridership, particularly in the early stages of operation.
- Support for HOT Lanes likely will increase after opening, once the public can observe the effects on congestion.

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Glossary of Key Terms and Acronyms

HOT—High Occupancy Toll
HOV—High Occupancy Vehicles
TDOT—Tennessee Department of Transportation
TSU—Tennessee State University
SOV—Single Occupancy Vehicles
MSA—Metropolitan Statistical Areas
GNRC—Greater Nashville Regional Council
GP—General Purpose Lanes
GEH—Geoffrey E. Havers statistic
FHWA—Federal Highway Administration

Chapter 1 Introduction

This project analyzed and evaluated the conversion of the existing HOV Lanes into HOT Lanes in Tennessee. Due to the misuse and high violation rate of HOV facilities in Tennessee, TDOT has been working with research partners on several High Occupancy Vehicle (HOV) lane studies. These previous studies focused on the usage, effectiveness, and operation. However, there was limited work examining the potential for converting current HOV Lanes to HOT Lanes. This study therefore evaluated the potential of converting the HOV Lanes in Tennessee to HOT Lanes as part of TDOT's managed lane strategies. Such conversion is anticipated to provide congestion relief, travel time reliability, and sustainability in terms of improving air quality. Currently, HOV Lanes in Tennessee experience underutilization during peak times and high violation rates. Previous work by Chimba and Camp [5] under TDOT's RES 2016-05 project showed that current violation rates for the HOV Lanes in Middle Tennessee are approximately 80 to 90 percent and that typical peak time utilization rates are approximately 15 to 20 percent [5, 12]. Further work conducted under TDOT's project RES 2017-01 showed that legal utilization of the HOV Lane drops significantly as congestion increases while the willingness of single occupancy vehicle (SOV) drivers to violate HOV Lane use restrictions increases with congestion in the mixed flow lanes [13]. The travel conditions on the HOV corridor have little to no impact on the mode choice behaviors of users of the corridor [13].

> *The current violation rates for the HOV lanes in Middle Tennessee are approximately 80 to 90 percent and typical peak time utilization rates of approximately 15 to 20 percent*

1.1. Background

In Tennessee, the HOV Lanes were introduced in 1993 to promote ridesharing, increase person throughput, and reduce congestion. Table 1.1 shows the HOV facilities available in Nashville and Memphis and their corresponding operating times. The HOV Lanes in Tennessee operate concurrent to the flow and are separated from General Purpose (GP) lanes by wider broken white strip pavement markings [21]. This helps to create a mental barrier for Single Occupant Vehicles (SOVs) when deciding to move into the HOV Lanes. A maximum fine of $50 and court costs was the penalty for HOV violations in Tennessee. Tennessee HOV Lanes previously operated with a Smart Pass program that allowed hybrid vehicles to use the lanes in addition to vehicles carrying two or more occupants. However, the federal rule supporting the HOV smart pass ended and so the program is no longer in effect [4]. To date, due to the configuration of the highways where HOV Lanes exist in Tennessee which pose safety hazards for officers trying to enforce the rules and other challenges, enforcement of the HOV Lanes has been almost non-existent. A study by Chimba and Camp [5] showed that HOV Lanes in Tennessee have high violation rates, estimated to be 80% during the operating hours (7 am to 9 am and 4 pm to 6 pm on the inbound and outbound directions, respectively). In relation to these findings, a study in Virginia showed that enforcement and penalty structures alone are not effective deterrents for violations in such facilities [6]. This study therefore aimed at understanding (1) the impacts on performance of converting the HOV facilities into HOT facilities and what are the potential improvements in mobility measures as a result of implementing HOT Lanes in Tennessee, (2) how have managed lanes been implemented in other cities/states and (3) what lessons are learned from other cities of similar population or traffic size/volume.

TABLE 1.1: NASHVILLE AND MEMPHIS HOV LANE FACILITIES

Location	HOV Facility	Mile Marker	Operating hours
Nashville	I-40E	216 to 232	Monday to Friday 7 am to 9 am (Inbound) 4 pm to 6 pm (Outbound)
	I-40W	232 to 216	
	1-24E	56 to 81	
	I-24W	81 to 56	
	I-65N	90 to 95	
	I-65S	95 to 90	
	I-65N	65 to 79	
	I-65S	79 to 65	
Memphis	I-40E	15 to 22	Monday to Friday 7 am to 9 am (Inbound) and 4 pm to 6 pm (Outbound)
	I-40W	22 to 16	
	I-55N	0.0 to 5	
	I-55S	5 to 0.0	

Figure 1.1: High-Occupancy Vehicle Lane Sign in Nashville, TN

Operationally, studies of traffic data and VISSIM simulations show that both the outbound and inbound HOV corridors for I-65, I-24, and I-40 in Nashville suffer from a series of bottlenecks that tend to form daily during peak times. While divergent bottlenecks are particularly prevalent for the corridors outbound from downtown Nashville, several divergent bottlenecks also plague the inbound direction in the peak hour. These bottlenecks suffer from a drop in capacity with increased volume in the HOV Lanes, as the HOV Lane is the leftmost lane and the exits are typically right-hand exits. Previous studies [5, 13] showed that under the current operational regime, in some locations the HOV Lanes are not currently attracting enough volume to increase the throughput of the divergent bottlenecks but are currently attracting enough volume to cause significant degradation to the capacity of the divergent bottleneck. Microsimulation studies performed in Project RES2017-01 [13] indicated that operations may be improved by either enforcing the HOV Lane or reverting it to a general purpose (GP) lane. Based on previous studies related to this topic in Tennessee, it was determined that, even if lane reversion can provide the ability to improve operations on Tennessee's HOV corridors, reversion of a HOV Lane to a general-purpose lane may not be a feasible outcome due to the current regulatory climate. However, the HOT Lane approach can provide the opportunity for operational improvements by combining the benefits of automated enforcement of tolling with the ability to open the lane to more drivers when increasing bottleneck throughput is beneficial. Hence the flexibility of the HOT Lane approach can allow TDOT to use pricing controls to influence driver behavior, enabling a more nuanced approach to improving operations on Tennessee's managed lanes.

Projects RES2016-05 [5] and RES2017-01 [13] both included public opinion surveys to elicit sensitivity of the public to pricing for HOT Lanes, in order to form a better understanding of the public's willingness to pay for access to HOV Lanes. The results of both studies showed that drivers in Middle Tennessee are very sensitive to pricing. It is not likely that large tolls would be required to divert drivers from the HOT Lane, as the HOT Lane is viewed as an inferior lane by drivers who must exit the corridor at a left-hand exit before traveling a significant distance along the corridor. Both studies support the idea that most drivers value time saved on the highway by use of the HOV Lane at less than minimum wage, even though the prevailing wage in Middle Tennessee is roughly three times minimum wage. This implies a sense of disutility for most drivers, though drivers going through the entire corridor are likely to value use of the HOV Lane. It was concluded based on the results of these two previous projects [5, 13] that pricing controls could be an effective mechanism to improve operations, which lead to this study.

1.2. Research Objectives

The objectives of this study were to assess what actions would be required and the implications of converting existing HOV Lanes in Tennessee into HOT Lanes. The project evaluated potential HOT Lane design considerations, operational options to consider, review of potential revenue, expected optimal routes/limits of HOT Lanes and their potential pitfalls, and review of Tennessee policies. The research focused on the technical issues and the likely impacts on the interstate corridors, system users (including commuters), land use patterns, existing transportation modes, and regional travel behaviors and patterns. The objective of the study was to answer the following questions with respect to converting HOV Lanes to HOT Lanes in Tennessee:

- Review of best practices from other cities and states on conversion of HOV Lanes to HOT Lanes, enforcement, violation and penalty structures, and policy initiatives.
- Evaluating the role of the HOT Lanes in congestion improvements.
- Evaluating how the HOT Lane system could operate/work in Tennessee considering projected population growth, system-based traffic changes, and ridesharing estimates.
- What the expected benefits for users with HOT Lane conversion in Tennessee will be.
- How patterns in land use development will impact future O-D estimates and corridor operations.

Chapter 2 Literature Review

As part of the "managed lanes" concept, the literature shows that the use of HOT Lanes has tri-fold appeal: (1) it can expand mobility options in congested urban areas by providing an opportunity for reliable travel times to users prepared to pay for this service (2) it can generate new source of revenue which can be used to pay for transportation improvements, including enhanced transit services, and (3) it can improve the efficiency of HOV facilities, which is especially important for locations with declined HOV mode share in some of the largest metro areas.

2.1. HOV Lane Related Studies in Tennessee

Chimba and Camp completed a TDOT funded research project titled "High Occupancy Vehicle (HOV) Detection System Testing (RES2016-05) in 2018 [5]. The study conducted a literature review on HOV Lane occupancy detection technologies which could be utilized to assist in managing both HOV corridors and evaluation of performance strategies to address high violation rates. Furthermore, the study evaluated HOV Lane utilization rates and HOV Lane occupancy violation rates in the state. It was found that the average HOV Lanes utilization in Tennessee is 23% and the HOV Lane violation rate is about 84%. Currently only 15% to 20% of vehicles using HOV Lanes in Tennessee are those with 2+ occupancy as required by law; the remaining 80% to 85% are single occupancy vehicles (SOVs). The study [5] also involved a public opinion survey where about 50% of respondents in Tennessee were interested in a HOT Lane option. Another study conducted by Lipscomb University [13] determined the current effectiveness and benefits of the HOV Lanes in Tennessee and made recommendations regarding enhanced effectiveness, including analysis of HOV Lanes operating under base conditions with variable violation rates. The study compared the current operational conditions as well as a case in which the HOV Lanes are converted to mixed flow lanes. The study considered choices based on the origin and destination of users and accounted for differences in the experience of these users [13]. RES2017-01 study findings indicated that reversion of the HOV Lane to a mixed flow lane will likely reduce overall delay and may reduce some classifications of emissions, but it will do so at the expense of losing a rapid way for carpoolers, emergency vehicles, and transit/paratransit vehicles to traverse the HOV corridor. Also, heavy enforcement of HOV Lanes will likely lead to a paradox shift in which more people seem to be willing to carpool, perhaps as a social response to having to drive daily in heavy traffic, but the heavy traffic will make the use of the HOV Lane undesirable. Further, the study found that a HOT Lane project may have some success in raising revenue from drivers who do find it worthwhile to violate the HOV Lane restrictions, as violation rates are very high [22].

2.2. HOV and HOT as a Managed Lane Strategies

Due to increase in transportation demand that has contributed to a dramatic increase in the number of vehicles and traffic congestion on roads, many highway systems are now experiencing losses in the form of excess fuel consumption, air pollution, lost time, and reduced productivity. The financial costs and logistical complexities of constructing new lanes have made it difficult to overcome these demand levels; thus, alternative methods of reducing congestion have been explored to find feasible solutions. One effective strategy has been the introduction of High Occupancy Vehicle (HOV) lanes, which convert existing lanes into managed lanes that encourage carpooling and incentivize environmentally friendly vehicles. [7]. High Occupancy Vehicle (HOV) lane facilities are intended for traffic congestion reduction. HOV Lanes emerged in 1963 as rapid transit busways rather than passenger lanes in Virginia. Three major expected benefits of HOV Lanes included cost savings, ride-sharing promotion, and trip time reduction and reliability. The idea behind the concept for HOV Lanes lies in the reward of a fast, more efficient drive to destinations by adding a passenger to one's vehicle [3]. High Occupancy Vehicle (HOV) lanes are primarily meant for vehicles carrying a predetermined number of occupants, and usually, no tolls are involved [1]. However, in some cases, other vehicle types such as hybrid vehicles, motorcycles, buses, emergency vehicles, law enforcement and low emission vehicles are also allowed to use the HOV Lanes [2]. Depending on the facility, the occupancy requirements vary based on the hour of the day, level of congestion, or the prevailing policies.

High Occupancy Vehicle (HOV) lanes are highway lanes reserved for vehicles with two or more occupants, including carpools and transit vehicles, and are designed to reduce traffic congestion in general-purpose lanes. However, according to Poole [8], HOV Lanes were initially introduced to reduce emissions and fuel costs and not primarily congestion. According to the FHWA [9], the use of HOV Lanes has been seen as a demand management strategy to influence the user demand and a provider of preferential services to more occupied vehicles [9]. In most scenarios, however, HOV Lanes have been perceived as a wasteful investment since most offer slower traffic flow relative to the general-purpose lanes. According to Poole and Orski [10], the "empty HOV Lanes" perception is familiar as users of general-purpose lanes conclude that HOV Lanes were meant to make solo drivers' lives miserable. Since the HOV Lanes were introduced to favor non-solo drivers, it was expected that people would share a ride to and from their working places. Some studies have showed that the HOV Lane users are mostly family members (83%) who took advantage of the fast lanes [8]. HOT Lanes were then introduced to accommodate the solo drivers with a toll, and they have been seen as more effective than the HOV Lanes [11].

High Occupancy Toll (HOT) lanes are limited access, normally barrier separated, highway lanes that provide free or reduced cost access to qualifying HOVs and provide access to other paying vehicles not meeting passenger occupancy requirements. HOT Lanes can further be identified as a combination of the HOV Lanes and a pricing system where the qualified occupancy vehicles can use the lane for free and the non-qualifying (Single Occupancy Vehicle – SOV) must pay a toll to use the lane. Nevertheless, this is not always the definition as some facilities use HOV3+ and all the users can be tolled. The aim of HOT Lanes is to maintain a free flow in the highways even during peak hours by allowing the non-qualifying to use the facility too [9]. History takes us to 1995 where the first HOT Lane facility was introduced in the United States in Orange County California, being the famous State Route 91 (SR 91). It was followed by facilities in three other states: Texas, Minnesota, and Colorado.

The HOT Lanes system acknowledges the fact that people's value for money and time differs depending on the purpose and urgency of the trip. Some prefer saving time by using the HOT Lanes and others prefer saving money by using the general-purpose lanes which are free [8]. Due to that fact, the reasons for an individual to use the managed lane can be grouped into three; (1) value for time, (2) value for travel time reliability and (3) value for urgency. Among all the three, it was discovered that the last (value for urgency) contributes about 87% in determining the motorists' willingness to pay for the toll lane [8]. In most cases where HOT Lanes have been applied, the toll price is charged depending on the level of congestion in the general-purpose lanes or the time of the day. Some other HOT Lane facilities use a flat/standard toll rate that is independent of the general-purpose lanes congestion level [15]. Figure 2.1 shows an example of HOV/HOT Lanes facility located in Denver [21]. The facility has two lanes, one for the free passing HOVs and another for the toll paying vehicles.

Figure 2.1: Express lanes in Denver, Colorado

2.3. HOT Lane Management Strategies

2.3.1. Occupancy requirements

Different states have different occupancy requirements in their operating HOT facilities. Vehicles with two or more passengers are allowed to use the facility for free or at a reduced cost while the SOV must pay a given toll. However, the detection of the exact number of occupants in vehicles has posed challenges.

2.3.2. Pricing systems

The set managed lane tolls mostly depend on the different commuter types, time of day, number of miles travelled, the traffic congestion level, and sometimes simply on the number of axles per vehicle [7]. The amount to pay can also differ depending on the occupancy requirements, with highly occupied vehicles paying less than solo drivers. Figure 2.2 shows a typical HOT Lane pass in Minnesota and the prices vary depending on the distance to be travelled. The pass also shows the distance to the HOT Lane access. This gives the drivers enough time to make a decision and eventually change lanes. Others have opted to use a standard toll that is constant and independent of the congestion level. Wang et al. [7] found that flat/standard tolls are suitable for revenue maximization, while dynamic tolls are suitable for congestion control, providing various advantages including general purpose lane performance, merging areas, and improvement of on and off ramps areas.

Figure 2.2: I-394 Pass in Minnesota (HOT Lanes)

2.3.3. Toll collection procedures

The multiple high occupancy toll lanes in the country operate in both manual and electronic toll collection systems. According to the FHWA, most HOT Lanes rely on Electronic Toll Collection (ETC) systems being displayed on Variable Message Signs (VMS) that show motorists the current price before deciding to use the facility [16]. The electronic payment systems have been seen to reduce congestion at the toll collection points [9]. Even though HOT Lanes allow HOVs to use the lane for free or for a reduced toll, the management policies can evaluate the passage of certain types of vehicles to also pass for free in HOT Lanes. Such vehicles can include low emission vehicles, motorcycles, emergency vehicles, transits, and taxis.

2.3.4. Access Points

These are entry and exit points to the HOT Lanes. An effective HOT Lane must have both entry and exit points for effective performance. These points must be designed and managed effectively to manage the traffic flow and avoid the creation of more bottlenecks. The HOT facility in Figure 2.3 shows an access distance of 1200 ft. The access and exit point locations are an important factor that determines the level of service of the facility. The separation method of the HOT Lanes from the general-purpose lanes has a great impact on the way vehicles cut in and out. Research by Booz Allen Hamilton Incorporation [16] identified the common separation ways, including, but not limited to, physical barrier (e.g., concrete), buffer, non-buffer (pavement marking), and flexible delineators such as pylons and grade separation. A disadvantage of the non-physical separators is the inability to control the cutting in and out of the vehicles.

Figure 2.3: HOT Lane Access Road Geometry in Minnesota

2.4. High Occupancy Toll Lanes in Different States

Previous studies on the effectiveness of managed lanes yielded mixed results. One of the examples of positive impacts includes I-35W in Minnesota, where carpooling increased in managed lanes. A neutral impact was reported in Denver where there was no change in carpooling. Negative impacts were reported in Atlanta and Miami where carpooling decreased or shifted to the free general purpose (GP) lanes in managed lane areas. In San Diego and Minnesota, carpooling increased then decreased. The US has almost 8 states operating HOT Lanes and many others are in the planning stages. This report summarizes experiences from four operating HOT Lanes including the I-15 FasTrak Lanes in San Diego California, State Route 91 (SR 91) Express Lanes in Orange County California, Katy Freeway Quick Ride Harris County, Texas, and Northwest Freeway (U.S. 290) Quick Ride Harris County, Texas [17]. Among these, the SR 91 is the only one that started as a HOT Lane. Others are a result of conversion of existing HOV Lanes into toll lanes. Most operate with 1 or 2 lanes in each direction, maintaining a minimum speed of 45 mph charging from $0.25 - $9.00 [11].

2.4.1. Managed Lanes along I-15 in San Diego, California

San Diego is among the counties in the country that have been able to effectively implement the HOT Lanes operating system. According to the I-15 Managed Lanes Value Pricing Planning Study Concept Plan by Wilbur Smith Associates [17], the I-15 lanes project has been described as the world's inaugural demonstration for the HOT operating system. It was first applied to an eight-mile two-lane reversible HOV Lane section that extends from S.R 163 to TED Williams Parkway [15]. The conversion took place in December 1996 [17]. The project has many unique features with its dynamic toll pricing that aims at ensuring a free flow of traffic in the managed lanes [15]. The lane also has one entry and one exit point located at the ends of the lane [17]. In addition, the express lanes operate in the Southbound during the morning peak hours and in the Northbound during the evening peak hours. Concerning the occupancy requirements for the I-15 San Diego express lane, vehicles with two or more (2+) passengers (or HOV) have been allowed to use the lane for free while the non-qualifying vehicles have been allowed to use it at a dynamic toll rate. The study shows that the managed lanes have been able to accommodate more SOVs compared to HOVs as summarized in Table 2.1.

TABLE 2.1: SUMMARY OF MANAGED LANE TRAFFIC IN THE I-15 LANE IN SAN DIEGO

Composition	Northbound	Southbound
SOV	82.9	83.7
2+ HOV	16.5	15.8
3+ HOV	0.6	0.5

2.4.1.1. *Managed Lanes along I-15 in San Diego Toll collection procedures*

All qualifying HOVs (2+) are allowed to use the lane for free while the SOVs use a special FasTrak transponder to pay for the HOT Lane service, Figure 2.4. An SOV vehicle must register for the FasTrak service and have a prepaid account to use the managed lane as special overhead antennas automatically deduct the portrayed toll from the customer's prepaid account.

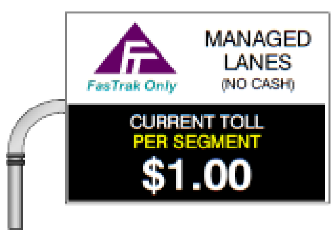

Figure 2.4: A typical variable message toll sign

2.4.2. SR 91 Express lanes in Orange County California

This is a 10-mile managed HOT Lane facility that was opened in December 1995 and was not a formerly existing HOV Lane but a toll road. Just like the I-15 lanes in San Diego, this also has no access points except at the ends of the lane. The fees are collected electronically, ranging from $0.75 to $4.75 depending on the time of day and the congestion levels. To use this toll lane, users must have both a prepaid account and a transponder [9]. As per vehicle occupancy requirements, HOV 3+ were allowed to use the lane for free until 1998, after which HOV3+ paid half of the toll rate. Since 2003, HOV3+ vehicles have been allowed to use the facility for free except during peak hours where they pay half the toll rate. According to the Wilbur Smith Associates, this is the first electronic HOT facility in the United States and was privately owned. AS of April 2002, the facility is publicly owned by the Orange County Transportation Authority, after it was purchased for a price of about $207 million [17].

2.4.3. Katy Freeway (I-10), Houston Texas

The Katy Freeway was also an existing HOV Lane facility that was converted into HOT facility in January 1998. It is a four-lane facility, 12 miles long and separated from the GPs by collapsible pylons [19]. Due to heavy congestion on the HOT Lane even during peak hours, a policy was established to charge a toll for all HOV 2+ vehicles only during the peak hours while the HOV 3+ could use the facility for free. The fees are also collected using electronic toll collection system [17]. The toll rates vary depending on time of day and length of trip from $0.30 to $7.00. The maximum toll rate was changed from $5 to $7 to maintain a free flow in the toll lanes [19].

The Katy Freeway Quick Ride has a similar pricing system to what most HOT Lanes have. Here are some scenarios of payment: [15] [16]

- All vehicles with 2 or more persons can ride in in the HOV Lanes free of charge.
- Buses are allowed to ride in the lanes free of charge. Passengers are required to pay a bus fee of anywhere from $1 to $3.50
- One Person vehicles are allowed to ride the HOT Lanes at a cost of $2 during the time of 6:45 A.M. – 8:00 A.M. and 5:00 P.M. – 6:00 P.M Monday thru Friday.

The Katy freeway uses an automated Quick Ride System to keep track of the vehicles that use the lanes daily. For a car to use the Quick Ride facility, it is required to have an electric transponder that pays for their ride through the freeway. The facility's Information Technology Services use this transponder to detect when vehicles enter and exit the freeway. These are provided by both the Houston Metro and the Harris County Toll Road Authority (HCRTA). With a Quick Ride account, applicants are required to pay a $40 fee. Once their transponder is detected in the system's overhead digital facility, their prepaid Quick Ride account is charged. After the account balance falls below $10, the applicant's corresponding checking account is charged.

2.5. Design of HOT Lanes

According to the FHWA [16] the basic operational strategies to consider when converting HOV Lanes to HOT Lanes include restricted egress and ingress at locations, limited vehicle eligibility, and use of dynamic pricing. Separation from the general-purpose lanes can be in the form of physical barriers, painting strips, or collapsible pylons.

2.6. Impacts of Conversion of Existing HOV Lanes to HOT Lanes

There have been various discussions on the impact of HOT Lanes on the number of carpools [8, 10, 20]. Earlier studies show that the HOT Lane introduction led to an increase in the number of carpools. This number was reduced dramatically after the occupancy policies moved from 2+ to 3+. A recent study in 2020 showed that the occupancy policies for managed lanes keeps changing depending on the need to keep the lanes at a free flow [8]. Most HOT Lanes started as HOV2+ where vehicles with two or more occupants could use the managed lane for free while SOVs could pay. The threshold nevertheless is reported to differ from state to state. In some other HOT Lanes, the policy adhered is a free pass to HOV3+ while HOV 2+ pay only 50% of the toll rate. Some HOT facilities are operated by private entities. A good example is the SR 91 in California where the conversion from HOV to HOT was done by SANDAG (San Diego Association of Governments) and TransCore operates the facility under SANDAG. [10] In addition, the facilities can be owned as Public-private-partnership. Another approach is where the project is fully financed by the state DOT [8].

2.7. Impacts of HOV/HOT Enforcement

Most HOT facilities depend on the local use of patrol officers. The officers have a duty to make sure no violators use the toll lanes. This method has been seen as both expensive and ineffective since the facilities available do not allow the officers to chase after violators and that doing so might again result in congestion in the toll lanes. There have also been reports on usage of electronic devices to spot violators, including on-road and in-vehicle detectors, but they have been deemed non workable [8]. The study further explains that most of the electronic detecting systems were designed to identify HOV 2+ passengers, but it is becoming difficult to detect HOV3+ passengers (others sitting in the back seat) due to tinted glasses and various back seat positions. Indra, TransCore, and Conduent are some of the companies trying to come out with camera technologies for occupancy detection, but none is in operation as of today. Hope lies in the use of smart phone technology where electronic devices can detect the number of smart phones in the vehicle.

2.8. Benefits of HOT Managed Lanes

i. Travel time reliability: HOT Lanes have been seen to offer travel time reliability to the traffic using them since they offer superior and consistent travel times, saving users time and are therefore seen as saviors during peak times.

ii. Effective way to reduce number of vehicle hours traveled: They have also been seen to reduce the number of hours traveled per vehicle therefore enhancing corridor mobility.

iii. Revenue generation: The collected toll is a good source of revenue that can be used in the development of the managed lane facility or the whole highway in general.

iv. Transit improvements: As a result of the use of HOT Lane facilities, the transit vehicles can now move faster and access the lane for free.

v. Environmental sustainability: HOT Lanes have been proved to be environmentally friendly as they reduce the number of emissions by generally reducing the number of vehicles (due to carpooling) and reducing the amount of stop-and-go traffic [10]. Most of the managed lanes also support the use of clean fuel vehicles [9]. However, some environmental analysts have gone further and criticized this point by arguing that for every space created for a vehicle to diverge, another vehicle fills the vacancy of the former, thus creating space for more vehicles and thus more emissions [4]. Others have gone further and studied the impact of HOT Lanes on carpools and generally (not definitively) concluded that HOT Lanes led to an obvious decrease in the number of carpools explaining that most carpools switched to SOV when the lanes changed from HOV to HOT Lanes, therefore posing a threat to the environment [19].

vi. Remedy for underperforming HOV Lanes: In most cases, HOT Lanes are a result of underutilized HOV Lanes, thus serving as a remedy for the latter.

vii. Trip options: HOTHOT Lanes give drivers an option to drive in non-congested lanes if they wish to pay for the service.

Chapter 3 Case Studies of Other Regions

As part of the effort to better understand HOT Lane conversion and best practices from other states, a set of case studies was developed. Key aspects of the case studies included (i) identifying comparable regions that had converted from HOV to HOT Lanes using a set of key metrics and (ii) interviewing state DOT staff and/or local consultants that had participated in the process or currently participated in management of the HOT Lanes. In the section that follows, we describe the metrics utilized and selection of the comparable regions, as well as the interview process and findings.

3.1. Overview

To evaluate the feasibility of High-Occupancy Toll (HOT) Lanes in Nashville, this portion of the study began with an exploration of currently existing HOT Lanes in other cities. Efforts were made to find all the cities which have HOT Lanes either in operation or in some stage of development. A search of publicly available documents online yielded several lists of all HOT Lanes in the United States. However, none of these inventories provided information that was current. Nonetheless, these sources were used as a starting point for curating a comprehensive and complete list of all HOT Lane locations in the U.S. The sources in question were the 2013 Urban Land Institute's report "When the Road Price Is Right Land Use, Tolls, and Congestion Pricing" (ULI 2013), the "Federal-Aid Highway Program Guidance on High Occupancy Vehicle (HOV) Lanes September 2016" (FHWA 2016), and "Toll-Managed Lanes: Benefit-Cost Analyses of Seven Projects" (Gomez-Ibanez et al, 2018).

The discovery process started by verifying the HOT Lanes listed in the three previously mentioned sources. In doing so, additional HOT Lanes were often found in a region when verifying the information. For instance, "Toll-Managed Lanes" stated there were three HOT Lanes in the Minneapolis-St. Paul region. However, a search for lanes in that area revealed that the MnDOT currently operates four HOT Lanes, the newest one opening on I-35W in August 2021, along with actively developing another one with plans to open in 2026. A check of all cities listed in the three inventories yielded more HOT Lanes in those locations. After exhausting the inventories for information, another search for more lanes was done by searching state Departments of Transportation, information on individual interstates, and sources discussing HOT Lanes.

3.1.1. Defining HOT Lane Regions/Cities

The term "cities" is being used in the context of identifying locations of HOT Lanes by their most significant and closest urban area, usually the core city of the metropolitan statistical area. This interpretation works for most situations, as the lanes typically fall within the scope of a singular metropolitan area with one core city. However, HOT Lanes in some areas fell outside the scope of this categorization.

The HOT Lanes in both Dallas, TX and Fort Worth, TX were considered as one combined system of lanes. The same applied to the HOT Lanes in Minneapolis, MN and St. Paul, MN.

HOT Lanes in southern California and northern California have been categorized as systems servicing Los Angeles and San Francisco, respectively. However, for both cases, the systems of HOT Lanes in question span outside of those respective metropolitan areas. Despite crossing into the jurisdiction of peripheral counties and other municipalities, because the HOT Lanes form a continuous and connected network, the system is being categorized as attached to those two cities for simplicity and efficiency.

3.1.2. Beyond the US

The intentions of this study were to analyze cities which were most similar to Nashville and had converted to HOT Lanes. With this goal in mind, the scope of the search was originally limited to just the United States. However, when broadening to international examples, two other cities were found to also have converted to a HOT Lane system: Toronto, Canada and Tel Aviv, Israel.

3.2. Metrics for Analysis

In order to determine the viability of HOT Lanes in Nashville, it was necessary to evaluate the identified cities to determine locations of highest similarity. Cities that best matched the profile of Nashville could be used as case studies and analyzed for their successes and challenges during their implementation of HOT Lanes. Six categories of metrics were used to analyze cities for their value as a case study for Nashville: HOT Lane Situation, Population, Growth Rates, Traffic Levels, Economic Rankings, and Political Environment.

The evaluation of a city's HOT Lane Situation looked at how many HOT Lanes existed in that location. Cities with a more extensive network of HOT Lanes, such as with lanes spanning longer distances and across multiple highways, were looked at more favorably than those with HOT Lanes on only one highway. Locations with better HOT Lane networks were assumed to have more experience in development and thus provide more extensive knowledge about implementation and impact of the managed lanes. Additionally, an analysis of a city's HOT Lane Situation looked at prioritizing cities with already completed HOT Lanes. Active HOT Lanes were viewed as more useful than projects in a development stage, as they would allow for a look at the direct impact of these lanes.

Population of a location involved an evaluation of both the urban population and the population of the area's metropolitan statistical area (MSA). These two values were used because although HOT Lanes typically route directly through the main urban center of an area, they also service the outlying suburbs and rural areas that are encompassed within the local MSA. Both values were considered necessary to draw a more accurate comparison of a location to that of Nashville and its surrounding area. Data from the 2020 US Census was used to establish the urban population of Nashville as 678,851 people, and the MSA population as 2,012,476 people.

Growth Rates were one of the most important comparison points for city analysis. The Nashville area has experienced extraordinary growth over the past decade, exceeding the capacity of its roadways to efficiently transfer drivers on the local highway system. In finding similar case cities to Nashville, prioritizing locations that have experienced similar levels of development was crucial. However, unlike the actual population comparison, only growth rates of the MSAs were used. This is due to the demographic shifts caused by the COVID-19 Pandemic, which caused unique migration patterns over the course of 2020 and 2021. Urban populations saw dramatic shifts in growth and/or decline over that time frame as a result of the public's response to the pandemic, yet MSA growth levels remained more consistent with previous years across nearly all cities analyzed. Therefore, only MSA growth levels were used for city comparisons to Nashville.

Traffic levels of locations were compared using two metrics: the TOMTOM 2021 Traffic Index Ranking and the INRIX 2021 Global Traffic Scorecard. TOMTOM is a vehicular navigation and location technology corporation which publishes a Traffic Index Ranking based on their collected user data. INRIX is a private data analysis company that produces a yearly analysis of traffic levels and mobility statistics. Both rankings provided valuable insight into the various traffic levels of identified cities, both on a scale of national and international comparison. Large cities with exponentially larger volumes of traffic, or conversely smaller cities with relatively miniscule levels of traffic, were considered not as valuable when compared to the congestion issues present in Nashville.

Three measures, mean individual income, median individual income, and cost of living, were used to compare Economic Ratings between case cities and Nashville. Mean and median individual income were extracted based on information from the US Census Bureau and looked at to compare the typical wealth levels of citizens within a particular city. This aspect is relevant to this study due to the tolling aspect of HOT Lanes; implementation requires collection of a portion of users' disposable income, and subsequently creates an economic impact on citizens. Cost of living was also compared to gauge which cities experience similar levels of economic prosperity and require similar amounts of living expenditure to that of Nashville.

Political Environment was a valuable analysis element, given the legislative and public opinion boundaries currently in place that prevent Nashville and the state of Tennessee from implementing HOT Lanes. This category looked at partisan split of the governorship of a state, that state's legislature, the local city mayorship, and the metro area's voting in the 2020 presidential election.

3.2.1. City Evaluation

The aforementioned metrics of analysis were used to gather information on each of the 17 identified locations of interest, as well as data on Nashville to be used for comparison. Once completed, data was compiled on a spreadsheet and cities were evaluated both quantitatively and qualitatively for similarity to Nashville (see Appendix A for data comparison). Following this analysis, three tiers of cities were established: Priority Cities, Cities of Interest, and Support Cities.

Priority Cities were locations determined to be of highest priority for analysis, due to their similarity to Nashville across a variety of metrics. Priority Cities all fit the profile of a top-35 sized metropolitan area experiencing high growth and moderately problematic levels of congestion, in addition to having stable and prosperous economies and existing within a split political environment. These locations were determined to provide the best example of what the implementation of HOT Lanes in Nashville would look like.

Cities of Interest did not have as many matching criteria as Priority Cities. However, these locations had components in their profile which could provide unique perspectives on the development of HOT Lanes. The HOT Lane systems in San Francisco and Los Angeles both span across multiple counties and hold a footprint larger than any other network. Toronto, Canada, and Tel Aviv, Israel, provide an international perspective on HOT Lanes. Hampton, VA, is by far the smallest city to have adopted HOT Lanes, being roughly 5 times smaller than Nashville. Salt Lake City, UT provided a look into an incredibly similar political environment.

Support Cities were locations which differed from Nashville in a number of regards, but they could still provide valuable information regarding the implementation of their respective HOT Lanes.

Priority Cities	Cities of Interest	Support Cities
Charlotte, NC Denver, CO San Antonio, TX Dallas/Fort Worth, TX Atlanta, GA Houston, TX	San Francisco, CA Los Angeles, CA Toronto, Canada Hampton, VA Tel Aviv, Israel Salt Lake City, UT	Washington, DC Minneapolis/St. Paul, MN Seattle, WA Miami, FL San Diego, CA

Figure 3 1: City Categorization

3.2.2. Source Veracity

When identifying HOT Lanes, particularly those in some stage of development rather than completion and active usage, the veracity and reliability of found documents sometimes required additional scrutiny and verification of accuracy. This usually was caused by the discovery of plans for a HOT Lane in its early development phase, only to later uncover that the said plan had changed or fallen through. For instance, according to a Statewide Inventory of Managed Lane Facilities published in 2017 by the Texas Department of Transportation, I-35 and Loop 1604 in San Antonio were planned HOT Lanes in future development. However, no sources beyond this state inventory list can be found with further information about the projects, and it is assumed that no additional work has been done to turn these plans into reality. Sometimes, newly found sources directly contradicted older sources. A prime example was the information found on the Mountain View Corridor operated by the Utah Department of Transportation. The original plans for the corridor from the early 2010s were found during the study, outlining HOT Lanes being an active part of the design. However, more up-to-date documents showed that as the corridor's development progressed, these plans were scrapped.

3.3. Data Collection on HOT Lane Conversion Across Regions

Once the comparable regions were identified, a further analysis of the HOT Lanes in those areas was necessary. Publicly available documentation was collected to build knowledge about the development and operation of the HOT Lanes in each city. However, in many circumstances specific information could not be collected through these means, particularly for HOT Lane projects more than a decade old. As such, it was determined that interviews with relevant engineers, DOT leaders, and local officials would provide the valuable missing information as well firsthand accounts on the impact of their HOT Lanes. The interview instrument was developed (found in Appendix B), which focused on the development and conversion of HOT Lanes in a city and their overall impact and management thereof. IRB approval was obtained prior to contacting any individuals and then efforts were made to identify and contact appropriate, knowledgeable individuals in each city/region.

Interviews were conducted via zoom and notes recorded utilizing the interview instrument. Several challenges arose in the interview process. Requests for interviews were made with appropriate DOT offices, tolling agencies, and regional officials using publicly available contact information. Email and phone calls were the method of contact for recruitment. Priority Cities and Cities of Interest were the focus of initial interview requests, but when those locations proved to provide little response, additional cities were also contacted. In many situations, requests for interviews were denied or the individuals who had been involved in the process of converting from HOV to HOT Lanes had left the agency/organization. To obtain adequate responses to create a case study evaluation, additional efforts were made to identify individuals that may have information about the HOT Lane conversion or management but may not have been involved in the conversion process. Efforts were made to utilize the project team's professional network to identify additional individuals to interview. In total, 10 out of 17 locations were contacted with an interview request. For some locations, requests were sent to multiple offices or departments resulting in 18 total interview requests being made: 7 yielded responses, and 3 yielded interviews. Due to time constraints of the study period, the interview process was concluded. The resulting in-depth case studies are presented in Appendix C.

3.4. Case Studies Key Findings

From the case study analysis, several key conclusions can be drawn about HOT Lanes and their viability for potential adoption in Tennessee.

- Cities with currently operating HOT Lanes view them as effective means to manage congestion.
- There are three different types of physical design for HOT Lanes, each requiring varying levels of commitment and resources in conversion:
    - The "Toronto" model of limited physical requirements, necessitating only the changing of signage.
    - The "Minneapolis" model requiring the painting of additional lineage and dashing, along with the implementation of sensors and beacons for payment detection.
    - The "Houston" model, with the development of dedicated HOT Lanes separated by hard barriers and the ability for adjustable flow direction.
- There is not a clear answer on which model is preferable, but there is evidence to show that all three functions in their given location.
- Establishment of a tolling system is one of the biggest challenges for a city or state's first HOT Lane development. For Tennessee, utilizing the EZ-Pass infrastructure that currently exists across most of the eastern United States would quickly connect potential HOT Lane users and provide a level of familiarity to users. Additionally, it would eliminate the need to establish a separate dedicated tolling agency.
- Codifying a dynamic payment structure with cost limits is key to having a highly effective way to adjust control for traffic levels while also maintaining public support.

- Automated enforcement will be key to a successful HOT Lane system. In addition, coordination with local law enforcement is an absolute necessity, and enforcement is best when there is a dedicated division to patrol the lanes. Using beacons to determine compliance is likely the easiest way for law enforcement to identify violators.
- Fostering trust and public support is vital to successfully operating HOT Lanes.
    - Dispelling commonly held myths is key to building belief in the system. HOT Lan
    - Educating the public on how HOT Lanes operate is necessary to drive ridership, particularly in the early stages of operation. This may be particularly important for regions that have no history of tolling or little usage of existing HOV Lanes.
    - Support for HOT Lanes likely will increase after opening once the public can observe the effects on congestion.
- Given the proper commitment by a DOT, HOT Lanes have the potential to be a better and more efficient usage of resources to relieve congestion on highways than the construction of more general-purpose lanes.

Chapter 4 Methodology

The research involved a comprehensive literature review and utilized simulation as the workhorse and heart of the analysis. The microsimulation utilized VISSIM software whose input was strengthened by reviews of HOT and managed lanes practices from other cities and states.

4.1. HOV/HOT Lanes VISSIM simulation

The research made the corridor the unit of analysis, which was also the base to formulate inputs and outputs of the study in VISSIM. The methodology went beyond merely doing VISSIM modeling, but also connected and integrated what was learned from VISSIM and practices from other states. The VISSIM microsimulation achieved the following:

- Analyzed the effectiveness of HOV and HOT Lanes compared to general-purpose (GP) lanes in Tennessee in reducing person-delay and harmful emissions.
- Evaluated if the road capacity, congestion, and person-delay will decrease or increase with presence or absence of HOT Lanes.
- Evaluated whether when HOV Lanes are converted to HOT Lanes, will congestion decrease or increase on the GP lanes? What percentage of SOV drivers will be expected to purchase HOT pass?
- Performed sensitivity analysis evaluating congestion and person-delay changes at different HOV/HOT compliance levels.
- Evaluated through simulation what the impact of future (horizon year) population increases, system-based traffic growth, and ridesharing projections will have on the operation of Tennessee's HOT system.

4.2. Traffic and Ridesharing Projections

The system-based traffic volume, demand, and available capacity (number of lanes, flow rates, travel speeds and Level of Services) were analyzed and the ridesharing projections planning models were created from TRANSCAD files from Greater Nashville Regional Council (GNRC), Figure 4.1. The Traffic and Ridesharing projections utilized GNRC adopted software for demand forecasting that combines the broadest array of demand modeling procedures and tools and built-in geographic information system for transportation (GIS-T). The travel demand modeling included four-step aggregate demand models, advanced disaggregate modeling techniques, simultaneous models for choices, and the traffic assignment models; hence, HOV/HOT Lanes were modeled with the network and performances evaluated. The TransCAD model was transferred to VISUM, a transport planning software for macroscopic simulation and modelling. The travel demand trips were forecasted using known peak time traffic distribution from traffic history data. Figure 4.2 illustrates I-40 Corridor Ridership Projections. The geometry including number of lanes, ramps, exit locations, distance, merging and diverging geometry were all set using both imagery view and field visit. The final model was then transferred to VISSIM software for microsimulation to analyze the scenarios and carry out a sensitive analysis study as per the scope and objectives.

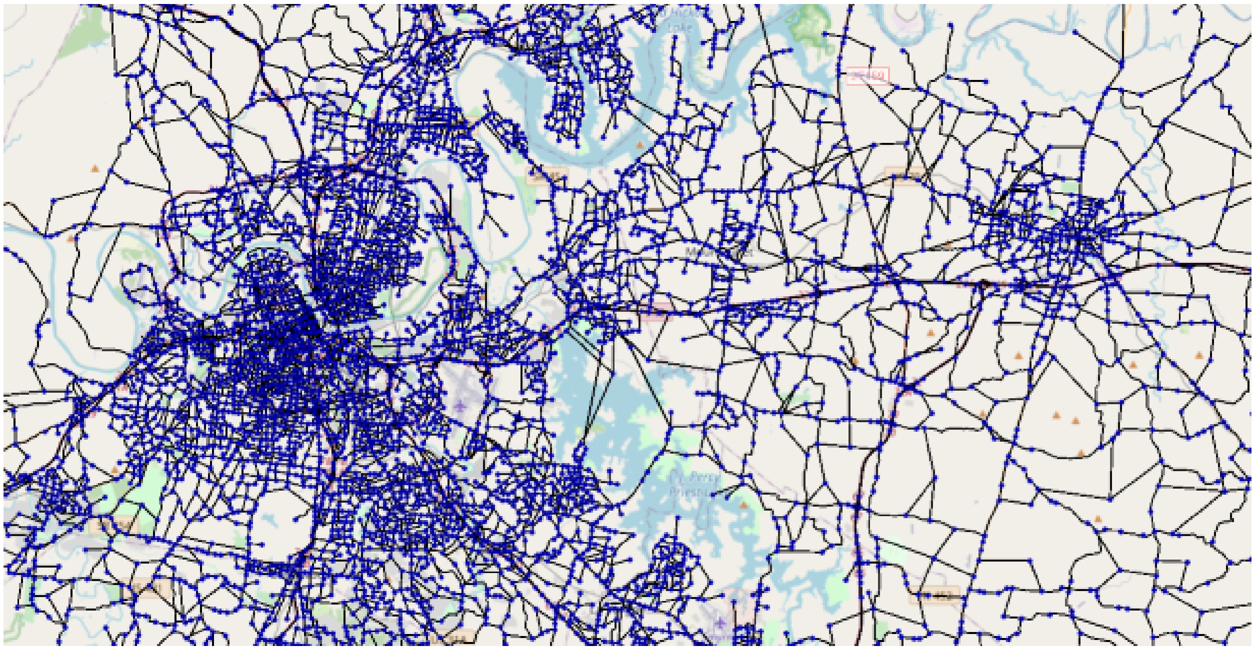

Figure 4.1: Traffic & Ridership Projections (Travel Demand Modelling)

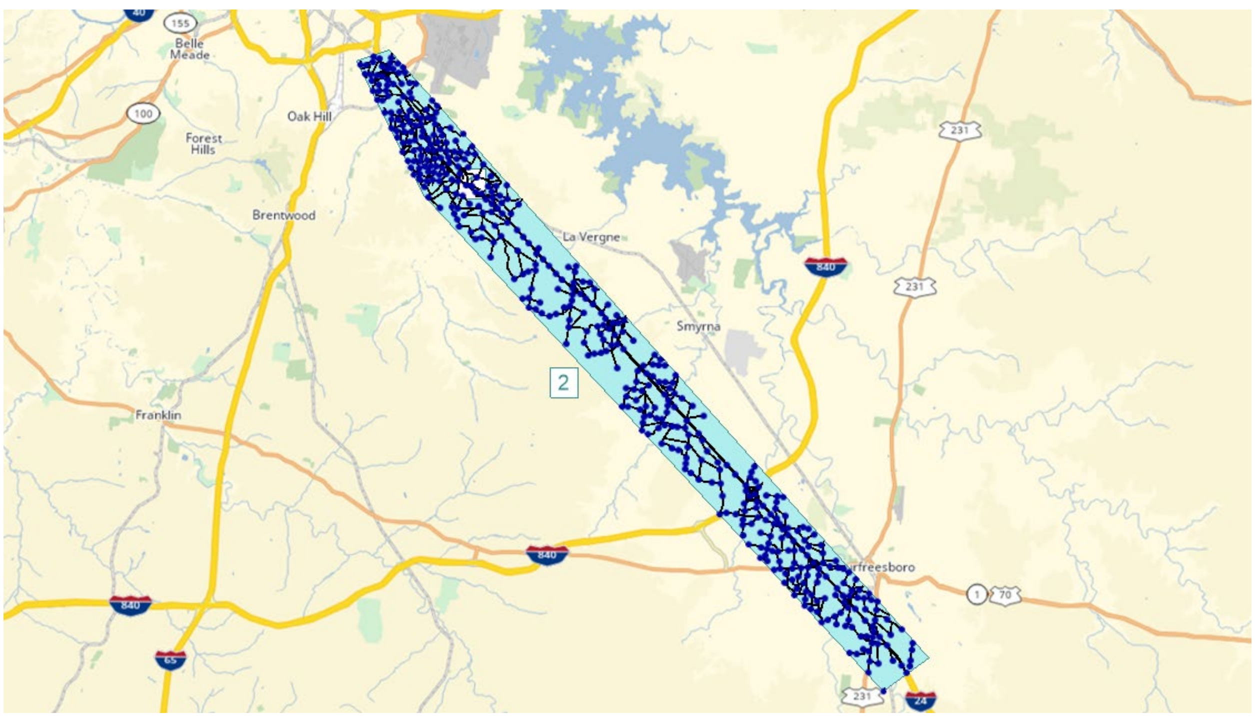

Figure 4 2: I-40 Corridor Ridership Projections Illustration

4.3. Traffic Distribution and Assignment

After the matrices were defined, the peak demand generation and distribution were computed by means of standard equilibrium assignment within VISUM software. The accuracy of the assigned traffic was measured by the magnitude of the mean relative error obtained which was

2% as shown on the following figure. Figure 4.3 Illustrates I-24 Corridor VISUM Model Assigned Vs Observed Traffic Correlation. Figure 4.4 shows I-24 Corridor VISSIM Balanced Peak Hours Traffic Assignment.

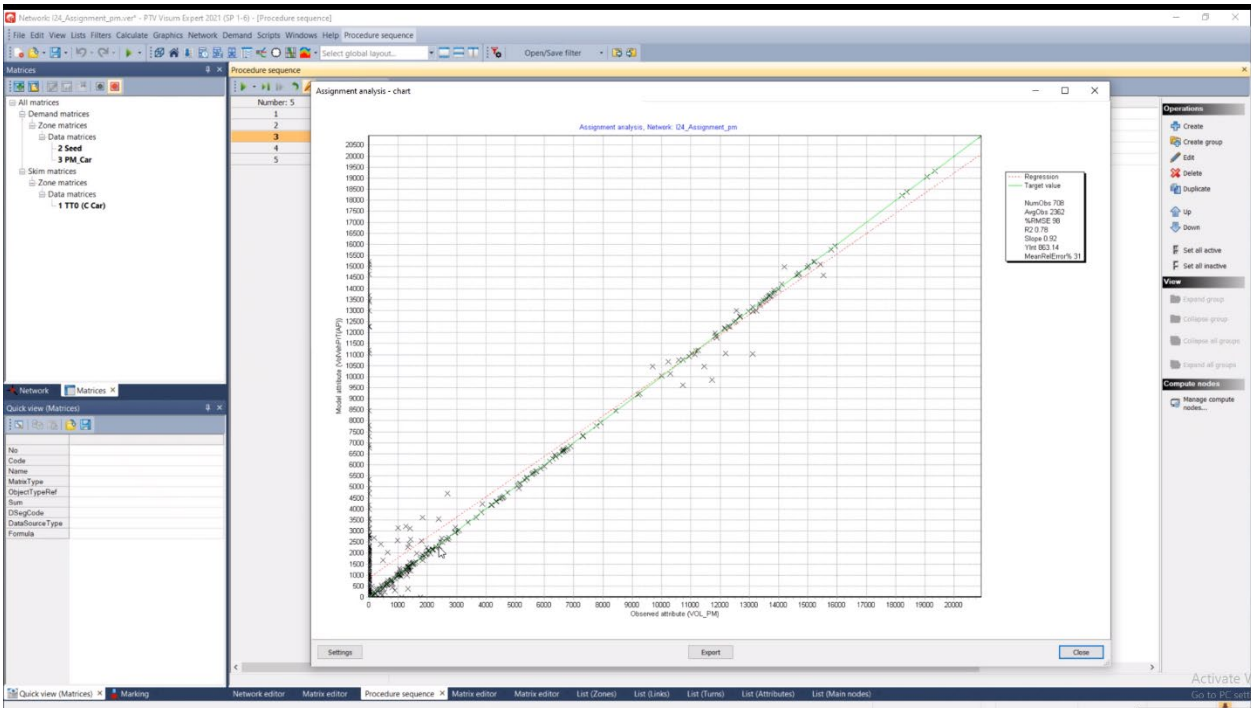

Figure 4.3: I-24 Corridor VISUM Model Assigned Vs Observed Traffic Correlation

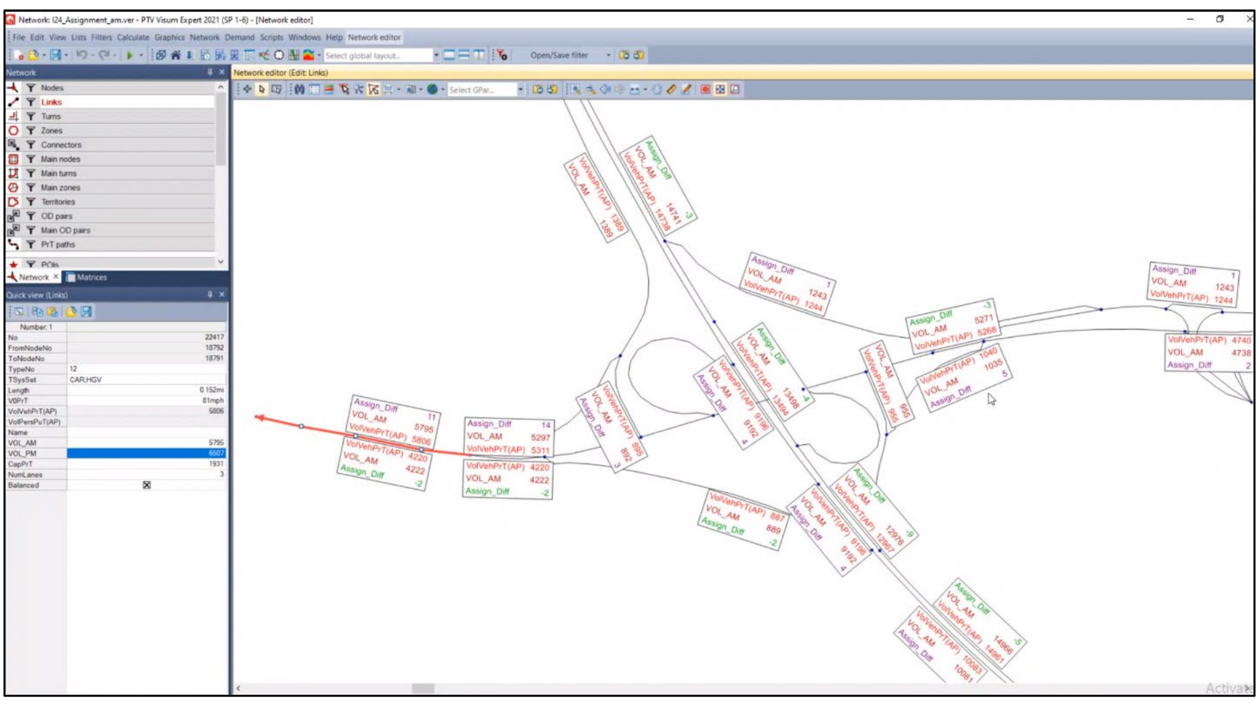

Figure 4.4: I-24 Corridor VISSIM Balanced Peak Hours Traffic Assignment

All the geometry was checked and corrected within the VISUM before importing to VISSIM. Google Earth and Bing Map were used to rectify the geometry of all nodes and links within the network to make sure they matched the real site situation. After passing the geometry check, the model was imported to VISSIM. The AM and PM models were joined to form one model but separated through scenarios. Dynamic traffic assignment was used which allowed use of demand matrices from the travel demand model (the matrices show the traffic volume travelling from one traffic analysis zone to another). Figure 4.5 shows VISUM/VISSIM import & Dynamic Traffic Assignment.

Matrix editor (Matrix '2 AM')

30 x 30			1	2	3	4
	Name		N of Thompsc	4 (S of Church	Thompson Ln	Briley Pkwy
		Sum	14713.96	3851.61	5808.01	4785.79
1	I-24 (N of Thompson Ln)	9655.48	0.00	420.73	486.64	924.06
2	I-24 (S of Church St)	5103.61	819.39	0.00	51.49	37.48
3	Thompson Ln	4261.26	386.48	36.75	0.00	3023.77
4	Briley Pkwy	6476.73	1259.11	36.54	4258.69	0.00
5	Averitt Express Dr	0.00	0.00	0.00	0.00	0.00
6	Harding Pl (W of I-24)	4668.37	992.15	32.15	109.14	88.81
7	Harding Pl (E of I-24)	3017.37	384.21	14.61	24.14	17.88
8	Haywood Ln (W of I-24)	4792.14	1597.56	32.77	254.87	214.06
9	Haywood Ln (E of I-24)	3503.23	1383.69	23.86	149.62	118.26
10	Bell Rd (W of I-24)	4294.42	730.80	144.02	70.64	57.42
11	Bell Rd (E of I-24)	4043.74	438.94	22.92	30.24	23.19
12	Hickory Hollow Pkwy	1538.56	455.28	124.89	28.62	21.43

Figure 4 5: VISUM/VISSIM import & Dynamic Traffic Assignment.

4.4. Microsimulation

Microsimulation through VISSIM was used as an approach to carry out sensitivity analysis of the scenarios to determine the difference in performance when the HOV Lanes are converted to HOT Lanes and operated under different management scenarios. Traffic microsimulation can be performed by a variety of software. The main objective was to assess the performance of the facility under the various scenarios. The main scenarios included existing HOV Lanes without enforcement (base scenario), HOV conversion to HOT Lanes without intermediate access point (access at the beginning of the HOT Lane only), HOT Lanes with one intermediate access point (access to HOT Lane at the beginning and at one other location) and HOT Lane access points at all major interchanges along the corridor.

4.5. Data collection

The data collected included hourly traffic counts at designated locations, speed and travel time data that was obtained through floating vehicles, and GPS trackers. Hourly traffic volumes were collected using Miovision equipment set at designated locations/interchanges (Figure 4.6).

Figure 4.6: Traffic data collection using Miovision Equipment

4.6. Model Calibration

The traffic count data was used to calibrate the VISSIM model. The model was calibrated by adjusting driver behavior and the traffic volumes at designated areas. Equation (1) shows the Geoffrey E. Havers (GEH) statistic summary for the different locations where site data was collected for the I-40 and I-24 and I-65 HOV segments in Nashville. The GEH statistic represents the goodness of fit of a model by utilizing the difference between the modelled and observed field traffic flows.

$$GEH = \sqrt{\frac{2(M-C)^2}{M+C}} \quad (1)$$

Where:

M = output traffic throughput volumes from the simulation model (veh/hr/lane)

C = traffic throughput volumes based on field data (veh/hr/lane)

The GEH statistic values obtained all fell within the maximum recommended value of 5 as stated by FHWA, Table 4.1. Moreover, travel time (41 minutes) and average speed (38 mph) also matched the existing field condition, thus proving validity of the model. Vehicle composition for the model was made under an assumption of 10% Heavy Goods Vehicles (HGVs), 72% SOVs and 18% HOVs. Trucks were restricted from using the HOV Lanes in all scenarios. Speed distribution curve had 85th percentile as the speed limit, with +/- 15 mph for upper limit and 15th percentile respectively. The simulation time for the models was 3 hours and an added seed time of 30 minutes. Evaluation results were collected only during the HOV operation hours, which are 7-9 am and 4-6 pm. The average vehicle travel time was calculated by dividing traveled distance by average travel speed. Average vehicle travel speed on lanes was determined using link analysis results in VISSIM and data was filtered to obtain values for specific lanes. The average speed on the HOV and GP lanes was therefore calculated, and the average travel time was calculated thereafter using equation (2).

$$T = {}^{D}\!/_{S} \qquad (2)$$

Where T is Travel time, D is distance in miles, and S is speed in m/hr.

TABLE 4.1: GEH CHARACTERISTIC VALUES OBTAINED FOR MODEL CALIBRATION

LOCATION	TIME	M (model) veh/hr/ln	C (field) Veh/hr/ln	GEH
Waldron	AM	1142	1215	2.13
Haywood	AM	1248	1305	1.60
Old Hickory	AM	1035	1058	0.71
Old Hickory (I-40 WB)	AM	3327	3578	4.27

4.7. Simulation model assumptions

4.7.1. Vehicle Composition

The type and number of vehicles used in the study were obtained from the previous study conducted by Chimba and Camp in 2018 [5]. The study showed a violation rate of 80% on the HOV Lanes. 10% of all vehicles were assumed to be trucks/HGVs. Of the 90% remaining vehicles, 20% of these were assumed to be HOV and thus HOV vehicles occupied 18% of the total vehicle composition. The remaining 72% of the vehicles were assumed to be Single Occupant Vehicles (SOVs).

4.7.2. *Trucks restriction*

Trucks were restricted from using the HOT Lane throughout the network for all the scenarios evaluated. To obtain this, the HGVs were modeled as a blocked vehicle class in the HOT Lane.

4.7.3. *Speed Distribution*

Speed limits for segments were assumed to be the 85th percentile in the speed distribution curve. +/- 15 mph from 70 mph were set as the upper and lower limit (55mph and 85mph) for most freeway segments with 70 mph as speed limits, Figure 4.7. Other segments have 65 mph-55 mph and their corresponding speed distribution curves were set accordingly. For non-freeway segments, ramps and arterials, their speed limits were obtained through visual imagery or field visits.

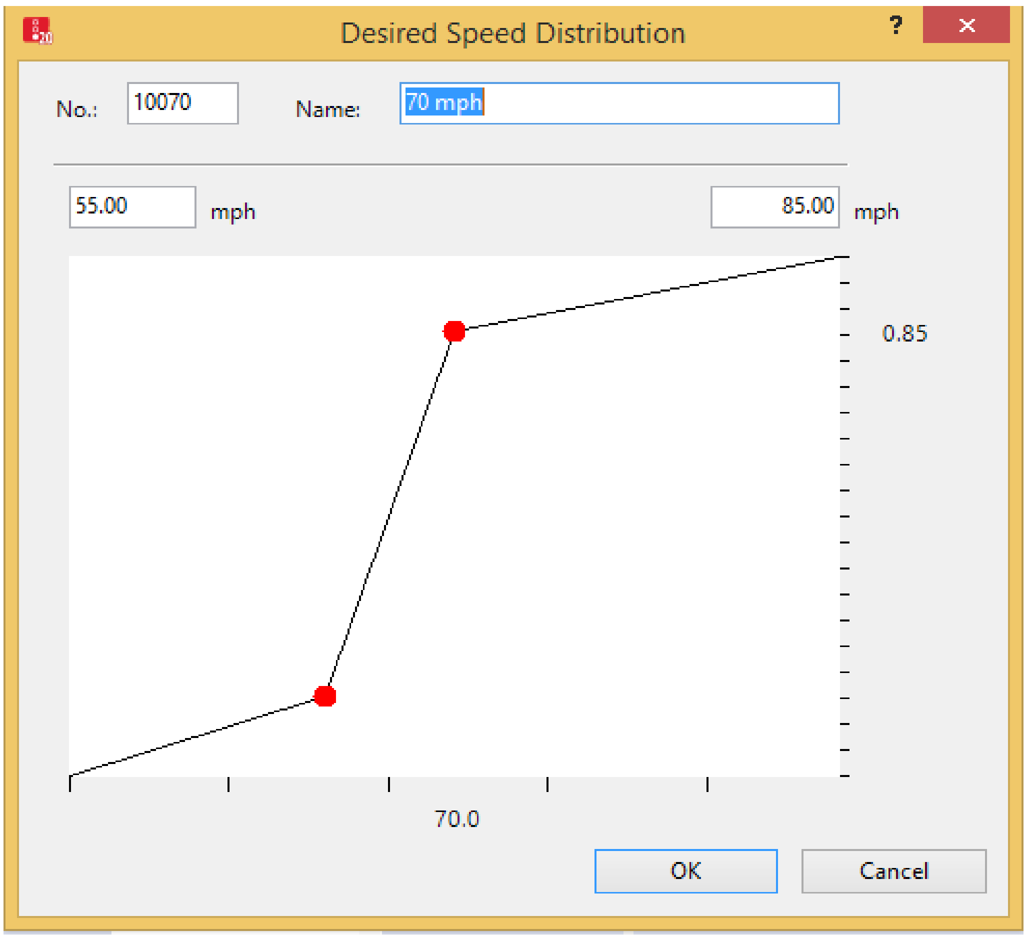

Figure 4.7: Desired speed distribution used on freeway for the model.

4.7.4. *Lane Separation*

A physical barrier separation was assumed under all scenarios. This was achieved by use of a solid line between HOT Lanes and General-Purpose lanes as vehicles utilizing the HOT Lane had no more access to the GP lanes until they reached the designated exit point on the HOT Lane, Figure 4.8.

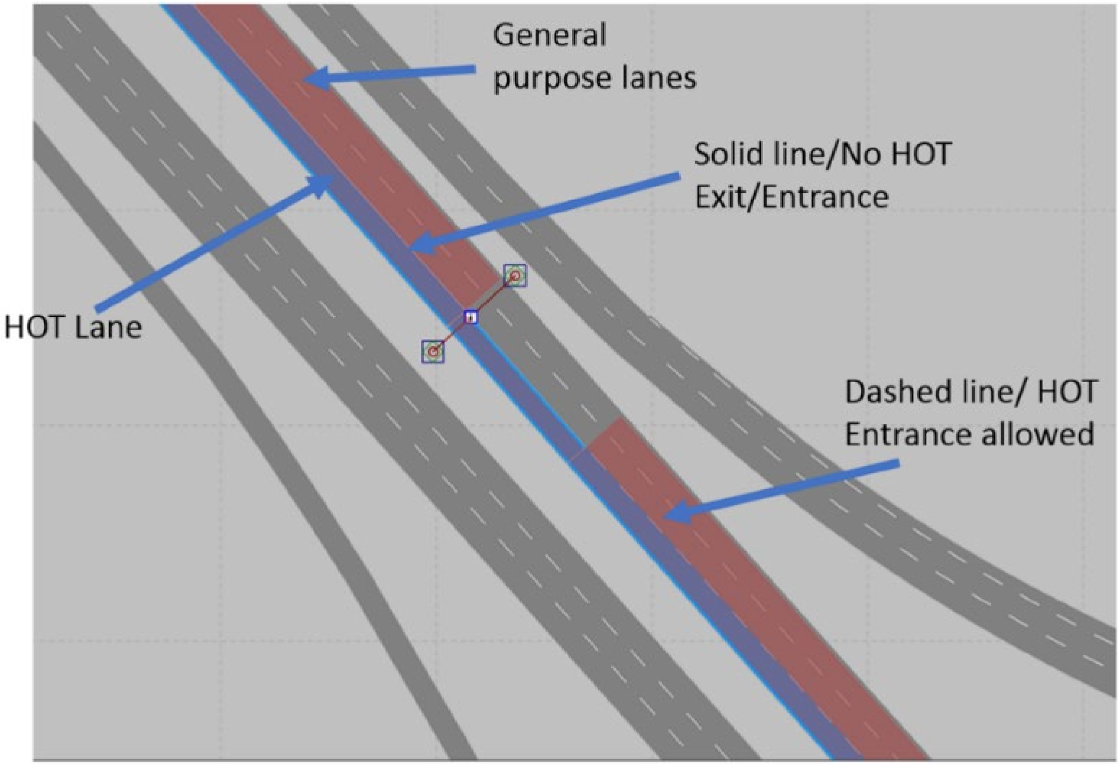

Figure 4.8: Lane separation mechanism as used in the model

4.7.5. Vehicle Occupancy

A minimum of 2 persons per HOV vehicle was used. Under HOT scenarios, all HOVs (2+) were exempt from toll payment. All SOVs were set to have an occupancy of 1 person per vehicle.

4.7.6. Tolling System: Static and Automatic Payment (No Tolling Booths)

Both static and dynamic tolling systems were used to determine the sensitivity of the two toll collection methods. With the static tolling system, a constant toll rate was set (10 cents per mile), while in the dynamic tolling system, the toll rates varied depending on the congestion level, travel time savings, and speed on the HOT Lane.

4.7.7. Decision Distances

This is the distance between the HOT Lane post (initial HOT road sign) and the exact starting point of the HOT Lane. The distance was varied for different scenarios and road segments depending on the geometry of the segment and the expected traffic, Figure 4.9. The location of these access points was extended to accommodate traffic from nearby arterials that merge with the freeway.

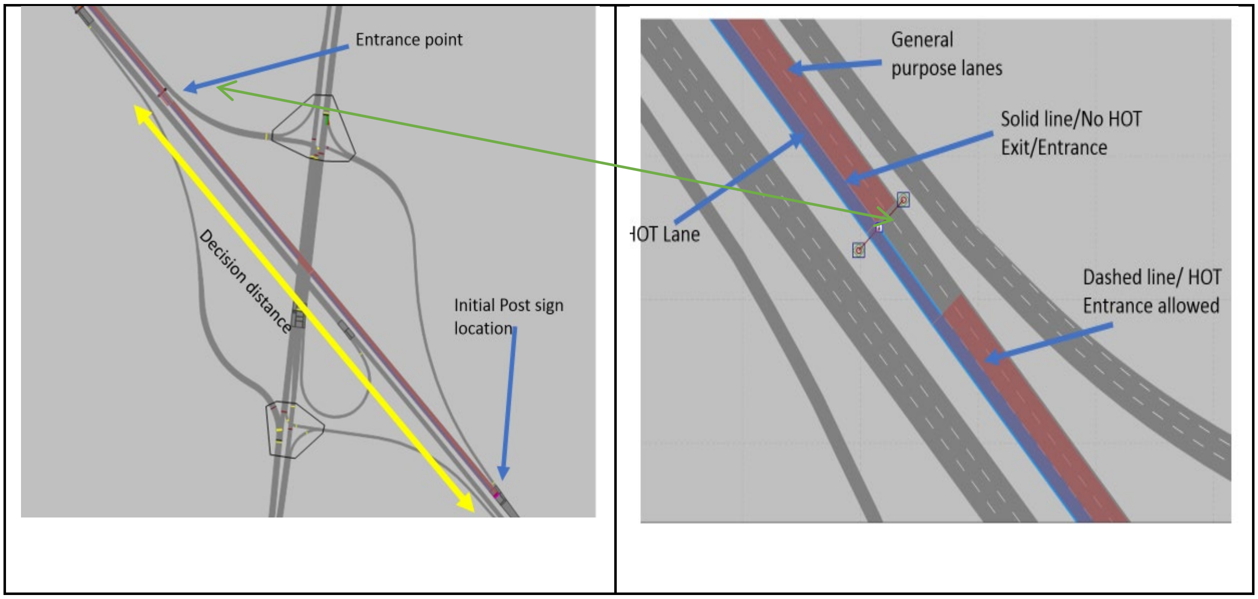

Figure 4 9: Entrance point geometry and decision distance

4.8. Scenarios Evaluated

A total of four scenarios were evaluated, Figure 4.10. These included the base scenario (HOV Lanes without effective enforcement), HOV Lanes converted to HOT Lanes with no intermediate access, HOT Lanes with one intermediate access, and HOT Lanes with multiple access points along the corridor.

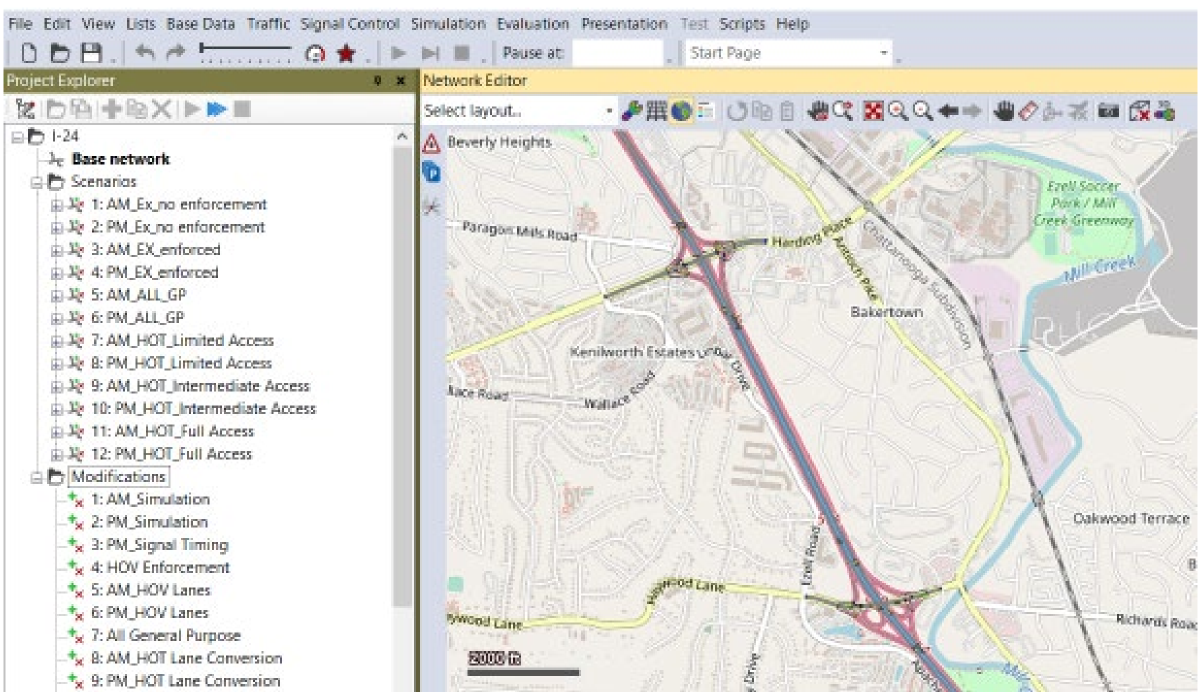

Figure 4 10: VISSIM HOV/HOT Model Scenarios

4.8.1. *HOV Lanes without enforcement (base scenario)*

This is the base scenario that portrays the existing/current situation. Under this scenario, all conditions were set to portray the existing conditions of HOV Lanes with the existing violation levels. HOV Lanes were present but there is no enforcement to ensure only High Occupant Vehicles use the lanes. Single Occupant Vehicles (SOVs) also use the lanes under this scenario and thus the distribution of traffic seems to be almost uniform on all the lanes. However, some drivers try to avoid the HOV Lane for fear of being penalized; however, there is no enforcement.

4.8.2. *HOT Lanes with entrance and exit at beginning and end of HOTs only.*

This scenario presents the conversion of a HOV Lane to a HOT Lane; hence a managed lane was introduced in the VISSIM model. A physical separation was assumed to separate the HOT Lane and the GP lanes. Once the vehicle entered the HOT Lane, it could only exit at the end of the HOT Lane. Under the static tolling system, the toll rate was predetermined to be 10 cents per mile of travel.

4.8.3. *HOT Lanes with an intermediate access point*

One more HOT Lane access point is added to the network for this scenario, to make a total of two access points. The first access point is located at the beginning of the HOT Lanes and the second access at a location halfway along the HOT segment. The toll rate is set so that it can be viewed by drivers before entering the HOT Lane. This creates ample time for drivers to decide before using the lane. The geometry of the highway at this point also allows the driver to exit the left-most lane before committing to the toll.

4.8.4. *HOT Lanes with multiple access points*

Under this scenario, a HOT Lane access point was introduced at every major interchange along the existing HOV segment. To make this simulation possible, the decision distance for every HOT segment was reduced to create a reasonable distance of travel between the major interchanges. After every segment, another decision distance was introduced to give a reasonable amount of time for drivers to choose to use the HOT Lane or not.

Chapter 5 Results and Discussions

Three case corridors with six travel patterns were used for VISSIM simulation as part of this study. This included I-24 WB from Murfreesboro to Nashville during AM peak hours, I-24 EB from Nashville to Murfreesboro. I-40 WB from Lebanon to Nashville, I-40 EB from Nashville to Lebanon, I-65 SB, and 1-65 NB (north of Nashville). Analysis determined performance when converted to HOT Lanes under the described scenarios.

5.1. I-24 Westbound HOT Case Study (AM Peak Duration)

Under this model, vehicles move from Murfreesboro towards Metro Nashville during the AM peak hours duration, Figure 5.1. Results indicate that the base scenario where the HOV operates without effective enforcement has the longest travel time of about 40 minutes for the 25-mile segment (from South Church Street in Murfreesboro to Harding Place) with an average speed of 38 mph on both lanes. When the HOV segment is converted to HOT segment, the shortest travel time is observed when the HOT Lane starts from the SR 840 interchange and goes to Harding Place, an 18-mile HOT Lane segment. When the HOT Lane starts at Old Fort Parkway in Murfreesboro and goes to Harding Place, a 22-mile HOT Lane segment, the average travel time is found to be 25 minutes with an average travel speed of 46 mph and 40 mph for the HOT and GP lanes respectively. The lowest average speed is observed when the HOV Lane operates with no enforcement with a value of 38 mph.

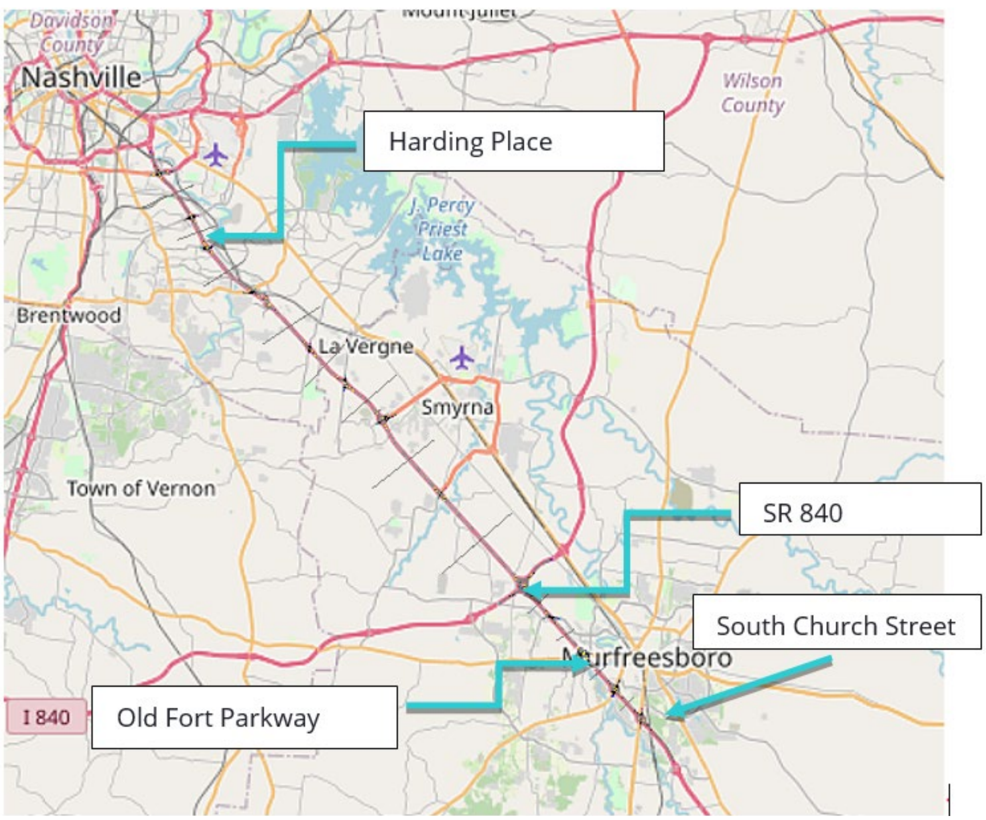

Figure 5.1: HOT Access points along I-24 WB

When an intermediate interchange is introduced, the average travel time on both lanes increases to 32 minutes. The HOT entrance and exit points are located at the Old Fort Parkway, Sam Ridley Parkway, and Harding Place, as shown in Figure 5.2.

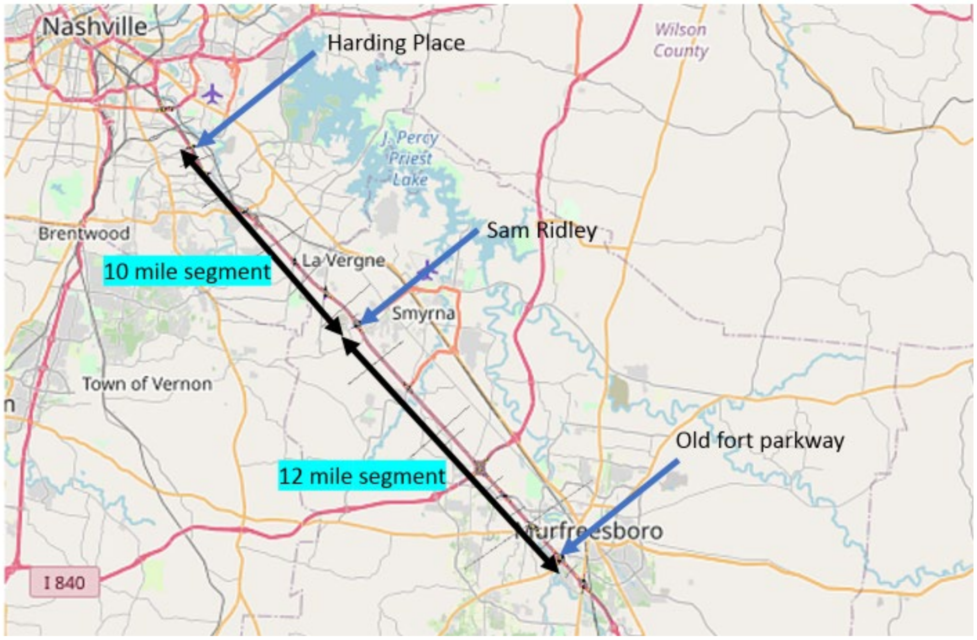

Figure 5.2: HOT access points along I-24 WB with intermediate access

Results also indicate a dramatic increase in revenue when the HOT access is located near Nashville. The SR 840 interchange is located closer to Nashville when compared to Old Fort Parkway and Murfreesboro (South Church Street) interchanges. This reflects a larger number of vehicles entering the access at a closer location compared to the farther. The presence of an intermediate HOT access also generates more revenue.

TABLE 5.1: SUMMARY OF TRAVEL TIMES AND AVERAGE SPEEDS FOR I-24 WB SCENARIOS

I-24 AM (4 SCENARIOS)	Distance (miles)	Travel time (min)		Speed (MPH)		Revenue ($)
		HOV/HOT	GP	HOV/HOT	GP	HOT
HOV No Enforcement	25	40	41	38	38	N/A
HOT No Intermediate Access: SR840 to Harding Pl	18	23	26	46	41	4,656
HOT No Intermediate Access: Old Fort Pkwy to Harding Pl	22	29	33	46	40	2,612
HOT No Intermediate Access: South Church Street to Harding Pl	25	32	37	47	41	1,750
HOT With Intermediate Access at Sam Ridley	22	31	34	46	45	4,080

From Figure 5.3 and Figure 5.4, it can be observed that converting the HOV Lanes to HOT Lanes has a significant impact on decreasing the travel time and increasing travel speed on both the HOV/HOT Lane and the GP lanes.

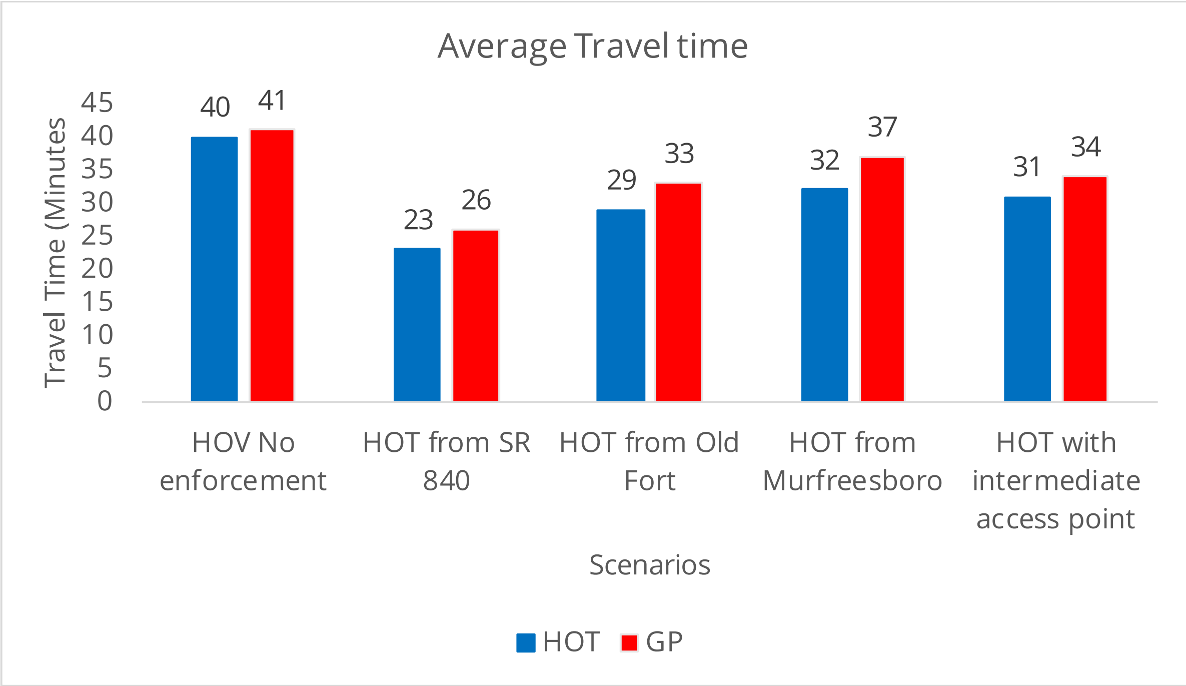

Figure 5.3: I-24 WB Average Travel Time Results

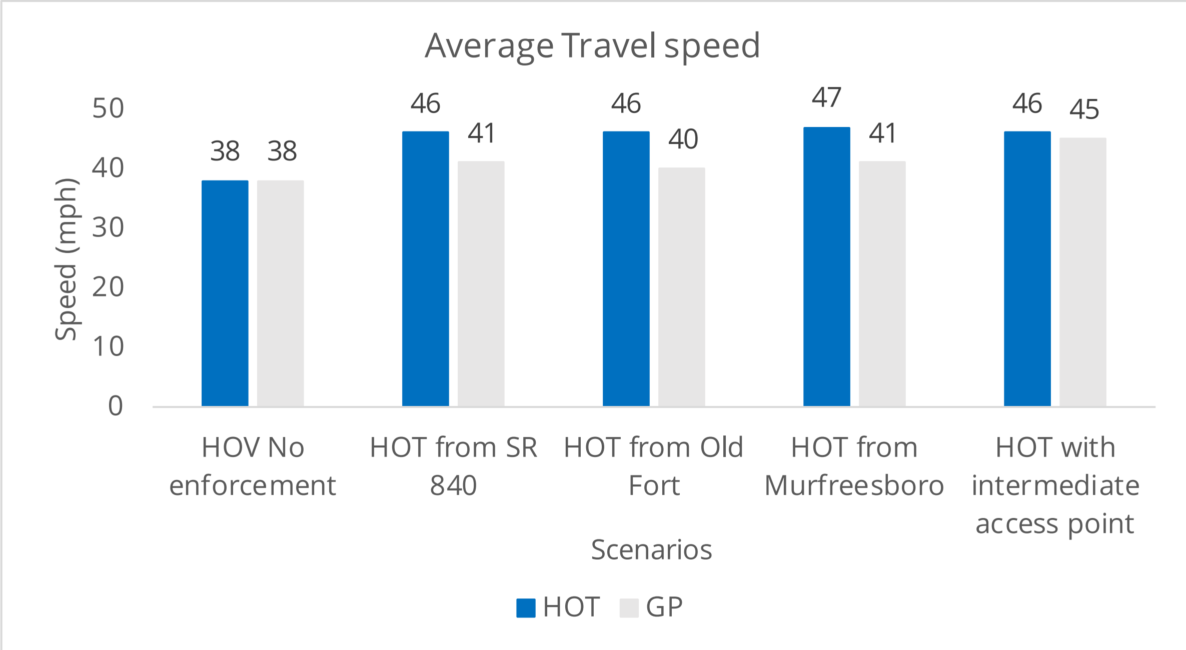

Figure 5.4: I-24 WB Average Travel Speed Results

5.2. I-24 Eastbound HOT Case Study (PM Peak Duration)

For I-24 eastbound, most of the traffic moves from Nashville towards Murfreesboro during the PM peak hours. A total of 5 scenarios were analyzed for this HOV segment. Like for the I-24 Westbound, the first scenario analyzed the base/field conditions with the HOV facility operating under no effective enforcement. SOVs could also use the HOV Lane without penalty under this scenario. Table 5.2, Figure 5.5, and Figure 5.6 show the results for I-24 Eastbound. Like the AM peak duration model, the first scenario with HOV under no enforcement has the longest travel time among all scenarios, with an average speed of 35 mph for both HOV and GP lanes. Converting the HOV Lane to a HOT Lane is seen to reduce a reasonable amount of average travel time whereby, for the first HOT scenario, drivers using the HOT/GP lane can save an average of 5 minutes of travel time for the same 25-mile segment. Introducing an intermediate access point is seen to substantially increase the average travel speed in both HOT and GP lanes. In addition, the total revenue also seems to increase when an intermediate access point is added. This is associated with the increase in the number of users (vehicles) that are expected to use the facility.

TABLE 5.2: SUMMARY OF TRAVEL TIMES AND AVERAGE SPEEDS FOR I-24 EB SCENARIOS

I-24 EB PM SCENARIOS	Distance (miles)	Travel time (min)		Speed (MPH)		Revenue ($)
		HOV/HOT	GP	HOV/HOT	GP	HOT
HOV No Enforcement	25	42	43	36	35	N/A
HOT No Intermediate Access: South Church Street to Harding Pl	25	39	37	39	41	1,850
HOT No Intermediate Access: SR840 to Harding Pl	18	28	27	39	40	3,250
HOT With Intermediate Access at Sam Ridley	25	36	36	42	41	9,145

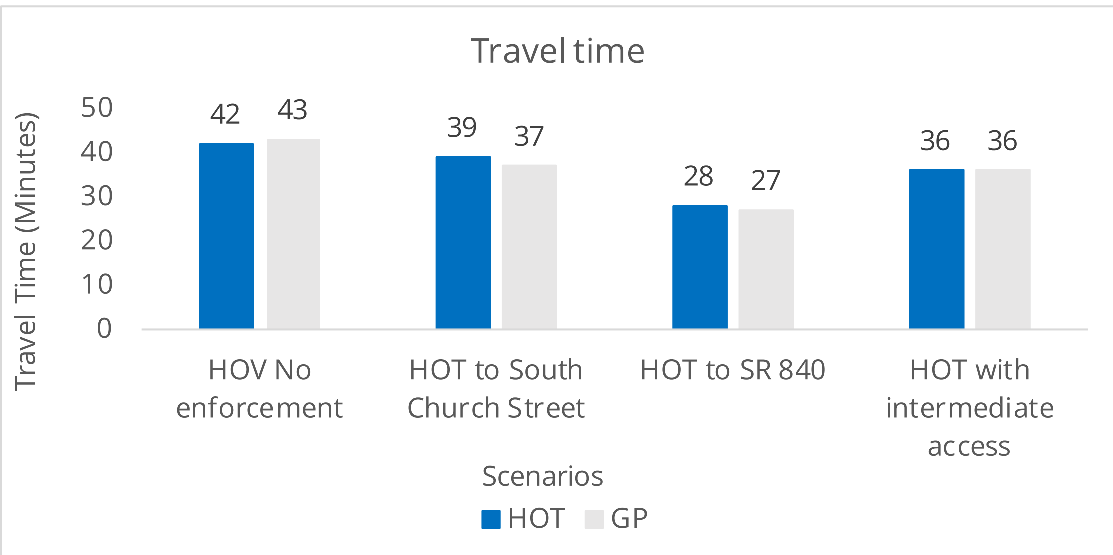

Figure 5.5: I-24 EB Average Travel Time Results

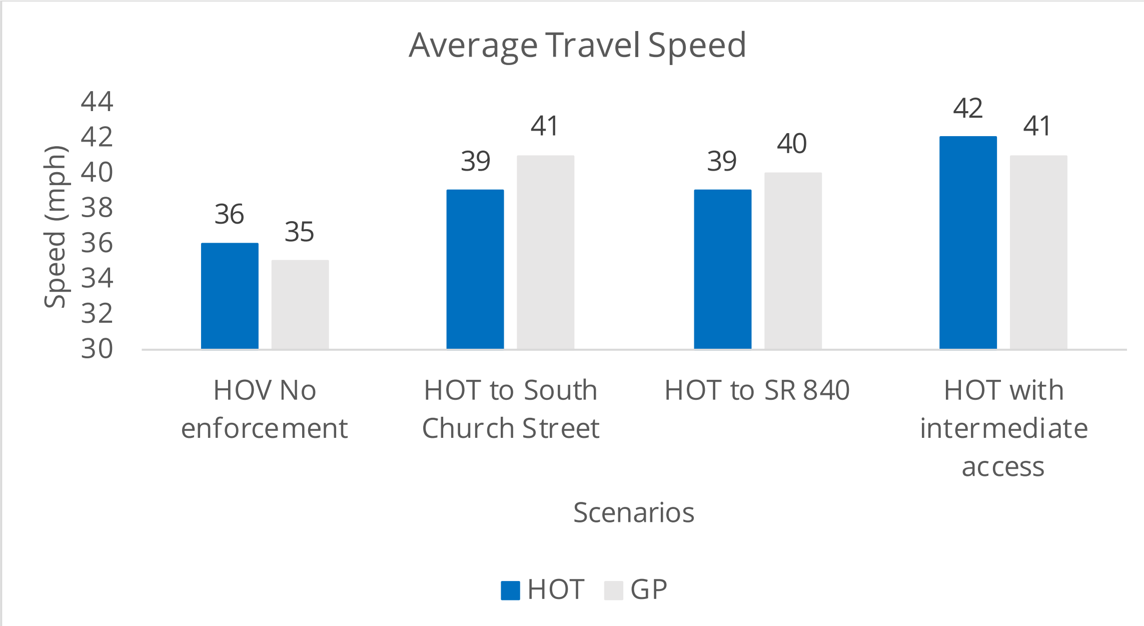

Figure 5.6: I-24 EB Average Travel Speed Results

5.3. I-40 Westbound HOT Case Study (AM Peak Duration)

The I-40 HOV Lane spans in both Eastbound and Westbound directions, Figure 5.7. The I-40 westbound peaks during the AM peak hour while the eastbound direction peaks during the PM peak hour. The I-40 HOV Lane is about 16 miles each direction and is operated from 7 am to 9 am and 4 pm to 6 pm for morning and evening peak hours, respectively. The base model was created to mimic the situation and thus the extra scenarios were used for sensitivity analysis to determine performance of the facilities under different management conditions/policies.

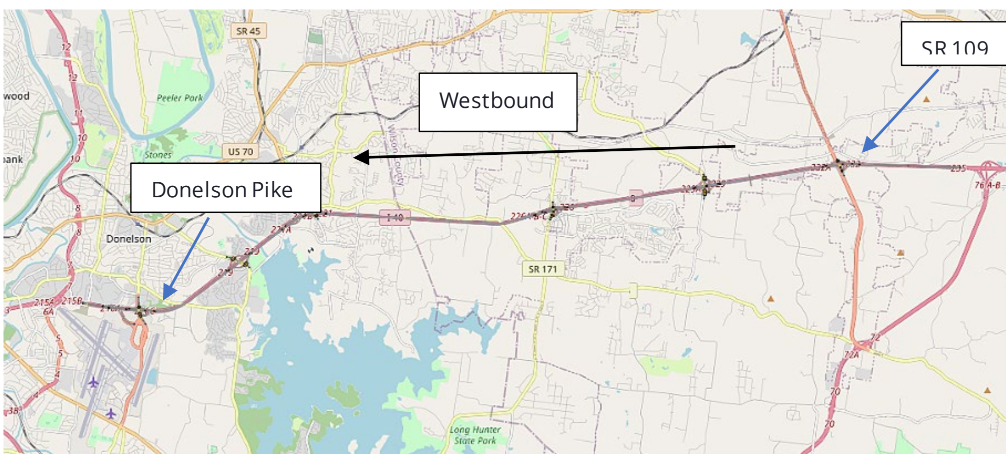

Figure 5.7: HOV/HOT Access and Exit point along I-40 WB

Table 5.3 summarizes the results from I-40 Westbound AM scenarios. Results indicate an average travel time of 18 minutes on both HOV and GP lanes under the existing field situation. When the HOV Lane is converted to the HOT facility, the travel time reduces to 16 minutes. The average speed reduces by 7% on the HOT facility and remains constant on the GP lanes. When the HOT access is located closer to Metro Nashville and the HOT Lane is reduced to 10 miles, the average speed on the HOT Lane is increased by 7% while that on the GP lanes remain constant. Introducing an intermediate HOT access point does not bring much improvement.

TABLE 5.3: SUMMARY OF TRAVEL TIMES AND AVERAGE SPEEDS FOR I-40 WB SCENARIOS

I-24 WB AM (4 SCENARIOS)	**Distance (miles)**	**Travel time (min)**		**Speed**		**Revenue ($)**
		HOV/HOT	**GP**	**HOV/HOT**	**GP**	**HOT**
HOV No Enforcement	16	17	18	58	54	N/A
HOT No Intermediate Access from SR 109 to Airport	14	16	16	54	54	1,580
HOT No Intermediate Access from Mt Juliet Road to Airport	10	10	12	58	54	1,161
HOT with Intermediate Access	16	18	17	53	56	2,921

Figures 5.8 and Figure 5.9 shows the travel time and average speeds along I-40 Westbound during the morning peak hours. The least travel time is obtained when the HOT access point is located at Mt Juliet Road Interchange.

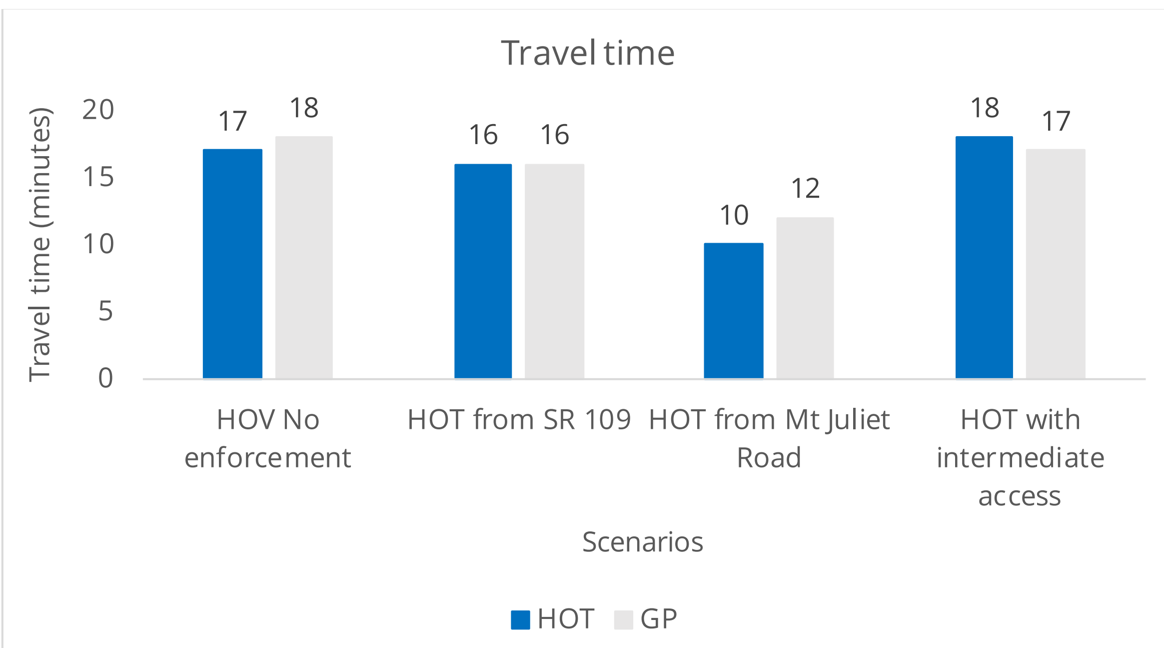

Figure 5.8: I-40 WB Average Travel Time Results

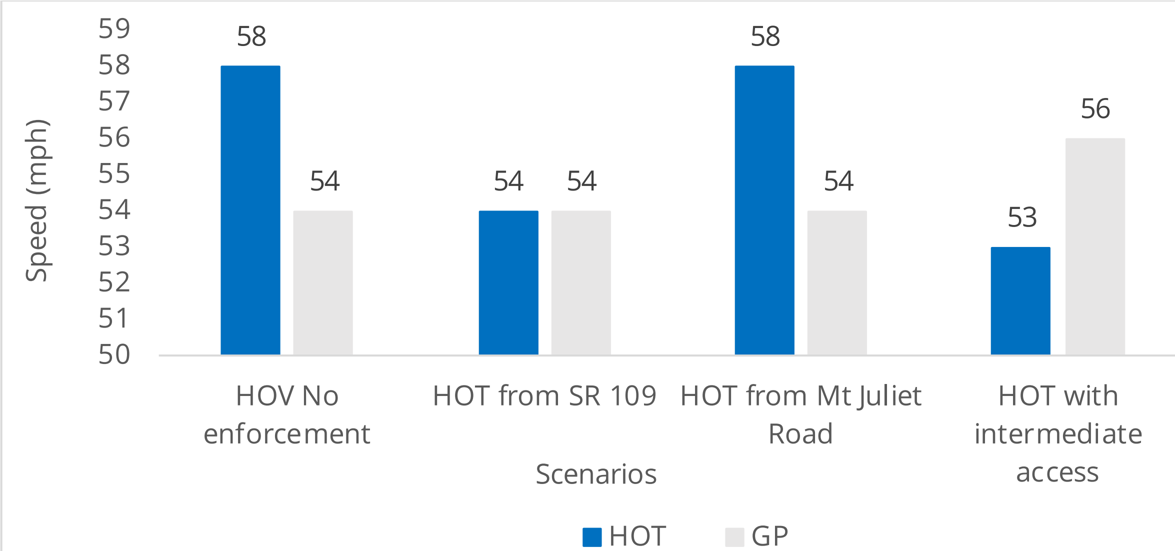

Figure 5.9: I-40 WB Average Travel Speed Results

5.4. I-40 Eastbound HOT Case Study (PM Peak Duration)

The I-40 Eastbound peaks during the PM peak hour (4 pm to 6 pm) and spans for a total of 16 miles. Table 5.1, Figure 5.10, and Figure 5.11 summarizes the travel time and average speed results.

TABLE 5.4: SUMMARY OF TRAVEL TIMES AND AVERAGE SPEEDS FOR I-40 EB SCENARIOS

I-24 EB PM	**Distance (miles)**	**Travel time (min)**		**Speed**		**Revenue ($)**
		HOV/HOT	**GP**	**HOV/HOT**	**GP**	**HOT**
HOV No Enforcement	16	17	19	55	51	N/A
HOT No Intermediate Access Starting at Stewarts Ferry Pike	13	20	19	40	41	1,550
HOT with Intermediate Access	13	26	19	40	45	1,411

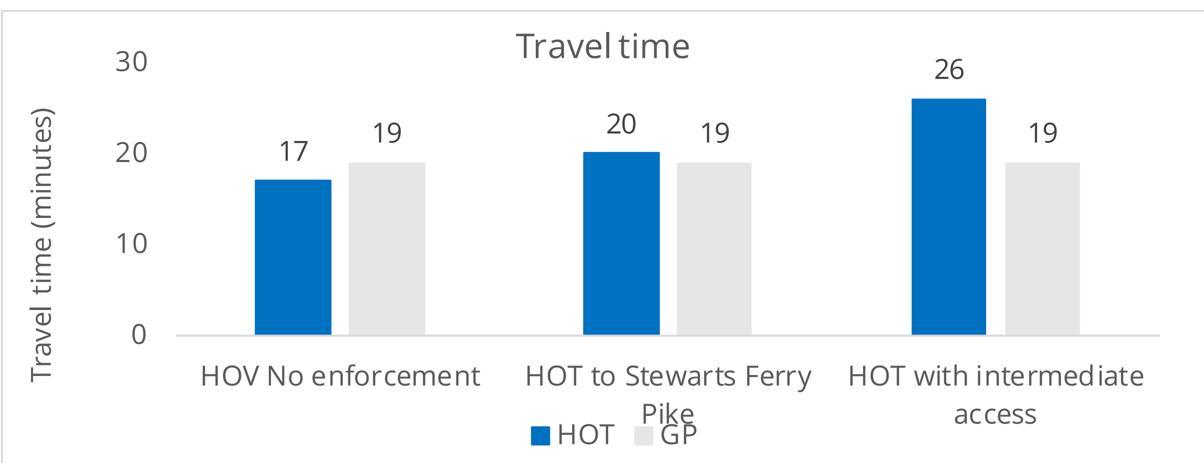

Figure 5.10: I-40 EB Average Travel Time Results

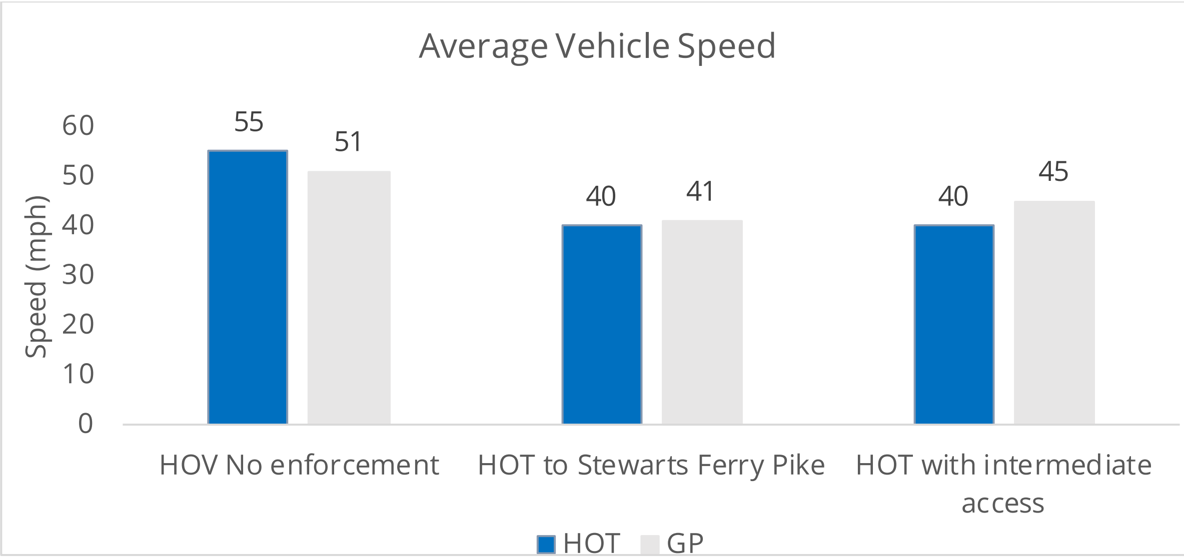

Figure 5.11: I-40 EB Average Travel Speed Results

5.5. Using Dynamic tolling system

The same models were used for sensitivity analysis to analyze the dynamic tolling system and identify the difference in performance of the HOT Lanes when it operates under the two tolling systems. The dynamic tolling system was modeled for SOV motorists to choose the HOT Lane based on travel time savings and average vehicle speed. Figure 5.12 shows one of the toll pricing models that was used for one of the modeled facilities. The travel time savings are in seconds while the average speed is in miles per hour. When a SOV motorist saves 0 to 60 seconds or when the average speed on the HOT Lane is between 0 to 30 mph, then the motorist must pay 50 cents. These dynamic costs will be displayed on the road toll sign board that motorist will be able to see prior to deciding on taking the HOT Lane. The design of the managed facility will also give the driver enough time/ distance to make the decision whether to take the managed lane or not depending on sense of urgency. Figure 5.13, Figure 5.14, and Figure 5.15 shows a combined graphical presentation of the travel time and average vehicle speed of vehicles using the facility under different tolling scenarios. It can be observed that the travel time is almost the same on the HOT Lane for both tolling systems with less significant differences. However, travel time on the GP lanes shows a significant difference for the dynamic and static tolling systems. The travel time on GP lanes when the facility operates under a dynamic tolling system seems to be higher than that under a static tolling system. This might be due to several reasons such as the toll pricing algorithm or more vehicles not opting for the managed lane due to insignificant travel time saving or speed change on the managed lane.

Count: 6	Pos	TravTmSavFrom	TravTmSavTo	Operator	AvgSpeedFrom	AvgSpeedTo	Toll
1	1	0.0	60.0	OR	0.0	30.0	0.5
2	2	60.0	120.0	OR	30.0	40.0	1.0
3	3	120.0	180.0	OR	40.0	45.0	1.2
4	4	180.0	240.0	OR	45.0	50.0	1.5
5	5	240.0	300.0	OR	50.0	60.0	1.8
6	6	300.0	360.0	OR	60.0	75.0	2.0

Figure 5.12: Sample of dynamic toll pricing calculation model as applied to simulation

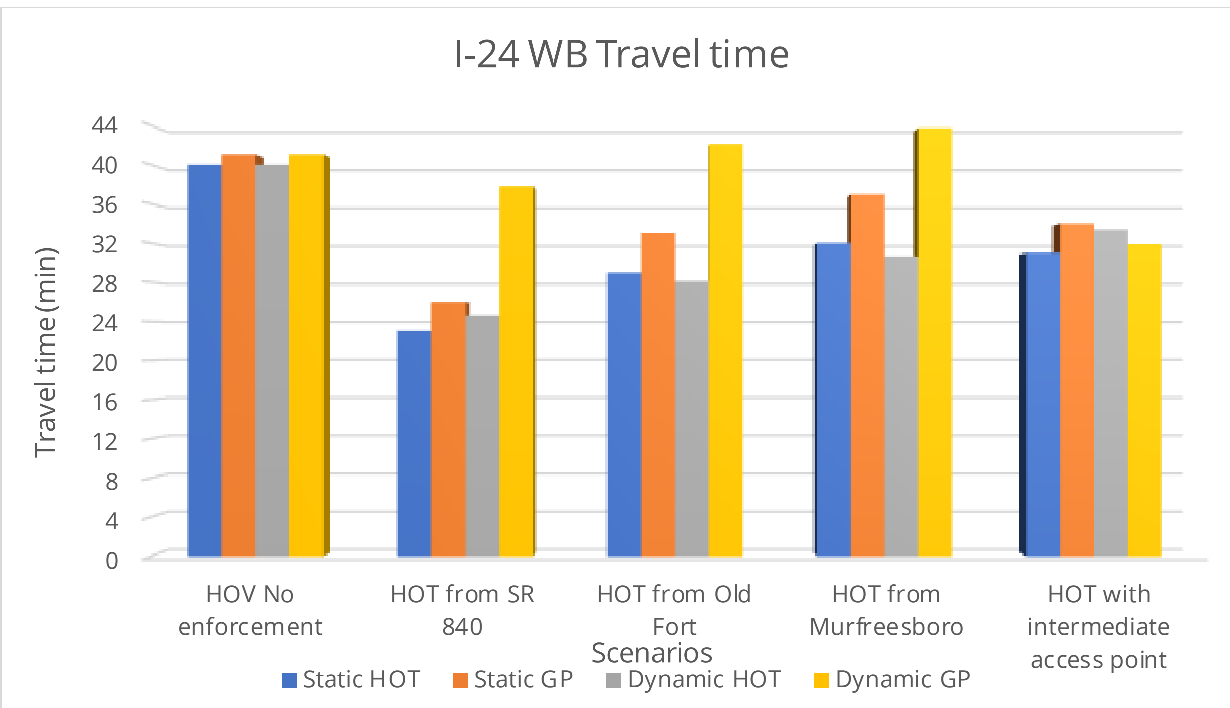

Figure 5.13: I-24 WB Travel Time Under Dynamic and Static Tolling System

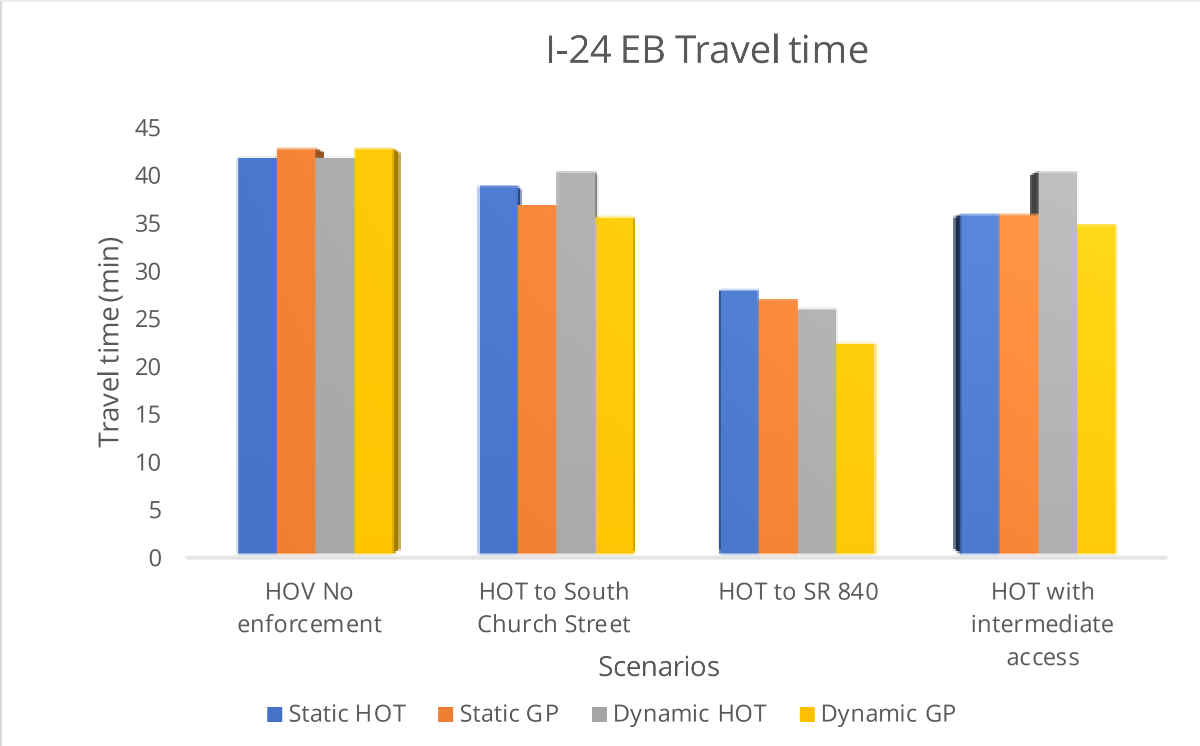

Figure 5.14: I-24 EB Average Speed Under Dynamic and Static Tolling System

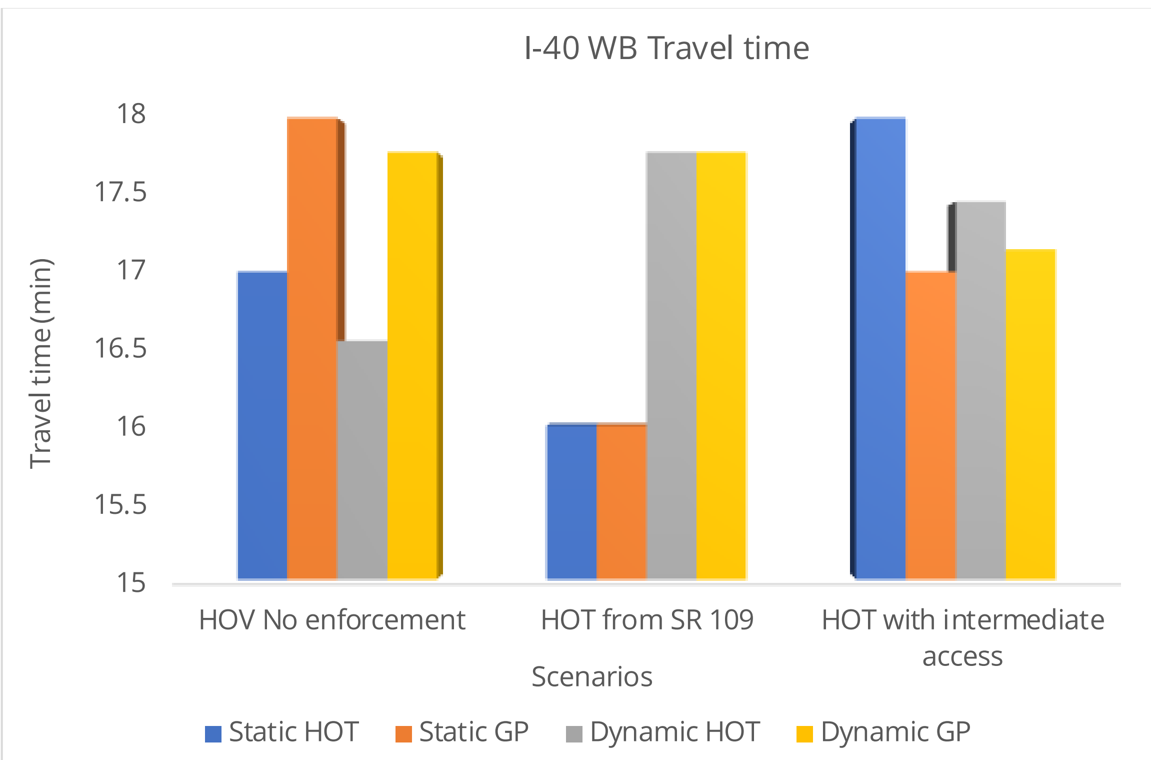

Figure 5.15: I-40 WB Travel Time Under Dynamic and Static Tolling System

Chapter 6 Conclusion

6.1. Conclusions on the Impact of Converting HOV to HOT Lanes

Table 6.1 and Figure 6.1 shows the percentage reduction in travel time with conversion of the current HOV Lanes into HOT Lanes in Tennessee. Overall, with the conversion of the current HOT Lanes to HOT Lanes, there will be on average a 23% reduction of travel time. Traffic on HOT Lanes will reduce travel time by about 24% and those in GP lanes will reduce travel time by approximately 21%. This will be associated with an approximately 13% increase in travel speed, Figure 6.2.

TABLE 6.1: % TRAVEL TIME REDUCTION WITH CONVERTING HOV TO HOT LANES

	% Travel Time Reduction with Converting HOV to HOT Lanes in Tennessee		
	Traffic on HOT Lane	Traffic on GP Lanes	All Lanes Averaged
HOT Lane No Intermediate Access	24%	21%	23%
HOT Lane with One Intermediate Access	18%	17%	18%

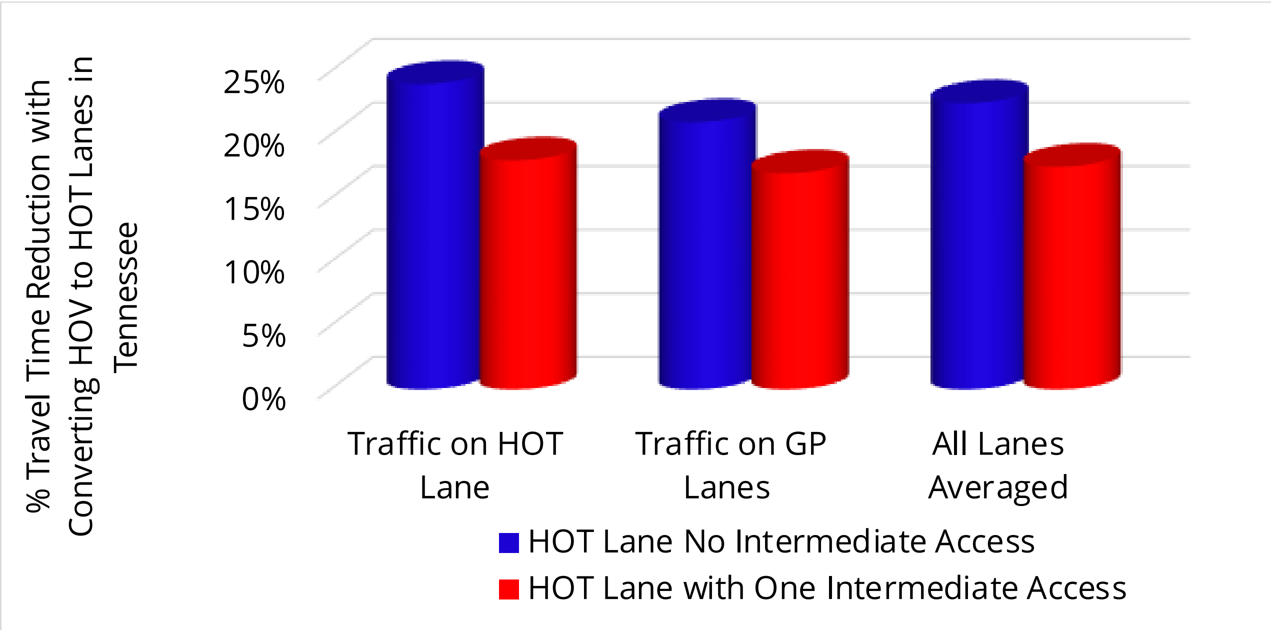

Figure 6.1: % Travel Time Reduction with Converting HOV to HOT Lanes

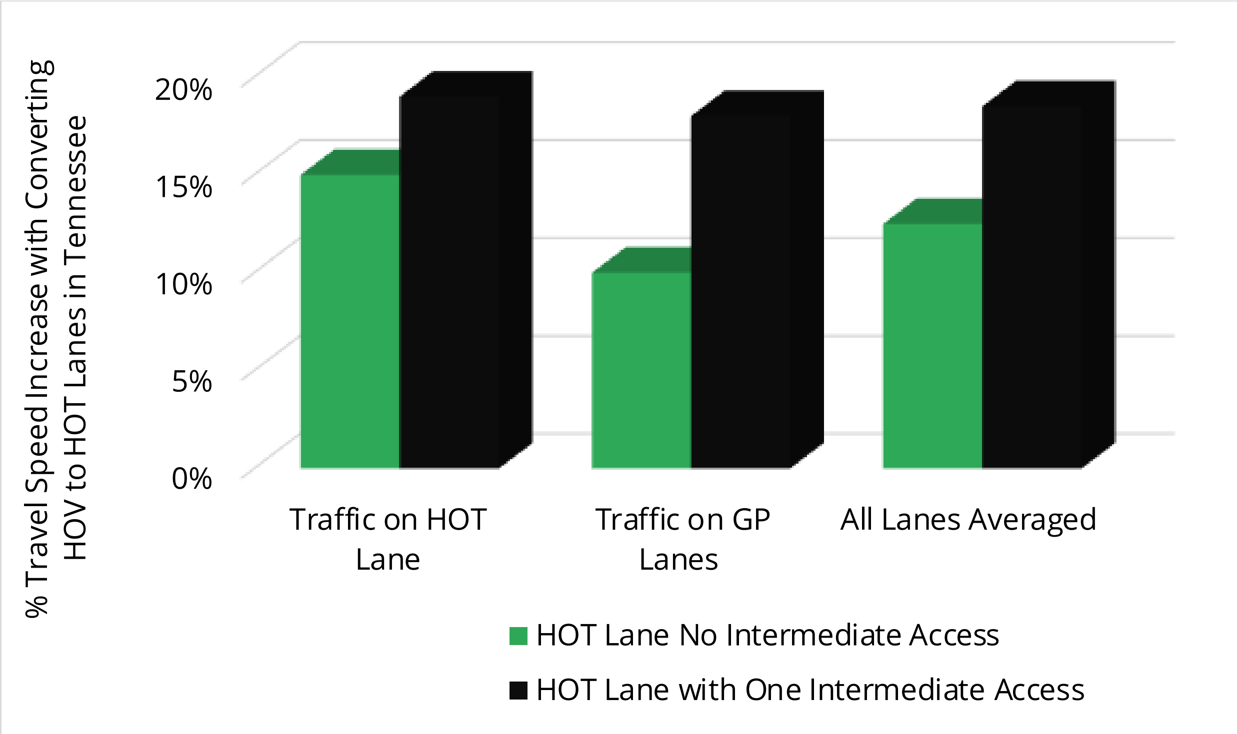

Figure 6.2: % Travel Speed Increase with Converting HOV to HOT Lanes

6.2. Conclusions from Other Regions Case Studies

- Cities with currently operating HOT Lanes view them as effective means to manage congestion.
- There are three different types of physical design for HOT Lanes, each requiring varying levels of commitment and resources in conversion:
  - The "Toronto" model of limited physical requirements, necessitating only the changing of signage.
  - The "Minneapolis" model requiring the painting of additional lineage and dashing, along with the implementation of sensors and beacons for payment detection.
  - The "Houston" model, with the development of dedicated HOT Lanes separated by hard barriers and the ability for adjustable flow direction.
- Codifying a dynamic payment structure with cost limits is key to having a highly effective way to adjust control for traffic levels while also maintaining public support.
- Automated enforcement will be key to a successful HOT Lane system. Also, coordination with local law enforcement will be necessary for additional enforcement with a dedicated division to patrol the lanes. Law enforcement might also use beacons to determine compliance and to identify violators.
- Fostering trust and public support is vital to having HOT Lanes operate successfully.
  - Dispelling commonly held myths is key to building belief in the system.
  - Educating the public on how HOT Lanes operate is necessary to drive ridership, particularly in the early stages of operation.

    - Support for HOT Lanes likely will increase after opening once the public can observe the effects on congestion.
- Given the proper commitment, HOT Lanes have the potential to be a better and more efficient usage of resources to relieve congestion on highways than the construction of more general-purpose lanes

6.3. Recommendations on HOT Lane Management Strategies

6.3.1. Occupancy Requirements

Qualifying HOVs should be allowed to use HOT Lane facilities at no cost or at a reduced toll. HOVs are usually defined as vehicles carrying 2+ or 3+ persons.

6.3.2. Fee Structures

Through literature review, ridership projections, economic analysis, and other state practice reviews, it was observed that the dynamic/static tolling mechanism is the best practice for operating managed lanes such as HOT.

6.3.3. Toll Collection Procedures

From the analysis, using automatic toll collection methods is observed to reduce both unnecessary congestion and simplify the toll collection process. Dynamic tolling, where the toll value varies depending on the time of the day and the congestion level on the managed lane, is recommended.

6.3.4. HOT Lane Pricing

From the previous survey studies and the simulation results, it is recommended that toll values range from $1-$3 but the range can fluctuate with inflation. This range is seen as optimal based on the previous survey results, and most expected users are willing to pay this amount.

6.3.5. Vehicle Type

Emergency vehicles, motorcycles, electric vehicles, buses, hybrid vehicles and the like are excluded from paying tolls when using the HOT Lane even if the occupancy requirement is not met.

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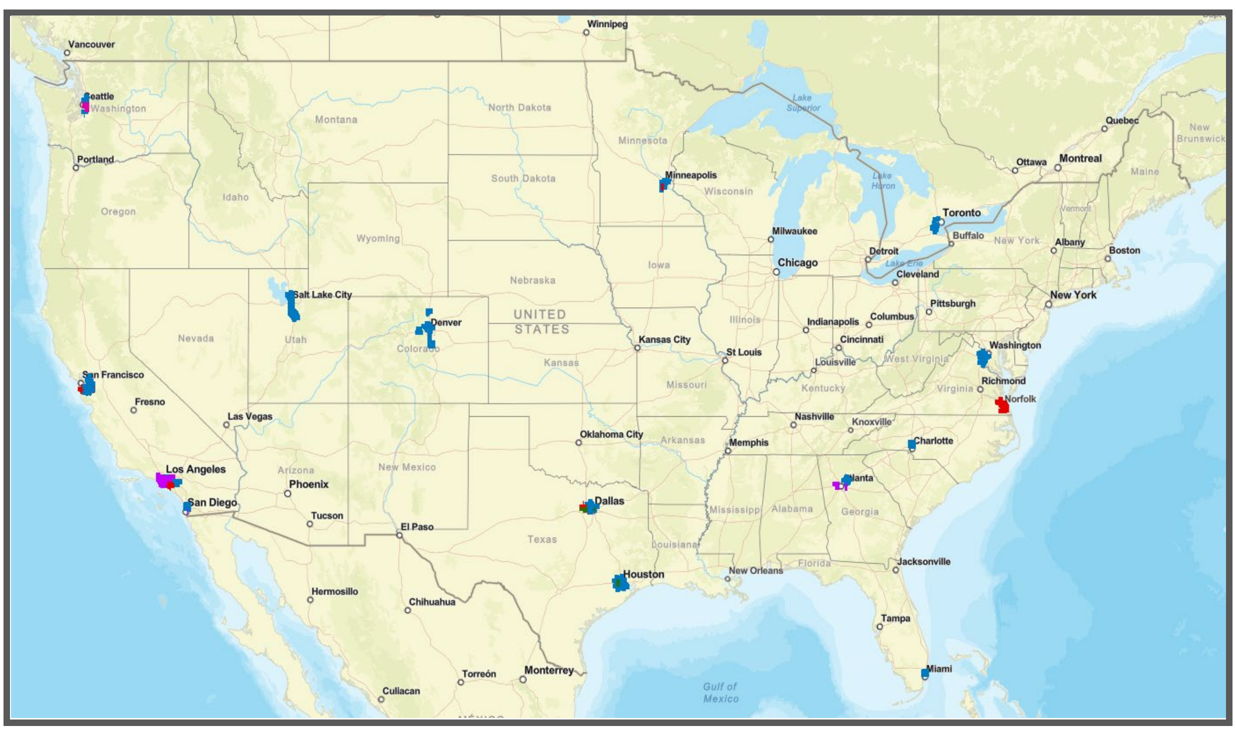
Appendices

Appendix A

Comparable Cities

Ranking	City	Hot Lanes	Urban Population	Metro Population	MSA % Change	Traffic (INRIX)	Traffic (TOMTOM)	Mean Indiv. Income	Median Indiv. Income	Cost of Living Index	Governor	State Legislature	Mayor	2020 Voting (Metro)
Baseline	Nashville	0	**678,851**	**2,012,476**	1.15%	**559**	**34**	**$62,786.67**	**$23,882.00**	**100.1**	R	R	D	**Trump 54**
1	Charlotte	1	***879,709***	***2,701,046***	***1.53%***	***541***	81	########	$27,515.00	**97.9**	D	R	D	Biden 49.4
2	Denver	5	***711,463***	***2,972,566***	0.30%	133	***41***	$77,875.58	***$25,400.00***	112.1	D	D	D	Biden 61.3
3	San Antonio	0+2	1,451,853	***2,601,788***	**1.71%**	390	**49**	########	***$23,500.00***	92.7	R	R	I***	Biden 50.8
4	Dallas/Fort Worth*	6+1	1,288,457	7,759,615	***1.60%***	97	***45***	$70,379.06	***$23,591.00***	**98.5**	R	R	Split*	Biden 49.9
5	Atlanta	2+2	496,461	6,144,050	***0.89%***	59	14	$70,356.69	$27,002.00	**100.3**	R	R	D	Biden 57.1
6	Houston	6	2,288,250	7,206,841	***1.19%***	42	***19***	########	$19,470.00	**95.8**	R	R	D	Biden 49.9
7	San Francisco Area	6+3												
8	Los Angeles Area	4+7												
9	Toronto	4	2,794,356	6,202,225	4.63%	22	8	$97,971.10						
11	Hampton**	1+1	137,746	***1,803,328***	0.20%	894	N/A	$56,005.38	$27,040.00	**99**	R	Split	D	Biden 55.5
10	Tel Aviv													
12	Salt Lake City	1	200,478	1,263,061	0.41%	759	53	$66,682.80	***$25,000.00***	**105.9**	R	R	D	Biden 51.7
13	Washington DC	4	***670,050***	6,356,434	−0.45%	98	**18**	$91,652.55	$31,440.00	120.1	N/A	N/A	D	Biden 72.3
14	Minneapolis	4+1	425,336	3,690,512	0.01%	***491***	85	$78,660.63	$29,002.00	**105.4**	D	Split	D	Biden 58.5
15	Seattle	2+1	***733,919***	4,011,553	−0.18%	250	11	$74,773.10	$28,000.00	124.6	D	D	D	Biden 66.9
16	Miami	1	439,890	6,091,747	−0.76%	32	4	$55,094.26	$20,600.00	110.1	R	R	R	Biden 57.7
17	San Diego	1	1,381,611	3,286,069	−0.38%	230	**29**	$68,874.40	$28,040.00	136.2	D	D	D	Biden 60.2

Summary table of comparable region analysis



Geographical map showing distribution of comparable regions/cities.

Appendix B

Interview Guide

Interview Guide for HOT Lane Feasibility Study

Date:

City or Region of Interest:

Interviewee ( ) (Insert number here and cut on dotted line for confidentiality)

Researcher Name:

—---

Introduction:

We would like to thank you in advance for taking time to talk to us today. We would like to assure you that all the information that you provide in this interview is confidential. We have developed an interview guide to help keep our discussion focused and want to note that the discussion should be free flowing and informal. The entire process should take no longer than 30 to 45 minutes. We are researchers working on a project for TDOT to analyze the viability of converting HOV Lanes in the Nashville metropolitan area to HOT Lanes. The primary goal of our research is to better understand the planning, development, construction, and impact of HOT Lanes in other cities in order to better understand the process, best practices and lessons learned.

We are interested in learning about your experience with the development of HOT Lanes in your city or region. Therefore, we would like to ask you a few questions related to these topics.

Your comments will never be attributed to you and we are not collecting any personally identifiable information. If at any time you feel uncomfortable with a question please let us know and we can either skip the question or come back to it later. All of our findings will be reported in aggregate – no statements will be attributed to any individual.

Before we begin, do you have any questions?

1. What city's HOT Lanes project have you a part of and during what time period?

2a. When were HOT Lanes first considered for implementation in your city?

2b. How or who originated the process (i.e., city, state, MPO, etc.)?

2c. How was it determined which highway(s) would become HOT Lanes and why?

3. Did you conduct public opinion surveys or town hall meetings to gather input or feedback on the project? If so, what was done and how? What level of participation was seen by the public?

4. Prior to installation of HOT Lanes, did you look at the utilization/infraction rate of HOV Lanes, and did that influence the decision to convert to HOT Lanes? If so, do you recall an estimate of violations or usage rates?

5. Were there any legislative/political boundaries that had to be overcome during the project?

6. Do you recall how much the project cost?

6a. How was the project funded (state, federal, local dollar percentages or did it include a public private partnership)?

6b. Was there resistance by community members to funding the project?

6c. Is there anything that you can add about how funding was secured for the project?

7. What did coordination with officials in other counties/municipalities look like during the planning and development phases?

8. How did you select the entry and exit points of the HOT Lane and what criteria did you look for in selecting them?

- What is the separation mechanism between HOT and GP lanes

- Do you have any HOT facilities with continuous access throughout?

- When do the HOT Lanes operate? (AM or PM peak hours only, Daytime only, 24 hours, Weekdays only etc)

9. In conversion to HOT Lanes, were major alterations necessary to the highway infrastructure? If so, how was that managed?

10a. How were the rates for the HOT Lane determined, and why did you elect to go with a (relevant system: mileage, dynamic, etc.) fee structure?

10b. If relevant, what was the process like for implementing a tolling system in your state?

11. What enforcement mechanism is used (manual/officer patrol, cameras, patrols etc)?

11a. What are the penalties for violations?

13. Do you have vehicle restrictions, and what have you done for emergency vehicle accessibility?

14. What impacts have the HOT Lanes made on traffic in the area (during and post-construction)?

15. Do you consider these HOT Lanes a success? Does your city/region plan on building more?

16. What were the biggest unexpected challenges throughout the development and implementation process? Were there any unexpected consequences of these HOT Lanes?

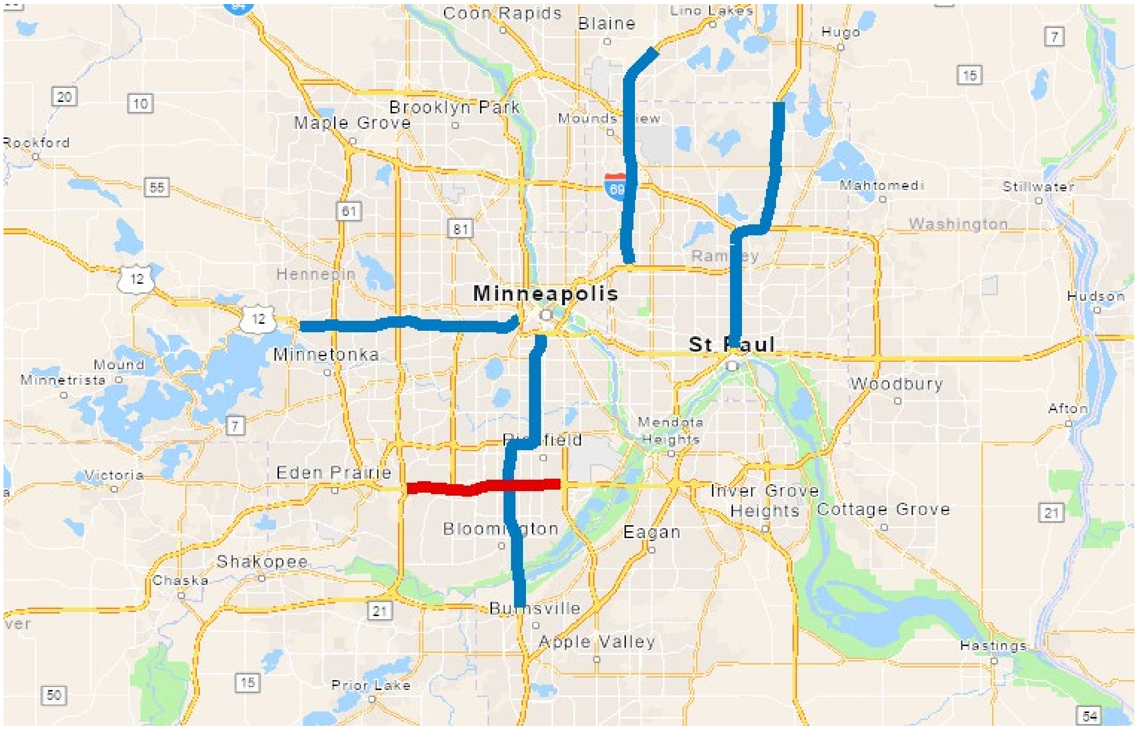
17. Do you have any

17. Finally, would you like to share any other information today such as lessons learned or best practices from the experience?

Appendix C

Sample Case Studies

Minneapolis - St. Paul



HOT Lanes

Route	Length	Opening Date	Terminals
I-394	11 miles	May 2005	Wayzata to Minneapolis
I-35W	16 miles	2009-2011	Burnsville to Minneapolis
I-35E	9 miles	December 2015	St. Paul to White Bear Lake
I-35W	10 miles	August 2021	Roseville to Blaine
I-494	7 miles	2026 (projected)	Minneapolis International Airport to Highway 169

City Demographics

MSA Population (2020)	MSA Growth (2020 to 2021)
3,690,512	+0.01%

Traffic Levels

Traffic Index (INRIX)	Traffic Index (TOMTOM)
491	85

Economic Levels

Mean Individual Income	Median Individual Income	Cost of Living Index
$78,660.63	$29,002.00	105.4

Political Environment

Governor	State Legislature	Mayor	2020 Presidential Voting
Democratic Party	Split	Democratic Party	Biden: 58.5%

At a Glance

The twin cities of Minneapolis and St. Paul together constitute the core of the largest metropolitan area in the state, serving as Minnesota's central hub for commerce, culture, and growth. With a total population of nearly 3.7 million people, the region oversaw some of its greatest growth during the 1980s and 1990s. Aggressive expansion of infrastructure during the 2000s allows the region to enjoy a relatively low traffic level as compared to its city counterparts of similar size and growth. A comparatively affluent region, the Minneapolis-St. Paul area still maintains a reasonable cost of living as compared to national standards. The political environment presents fairly strong support for the Democratic Party across votes in local, state, and national elections.

History

Proposals for HOT Lanes for the Minneapolis - St. Paul region arose beginning in the late 1990s. However, serious considerations were not made until the early 2000s, after MnDOT partnered with the University of Minnesota's Humphrey School of Public Affairs to publish a report on the viability of the lanes. Following the release of the report, MnDOT began the formation of a project task force, composed of key figures in the Minnesota Legislature, transportation policy analysts, MnDOT staff, regional and municipal elected officials, and the Federal Highway Administration. The task force was sent to analyze some of the newest HOT Lanes in the country at the time, located in Southern California. These visits, which allowed for members of the task force to see HOT Lanes in action and have conversations with officials at CalTrans, paved the way for the task force to recommend a similar system of lanes in Minnesota. Support within the Minnesota Legislature was successfully lobbied and the first HOV to HOT conversion was successfully completed in mid-2005 on I-394. In doing so, Minneapolis would become a pioneering city for the adoption of HOT Lanes. Following positive results from this HOT Lane, MnDOT would construct three more; as of publication of this report, a fourth HOT Lane is currently under construction. These HOT Lanes themselves operate under HOV +2 conditions during only peak rush hour. For 90% of the day, they operate as general purpose lanes.

Conversion Type

The first two HOT Lanes, on I-394 and I-35W, were direct conversions from HOV to HOT Lanes. However, Minnesota has been the only state to convert directly from general purpose to HOT Lanes; the two lanes completed later and the one in progress are all of this type. MnDOT plans to only convert directly from general purpose in the future.

Physical Design

The original HOV Lanes on I-394 were separated from general purpose lanes by skip lines, and there was consideration to use the same lines to demarcate the HOT Lane after conversion. However, the Federal Highway Administration was concerned with limiting weaving and required closed off access to the lane. Double white lines were used, with access points every 1000 to 2000 ft and major interchange proximity kept in consideration. MnDOT found that such a closed off access point model caused major bottlenecks and congestion at access points when rush hour began. During the development of the I-35 lanes, MnDOT proposed for the lanes to have more open access; following compromise with the FHWA, the HOT Lanes were designed to have double white lines only in areas where weaving was prevalent and near interchanges. This open approach has been applied to all projects in the Minneapolis - St. Paul area since; for example, the I-35 HOT Lanes are 80% open and 20% closed. A University of Minnesota study sponsored by MnDOT found that both open and closed approaches are viable, and it is a recommendation by MnDOT to apply an open approach to all future HOT projects.

Payment

The MnDOT HOT Lanes utilize a dynamic price structure system, as loop detectors built into the pavement allow for a real-time evaluation of traffic levels in the lane. In order to maintain at least 50 mph within the HOT Lanes, prices can vary from 25 cents to a maximum of $8. It has not been necessary to adjust these pricing caps. Raytheon was contracted to develop an algorithm to maximize traffic efficiency; that software has since been taken in-house by MnDOT and still used to determine pricing on the lanes. Pricing occasionally will hit the max of $8, typically during accidents on the road and during snowstorms. Users pay by switching the HOV or single occupancy switch on their transponder.

Previously, users were required to adopt Mn-Pass to drive in the HOT Lanes. However, in order to meet requirements of the MAP 21 Federal reauthorization bill, MnDOT adopted EZ-Pass for its toll lanes. EZ-Pass is a nonprofit consortium which provides electronic toll collection services. Adoption of EZ-Pass eliminated out of state transaction fees, as EZ-Pass is working to develop full national operability. The switch greatly improved user experience, as the Minneapolis region saw many drivers from the Chicago area, many of whom already possessed EZ-Pass transponders. Under the current structure, all funds collected by EZ-Pass stay with MnDOT.

Enforcement

MnDOT has found that the HOV Lanes presented a 30% to 40% violation rate; following conversion to HOT, violation rates dropped on both lanes to 10%. At first, local and state troopers were provided overtime pay to patrol the lanes. MnDOT has since moved to establish a dedicated team of eight State Troopers for patrol. Handheld sensor technology was initially used to detect payment by vehicles; this was considered unwieldy and unreliable. A system of beacons is now used to visually alert troopers of lack of payment. No license plate video enforcement is currently in usage, and violation rates are considered low enough that enforcement of the lanes is not a high priority for MnDOT. A push towards automation detection is being made, including automated occupancy detection. However, this requires the passing of legislation and further development of the technology.

Public Opinion

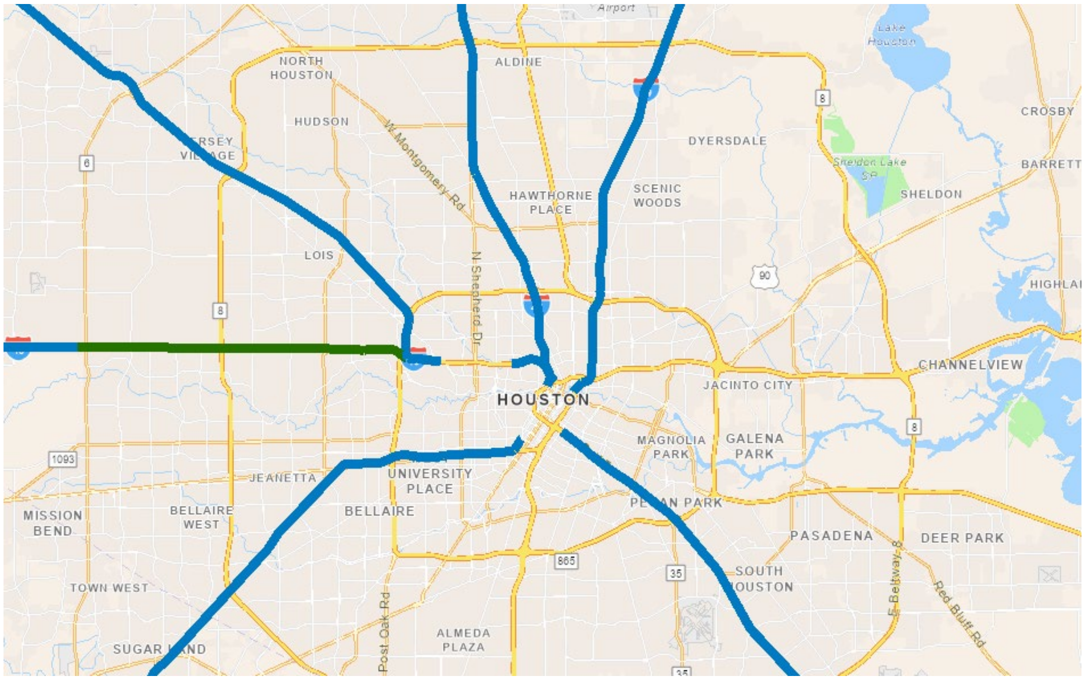
MnDOT officials stated that public perception was the greatest challenge towards implementation of HOT Lanes. The assessment process prior to construction involved significant community feedback and study. During the two HOV to HOT conversions, mutual consent was acquired from all impacted cities and counties. MnDOT developed a "corridor coalition," working to build coordination and cooperation with the local municipalities along developed lanes. MnDOT has found from surveys taken before and after completion that communities are initially extremely hesitant about HOT Lanes. However, once drivers are able to actually use and see the impact of HOT Lanes, public support goes greatly up. For instance, the I-35E project saw support along the corridor go from 40% prior to construction to 80% two years after completion.

Marketing and education about the lanes is considered vital. MnDOT has established a permanent communications director position to lead messaging on specifically the HOT Lane network. Public surveys on the lanes are taken roughly every three years, and public engagement is necessary to dispel myths about the lanes. A key message for the public is that traffic management is the ultimate goal of the lanes; although revenue is collected, pricing is used as a means to regulate traffic flow and minimize congestion. Additionally, there is a conception that the HOT Lanes serve as "Lexus lanes" for the wealthy. MnDOT has found that 80% of lane users are HOV or on public transport, and all income levels are represented in paying customers. MnDOT recommended that emphasis should be placed that the lanes increase travel reliability and move people through the interstate corridors during peak hours more efficiently. Additionally, they are also not mandatory and drivers should understand they are not obligated to use them.

Conclusions

As indicated by its rich history of developing HOT Lanes, and its future plans to develop more, the Minneapolis - St. Paul region can be used as a prime example of HOT Lanes being effective tools to reduce traffic congestion. MnDOT officials conclude that while not perfect, HOT Lanes are better than any other alternative to address congestion in a high demand urban corridor.

Houston



HOT Lanes

Route	Length	Terminals
I-45 South	20 miles	Pierce to Clear Lake City Blvd.
I-45 North	19 miles	Louisiana St. to Cypresswood
I-69N/US 59N	21 miles	Chenevert to Loop 494
I-69S/US 59S	23 miles	Spur 527 to West Airport
US 290	29 miles	I-10 to FM 1960
I-10 West*	20 miles	I-610 to SH 6

*A portion of this segment on I-10 West consists of the Katy Freeway, which is a permanently tolled managed lane which allows HOV to drive for free. Past the Katy Freeway, the rest of the route returns back to HOT Lane.

City Demographics

Urban Population	MSA Population (2020)	MSA Growth (2020 to 2021)
2,228,250	7,2065,841	+1.19

Traffic Levels

Traffic Index (INRIX)	Traffic Index (TOMTOM)
42	19

Economic Levels

Mean Individual Income	Median Individual Income	Cost of Living Index
$59,861.94	19,470.00	95.8

Political Environment

Governor	State Legislature	Mayor	2020 Presidential Voting
Republican Party	Republican Party	Democratic Party	Biden: 49.9%

At a Glance

The fourth largest city in the United States, the Houston area is one of the fastest growing regions in the country. Powered by a thriving energy sector and aerospace economy, Houstonians enjoy a relatively low cost of living and an abundance of available jobs. The decades-long population boom, paired with cheap land for expansion in the surrounding areas, has contributed to extensive suburban sprawl. As such, accommodating the transportation needs of the Houston area's 7.2 million residents has created many challenges for TxDOT and local officials. Congestion on the highways poses a serious burden to further expansion and growth, and the state DOT has historically applied innovative new methods in an attempt to alleviate the region's traffic issues. Politically, the city presents moderately more support for the Democratic party while presiding in a state primarily controlled by Republican officials.

History

During the city's initial population boom in the 60s and 70s, Houston saw significant congestion on its new highway system. Notably, oil companies began bussing their employees to and from the suburbs. In 1979, the city would attempt to tackle these issues head on by pioneering the usage of express buses in newly developed HOV Lanes. These contralane HOV Lanes were highly successful and operated by the newly formed Metropolitan Transit Authority of Harris County, also known as METRO. There was a significant push to implement more of these lanes across the entire urban highway network. However, in the 2000s commuter usage began to exceed capacity of these HOV Lanes and vehicle speeds within the lanes began dipping near the FHWA's mandated minimum speed of 45 mph. In response, Houston would become the first city in the state of Texas to implement tolling, converting some of the HOV Lanes into HOT Lanes. With positive results from this conversion, TxDOT would implement conversions for five more sections of highway in the next decade.

Physical Design

The HOT Lanes in Houston are dedicated median lanes separated by barriers and with strict access points every 2 to 4 miles. At access points, drivers are to select whether to drive in HOV only or in tolled sections, depending on time of day and occupancy in the vehicle. Direction of flow is dependent on time, with HOT access provided in the morning towards the city and outward from the city during the evening. The lanes were designed to be 18 feet wide, in theory large enough to allow two buses to drive side-by-side, and thus able to allow for emergency vehicles and tow trucks to operate in the case of an accident.

Capacity and Operation

The Houston area currently has about 100 miles of HOT Lanes, with goals to push that value to 120 in the coming years. Operationally, the current HOT Lanes provide free travel for vehicles with 2 or more passengers and operate only at peak rush hours, converting back to standard HOV Lanes during all other times. The timing is somewhat dynamic, with switch times requiring analysis of active traffic flow. Due to increased traffic flow for the HOT Lanes on I-290 and I-45N, there has been consideration in increasing passenger requirements from HOV 2+ to HOV 3+ in those locations. The Texas A&M Transportation Institute has found that those lanes currently carry 1600 to 1800 vehicles per hour, and that increasing passenger requirements to HOV 3+ will decrease that rate to roughly 300 to 600 vehicles per hour.

Wrong Way Travel

Because the lanes in Houston are contraflow and monodirectional, there have been incidents of wrong way accidents. Initial cases occurred from a lack of driver understanding, but recent incidents are typically due to drunk drivers in the early morning. These tragedies occur roughly once every two years, and there is active research being done to prevent future occurrences. Options that have been researched include the employment of kevlar nets, one way spikes, and optical sensors.

Public Opinion

Public support for the Houston area's HOV Lanes has generally been high, particularly due to the region's longstanding history of developing managed lanes. However, there was initial pushback for the implementation of the HOT Lanes, as tolling is inherently unpopular. In turn, METRO and TxDOT have emphasized that tolling on the lanes allows for paying back on infrastructure projects and the faster construction of new roads. The HOT Lanes provide an important source of funding; the gas tax, which was used to build HOV Lanes in Houston, has not been increased since 1993. Some HOT Lanes also suffered from "empty lane syndrome" in the months after opening. Low ridership induced negative public perception of the lanes, and combatting this effect required the steady buildup of the rider base over the course of many months. There also exists from public perception of the HOT Lanes functioning as "Lexus Lanes." However, there has been no indication that this is the case and the TTI has found that blue collar workers consist of the majority of the rideshare. Overall, however, support for toll lanes has increased with the subsequent reduction in traffic levels.

Payment

The payment structure for the HOT Lanes is based on flat rates, ranging anywhere from $1.00 to $7.00 depending on route and time of day. Originally, the lanes were staffed with toll booths to accept physical money. However, METRO has since converted to an electronic tolling system, with drivers using a RFID tag within their vehicle. In doing so, METRO has observed a 20% increase in revenue.

Tolling Increases

One of the primary challenges for the Houston area's HOT Lanes, as stated by a member of the Texas A&M Transportation Institute, is the static nature of the tolling fees. Under the current codified structure of tolling, any increases in fees must be approved by the Harris County Board. This has caused issues, as requests to increase toll fees when lanes become too congested have been denied by the board due to public backlash. An example of this is the West Park toll road project, which had planned to begin operation under a static pricing system before eventually converting to dynamic pricing. However, backlash has meant the toll has maintained its fixed tolls system. Recommendations from the TTI official include codifying a strong dynamic pricing system that can not be interfered with by outside sources. Codifying such automatic increases reduces public backlash and allows for easier operation of the lanes.

Enforcement

Enforcement on the lanes was another serious challenge as stated by the TTI official. Violations have primarily been occupancy level violations rather than tolling infringements. These types of violations are particularly difficult to detect, as attempts to use cameras and infrared to identify vehicle occupancy have failed. Currently, law enforcement is stationed at entrance and exit points to determine compliance with HOT rules. However, because the lanes are walled-off and contain only dedicated entrance points, police vehicles stationed at these points have led to the slowing down of traffic and bottlenecks. A suggestion by the TTI official was to employ motorcycle police to operate on the lanes in bursts, pulling over many violators for only a brief period of time. This "hit and run" approach means that there are no complaints from the public for too much enforcement.

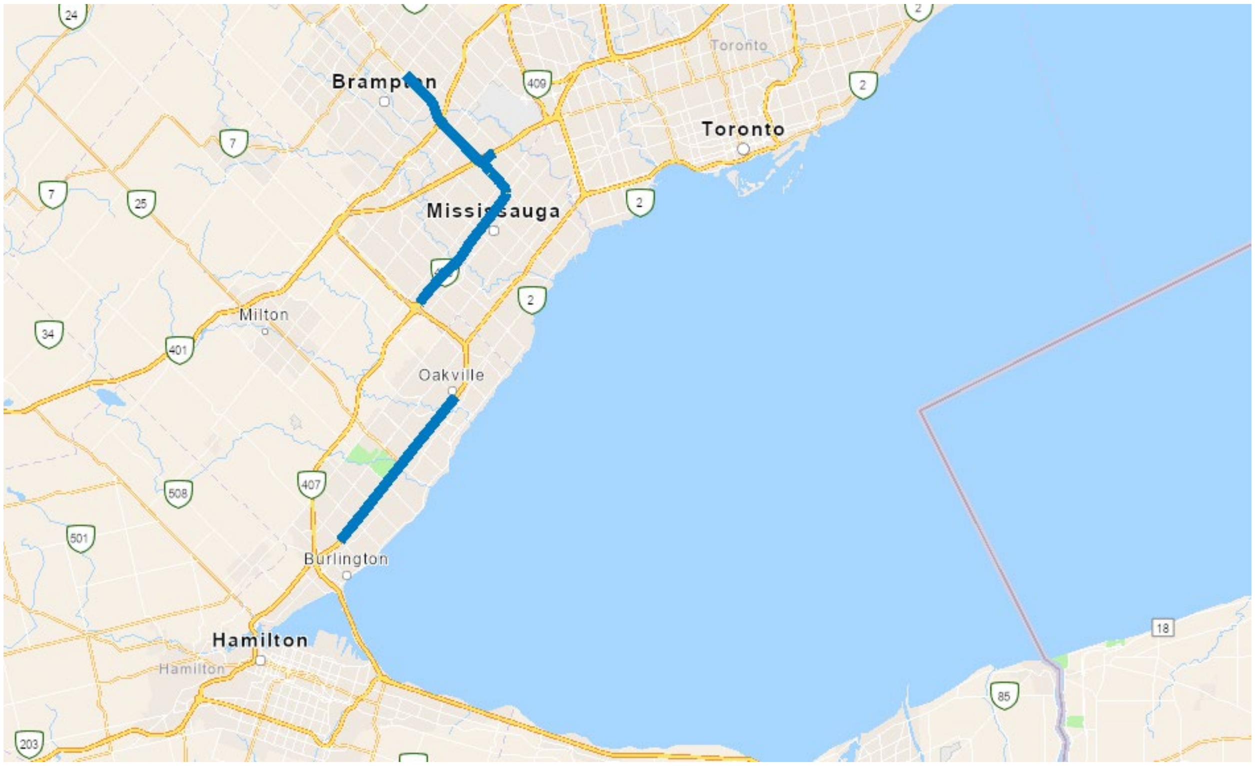
State Legislation

Previously, state legislation has allowed for the establishment of tolling authorities to create and operate the HOT Lanes. However, recent new legislation has prohibited the construction of new tolling lanes and has killed several projects throughout the state. Despite this, specific interpretation of the law and the term "new" may allow for future plans to implement additional HOT Lanes in the Houston area.

Conclusions

The Houston area has exhibited extreme growth and has required unique solutions to manage traffic levels. With a rich history of HOV Lanes, the conversion to HOT has generally been a success. The HOT Lanes currently carry more passengers in the city than any other form of public transportation, at over 145,000 people a day. Traffic flow on the lanes has been heavily dependent on economic cycles, with economic boom periods inducing more traffic. Conversion to the level that Houston has completed requires significant funding and effort, but has ultimately produced positive results. Core recommendations by the TTI official include codifying a strong dynamic pricing system, establishing a non-impactful on traffic flow form of enforcement, and spaced out entry/exit points.

Toronto, Ontario, Canada



Map indicating the locations of the HOT Lanes in Toronto, Canada.

HOT Lanes

Route	Length	Terminals
Queen Elizabeth Way	10.25 miles	Oakville to Burlington
Highway 410	6.8 miles (Northbound) 4.3 miles (Southbound)	Eglinton Avenue to Clark Boulevard
Highway 403	8 miles (Eastbound) 7.5 miles (Westbound)	Highway 407 to Highway 401

City Demographics

Urban Population	MSA Population (2020)	MSA Growth (2020 to 2021)
2,794,356	6,202,225	+4.63

Traffic Levels

Traffic Index (INRIX)	Traffic Index (TOMTOM)
22	8

Economic Levels and Political Environment

Mean Individual Income (USD)	Province Legislative	Province Premier
$97,971.10	Progressive Conservative	Progressive Conservative

At a Glance

Forming one of the fastest growing regions in all of North America, the over 6.7 million residents in the Greater Toronto Area constitute the economic and cultural center of Canada. As the largest city in the entire country, Toronto also stands as a global city highly integrated into the international economy. Bolstered by thriving industries in media, banking, and technology, Toronto has experienced massive expansion in recent decades and required extensive investment by local, provincial, and federal governments to maintain the transportation needs of its citizens. While its location outside of the United States brings a unique environment and set of challenges in regard to HOT Lanes, valuable lessons can still be learned from the Toronto area's relatively new foray into the development of these managed lanes.

History

With such rapid growth of the Greater Toronto Area (GTA), the Ministry of Transportation of Ontario (MTO) has been actively looking for innovative solutions to the rising congestion issues on local highways. Beginning in 2016, the Ministry began a pilot program testing a HOT Lane system in the existing HOV Lanes on Queen Elizabeth Way (QEW), a major route connecting the urban center of Toronto with its western suburbs and periphery towns. Following successful results and positive public feedback, the pilot program was expanded in 2021 to implement additional HOT Lanes on two other major roads, Highway 410 and Highway 403. The continuation of this pilot program to the present day makes the Toronto region one of only two areas outside of the United States to adopt HOT Lanes as a measure to control traffic congestion.

Conversion Process and Physical Design

Initial identification of which lanes to begin the pilot program on required analysis of existing HOV Lane infrastructure and traffic flow patterns. These considerations meant QEW was selected to open the pilot program, as a result of its high traffic volume and robust HOV Lane usage. In implementing HOT Lanes on the QEW, the Ministry of Transportation of Ontario adopted an approach that was highly discrete, at least comparative to many other locations in the United States. The only major infrastructure change completed was the utilization of new signage that informed drivers of the new requirements to use the lanes. In another stark contrast to typical American systems, the HOT Lanes are in operation for all 24 hours a day.

Payment and Selection Process

In the rollout of the pilot program, the MTO looked at both a dynamic pricing system and a flat fee model. Ultimately, a flat fee program with permit stickers was selected, removing the need for drivers to purchase a transponder or the construction of electronic readers on the lanes for detection. Under the current pilot program, permits for the HOT Lanes are issued in a random draw in order to ensure fairness. 1,350 permits are issued in rolling cycles, and owners of the permits are allowed to renew twice before needing to re-enter the drawing. These permits are valid for a three month period and cost 180 CAD (135.40 USD). Eligible vehicles must be registered in the province of Ontario and meet the oversized vehicle regulations; no vehicles weighing more than 4500 kg (9920 lbs) and more than 21 ft are permitted.

Enforcement

Ensuring user compliance on the lanes has relied on quality communication and coordination between the MTO and law enforcement. In the implementation of the pilot program, the ministry addressed the law enforcement division specific to the region and informed them about the nature of the project. Law enforcement was made aware of the nature of the pilot program, what the permit tags looked like, and what enforcement responsibilities would entail. The ministry also made clear points of contact with relevant departments in order to ensure that any clarifications and future expansion news would be clearly communicated.

There are occasional violators caught driving on the lanes, but it is not a significant enough of a number to raise major concern about the viability of the project. Violations on the HOT Lanes are treated in the same way violations on HOV Lanes are considered, all falling under the stipulations of the Highway Traffic Act of Ontario.

Political Support
The MTO has received significant political support, particularly in the expansion of the pilot program to Highway 410 and Highway 403. Unlike the implementation of HOT Lanes in many other locations, there were no major legislative boundaries which prevented or hindered the conversion. Along relevant stretches of highway, indigenous land permits were evaluated to ensure lawfulness.

Public Opinion
Prior to program launch, MTO engaged in public polling in order to understand any concerns that the community may have had about the HOT Lanes. A sentiment found among some was the belief that taxpayer dollars should not go towards funding a project of this type. A more commonly found concern, however, was the idea that HOT Lanes were inherently unequal and not accessible for some in the community. The concept of “Lexus lanes” was prevalent, as requirements to purchase a permit cause concern of an inequitable system dominated by users of high income. In response, MTO established a random draw system for permits and required all participants in the program to fill out a survey, ultimately concluding that primarily middle-income earners utilized the HOT Lane system. Additionally, MTO conducted polling following the conversion on the QEW and found an overall net-positive at launch. Based on additional feedback, drivers approved of the improved traffic flow across all lanes on the QEW as a result of the HOT Lane implementation.

Conclusion and Future Plans
The three HOT Lanes currently in the MTO’s pilot program are a clear success, reducing congestion and ensuring more optimal speeds on major highways. Because of the conversion of the two newest lanes within the last two years, there are no current plans by the MTO to expand the pilot to additional routes. However, the MTO sees the current program as a learning experience and a useful way to understand the viability of HOT Lanes in the region. Despite an extensive implementation and approval process, the MTO sees the benefits of improved travel times and reduced congestion as an overall net positive as valid justification for the current HOT Lane system.