High Occupancy Vehicle (HOV) Detection System Testing

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16. Abstract

This study supports TDOT's evaluation of existing HOV lanes as travel-time incentives for promoting carpooling and reducing congestion. While the overall person-moving capacity of the HOV lanes may be slightly higher than the general-purpose lanes, the travel–time incentives for legitimate HOV lanes users have been severely diminished by violators in Tennessee. The first part of this study researched and conducted literature and product review on HOV lane occupancy detection technologies that could assist TDOT in managing Tennessee's HOV corridors while also providing insight through evaluation of performance strategies to address high violation rates. The review identified possible technologies which could be used for such detection and recommended acquiring and testing infrared (IR) technology from Xerox known as Xerox Vehicle Passenger Detection System (XVPD) for pilot testing for possible implementation in Tennessee in the future. The XVPDS has already been tested in California. However, TDOT chose to not move forward with pilot testing the XVPDS as part of this study. The second part of the project focused on evaluating 1) HOV lane utilization rates and 2) HOV occupancy violation rates, and (3) a stakeholder/public opinion survey on the current use and possible future expansion of HOV lane policy in the state. The HOV lane utilization and occupancy violation evaluations covered HOV segments in Davidson County, Williamson County, Wilson County and Rutherford County (i.e., the greater Nashville area), and Shelby County (Memphis area). Findings are expected to support TDOT operational goals on HOV systems improvement strategies. The final part of the study focused on conducting an online, public opinion survey about the HOV lanes in the Nashville area to explore options for improved management such as automated enforcement, conversion to high occupancy toll (HOT) lanes, fees for violations, etc. The survey instrument was distributed across the state via email and social media. Over 750 responses were received with the majority of participants (75%) residing within a 50-mile radius of Nashville. The study found that the average HOV lanes utilization in Tennessee is 23% and the HOV lane violation rate is about 84%. 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). Through individual commentaries, many voiced concerns on the ineffectiveness of the HOV lanes in the Nashville area, including but not limited to lack of enforcement. The vast majority (over 65%) of survey respondents never use the HOV lanes, and approximately 20% indicated that they utilize it 3-5 times per week as individuals or 2-person carpoolers. 56% reported knowing someone who has violated the HOV lane restrictions; 50.36% are in favor of keeping the HOV lanes in place, while 49.64% want to see them removed. 50.29% are in favor of automated enforcement, with 49.71% against it. A little over 50% expressed interest in HOT lanes, with a preferred rate for access being $1-$2/day.

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EXECUTIVE SUMMARY

This study supported TDOT's desire to evaluate HOV lanes as a travel-time incentive aimed at promoting carpooling. While the overall person-moving capacity of the HOV lanes may be slightly higher than the general-purpose lanes, the travel–time incentives for legitimate HOV lanes users have been severely diminished by violators in Tennessee. The first part of this study focused on examining the literature and product review on HOV lane occupancy detection technologies that could assist TDOT in monitoring Tennessee's HOV system and evaluating management strategies to address high violation rates. The review identified multiple technologies which might be used for such detection. From this review, the study found the infrared (IR) technology from Xerox, known as the Xerox Vehicle Passenger Detection System (XVPD), to be an ideal candidate for pilot testing and possible future implementation in Tennessee. The XVPDS has already been tested in California. However, TDOT chose to not move forward with pilot testing the XVPDS as part of this study.

The second part of the project focused on evaluating 1) HOV lane utilization rates, 2) HOV occupancy violation rates, and 3) a stakeholder/public opinion survey on the current use and possible future expansion of HOV lane policy in the state. The HOV lane utilization and occupancy violation evaluations covered HOV segments in five counties: Davidson, Williamson, Wilson and Rutherford (the great Nashville area), and Shelby County (Memphis area). In this study, the "utilization rate" is the percentage of vehicles that use the HOV lane compared to those using only the general purpose (GP) lanes. Findings are expected to support TDOT's operational goals on HOV systems improvement strategies. The average combined utilization of HOV lanes in Tennessee is 23%. The following are the major findings from the study:

HOV Lane Utilization Rates

	HOV Utilization Rates	
	A.M.	P.M.
I-65, I-24, and I-40 toward Nashville Downtown (averaged)	22%	20%***
I-65, I-24, and I-40 outward from Nashville Downtown (averaged)	22%***	25%
I-40 and I-55 toward Memphis Downtown (averaged)	25%	20%***
I-40 and I-55 outward from Memphis Downtown (averaged)	19%***	27%

**Note ***2+ HOV lane occupancy not enforced/ required at those directions

The average HOV lane utilization rates per individual corridors during peak flows (to and from downtown areas) is as follows:

	Average HOV Utilization Rates
I-65 North of Nashville	14%
I-65 South of Nashville	26%
I-40 East of Nashville	28%
I-24 East of Nashville	26%
I-55 South of Memphis	23%
I-40 East of Memphis	29%

HOV Lane Occupancy Violation Rates

The study found that 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 detailed HOV lane violation rates are summarized as follows:

	HOV Violation Rate
I-65, I-24 and I-40 toward Nashville Downtown	82%
I-65, I-24 and I-40 outward from Nashville Downtown	81%
I-40 and I-55 toward Memphis Downtown	88%
I-40 and I-55 outward from Memphis Downtown	86%

Average HOV lane occupancy violation rates by individual corridors during peak flows (to and out of downtown areas) is as follows:

	A.M. Violation Rate (Toward Downtown)	P.M. Violation Rate (from Downtown)
I-65 North Side of Nashville	83%	83%
I-65 South Side of Nashville	81%	82%
I-40 East Side of Nashville	85%	79%
I-24 East Side of Nashville	79%	79%
I-40 East of Memphis	87%	86%
I-55 South of Memphis	88%	86%

**Note *****2+ HOV lane occupancy not enforced/ required at those directions

HOV Lane Public Opinion Survey

The public opinion survey focused on the HOV lanes in the Nashville area and explored options for improvements, such as automated enforcement, conversion to high occupancy toll (HOT) lanes, higher fees for violations, etc. An online survey instrument was developed and distributed across the participating research institutions, TDOT, and other groups across Tennessee via email and social media. Over 750 responses to the online survey were received, with the majority of participants (75%) residing within a 50-mile radius of Nashville, Tennessee.

In general, 56% reported knowing someone who has violated the HOV lane restrictions. The majority of respondents that utilize the HOV lanes do so 3-5 times per week and have only two individuals in the vehicle. The respondents were split nearly in half in regard to whether or not the HOV lanes should remain in effect and also in regard to utilizing automated enforcement. Similarly, slightly more than half of the respondents expressed an interest in HOT lanes, with the preferred daily fee for HOT lane access being $1-2. However, anecdotal requests for improved enforcement (not necessarily automated) were common comments among participants.

1. INTRODUCTION

High Occupancy Vehicle (HOV) lanes are reserved to offer a fast, reliable, and safe trip option for shared-ride vehicles such as buses, carpools, and vanpools, thereby encouraging travelers to utilize theses modes in preference to driving alone to reduce congestion in urban transportation corridors. HOV lanes are most effective during peak travel periods, when general-purpose lanes become congested and slower than posted speeds. The success of an HOV lane relies on its ability to be used exclusively by legitimate users. If violations occur by non-compliant drivers, not only is the HOV lane's performance severely diminished, but the public perception of the value of the lane is also reduced. A number of rules and regulations to guide the use of HOV lanes have been enacted across the United States [1].

In general, HOV lanes are typically designated to drivers by the use of signage and pavement markings. Typically, HOV lanes are designated on highways by a diamond-shaped marking in the center of the lane. In some cases, HOV lanes may be separated by a painted buffer, while others are distinguishable from general lanes by signage only. For easier enforcement, HOV lanes can be separated from other lanes by a physical barrier, such as utilizing concrete barricades or pylons. Enforcement on such barrier-separated lanes has proven to be easier and tends to have lower violation rates than non-separated lanes. Enforcement of the occupancy restrictions on HOV lanes is often facilitated by police monitoring and enforcement activity in the field. However, deployment of police to monitor activities has been criticized, as manual enforcement is seen as labor-intensive, costly, and potentially adversely impacting safety for both police officers and traffic. Another criticism associated with manual enforcement is that unfavorable environmental conditions, such as inclement weather, darkness, and sunlight reflections, can hinder correct identification of violators. Moreover, HOV lane traffic operates at high speeds, which hinders officers in identifying vehicle occupancy in cars with tinted glass, sleeping occupants, and/or children. It is not uncommon for police officers to chase and stop vehicles that are non-violators, which consequently severely reduces HOV lane incentives.

In Tennessee, the violation rates are often in the double-digit percentage range, with state officials estimating that as many as 85 to 90 percent of drivers who are using the HOV lanes during morning and evening rush hours are violating the

two-or-more-occupants-per-vehicle rule. These levels are clearly undesirable, as they result in public mistrust and lack of support of HOV initiatives, which exacerbates the apparent impracticality of effective manual enforcement of HOV lanes. An option to circumvent this problem involves improving the accuracy in identifying violators so that officers can be more efficient in accurately ticketing violators. As a result, the first part of this study was undertaken to identify and evaluate leading technologies to automate enforcement practices to achieve proper use of HOV facilities while allowing for safer and more cost-effective implementation. While attempts have been made to develop automated systems for detecting vehicle occupancy, these systems are limited in number and often have not had the desired accurate results for effective use. This report summarizes the findings of a preliminary study to evaluate the potential use and effectiveness of deploying occupancy detection system technologies for highways in Tennessee to address the misuse of HOV lanes.

Part two of the study evaluated utilization of HOV lanes and the occupancy violation rates, as well as providing some insight into the public's perspectives regarding the use and management of the HOV lanes in the Nashville, Tennessee area. Utilization of the HOV lanes during peak hours were evaluated along select segments of the HOV lanes in five counties: Davidson, Williamson, Wilson and Rutherford (the greater Nashville area), and Shelby (the Memphis area). The utilization rate in these areas irerpresents the percentage of vehicles that use the HOV lane compared to those that use only the general purpose (GP) lanes. Data collection through video, visual observation, and manual counts captured a sample portion of traffic flow for at least 120 minutes within a.m. and p.m. peak hours along the study segments. The collected data was screened and evaluated to determine the distribution of vehicles by lane configurations. The HOV lane occupancy violation rates were estimated by visually counting the number of persons in the front seats of vehicles using the HOV lane. The violation rate is taken as the ratio of single occupancy vehicles (SOV) to the total number of vehicles using the HOV lane. The rates observed along HOV corridors in Tennessee are presented in this report.

2. LITERATURE REVIEW

2.1. HOV Lane Use

HOV lanes are reserved for vehicles with a driver and one or more passengers. In some cases, other vehicles are also exempted (permitted in the HOV lanes). Such examples include motorcycles, transit and charter buses, emergency and law enforcement vehicles, low emission vehicles, hybrid or alternative fuel vehicles, and/or single-occupancy vehicles (SOVs) with a toll. These lanes, which usually run parallel to general-use highway lanes, were first introduced in the early 1970's in the United States.

The main rationale behind the use HOV lanes is to encourage carpooling and therefore increase mobility by increasing the number of passengers in individual vehicles. Other potential benefits of HOV lanes include providing travel options to meet user needs, such as "time-sensitive" travel, and improving air quality through potentially increased and incentivized carpooling. Since transit programs and ride-sharing are the key to the success of a HOV system, restrictions in these lanes are imposed to limit traffic demand, thus providing travel time savings along a corridor compared to adjacent general-use lanes. This travel time advantage is an incentive for legitimate users to form carpools in order to bypass congestion.

Currently, about 350 HOV facilities are operated across 20 states in North America. While the overall person-moving capacity of the HOV lane may be slightly higher than the general-purpose lanes, HOV lanes do not always provide the expected advantages. TDOT is investigating the potential use of occupancy detection technologies to assist in monitoring Tennessee's HOV system and possible implementation considerations to address high violation rates.

Since 1993, Tennessee has used HOV lanes as a tool to promote ridesharing to reduce congestion on urban interstates. The central concept for HOV lanes is to move more people rather than more cars. During heavy traffic periods, HOV lanes are reserved for buses, vanpools, motorcycles, carpools, and other high-occupancy vehicles. Road markings and signage are shown in Figures 2.1 and 2.2.

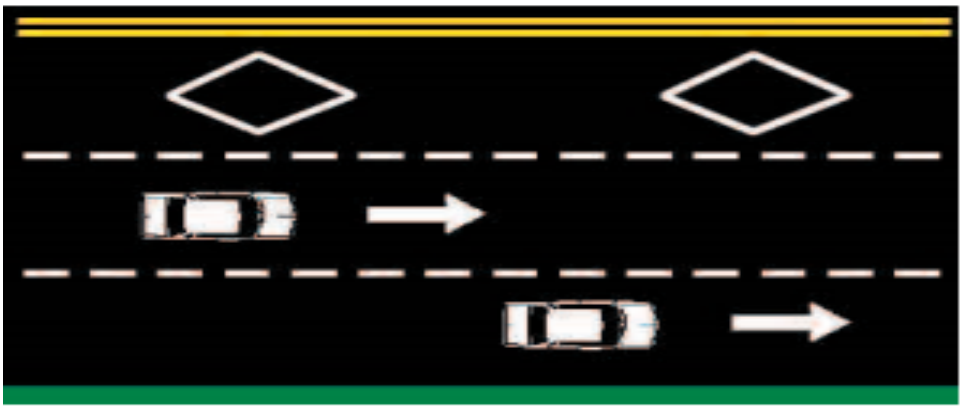

Figure 2.1: Diamond Shape on HOV Lane

Figure 2.2: HOV Lane Sign

Figure 2.3: Smart Pass Sticker for Hybrid Vehicles

2.2. HOV Facilities and Operation in Tennessee

As shown in Table 2.1, HOV lanes in Tennessee are located in Memphis and Nashville. Each vehicle traveling in an HOV lane is required to carry the minimum number of people posted on the HOV signs. In Tennessee, the minimum number of people is two. Exceptions include motorcycles and hybrid vehicles with the Smart Pass sticker, as shown in Figure 2.3. Beginning in 2009, the Smart Pass program allows eligible low-emission and energy-efficient vehicle owners to obtain a special decal at no cost which allows drivers access to the HOV lanes without adhering to the occupancy requirement. Qualified applicants are each advised to place the decal on the outside of the vehicle's rear window in the lower right (passenger side) corner. The HOV operation hours are in effect from 7 a.m. to 9 a.m. inbound and 4 a.m. to 6 p.m. outbound from Monday to Friday, and the lanes are open to general-purpose traffic at other times [2].

2.3. HOV Lane Utilization

Previous studies regarding HOV facilities have largely focused on the general decrease in travel time, air quality improvement, and overall perception of the carpool experience by users [3] [4] [5] [6]. While a few studies have comprehensively served for inventory purposes, it is imperative to look at all of them individually, as each study brings a unique contribution to the pool of literature [7] [8]. For example, the state of California introduced a statewide policy allowing hybrid vehicles to use the HOV lanes [9]. In a study of the impacts of this policy, a freeway network in Orange County, California was evaluated using microsimulations and travel demand models. , The study modelled the base conditions of the network and analyzed the policy's effect in reducing emissions, as well as the performance of the HOV lane. The findings suggested that a change in policy to allow hybrid vehicles could significantly improve the air quality of the corridor; however, due to existing heavy congestion of the HOV lanes, redesign of the those lanes is necessary to accommodate the 85,000 hybrid vehicles that have already requested permits [9].

Table 2.1: Tennessee's HOV Lane Facilities

Location	HOV Facility	Mile Marker (m.m.)	Passenger Requirements	Hours of Operation
Memphis	I-40E	15 to 22	2+	Monday to Friday 7 a.m. to 9 a.m. inbound 4 a.m. to 6 p.m. outbound
	I-40W	22 to 16		
	I-55N	0.0 to 5		
	I-55S	5 to 0.0		
Nashville	I-40E	216 to 232	2+	Monday to Friday 7 a.m. to 9 a.m. inbound 4 a.m. to 6 p.m. outbound
	I-40W	216 to 232		
	I-24E	56 to 81		
	I-24W	56 to 81		
	I-65N	90 to 95		
	I-65S	90 to 95		
	I-65N	79 to 65		
	I-65S	79 to 65		

In a study on the effectiveness of HOV lanes, historical data on California HOV facilities was used to analyze the current operating status of the HOV system [10]. This study analyzed several key factors that may affect the operations and performances of the HOV lane. The factors ranged from driving behavior, direction of travel, violations, and effects of hybrid vehicles in the lane. Periodical violation rates explored the trends over time and how the differences in policies and designs has affected performance. Other factors, such as intermittent HOV lane barriers, crash analyses, and travel times, have also contributed to disparities in performance measurements. The study concluded that it is essential to have accurate data on occupancy and traffic demands. The benefits of the lane can be linked to ridesharing choices that require continuous monitoring and further analyses [10].

2.3.1. Utilization Evaluations

Last year, researchers from Brigham Young University, Utah, published an article analyzing express lanes in the state [11]. Six (6) zones were selected, and the specific northbound and southbound corridors were both analyzed. Average vehicle occupancy was calculated from a sample of passenger cars, express pass vehicles, and "C" decal vehicles, while other vehicles such as buses, freight vehicles, and motorcycles were excluded. Data on restriction violations was also collected for both occupancy and commercial vehicles during a.m. and

p.m. peak hours. During this period, the results for HOV lane utilization versus express lane utilization were compared. Additional data was collected after proposed recommendations were made to reduce violation rates on both HOV and express lanes. The objective of the study was to improve speeds on the toll lanes and managed lanes, and education programs and increased enforcement did indeed reduce the violation rates on the lanes. Additional recommendations, aimed at a toll increase in the "C" decal vehicles, were made to further improve speed.

California has some of the most extensive and continuous strategic implementation of HOV lanes. As stated previously, the primary purpose of HOV lanes is to increase person throughput through carpooling, vanpooling, and express bus use. According to Varaiya, the investigation of lane utilization as well as other factors concerning HOV lanes provided empirical data for the HOV facility. The study pointed at violation rates and HOV qualifiers as being significant inputs in assessing the performances of these lanes. However, the major finding was the underutilization of HOV lanes in comparison to general-purpose lanes. It was also concluded that HOV lanes suffer a 20% capacity loss compared to other multilane freeways, and they ultimately do not reduce overall congestion, even in a well-managed system [12].

A different HOV lane study measured operational performances by comparing travel time savings and utilization levels [13]. Contiguous and limited access HOV facilities were compared with relative site data on different measures in California.. VMT and PMT were calculated relative to each lane and compared to 0.5, a ratio that indicates the utilization level. The study remarked that HOV lanes have relatively less VMT ratios than general-purpose lanes, indicating that HOV lanes have fewer vehicles but greater travel speed than that of general-purpose lanes [13].

2.4. Enforcement

In Tennessee, enforcement of the occupancy restrictions on HOV lanes is currently done visually by patrol officers external to the vehicles using the HOV lanes. Tennessee law provides a fine not to exceed $50, plus court costs, for violations of HOV lane requirements. This value is lower than other states researched. For example, violators in California are subject to a minimum $490 fine [14]. As of February 2016, violators in Northern Virginia are subject to a $125 fine for the first

offense and up to $1,000 and 3 points on the violator's driving record for the fourth offense [8].

2.5. Tennessee HOV Educational Programs

Public awareness is key in maintaining the effectiveness of HOV lanes. In order to gain public acceptance of HOV usage, TDOT ran a campaign which utilized free media and paid television and newspaper advertising [15]. Information was sent by mail to 38,000 residents, and newsletters were sent to public policy makers. In addition, outdoor billboards, bus bench boards, and signs on buses were used. The campaign cost approximately $100,000 [15]. These forms of public information and marketing have been utilized by other states and agencies. New Jersey implemented a $2.5 million marketing campaign to promote a new HOV lane on I-80 in Morris County. The campaign included radio and newspaper advertisements, direct mail flyers, and other techniques. In addition, one million people were contacted through direct mailings, windshield fliers, and notices accompanying license renewal forms [16]. During the operation of the HOV lanes from 1994 through 1998, press coverage was generally positive. The goals of the marketing campaign were to:

- Heighten public awareness of the HOV mission
- Increase public confidence and develop accurate expectations
- Encourage HOV facility use and mode shift
- Enhance future HOV project planning

Long Island's HOV lane, which opened in 1994, underwent extensive marketing long before its operation. The marketing sought to achieve the following objectives [3]:

- To promote the HOV project to stakeholders as a highway improvement project to gain support for the project
- To build a constituency among potential HOV lane travelers

3. REVIEW OF CURRENT OCCUPANCY DETECTION TECHNOLOGIES

The purpose of this portion of the study is to review and document the state of current practices in vehicle occupancy detection (VOD) by HOV operating agencies and to summarize the state of research results by others in this field. The literature review studied available/current technologies in VOD and enforcement of HOV lanes. Literature review indicates two major categories of technology-based high occupancy detection systems: roadside detection systems and in-vehicle systems.

3.1. Roadside Detection Systems

Roadside detection systems often involve the use of photographic-based systems to record vehicle occupancy from outside the moving vehicle. This review summarized studies and tested methods utilized in roadside detection system and photographic technology for HOV lane surveillance and enforcement.

3.1.1. Xerox Caltrans Pilot

The most recent study on video HOV detection technology was conducted by Xerox for the California Department of Transportation (Caltrans) pilot in Orange County, California, using the Xerox Vehicle Passenger Detection System (VPDS) [17]. Xerox installed VPDS equipment on the northbound lane of Interstate 5 with a view to the inside lane. Xerox VPDS was mounted on the driver side of the road in the shoulder area. This system employed two cameras. The front camera and front illuminator were mounted on a pole erected by Xerox and were aimed at the front windshield. The front camera was approximately 10-12 feet above the road surface, as shown in Figure 3.1. The side camera and side illuminator were mounted at approximately 3.5 feet on a structure installed by Xerox. The two cameras were separated by approximately 60 feet. The system utilized a laser to detect the presence of a vehicle in the lane. The laser was mounted on the Rear Seat Camera structure and aimed at the lane nearest the equipment. The laser was calibrated to not activate for vehicles in other lanes but to detect only those vehicles in the nearest lane. When the laser detected a vehicle in the lane adjacent to the equipment, both the Front Camera/Illuminator and the Rear Camera/Illuminator (Figure 3.2) were actuated and the front seat image and rear seat images were captured. Xerox collected a series of images in mid-January, 2015 to establish the scoring model.

Figure 3.1: Front Seat Camera and Illuminator

Figure 3.2: Rear Seat Camera and Illuminator

The scoring model was based on training data, which consisted of images collected and then scored by Manual Image Review. The Automated Model was created by humans sitting at computer screens reviewing images one by one. Through this painstaking process, the Manual Image Review scored each image as Occupied, Not Occupied, or Result Cannot Be Determined. The Xerox algorithm "learned" what constitutes as an occupied vehicle and what does not. This combined process uses computer machine vision and machine learning to establish a model that is then used by the system to automatically

score the vehicles it captures. Xerox established the ground truth model by reviewing 10,000 front camera images and 10,000 rear seat images, which were collected in mid-January, 2015. This model was then used over the period of January-March to gather images and assess the performance of the Xerox Vehicle Passenger Detection System, as well as to measure the performance of Human Roadside Observers and determine a violation rate for the HOV facility. Results of the pilot are shown in Table 3.1 [17].

Table 3.1: Summary of results of the Xerox Caltrans Pilot

		Declared	
Actual		SOV	HOV2+
	SOV	1781 (14.75%)	320 (2.65%)
	HOV2+	170 (1.41%)	9802 (81.19%)
		Total	12,073
Total Accuracy (TA)	95.94%		
Declared Violator Accuracy (DVA)	91.29%		
Missed Violator Error (MVE)	2.65%		
Violation Rate (Ground Truth)	17.40%		

The findings from the Caltrans Pilot of the Xerox Vehicle Passenger Detection System indicated that:

- The system was able to perform at an accuracy rate of 95+% for the purpose of identifying SOVs in the HOV lanes.
- Human Roadside Observers achieved a 36% accuracy rate during the pilot. This rate was lower than the automated rate due to the inability of human beings to identify occupancy status in vehicles driving past at 60-80 mph under various lighting and weather conditions.
- The Xerox system captured images at the rate of one every 0.3 seconds, which were immediately scored.
- The Xerox Vehicle Passenger Detection System showed great potential to detect vehicle occupancy at a high accuracy rate, which represents an opportunity to improve both throughput and enforcement.

3.1.2. California Department of Transportation (Caltrans)

Caltrans tested the use of videotaping in HOV lane surveillance and enforcement in 1990 [18] . The purpose of the study was to demonstrate and test video equipment in determining vehicle occupancy, documenting violator identity, and improving enforcement of HOV lanes. Field tests were conducted

for a period of six days to obtain vehicle occupancy information. The results were then analyzed to determine the feasibility, accuracy, and cost-effectiveness of using video cameras in HOV lane surveillance and enforcement. The preliminary findings made from field and subsequent tape review concluded that:

- After-dark videotaping was not feasible for gathering occupancy information; i.e., results were not clear in darkness or low visibility. However, was possible to videotape license plates from the rear using an infrared camera and light sources. It was necessary to play back the videotape to confirm that the suspected vehicle violated HOV requirements.
- The VOD false alarm rate was 21% when three cameras were utilized. When the third camera was removed and the remaining two cameras were tested, the false alarm rate increased to 51%.
- The missed occupancy observations for most vehicles depended on car design, camera angles, presence of glare-tinted windshields, and changing light conditions. These factors made it impossible to obtain 100% accuracy.
- The study concluded that video cameras operating alone could not identify the number of vehicle occupants with sufficient precision to support citations for HOV lane violations.

3.1.3. Minnesota Department of Transportation

The Minnesota Department of Transportation tested the potential of mid-infrared and near-infrared cameras for VOD. This study was carried out with the Department of Computer Science from the University of Minnesota from April 1998 to April 1999 [19]. The goal of the study was to determine if a reliable wave band and computer vision method could be used to automatically detect the number of vehicle occupants. The study first gathered images using mid-infrared cameras which did not require infrared illumination; then it conducted testing with near-infrared cameras. The tests were conducted under both day and night conditions. Key findings of this study indicated that the mid-infrared setup was not able to produce clear images at highway speeds or images through the front windshield, which is made of a material that blocks certain types of radiation. However, the mid-infrared setup was able to produce clear images through side windows. The near-infrared setup produced clear images under conditions of tinted windshield or side glass. These cameras could detect occupancy information at highway speeds. This study proposed the potential development of an automated vehicle occupant detection system using near-

infrared wavelengths. It also recommended future research to consider additional experimentation to analyze the performance of near-infrared technology under different conditions, such as diverse vehicle types and seating configurations and reclining passengers.

3.1.4. Georgia Tech-Developed Prototype

A study carried out by Georgia Tech Research Institute with the Georgia Department of Transportation (GDOT) focused on evaluating a reliable system of sensing HOV occupancy and acquiring vehicle data on the HOV/HOT lanes. A lab prototype imaging system was developed to capture images at a rate of two per second; the equipment consisted of a camera, an infrared illuminator, a vehicle trigger, a computer, and software to control the system [5]. Data was collected from selected points: the Georgia Tech Research Institute, other parts of the campus, and specific points on I-85. After analyzing images collected at varying distances, it was concluded that this technology was feasible in creating a detection tool for the HOV/HOT lanes [5]. Since then, the Georgia Tech Institute researchers have not reported any additional development of thedetection system prototype.

3.1.5. Leeds, United Kingdom

A research study funded by the United Kingdom Department of the Environment, Transport and the Regions began in Leeds 2003 with the intent to develop an automated VOD camera system. The resulting Cyclops system (Figure 3.3) used visible and near-infrared wavelengths to count vehicle occupants through the front windshield of oncoming vehicles at highway speeds. Testing of the system was conducted on the U.K's first HOV lane on A467 in Leeds in 2005. The system successfully detected vehicle occupancy at an accuracy rate of 95%, showing that infrared cameras under bright sunlight can detect human skin as a means of determining occupancy. However, challenges still remain in creating an infrared system to work under overcast lighting conditions or at dusk. Moreover, the cost of Cyclops technology is very high, coming at an estimated $165,000 per single lane [1].

3.2. In-Vehicle Detection Systems

VOD systems have largely focused on occupancy detection from the outside of the vehicle. However, there are emerging technologies of in-vehicle systems to detect the number of occupants within a vehicle. In-vehicle detection relies on the sensors that vehicle manufacturers place in cars. These developments rely

on the presence of air bag technology. The U.S. Federal Motor Vehicle Safety Occupant Crash Protection Standard requires the use of smart air bags in the front seats in all 2006 and later vehicles sold in the U.S. This review summarizes some of the in-vehicle systems.

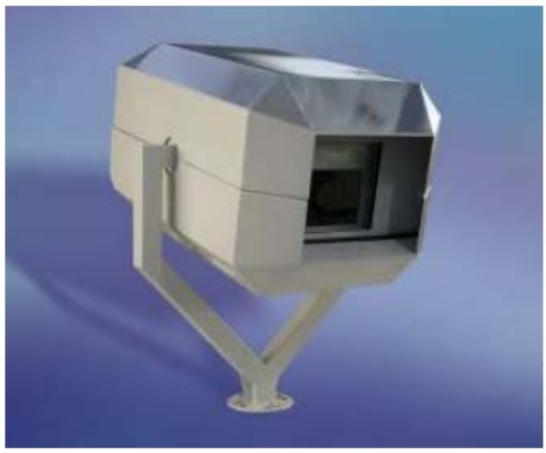

Figure 3.3: Cyclops Vehicle Occupancy Detection System

3.2.1. Weight Sensors

Weight sensors determine occupancy by measuring the weight applied on the seat by a passenger. Weight sensors are mostly used with air bag systems. Although these sensors have great potential for measuring occupancy, they may not be feasible for occupancy enforcement, given the possibility of fooling the sensor by placing a large weight in a seat to mimic a human occupant. However, this technology could still prove to be feasible if applied in combination with other occupancy-sensing systems.

3.2.2. Safety Belts

Safety belts are a basic device that could be utilized to determine vehicle occupancy. Similar to weight sensors, seat belts use sensors that are incorporated in the vehicle electronics. The challenge with using seat belts as indictors of occupancy is that a driver is able to leave the passenger belt buckled when there is no occupant. Moreover, this method of occupancy determination would still rely on an individual's willingness to buckle up, and 100% compliance in the general use has never been achieved [20]. This implies that seat belt use can lead to partially successful HOV lane enforcement only in situations where seat belt use is mandatory.

3.2.3. Ultrasonic / Radar Sensors

Radar sensors use acoustic sound with frequencies above the range audible to human ears and can be used to detect occupants within a confined space. Despite the equipment's high costs, the accuracy levels of this technology seem acceptable for HOV lane enforcement and monitoring [20].

3.2.4. Smart Cards and Readers

It is likely that items such as personal identity cards, driver's licenses, transit passes, toll highway transponders, and cellular telephones could be used to determine the number of occupants in a vehicle. However, the Smart Card technology may not be feasible given the fact that reading Smart Cards from the roadside at highway speeds could be challenging [20].

3.3. Summary of the Current HOV Occupancy Detection Studies

Based on the literature review completed as part of this study, the following observations were made:

- Most HOV lane monitoring and enforcement is largely done manually.
- While research indicates that no automated HOV detection systems have been established to detect 100 percent occupancy, commendable efforts have been made to develop systems to determine occupancy with a high degree of accuracy. The majority of these systems utilize roadside photography to detect the number of occupants within a vehicle.
- Past research indicates that there is great potential in improving photographic methods such as video, infrared, and near-infrared technologies to effectively detect the number of people within a vehicle. However, these technologies have challenges which need to be addressed when operating under various conditions involving lighting, weather, vehicle types, and small occupants.
- Most recent technologies are developing in-vehicle occupancy-sensing systems that rely on airbag safety requirements. These technologies might be utilized to communicate occupancy information to the outside roadside detection systems.

Additionally, there are issues associated with the privacy of occupants. In order for occupancy detection technologies to gain full acceptance, these issues need to be addressed. Some public awareness and educational programs have been utilized by some HOV lane operators to market their facilities.

4. REVIEW AND EVLAUATION OF OCCUPANCY DETECTION PRODUCTS

As discussed in Section 3.0, a wide range of technologies has been previously considered for use for vehicle occupancy detection (VOD) systems. Some technologies considered for monitoring and enforcement include:

- Mechanical systems,
- Photography/video,
- LED imaging,
- Infrared/thermal imaging,
- Weight sensors, and
- Ultrasonic/radar sensors [21].

Of these technologies, visible (photography/video) and infrared technologies have been identified through previous research as successful ways to capture evidence of the number of people (occupancy) in a vehicle [21]. Visible light and infrared-based technologies have been evaluated because they are not harmful to the human body, as other electromagnetic spectrum wavelengths are (for example, x-rays, gamma rays, and ultra-violet rays) [22] and are appropriate for use along highways. Visible light-based technologies utilize the visible spectrum, which can be seen by the unaided eye. The technology utilized for these systems are based on a wide variety of existing technologies [22]. Two bands of infrared have been determined to be applicable for use in VOD systems: reflected infrared and thermal infrared. Reflected infrared (0.7-3.0 µm) is associated with reflected solar radiation and contains no information about the thermal properties of a material, whereas thermal infrared (3.0-5.0 µm and 8.0-14.0 µm) is associated with the thermal properties of a material. Research has shown that EM radiation above 2.4 µm is severely attenuated when passing through glass and is not appropriate for vehicle occupancy detection. However, infrared (0.7-2.4 µm) has been shown to work for detection systems [22].

4.1. Evaluation of Technologies

A review was done to determine current vendors/developers of visible spectrum and infrared technologies. As seen through the literature review, a considerable amount of research has gone into the evaluation of visible and infrared VOD systems, but limited activity has occurred in the full-scale development of these technologies for commercial use. Despite the thoroughness of the research to

establish the technologies applicable for vehicle occupancy detection, only two developers of commercial scale systems were found: VODC and Xerox. At this time, Xerox was identified as having developed a visible light spectrum VOD system, while the Vehicle Occupancy Detection Corporation (VODC) was identified as a developer for an infrared product. To compare these technologies, a list of criteria and subcriteria were developed to aid in organization of collected information. The criteria included the following categories:

- Cost (renting/owning, educational equipment discount, contracting, technical support fees)
- Installation (installation type, ease of installation, equipment/software requirements, training provided)
- Maintenance and technical support (technical support, reported accuracy, calibration, operational life equipment)
- Operations (method of detection, system output, privacy of occupants, data format, data transfer technology, data collection per vehicle, sensitivity to environmental conditions)
- Additional information

A discussion of VODC and Xerox's technology is provided in the following section.

4.2. Vehicle Occupancy Detection Corporation Infrared Camera System

VODC is a start-up company based in Northern California and the United Kingdom that has developed an infrared-based technology to detect vehicle occupancy. The VODC system operates by projecting two wavelengths of low intensity infrared at an oncoming vehicle. As the beams are sent, a photo is taken. The system is housed in a weather- and vandal-proof housing, as shown in Figure 4.1 [23].

Figure 4.1: VODC Camera System

This system has been under development for the past few years and is not currently in full-scale production. In 2011, it was utilized in a research study conducted by the California Partners for Advanced Transit and Highways (PATH) [24]. This study found that the system had lower than expected accuracy rates of identifying passengers, ranging from a passing rate of 4.2% for controlled tests, 5.4% for semi-controlled tests, and up to 30% for uncontrolled tests. In the report, the main reason for this technical issue as identified by Vehicle Occupancy Limited (predecessor to VODC) was that the speeds used in the study were faster than the design speed of the equipment and that the equipment was not set up as recommended. In 2011, Vehicle Occupancy Limited had no United States-based staff to participate on site, and a third-party vendor was utilized [23]. The company is now headquartered in Northern California but retains its United Kingdom staff.

As discussed above, the tested system was designed to operate for vehicle speeds of up to 30 miles per hour. This system is called the P30 unit. VODC recently tested their P30 unit at the off-ramp of a dedicated carpool ramp in Southern California [23]. Vehicles in this location were estimated to be operating at 5-10 miles per hour. VODC stated that it was developing the P90 unit, which will be capable of taking images at highway speeds. At this time, the unit has not been fully tested. VODC is currently looking to secure outside financial support to fully implement production plans for their VOD systems. Information

about the VODC VOD system was provided through email correspondence, phone conversations, and an interview with Kenneth Brown, CEO and lead innovator for VODC. There are no current technical documents available for the system.

4.2.1. Cost

At this time, VODC did not provide a purchase or rental price for their VOD. Due to the capital required in the manufacturing of the VOD system, VODC is unlikely to provide equipment for free. VODC stated that costs may be high at this time because systems are custom made [25]. In the 2011 report, the estimated cost for the VDOC unit was listed at $150,000 [26]. This cost was not verified through correspondence with Ken Brown. VODC stated that a leasing arraignment for testing purposes might be possible, as well as the possibility of an educational discount. If TDOT wishes to procure this equipment, Mr. Brown stated that using a leasing company through a public-private partnership (P3) arraignment might be an advantageous means to facilitate the implementation of this system. VODC would potentially install the equipment for free and either guarantee that the revenue on each unit is greater than its monthly lease payment or provide some sort of shared revenue mechanism [25]. No information on contracting or technical support fees are known at this time.

4.2.2. Installation

The VODC system would be installed as a permanent hardwired system. The system requires dedicated electrical and internet connections for uninterrupted use. The system can be installed on sign gantry or on a pole on the side of the road. The system requires one camera for facial recognition. If a camera is installed on the driver side of the vehicle, it may only be able to see the driver, the front seat passenger, and the passenger side backseat passenger. Two cameras may be necessary to detect the driver side backseat passenger. The cameras are configured to look down at a 15-degree angle into the car and sideways at a 15-degree angle on the driver side. These angles allow the cameras to capture images of people in the front seat and, depending on where the camera is located, the back seat [25]. Limited information was provided on the software needed for the system. No information was provided on training, but it is expected that VODC would provide necessary training for the implementation of the system.

4.2.3. Maintenance and Technical Support

VODC reports that its system has a 96% accuracy, though no speed is indicated. At this time, it is assumed that accuracy is based on low vehicle operating speeds (30 miles per hour), since this is the speed used when the system was tested. As discussed above, the P90 system has not been fully implemented or tested at highway speeds; therefore, it is unclear what level of accuracy would be expected for its use in an HOV lane. No information was provided for technical support or calibration. Since VODC has no permanent installation, there is no information on the operational life of the equipment.

4.2.4. Operations

As discussed above, the VOD system utilizes shortwave infrared technology. Oxygen-rich, iron-carrying red blood cells in the human body reflect certain short-wave infrared frequencies at different rates. By illuminating a vehicle with these two wavelengths, taking a picture at each wavelength, and then superimposing the images on top of each other, the VODC system is able to differentiate a human being from a pet, a dummy, or an image [25]. The system provides software with timestamps, a geostamp, a picture of vehicle occupants, and a count of the people in the car. Examples of captured images are shown in Figure 4.2.

A mechanism is in place within the operating system to provide identity protection. The raw images can be used only within the agency collecting the images. If the images are sent to an outside agency, green dots are placed over the faces of the driver and passengers, as shown in Figure 4.3 [24]. This practice protects the privacy of the individuals in the images. This system is expected to operate under a variety of environmental conditions. Since visible light is not needed to capture an image, this system can operate in all lighting conditions, whether day and night and whether sunny or overcast. To keep the lens free of debris, an air knife is utilized.

Figure 4.2: Examples of Images Taken by VODC System

Figure 4.3: Examples of Images with Green Dots for Privacy

Through discussions with VODC, it was discovered that the camera system does not include a camera to capture license plate numbers. A license plate

recognition (LPR) system would be needed record the license plates of vehicles traveling in the HOV lane. Vigilant Solutions was contacted to provide technical information on the operation of an LPR in conjunction with a VOD system. The LPR consists of an integrated camera/processor unit which utilizes infrared and color imaging. The unit is hardwired and is connected to the internet. The unit can be installed on a pole or gantry to allow for the capture of a license plate. The camera can capture images at distances of up 65 feet, at speeds of up to 120 miles per hour. The unit calculates speed in order to report high-speed areas, average speed calculations by lane, and plan targeted speed enforcement. The system is not directly connected to the VOD system, but it utilizes a full-featured application programing interface (API) that is used by an integrator. The collected information from the VOD system can then be reviewed with the LPR, based on the timestamp of the non-compliant vehicle.

4.3. Xerox Vehicle Passenger Detection System

Xerox is a multibillion-dollar company headquartered in Norwalk, Connecticut with more than 140,000 people, serving clients in 180 countries. With its long history and expertise in image processing, video analytics, and computer vision, Xerox has translated these capabilities into developing the Xerox Vehicle Passenger Detection System (XVPDS), which uses video analytics to identify the number of occupants in a vehicle. Geometric algorithms detect whether a seat is vacant or occupied without using facial recognition. The system has been tested to identify the number of occupants in a vehicle with 95% accuracy, at speeds ranging from 5 to 100 mph. The high-quality images provided by the system, along with the evidence package, enable full automation of violations, as legislation allows.

4.3.1. Operations

The XVPDS uses video analytics to identify the number of occupants in a vehicle. The system is comprised of cameras, illuminators, and an algorithm based on computer vision techniques. The system is constructed using a front image camera and a side image camera to capture interior pictures of the vehicle. The system relies on standard, commercial-off-the-shelf traffic cameras, and it also utilizes standard loops or lasers for detection and triggering. The Xerox algorithm operates within the roadside video image processor and performs image analysis and establishes the count. Geometric algorithms detect whether a seat is vacant or occupied. If the system determines that the number of occupants in the vehicle does not meet HOV lane criteria, the license plate and

images from the vehicle can be transmitted to an enforcement officer. The enforcement office can then take appropriate action. The system can be configured to connect to fiber optics, Wireless Wide Area Networks (4G LTE), or Wi-Fi, depending on the needs of the installation. In addition, the system can include a removable hard drive (which is currently up to 3 TB but will expand as storage densities increase) to store the images.

Xerox states that its XVPDS has the capacity to identify the number of occupants in a vehicle with 98.9% accuracy for HOV-2 and 95.1% accuracy for HOV-3, up to highway speeds of 100 mph. The high-quality images provided by the system, along with the evidence package, could enable full automation of violations. The Xerox system protects the privacy of occupants by redacting the facial images as shown in Figures 4.4a, 4.4b, and 4.4c. There is also an option of reversing the redaction, but this process must be done by people with appropriate authorization, such as law enforcement or court personnel with a key enabling them to view the unredacted photographs.

Figure 4.4a: Original Xerox image

Figure 4.4b: Permanent Facial Redaction

Figure 4.4c: Reversible Reduction

4.3.2. Cost

At this time, the cost for Xerox and the three different packages have not been confirmed. It is uncertain whether or not Xerox will offer special educational pricing.

4.3.3. Installation

The installation options available for the Xerox systems include both fixed and mobile installation. Both options have the same accuracy rating, but both offer different benefits. With fixed installation, the system is designed to be attached on an existing structure such as a pole or mounted on a newly installed structure where it can source power and WiFi signals, etc.. The cameras, illuminators, and electronics package must be firmly attached to the structure and trained to ensure high preciscion system performance. Figure 4.5 is an illustration of a fixed installation unit. The Xerox equipment is also available as a mobile unit. The mobile unit is designed to be used in more than one location. This unit is a self-contained system that is mounted on a trailer, which allows it to be transported from place to place. This portability is especially advantageous for when changes occur in areas of frequent violations, however, it must be recalibrated at each new location which can be timely and expensive;. Safety and security of the mobile units are also considerations. Figure 4.6 is an illustration of a mobile installation unit.

Figure 4.5: Xerox Fixed installation System

Figure 4.6: Xerox Mobile installation System

The vehicle passenger detection system is offered in three different installation packages. The first package is the base configuration that comes with every installation and includes a front image camera, front illuminator, side image camera, side illuminator, video image processor, power conditioning unit, and trigger sensor to activate the illuminators and cameras. The other two packages depend on the interests of the user. Option 1 allows users to utilize existing

sensors by connecting XVPDS to sensors that are already installed as part of the existing infrastructure. Loop-based sensors or laser-based sensors are supported by the system using standard industry interfaces. Option 2 allows the system to Integrate with License Plate Recognition to create a violation and transaction package that includes license plate images and the results from a LPR module. The system can also be connected to a license plate recognition system—either an existing LPR system, or to a state highway patrol License Plate Recognition System.

4.3.4. Maintenance and Technical Support

Information on the Xerox system's operating parameters are shown in Table 4.1. No information was provided from Xerox on long-term operation or maintenance issues and support.

Table 4.1: Xerox Equipment Specifications

Specification	Value
Operating Temperature	-40º C to +70º C ambient*
Storage Temperature	-20º C to 80º C
Operating Humidity	20%-80% RH non-condensing
Operating Supply Range	208/240 VAC
Operating Supply Voltage Frequency	47-63 Hz
Rate of Speed	5-100 MPH
Data Storage	The data is encrypted and stored locally
Data Communications	Stored on local hard drive or connected to a wireless or landline network

5. HOV LANE UTILIZATION RATES

5.1. Evaluation Overview

Table 5.1 lists the coverage of HOV lanes in the state of Tennessee. Data was collected in selected locations along these HOV lane corridors (Figure 5.1), and operational performances were then evaluated with respect to 1) HOV lane utilization rates and 2) HOV lane occupancy violation rates. Data collection was aimed at gathering flow patterns by lane and vehicle occupancy. Nashville, as the metropolitan capital of Tennessee, hosts approximately 122 miles of the HOV lanes. Major traffic flows are often observed toward the downtown area on a.m. peaks, with I-65, I-24, and I-40 all feeding traffic to and from the city's outskirts. In Memphis, I-40 has approximately 13 total HOV lane miles, while I-55 has about 10 miles of HOV lanes.

Table 5.1: HOV Lane Miles in Tennessee

Location	Corridor	Direction	HOV Lane Miles
Nashville	I-40 East	Eastbound and Westbound	32
	I-24	Eastbound and Westbound	52
	I-65 North	Northbound and Southbound	10
	I-65 South	Northbound and Southbound	28
Memphis	I-40	Eastbound and Westbound	13
	I-55	Northbound and Southbound	10

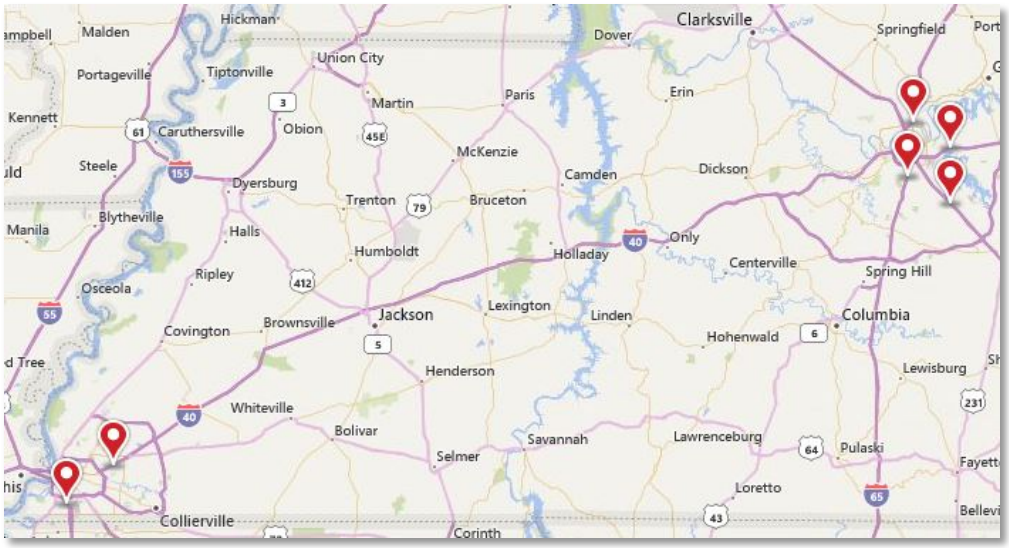

Figure 5.1: HOV Study Locations in Tennessee

5.2. Traffic Flow per Lane Data

Two sources of data collection were used: (1) a high-speed traffic video unit called Miovision Scout to measure traffic flow by lane and (2) manual/visual counting of-vehicle occupancy by observation of the HOV lanes only from overpasses. Data from an initial, physical drive along each of the identified HOV lane corridors for the study and use of GoogleEarth™ helped identify a number of sites as possible areas for traffic counts and occupancy observations. Elevated locations above the travel lanes were considered especially preferable for traffic-per-lane monitoring and visual/manual in-vehicle occupancy observation. Overpasses and bridges on top of the HOV segments were therefore considered to be the safest and best positions for gathering such data. The following sites were selected as data-gathering locations:

<u>I-65 corridor north of Nashville (mile markers 90-95)</u>

1. Due West Avenue bridge at mile marker 91.2 was used to place a Miovision Scout camera to count traffic flow by lanes (capturing both directions).
2. Chadwell Drive overpass at mile marker 91.8 was used for HOV lane in-vehicle occupancy counts.

<u>I-65 corridor south of Nashville (mile markers 79-62)</u>

1. Harding Place overpass at mile marker 78 was used to set up a Miovision Scout unit and record traffic flow by lanes (capturing all directions).

2. Cool Springs Boulevard bridge at mile marker 68 was used for occupancy counts.

I-40 east of Nashville (mile markers 216-232)

Old Hickory Boulevard overpass at mile marker 221 was used both for Miovision Scout unit traffic counts by lanes and for occupancy counts.

I-24 east of Nashville (mile markers 56-81)

1. Waldron Road overpass at mile marker 64.0 was used to set up a Miovision Scout unit and record traffic by lanes.
2. Fortress Boulevard overpass at mile marker 72.4 was used for occupancy counts.

I-55 in Memphis (mile markers 0-5)

Winchester Road overpass at mile marker 5.0 was used to set up a Miovision Scout unit and record traffic by lanes.

I-40 sites in Memphis (mile marker 15-22)

Whitten Road overpass at mile marker 14.0 was used to set up a Miovision Scout unit and record traffic by lanes.

5.3. Equipment and Personnel

The Miovision Scout unit (Figure 5.2) was used to measure traffic flow per lane, and occupancy counts were made using simple visual observation, supported by a tallying app (Figure 5.3). The Miovision Scout unit is a traffic-counting device with video recording attributes that count and classify traffic per lane. This camera system was mounted on a stand with its top camera directed toward one direction of traffic, fixed right above the overpass sidewalk rails, looking down on traffic. The team set up the camera to record vehicles in all lanes, moving in both directions. Figure 5.2 shows the Miovision Scout system and its stand. The data collection was conducted by two teams, each of which included two students from either Tennessee State University or Vanderbilt University. Each group conducted similar data collection of weekday counts on the same corridor but on different segments of the HOV lane.

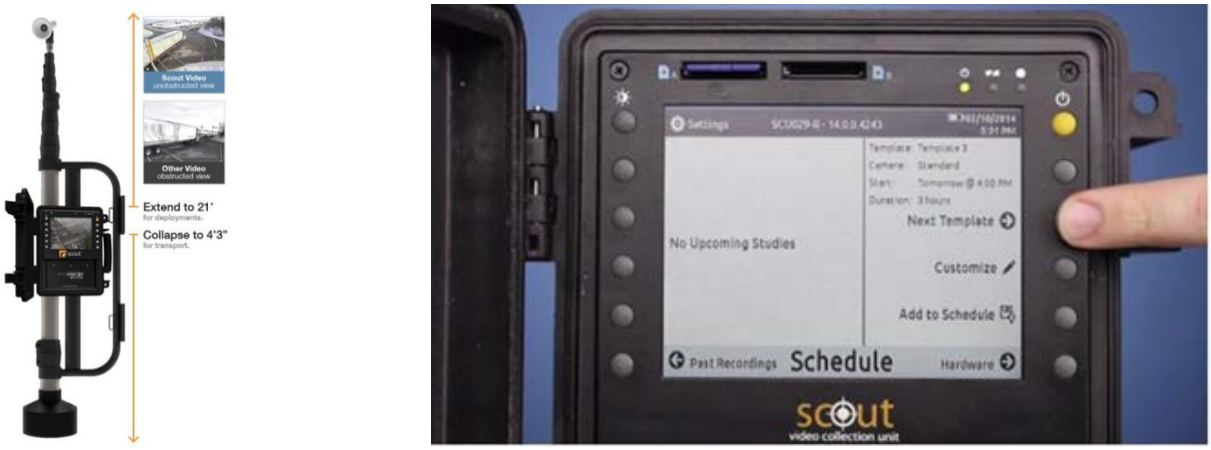

Figure 5.2: Miovision Scout (Traffic Counting Device)

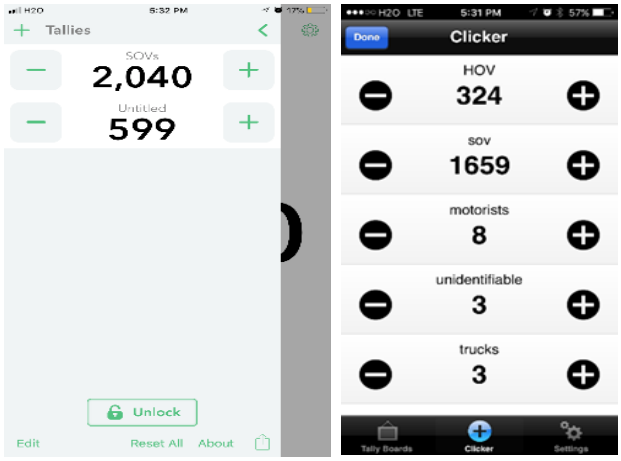

Figure 5.3: Snapshot Tallying App

5.4. Utilization Data Collection Dates and Times

Data was collected in two rounds, with round 1 occurring in summer (June and July) and round 2 in fall (September and October) to capture seasonal traffic flow variations. Table 5.2 summarizes the data collection dates at each site. All data was collected during morning peak hours (7:00 to 9:00 a.m.) and evening peak hours (4:00 to 6:00 p.m.)

Table 5.2: Utilization Data Collection Dates

	Round 1 Data			Round 2 Data		
	Date	A.M. Hours	P.M. Hours	Date	A.M. Hours	P.M. Hours
I-65 @ West Due W. (North of Nashville)	6/21/2017	7-9 a.m.	4-6 p.m.	09/27/2017	7-9 a.m.	4-6 p.m.
I-65 @ Harding Pl. (South of Nashville)	6/27/2017	7-9 a.m.	4-6 p.m.	10/04/2017	7-9 a.m.	4-6 p.m.
I-40 @ Old Hickory Blvd. (East of Nashville)	6/28/217	7-9 a.m.	4-6 p.m.	09/28/2017	7-9 a.m.	4-6 p.m.
I-24 @ Waldron Rd. (East of Nashville)	6/29/2017	7-9 a.m.	4-6 p.m.	10/05/2017	7-9 a.m.	4-6 p.m.
I-55 @ Winchester Rd. (South of Memphis)	7/19/2017	7-9 a.m.	4-6 p.m.	10/18/2017	7:30-9:30 a.m.	4-6 p.m.
I-40 @ Whitten Rd. (East of Memphis)	7/20/2017	7-9 a.m.	4-6 p.m.	10/17/2017	7-9 a.m.	4-6 p.m.

5.5. HOV Lane Utilization Rates

Table 5.3 summarizes the data collected by lanes and the utilization rates. The per lane traffic counts using the Miovision Scout video unit were disaggregated and sorted before calculating utilization rates. The maximum recorded HOV lane flow was 3,287 vehicles along I-40 westbound near Whitten in Memphis. The utilization of the HOV lanes during peak hours was evaluated as the percentage of vehicles that use the HOV lane to those using general purpose (GP) lanes, as shown in equation 5.1.

$$\text{HOV Utilization Rate} = \frac{\sum \text{HOV lane traffic}}{\sum \text{GP lanes traffic} + \text{HOV lane traffic}} \qquad 5.1$$

Table 5.3 shows I-65 on the north side of Nashville having the lowest utilization rates, especially during a.m. hours. This section of I-65 has a high number of lanes per direction (7 through lanes for each direction) which might have distributed the traffic, resulting in this low HOV lane utilization rate. The study section has seven lanes in northbound and southbound directions.

Table 5.3: Traffic Flows by Lane and Utilization Rates

	A.M.							
	Toward Nashville Downtown				Out of Nashville Downtown			
	HOV Lane	GP (Adjacent to HOV)	All other GP lanes	Utilization	HOV Lane	GP (Adjacent to HOV)	All other GP lanes	Utilization
I-65 South of Nashville	3312	3994	6530	24%	3210	3818	4903	27%
I-65 North of Nashville	1952	2258	11131	13%	353	1208	5976	5%
I-24 East of Nashville	2090	2609	3374	26%	1589	2138	3620	22%
I-40 East of Nashville	1897	2469	2804	26%	618	1361	1732	17%
	P.M.							
	Toward Nashville Downtown				Out of Nashville Downtown			
	HOV Lane	GP (Adjacent to HOV)	All other GP lanes	Utilization	HOV Lane	GP (Adjacent to HOV)	All other GP lanes	Utilization
I-65 South of Nashville	2820	3479	4777	25%	3248	3017	5384	28%
I-65 North of Nashville	834	1399	6680	9%	2369	2554	10508	15%
I-24 East of Nashville	2139	2495	3061	28%	3634	3554	6269	27%
I-40 East of Nashville	748	1525	1980	18%	2444	2788	3008	30%
	A.M.							
	Toward Memphis Downtown				Out of Memphis Downtown			
	HOV Lane	GP (Adjacent to HOV)	All other GP lanes	Utilization	HOV Lane	GP (Adjacent to HOV)	All other GP lanes	Utilization
I-55 South of Memphis	2062.5	2339.5	5002	22%	934	1492	2389	19%
I-40 East of Memphis	2661	2895	4007	28%	1120	1870	3166	18%
	P.M.							
	Toward Memphis Downtown				Out of Memphis Downtown			
	HOV Lane	GP (Adjacent to HOV)	All other GP lanes	Utilization	HOV Lane	GP (Adjacent to HOV)	All other GP lanes	Utilization
I-55 South of Memphis	900	1764	3223	15%	2626	3125	4825	25%
I-40 East of Memphis	1867	2461	3301	24%	3436	3314	4871	30%

Table 5.4 shows the average utilization rates in and out of Nashville and Memphis downtown areas; (the 5% utilization is excluded in the average, as it seems to be an outlier). As shown, the average HOV lane utilization during morning (a.m.) hours toward downtown areas is 22% for Nashville area and 25% for Memphis area. The HOV lane utilization when traffic is moving outside

downtown areas during p.m. peak hours are 25% for Nashville area and 27% for Memphis area. Combining Nashville and Memphis area numbers, the a.m. HOV lane utilization rates toward downtown areas in Tennessee is about 24%, and the utilization rate during p.m. peak hours from downtown areas is 26%. Overall, the average of combined utilization of HOV lanes in Tennessee is 23%.

Table 5.4: Average Utilization Rates to and from Downtown Areas

	HOV Utilization Rates	
	A.M.	P.M.
Toward Nashville Downtown	22%	20%
Out of Nashville Downtown	22%	25%
Toward Memphis Downtown	25%	20%
Out of Memphis Downtown	19%	27%

6. HOV LANE OCCUPANCY VIOLATION RATES

HOV lane occupancy data was gathered during peak hours within the same periods the traffic flow per lane data was collected. These in-vehicle occupancy visual inspections were conducted from a high point (bridge/overpass) above the subject HOV lane. The aim was to determine whether the occupants in the vehicles traveling on the HOV lane had one (single occupancy vehicle (SOV) or two or more people (HOV). Observation line of sight were restricted to the front of the vehicle, with the basic assumption that for users in ride sharing, occupants are mainly expected to sit in the two front seats. This assumption might have falsely counted as single-occupant vehicles (SOVs) some vehicles with passenger occupants seated in the back seat. The HOV lane occupancy violation rate is therefore determined as shown in equation 6.1.

$$\text{HOV Lane Violation Rate} = \frac{\text{SOVs on HOV Lane}}{\text{SOVs+HOV on HOV Lane}} \qquad 6.1$$

There were two observers at each data collection location, each independently counting SOVs and HOVs along the HOV lane while observing traffic from a single point. The data collection segments were the same as the utilization data locations (Table 5.2). The Miovision video units recorded traffic footage from the start to end of the HOV operational time (7-9 a.m. and 4-6 p.m.); the footage was used to confirm occupancy manual counts. An app called "TallyIt!" (Figure 5.3) was used to log vehicle type as either an SOV or an HOV.

6.1. HOV Lane Occupancy Violation Results

Tables 6.1 and 6.2 summarize and provide detail about the average HOV occupancy violation rates per HOV highway segment; HOV traffic data collected in round 1 and 2 were averaged. As shown, violation rates vary by route and location. Overall, the HOV violation rates are around 83% along all HOV lane corridors. The summary shows that the HOV lane occupancy violation rate traveling toward downtown Nashville (a.m. hours) is 82%, and outward from downtown Nashville (p.m. hours) is 81%. Likewise, the HOV lane occupancy violation rate traveling toward downtown Memphis (a.m. hours) is 88%, and the rate outward from downtown Memphis (p.m. hours) is 86%. Rates in Table 6.1 and 6.2 indicate that HOV lane violations are high in Memphis compared to Nashville HOV corridors (87% vs. 81%). Only 15% to 20% of vehicles using HOV lanes were those with 2+ occupancy, as required by law. A higher percentage

of the vehicles using HOV lanes during HOV operational hours were SOVs. The p.m. traffic was found to be slightly higher than that of the a.m. traffic; however, the a.m. violation rates were higher than p.m. violation rates.

It was also observed that some corridors have a substantial variation in the number of violations between two exit/entrance ramps. For instance, along I-65 north of Nashville, the northbound p.m. HOV lane traffic increased by about 27% between Due West Avenue and Chadwell Drive, probably due to incoming northbound traffic from Briley Parkway (SR 155) and the effect of the upstream Old Hickory Boulevard exit ramp. Also of note are the number of general occupancy lanes available. For example, at Due West—the fact that there are five lanes to choose from as multiple roadways come together may contribute to traffic utilizing or not utilizing the HOV lanes.

During data collection, a few observations were made. First, some SOVs noticed the field crew and moved out of the HOV lanes just before arriving at the data collection site. These were counted as being in violation because they likely only moved due to fear of being caught. Secondly, the volume of traffic varied during the HOV lane period; traffic appeared to be lighter early in the afternoon HOV duration. Some vehicles had heavily tinted front windshields that prevented the viewing of drivers and/or passengers. Therefore, these vehicles were counted as violators among the broader population. Utilization of the HOV lanes appeared to vary with distance from the core Nashville area; however, it was impossible to conduct data collection at a similar distance on each corridor due to safety requirements involved in selecting the data collection sites along each corridor. These factors may affect the results obtained.

Table 6.1: Summarized HOV Lane Occupancy Violation Rates

	A.M. HOV Lane Violation Rate (Toward Downtown)	P.M. HOV Lane Violation Rate (Out of Downtown)
I-65 North Side of Nashville	83%	83%
I-65 South Side of Nashville	81%	82%
I-40 East Side of Nashville	85%	79%
I-24 East Side of Nashville	79%	79%
I-40 East of Memphis	87%	86%
I-55 South of Memphis	88%	86%

Table 6.2: Detailed HOV Lane Occupancy Violation Rates

Data Location		A.M. Peak		P.M. Peak	
		Violation Rate	Total on HOV Lane (SOV)	Violation Rate	Total on HOV Lane (SOV)
I-65, North of Nashville	Chadwell Dr.	83%	1970 (1635)	84%	2639 (2201)
	Due West Ave.	Data Not Collected		80%	2083(1669)
	Average	83%		83%	
I-65, South of Nashville	Cool Springs Blvd.	79%	1275(1005)	83%	1545(1278)
	Harding Place	82%	2673(2208)	81%	3071(2477)
	Average	81%		82%	
I-40, East of Nashville	Old Hickory Blvd.	85%	1820(1543)	79%	2500(1983)
I-24, East of Nashville	Waldron Rd.	85%	2036(1731)	79%	2757(2161)
	Fortress Blvd.	73%	1224(898)	Data Not Collected	
	Average	79%		79%	
I-40, East of Memphis	Whitten Rd.	87%	2414(2110)	8i6%	3323(2861)
I-55, South of Memphis	Winchester Rd.	89%	1924(1712)	85%	2584(2187)

7. PUBLIC OPINION SURVEY

Another portion of the project focused on creating and administering a public opinion survey with a emphasis on HOV lane usage, violations, and interest in options to reduce congestion, such as the conversion of HOV lanes to high occupancy toll (HOT) lanes. The Vanderbilt portion of the team was responsible for leading this effort.

7.1. Survey Design and Administration

The research team first performed a review of best practices for survey design and implementation. REDCap was chosen as the platform for creating an online survey to most efficiently reach a large number of participants and manage survey results effectively. REDCap is a secure web application for building and managing online surveys and was an application to which Vanderbilt team members had access. Vanderbilt IRB approval was obtained for the survey, as well as the approval of appropriate TDOT personnel.

A sample survey was administered and tested among members of the Department of Civil and Environmental Engineering at Vanderbilt to ensure that questions were not confusing in their wording and the survey was not cumbersome to complete. From this beta test, in addition to input from TDOT personnel, the survey was refined to reflect feedback and improve the user experience. The final survey instrument consisted of fourteen questions, including branching logic, as well as an opportunity to provide additional comments at the end of the survey. The final survey instrument can be found in Appendix 4; however, question logic and the online pagination is not easily represented in the paper version.

Targeted survey participants included anyone within the vicinity of Nashville or Memphis that utilized the interstate corridors of interest to this study, whether they utilized the HOV lanes or not. The objective was to garner as much information as possible about public opinion of the utilization of the HOV lanes currently in operation, violations, interest in alternatives for promoting use and reduction in congestion, etc.

The Research Electronic Data Capture (REDCap) online survey software allowed for creation of a link[1] that could be shared with participants. This link was used to recruit participants to the survey through an advertisement through Vanderbilt media to employees, emails to TDOT employees, TSU employees, and others across the state. Individuals interested in participating were also encouraged via email to pass the survey along to anyone they knew who might be interested to broaden the exposure. The Vanderbilt Co-PI and others involved in the project or simply interested in HOV lane usage shared the survey link and information via social media such as Facebook and Twitter.

7.2. Overview of Survey Responses

Survey responses were collected from November 30, 2017 to February 6, 2018. This range allowed for reminders to be sent out and to ensure that surveys were administered throughout both TDOT and the universities involved in the study. In total, 767 responses were collected. Of these, 101 surveys were incomplete; however, they were still considered to be valid, since their incompletion may have been due to individuals becoming interrupted. Therefore, any completed answers on both complete and incomplete surveys were included in the analysis. The majority of respondents were from the middle Tennessee area, but those outside the Middle Tennessee or Memphis area were not excluded from the analysis due to consideration that other tax-paying members of the state who travel to Nashville or Memphis may also utilize these corridors for work or leisure. The survey was focused primarily on the Nashville-area HOV lanes, due to the high violation rates. A similar effort to collect pertinent information for the Memphis area could be performed at a later date. Preliminary geographic distribution analysis found that 574 of the survey respondents reported zip codes within 50 miles of Nashville and 623 within a 100-mile range of Nashville city center. Only 33 respondents were within a 100-mile range of Memphis. Figure 7.1 provides a distribution of survey respondents across the state.

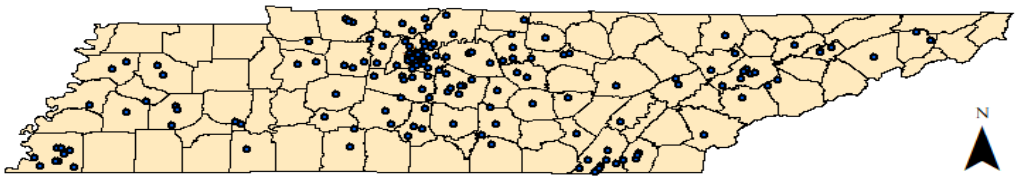

Figure 7.1: Distribution of Survey Respondents Across Tennessee

[1] The link to this online survey is https://redcap.vanderbilt.edu/surveys/?s=MPW4LRAAWR.

7.3. HOV Survey Results

Responses to individual survey questions are provided below in their order of appearance in the survey. These questions inquire about which corridors are traveled in order to better understand the distribution of respondents, with a key focus on the Nashville area. Participants were asked about HOV lane usage, knowledge of violations, carpooling, automated violation detection, fines, etc. When asked about the corridors of interstate used, those using the I-40 corridor for both morning and evening were represented in greatest numbers among survey participants, representing more than 20% in either direction, but all corridors were represented (Figure 7.2). Interstate 65 was the least represented in respondents for both a.m. and p.m. usage.

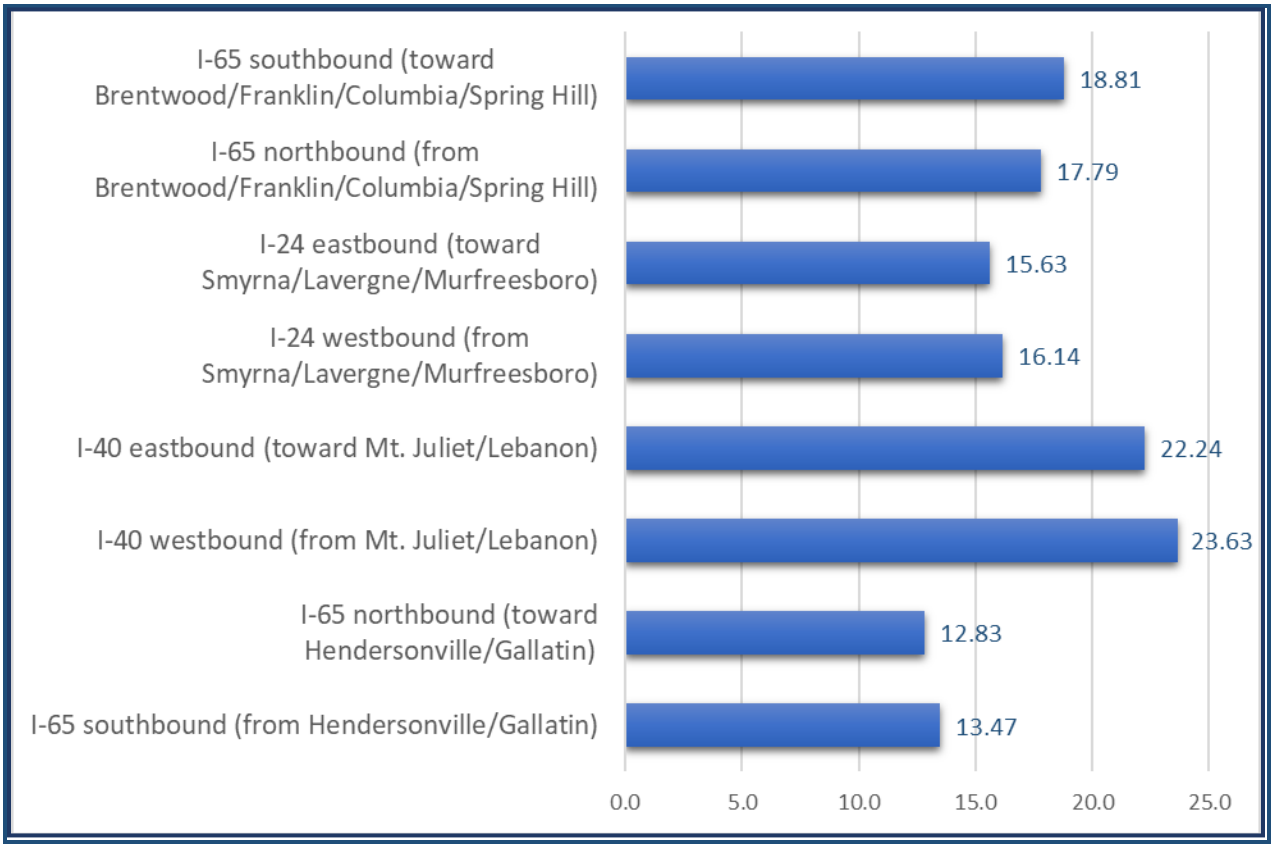

Figure 7.2: Distribution of Survey Respondents Across Nashville Area HOV Corridors

The vast majority (over 65%) of survey respondents never use the HOV lane, with approximately 20% of respondents utilizing it three to five times per week (Figure 7.3). Surprisingly, the percentage of respondents who utilize the HOV lanes 10 or

more times per week (presumably as part of their regular workweek commute) totaled only 4%.

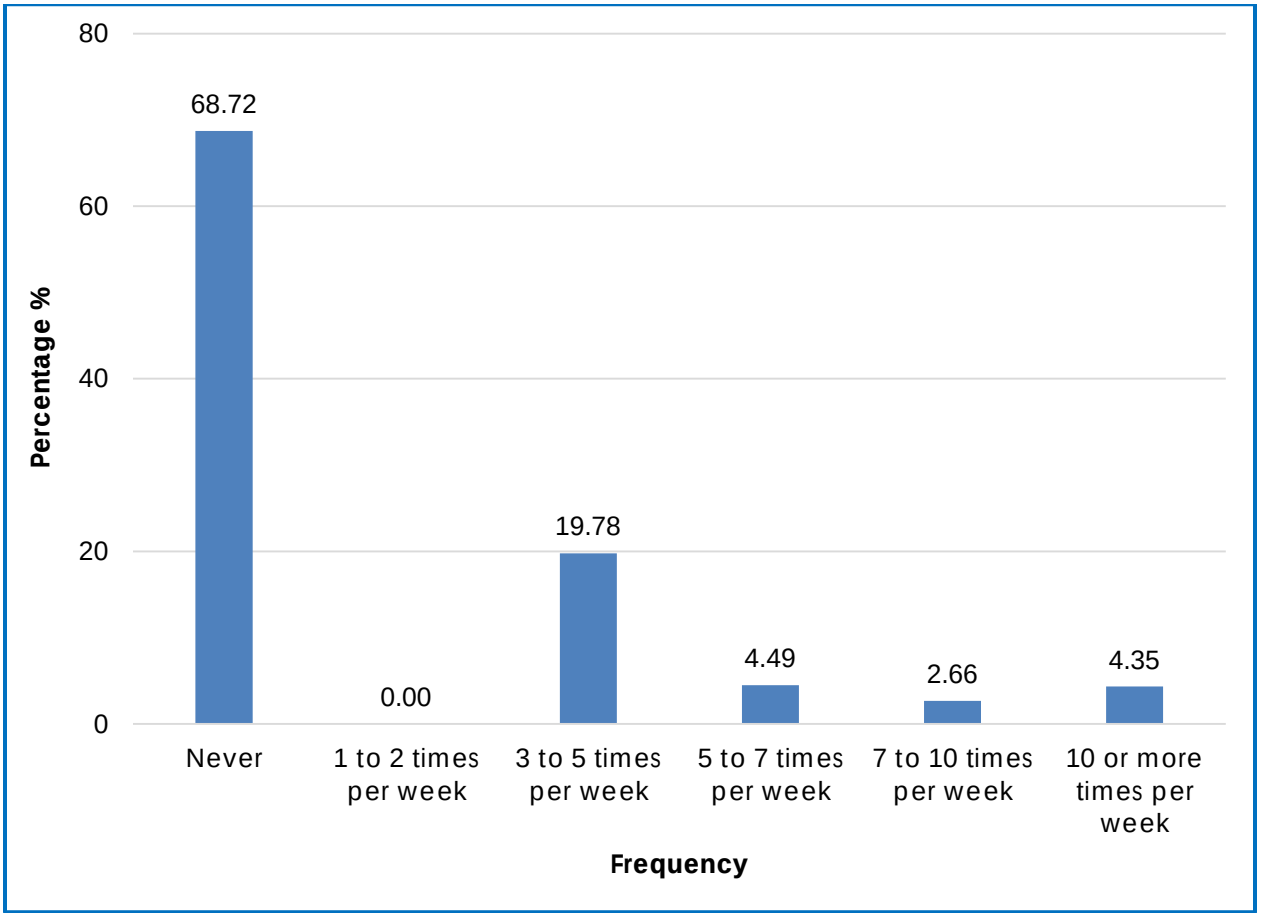

Figure 7.3: Weekly Usage of HOV Lanes

While nearly 69% of respondents say that they never use the HOV lane, when asked about peak hour driving activities, the more popular responses for usage of the HOV lanes were for driving alone, carpooling with non-household members, and carpooling with household members (Figure 7.4). Approximately 19 percent and 20 percent of individuals said they drive alone always and very often, respectively. Additionally, 56% of respondents indicated that they personally know someone who has violated the HOV lane rules. The primary destinations for using the HOV lane was driving to and from work (78%), while only 2% were traveling to or from school, and approximately 20% use HOV lanes for errands or other purposes.

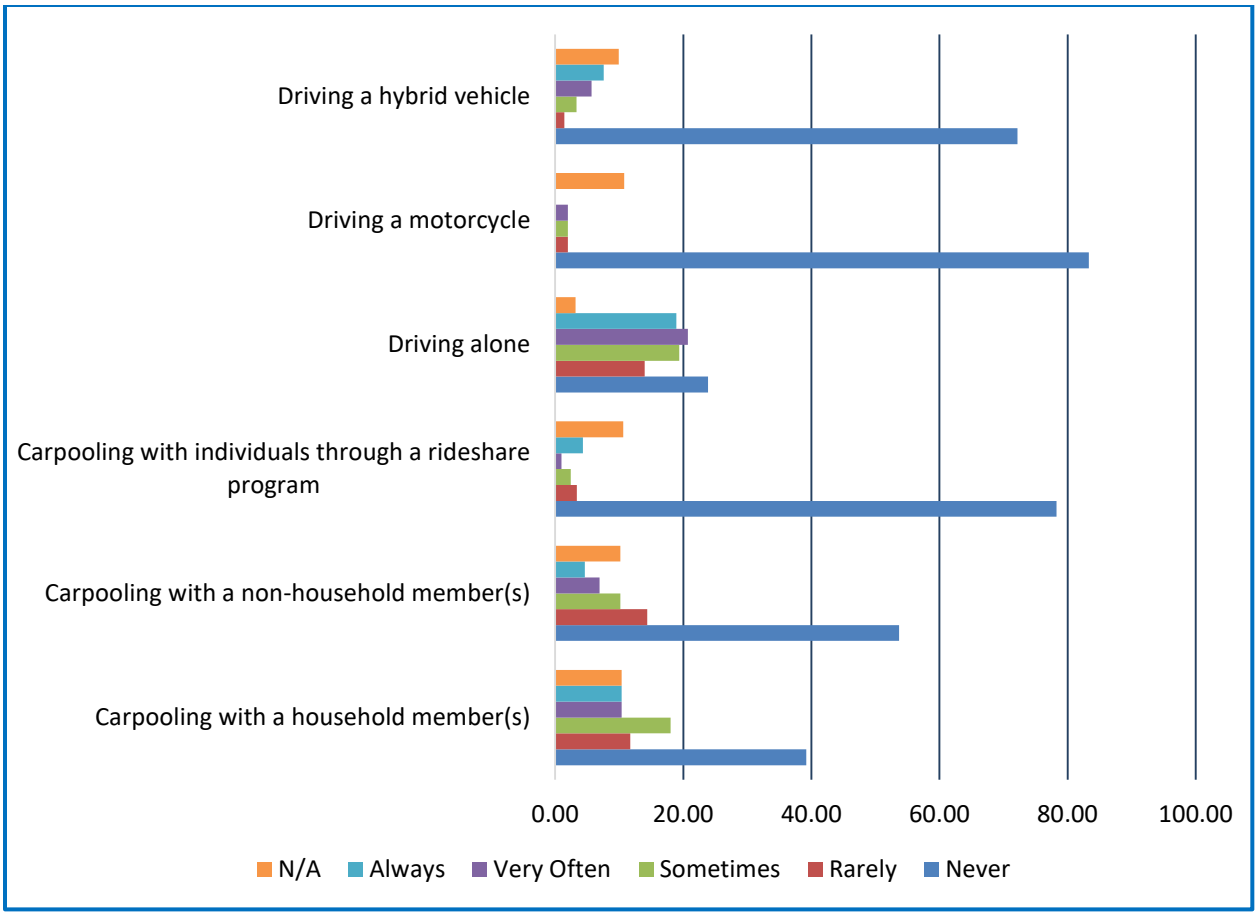

Figure 7.4: Peak Hour Usage of HOV Lanes

The average number of individuals when carpooling is 2, as indicated by 76% of respondents that said they carpool. Nearly 15.5% of individuals indicated that they carpool in groups of 3 to 4 individuals, and 8.65% of individuals travel in groups of 6 or more, such as vanpools. Only 2% of respondents reported having a SmartPass. The group of participants was split on whether or not the HOV lanes should continue to be implemented, with 50.36% in favor of keeping the HOV lanes and 49.64% in favor of having them removed. A similar split occurred when asked about support of automated systems such as high-resolution cameras and license plate readers to identify and fine HOV lane violators. On this topic, 50.29% were in favor of automated enforcement, while 49.71% of respondents were against it. Respondents were also asked what they felt was an appropriate fine for HOV lane violations. The majority (62%) was in favor of a fee of $50 to $100, which is in agreement with the current $50 fine. Only 14% thought the fine should be $101 to $150, and about 13% felt it should be as high as $251 to $300.

Many states have moved toward a high-occupancy toll (HOT) lane option to allow single-occupant drivers the ability to benefit from the faster speeds associated with HOV lane usage for a fee. This option has raised concerns (in the comments provided by respondents and others) that this alternative is a privilege tax for those who can afford to pay. Of those responding here, only 44% indicated that they would be interested in conversion of the HOV lanes to HOT lanes. However, 69% of respondents would favor a $1-2/day fee for HOT lane access, with 17% in favor of a $3-4/day fee, 11.5% in favor of a $5-6 fee and only a few (less than 2.5%) in favor of fees greater than $7/day (Figure 7.5).

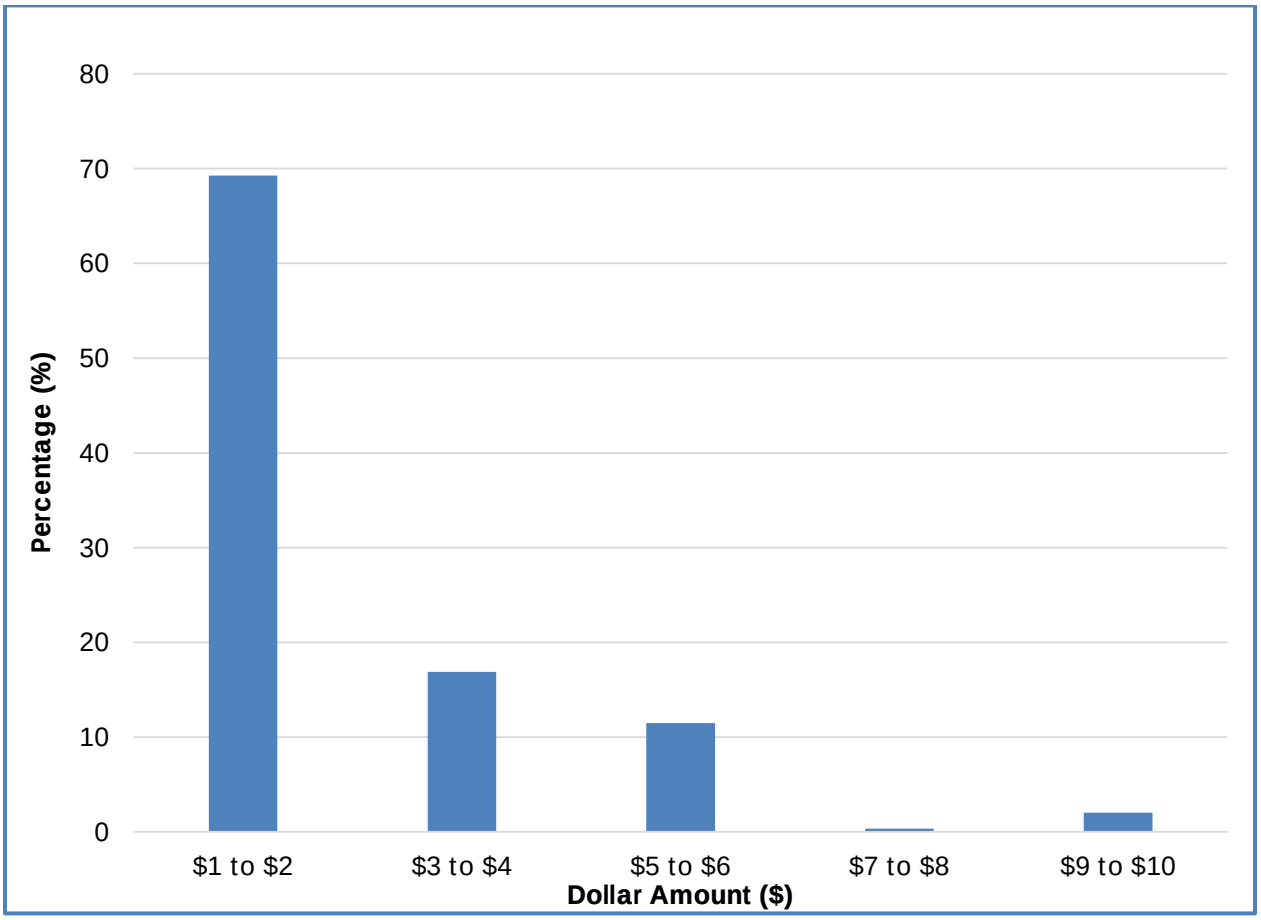

Figure 7.5: HOT Lane Fee Preferences

In addition to the questions provided, participants had the opportunity to provide unsolicited comments at the end of the survey. One hundred sixty-six individuals chose to utilize this option. A compilation of the unedited comments is provided in Appendix 5. A few additional commentaries were provided to the research team via emails that were similar in nature but not included here.

Many voiced concerns and grievances about the ineffectiveness of the HOV lanes in the Nashville area, and several stated their opinion of what the problem is, including but not limited to lack of enforcement. The comments make it apparent that many recognize that the HOV lanes in the Nashville area have issues and appear to want improvements. However, it is not apparent that HOT lanes would be highly favored or that the rates that individuals are willing to pay would offset the cost of the infrastructure required facilitate HOT lanes in the area. The majority of respondents did not favor higher fees as a deterrent for violations, while many commented on their interest in seeing enforcement.

The public, at least those who participated, with a large majority of representation coming from the I-40 corridor, is split on whether or not HOV lanes should remain in effect in the Nashville area. Given the high violation rates observed by the research team, only enforcement or alternatives such as HOT lanes will likely lead to more efficient traffic movement and reduced congestion in the area. Educational programs, coordinated ride share opportunities, or expansion of vanpools may also provide some relief to the congestion in key areas.

8. CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to evaluate the HOV lane operations in Tennessee with the expectation that the findings could be used by TDOT to enforce and detect HOV lane occupancy, improve person-moving capacity and travel reliability, and promote ride-sharing. The study was conducted in two parts. The first part focused on a comprehensive literature review on the use of HOV occupancy detection systems from other states or countries. The second part evaluated the utilization of the HOV lanes, as well as the HOV lane occupancy violation rates in Tennessee.

Through literature review, the study evaluated state-of-the-art occupancy detection technologies that can assist TDOT in monitoring Tennessee's HOV system. This evaluation was also aimed as a strategy to address HOV lane high violation rates and provide recommendations for the most appropriate technology for TDOT to employ. The study found that infrared (IR) technology is superior to the visible light-based technology. The study identified and recommended acquiring and testing infrared (IR) technology from Xerox, known as the Xerox Vehicle Passenger Detection System (XVPD), for piloting and possibility implementing in Tennessee in the future. XVPDS has off-the-shelf technology available for near-immediate testing and implementation. The XVPDS system is available as a stand-alone product and can be installed as a fixed or mobile unit. The XVPDS system has been tested under pilot studies in the United States and is able to determine occupancy at highway speeds of up to 100 mph. The accuracy of XVPDS is reported to be 98.9% for HOV2 lanes and 95.1% for HOV3 lanes. Though TDOT discontinued piloting XVPDS as part of this study, Xerox is offering the system for pilots and is seeking interested parties that will participate in the test and evaluation of the system.

The second part of the study evaluated utilization of the HOV lanes during peak hours. This utilization encompassed the percentage of vehicles that use the HOV lane compared to all other general purpose (GP) lanes. The traffic flow per lane was collected for two hours during both a.m. and p.m. peak periods (7-9 a.m. and 4-6 p.m.) along HOV lane segments on I-65, I-24, and I-40 in Nashville areas and I-55 and I-40 in Memphis areas. The study found that the average HOV lane utilization during morning (a.m.) hours toward downtown areas is 22% for Nashville areas and 25% for Memphis areas. The HOV lane utilization when traffic is moving outside downtown areas during p.m. peak hours are 25% for Nashville

and 27% for Memphis. Combining Nashville and Memphis area numbers, the a.m. HOV lane utilization rates toward downtown areas in Tennessee is about 24%, and the utilization rate during p.m. peak hours from downtown areas is 26%. The average of all segments combined translates to 23% utilization of HOV lanes in Tennessee.

The HOV lane occupancy violation rates was evaluated by taking the percentage of single occupancy vehicles (SOVs) to the total vehicles using HOV lane during the study's a.m. and p.m. peak hours. The data was collected manually by having two people observing inside the vehicles on HOV lanes from an elevated location (bridge/overpass). The two observed traffic from a single point, gathering the same data on the same vehicles, and the two sources of data were used to validate each other; (they were mostly identical). The number of manual traffic counts were verified using the traffic flow per lane counts. The analysis of data showed that the HOV lane violation rates are around 83% along all HOV lane corridors in Tennessee. The HOV lane occupancy violation toward Nashville downtown (a.m. hours) is 82%, and outward from Nashville downtown (p.m. hours) is 81%. The HOV lane occupancy violation toward Memphis downtown (a.m. hours) is 88%, and outward from Memphis downtown (p.m. hours) is 86%.

The final portion of the study focused on gathering input from the public on the usage of HOV lanes in the Nashville area, interest in HOT lanes, knowledge of violations, and appropriate willingness to pay for alternatives. In general, 56% reported knowing someone who has violated the HOV lane restrictions. The majority of respondents that utilize the HOV lanes do so only 3-5 times per week, with only two individuals in the vehicle. The respondents were split nearly in half as to whether or not the HOV lanes should remain in effect and also in the utilization of automated enforcement. Similarly, slightly more than half of the respondents expressed interest in HOT lanes, with the preferred daily fee for HOT lane access being $1-$2. However, anecdotal comments about improved (not necessarily automated) enforcement were common among participants. Therefore, a challenge remains as to which options would most benefit the users of the Nashville area HOV lanes.

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Appendix 1: Individual Sites Utilization Rates

HOV Lane Utilization Rates (Summer 2017, June and July Data)

I-65 @ West Due W. (North of Nashville)	Northbound	4.4% (from Nashville)	14.7% (from Nashville)
	Southbound	11.7% (to Nashville)	9.4% (to Nashville)
I-65 @ Harding Pl. (South of Nashville)	Northbound	20.5% (to Nashville)	21.5%
	Southbound	20.7%	26.7% (from Nashville)
I-40 @ Old Hickory Blvd. (East of Nashville)	Eastbound	16.7%	29.9%(from Nashville)
	Westbound	23.3%(to Nashville)	17.9%
I-24 @ Waldron Rd. (East of Nashville)	Eastbound	19.8%	27.5% (from Nashville)
	Westbound	26.2% (to Nashville)	26.7%
I-55 @ Winchester Rd. (South of Memphis)	Northbound	17.7% (to Memphis)	15.0%
	Southbound	17.4%	24.4% (from Memphis)
I-40 @ Whitten Rd. (East of Memphis)	Eastbound	17.7%	29.1% (from Memphis)
	Westbound	27.9% (to Memphis)	23.8%

HOV Lane Utilization Rates (Fall 2017, September and October Data)

I-65 @ Chadwell Dr. (North of Nashville)	Northbound	5% (from Nashville)	16% (from Nashville)
	Southbound	14% (to Nashville)	9% (to Nashville)
I-65 @ Harding Pl. (South of Nashville)	Northbound	28% (to Nashville)	30%
	Southbound	34%	29% (from Nashville)
I-40 @ Old Hickory Blvd. (East of Nashville)	Eastbound	17%	29%(from Nashville)
	Westbound	30%(to Nashville)	17%
I-24 @ Waldron Rd. (East of Nashville)	Eastbound	22%	26% (from Nashville)
	Westbound	28% (to Nashville)	29%
I-55 @ Winchester Rd. (South of Memphis)	Northbound	25% (to Memphis)	16%
	Southbound	21%	25% (from Memphis)
I-40 @ Whitten Rd. (East of Memphis)	Eastbound	19%	30% (from Memphis)
	Westbound	28% (to Memphis)	25%

Appendix 2: Individual Sites Violation Rates

HOV Lane Violation Rates (Summer 2017, June and July Data)

Data Location		A.M. Peak		P.M. Peak	
		Violation Rate	Total on HOV Lane (SOV)	Violation Rate	Total on HOV Lane (SOV)
I-65 North Side of Nashville	Chadwell Dr. (mile marker 91.6)	81.45%	1896 (1545)	80.59%	2859 (2304)
	Due West Ave. (mile marker 91.2)	n/a	n/a	80.12%	2083(1669)
	Average	81%		80%	
I-65 South Side of Nashville	Cool Springs Blvd. (mile marker 68)	78.86%	1275(1005)	80.76%	1545(1278)
	Harding Pl. (mile marker 68)	78.39%	2013(1578)	78.79%	2890(2277)
	Average	79%		80%	
I-40 East Side of Nashville	Old Hickory Blvd. (mile marker 221)	84.7%	1562(1323)	76.9%	2593(1994)
	Average	85%		77%	
I-24 East Side of Nashville	Waldron Rd. (mile marker 64)	82.93%	2162(1793)	80.12%	2083(1669)
	Fortress Blvd. (mile marker 76)	73.37%	1224(898)	n/a	n/a
	Average	78%		80%	
I-40 East of Memphis	Whitten Rd. (mile marker 14)	86.50%	2793(2416)	84.25%	3129(2630)
I-55 South Memphis	Winchester Rd. (mile marker 4.2)	86.96%	1634(1421)	83.14%	2467(2051)
	Average	87%		84%	

HOV Lane Violation Rates (Fall 2017, September and October Data)

Data Location		A.M. Peak		P.M. Peak	
		Violation Rate	Total on HOV Lane (SOV)	Violation Rate	Total on HOV Lane (SOV)
I-65, North Side of Nashville	Chadwell Dr. (mile marker 91.6)	84.43%	2043 (1725)	86.69%	2420 (2098)
	Due West Ave. (mile marker 91.2)	n/a	n/a	n/a	n/a
	Average	84%		87%	
I-65, South Side of Nashville	Cool Springs Blvd. (mile marker 68)	n/a	n/a	n/a	n/a
	Harding Pl. (mile marker 68)	85.18%	3333(2839)	82.29%	3253(2677)
	Average	85%		82%	
I-40, East Side of Nashville	Old Hickory Blvd. (mile marker 221)	84.80%	2079(1763)	81.93%	2407(1972)
	Average	85%		82%	
I-24, East Side of Nashville	Waldron Rd. (mile marker 64)	87.38%	1910(1669)	77.35%	3431(2654)
	Fortress Blvd. (mile marker 76)	n/a	n/a	n/a	n/a
	Average	87%		77%	
I-40, East of Memphis	Whitten Rd. (mile marker 14)	88.56%	2036(1804)	87.92%	3518(3093)
I-55, South Memphis	Winchester Rd. (mile marker 4.2)	90.47%	2214(2003)	85.97%	2702(2323)
	Average	90%		87%	

Appendix 3: Sample MioVision Traffic per Lane Outputs

Study Name	Old Hickory Blvd
Start Date	06/28/2017
Start Time	4:10 PM
Site Code	2

Channel	Lane 1	Lane 2	Lane 3	Lane 4	Lane 1	Lane 2	Lane 3	Lane 4
Direction	Westbound	Westbound	Westbound	Westbound	Eastbound	Eastbound	Eastbound	Eastbound
4:10 PM	45	107	171	85	111	190	280	274
4:25 PM	40	115	155	79	100	190	271	243
4:40 PM	43	108	153	74	83	185	297	245
4:55 PM	39	99	181	83	109	200	282	257
5:10 PM	51	113	166	84	104	198	305	288
5:25 PM	31	109	162	81	95	190	336	294
5:40 PM	36	105	151	98	80	160	268	243
5:55 PM	10	28	34	23	16	62	98	89

Study Name	Winchester Rd
Start Date	07/19/2017
Start Time	3:57 PM
Site Code	2

Channel	Lane 1	Lane 2	Lane 3	Lane 4	Lane 1	Lane 2	Lane 3	Lane 4
Direction	Southbound	Southbound	Southbound	Southbound	Northbound	Northbound	Northbound	Northbound
3:57 PM	178	235	292	250	118	185	161	68
4:12 PM	141	245	356	278	146	158	169	88
4:27 PM	186	263	365	302	141	156	126	114
4:42 PM	182	313	369	330	147	148	146	113
4:57 PM	209	287	332	270	131	170	158	75
5:12 PM	219	307	389	364	136	182	187	110
5:27 PM	149	269	329	288	123	160	155	109
5:42 PM	128	231	296	230	138	162	163	91
5:57 PM	41	70	91	45	47	41	36	33

Appendix 4: Public Opinion Survey Instrument

HOV Lane Survey

The Tennessee Department of Transportation (TDOT) is conducting a study to explore use and efficiencies of our High Occupancy Vehicle (HOV) lanes. It has been reported that Tennessee HOV lanes have a violation rate of nearly 90%. Thus, the main goal of this study is to better understand and manage congestion along key highway corridors.

This survey is completely voluntary and your responses will be kept anonymous and confidential. Should you have questions or concerns about this study or survey, please contact Janey Camp at Vanderbilt University (janey.camp@vanderbilt.edu, 615-322-6013).

Please provide your zip code. This is simply to ensure that we have representation from across the entire region.

_____

Which Interstate corridors do you travel frequently during peak hours (7 a.m. to 9 a.m. and 4 p.m. and 6 p.m.)? You may select more than 1 option.

☐ I-65 Southbound (from Hendersonville/Gallatin)
☐ I-65 Northbound (toward Hendersonville/Gallatin)
☐ I-40 Westbound (from Mt. Juliet/Lebanon)
☐ I-40 Eastbound (toward Mt. Juliet/Lebanon)
☐ I-24 Westbound (from Smyrna/Lavergne/Murfreesboro)
☐ I-24 Eastbound (toward Smyrna/Lavergne/Murfreesboro)
☐ I-65 Northbound (from Brentwood/Franklin/Columbia/Spring Hill)
☐ I-65 Southbound (toward Brentwood/Franklin/Columbia/Spring Hill)

I personally know someone who has driven in the HOV lane by themselves during peak hours.

◯ Yes
◯ No

During peak hours, how often do you typically use the HOV lane each week?

◯ Never
◯ 3 to 5 times per week
◯ 5 to 7 times per week
◯ 7 to 10 times per week
◯ 10 or more times per week

During peak hours, I use the HOV lane for:

	Never	Rarely	Sometimes	Very Often	Always	N/A
carpooling with a household member(s)	○	○	○	○	○	○
carpooling with a non-household member(s)	○	○	○	○	○	○
carpooling with individuals through a rideshare program	○	○	○	○	○	○
driving alone	○	○	○	○	○	○
driving a motorcycle	○	○	○	○	○	○
driving a hybrid vehicle	○	○	○	○	○	○

Do you have a Smart Pass sticker for your hybrid vehicle?

○ Yes
○ No

Free Smart Pass stickers are available through the TDOT website.

My primary destination while using the HOV lane is:

○ To and from work
○ To and from school
○ Errands or recreational purposes unrelated to work
○ Multiple purposes
○ Other

You selected "Other." What is your primary destination while using the HOV lane?

When carpooling in the HOV lane, how many individuals on average are in the vehicle (including yourself)?

○ 2
○ 3
○ 4
○ 5
○ 6 or more

Recent research shows HOV lanes in Tennessee have a violation rate of nearly 90%.

Do you think TDOT should keep the HOV lanes in place?

◯ Yes
◯ No

Given the high violation rate mentioned above for existing HOV lanes in Tennessee, would you support the use of automated systems (i.e., resolutions cameras and license plate readers) to identify and fine HOV lane violators?

◯ Yes
◯ No

What do you think is an appropriate fine for HOV violations?

◯ $50 to $100
◯ $101 to $150
◯ $151 to $200
◯ $201 to $250
◯ $251 to $300

One alternative to HOV lanes is high occupancy toll (HOT) lanes. A high-occupancy toll lane (or HOT lane) is a type of traffic lane or roadway that is available to high-occupancy vehicles and other exempt vehicles without charge; single occupancy vehicles are required to pay a variable fee that is adjusted in response to demand.

If new enforcement initiatives yielded underutilized HOV lanes, would you be interested in potential conversion of HOV lanes to HOT lanes?

◯ Yes
◯ No

What is the maximum amount you would be willing to pay for daily access to HOT lanes?

◯ $1 to $2
◯ $3 to $4
◯ $5 to $6
◯ $7 to $8
◯ $9 to $10

Thank you for your time and feedback. Your responses are extremely valuable as TDOT works to ensure safe and efficient roadways. For additional comments or questions about this project, please complete the form below.

Email: _____

Comments:

_____

Appendix 5: Individual Unedited Comments FromSurvey

Individual Comments Received (Unedited)
Fluctuating market systems could be extremely useful. Something to take into account is that as long as there is no money in enforcing laws then the precedent will always go toward whatever politic is ruling the day. Effective enforcement and methods of deployment of monitoring systems that cannot be circumvented will have to be employed or it will be a useless endeavor. Historically when the lanes were put in, they were enforced for a short while (which seems to be the same time that there were funds available because of their creation). When that extra money ran out enforcement more or less stopped. In an economic sense there are not enough officers available period to monitor and enforce what has become a common habit of poorly disciplined drivers. If businesses use land labor and capital then the only thing to bring to the table is capital in the form of automated systems.
It is not how many lanes we have, it is the bottlenecking as you get closer to downtown. A good example is going from 40 to 65 on 440. you are taking, basically, 2 lanes down to one to get on 440. If you allow two lanes, this would help the slow down.
My husband and I both drive hybrids and carpool often on top of that. We are continually frustrated by the people who use the carpool lane as individuals. In addition to violating the rules, they tend to drive aggressively fast and tailgate us, sometimes honking or flashing at us to get over even when we are at or above the speed limit. We have seen state troopers completely ignore these drivers. We have said to ourselves for years that camera traps would be very easy and generate a lot of revenue. We strongly support this.
I will accept the fact that I contribute to the problem. I know there is an HOV lane and I understand what it is used for and the hours of HOV only. I also admit that I use the HOV lane during RUSH hours for multiple reasons. Going around vehicles that pace the vehicle beside them, SEMI trucks that are in far left lanes that have a large gap between them and the vehicle in front of them, rubber necks, texters, or just people who like to hang out in passing lanes at an alarming slow speed. I will add, the main problem is no enforcement. Using the HOV, I passed plenty of State Troopers and Metro Police during rush hour with no punishment. I believe once they start trolling our interstates and giving fines, it'll change. The system is already there, all that should be done now is actually implementing it.
Since buses weren't an option I considered carpooling/rideshare as equivalent.
I would love for the HOV lane to be monitored. It has gotten out of hand. I only use when I carpool. We see so many cars with only one person that use it and that isn't fair.
If HOV lanes are not enforced, then they are simply a waste of paint and signage. Then again, it seems like the speed limits and other safe driving initiatives are enforced on Middle Tennessee interstates.
I think one of the problems causing the 90% violation rate is the lack of any enforcement whatsoever. Anybody who commutes regularly knows that there is no penalty for violating.

Traffic has increased rapidly in past few years. My commute has gone from 30-45 minutes each way to 1-1.5 hours each way. There is just too much volume to also have an HOV lane. Other than exempt vehicles, HOT lanes would only benefit those who could afford to pay the tolls, creating another awesome perk for the wealthy.
I moved here from Atlanta, where they have HOT lanes. They.were.AWFUL! It did not reduce my commute any great deal. Suburban growth is going to continue. On paper, the 'Lexus Lanes' (as we called them) sounds like they would work. At best, I would pay $6 one way to shave off about 10 minutes from my commute. For people who didn't pay, they would save about 5 minutes (reduction in cars from people in the Lexus Lanes). But, I was perturbed at having to pay to drive on public roads!!! They have a cap of $14 that ATL can charge; they have hit that mark a couple of times. I cannot understand how, if tax dollars paid for the road, we can charge a toll on it. It is literally highway robbery. A better option might be to make 18-wheelers have to bypass the city. Build 840 around the north part of the city and make them take that. Or, ticket the folks who drive slow in the left hand lane. Work with communities to attract businesses and affordable housing together, so people can live where they work. I'm very concerned with all the growth in downtown Nashville that the interstates will be like spokes on a wheel to the center. I moved here four years ago and traffic would add about 5 minutes to my commute. Nowadays, it's more like 20 minutes. 65 is getting as bad as 24.
Get rid of those stupid hov lanes.
The most efficient method of moving cars on highways is to have lane use based on speed with the fastest being furthest left. HOV lanes inhibit this hierarchy by putting slower people in the left lane and reducing the highway throughput. Designating highway use for certain types of vehicles is morally wrong. Economics should motivate people to carpool or drive certain types of vehicles, not legislation.
My husband and I live in Fairview and drive in and home via hwy. 100. I-40 West, when we use it, doesn't have an HOV lane.
It's going to be very difficult to enforce HOV on I-65 south of Nashville due to several areas of really tight logistics but I'd love to see enforcement! There should be a greater delineation of what is HOV and what isn't for sure. It's also difficult to have inbound HOV lanes be useful when the end of them is prior to the highly congested area of downtown but anything helps. We need to have fewer cars on the road!
When I was visiting in Boston, they had the HOV lane barricaded and had a law enforcement office at the start of the lane and would ticket those who were single riders if they tried to get in the lane. The barricaded lane went all the way into town (or in our case would dump out at the 440/40 split). This allowed those carpool drivers who did not need to get off an exit be able to drive straight into town in a barricaded lane.
Most states utilize blocked off HOV lanes (Boston, MA is a good example of this on 93) so that drivers cannot get in and out of the lane except at specific breaks in the lane. That helps control who goes in the lane and keeps the movement flowing.
HOV lane violators are never pulled over as it would create a worse traffic jam with our move-over law than just letting them go on their way. No room as we have very little emergency room on our interstates.

I'd actually like to see the HOV lanes used for public transit (buses or high occupancy vehicles) and semi-trailer traffic or, have as an additional lane for all traffic to use without restriction.
HOV lanes are not effective, we should get rid of them
Keep HOV
I think the HOV lanes should be enforced by THP
We need less gov. in traffic. There are more single person vehicles on the road. Fast in left should be enforced. Slow drivers to the right.
I relocated from southern California and am still appalled that people completely disregard the HOV regulations. I have never seen a law enforcement officer cite individuals for abusing the HOV lanes. There should be consequences for violations.
I feel that tv and radio spots could inform the public about HOV lanes. If using cameras, I believe a warning can be sent. For multiple infractions, maybe a fine could then be charged - $20? But what would be the enforcement if a driver has multiple unpaid fines? Educate and inform is best.
Is it possible to limit the semi-trucks usage during the high peak hours? Or limit the lane usage during those times.
unanswered questions due to my never using the interstates during peak travel times.
I can remember an event (storm, flood, or ?) during which the mayor suspended enforcement of HOV lanes to 'expedite traffic flow'. Why not get rid of them completely to 'expedite traffic flow'?
Traffic is so bad in the other lanes that to use HOV lanes means difficulty in getting over for an exit, so negating the intent. We need two more lanes each way on each interstate direction (6 total) for HOV lanes to be useful. Each interstate crossing over the Cumberland River is 2 lanes each way, which bottlenecks all directions; these should be expanded to 3-4 lanes each way to release these bottlenecks. HOV lanes will not be useful until the congestion is brought under control.
I do not see the use of the HOV lanes on the routes I travel.
I'm very frustrated by the congestion and misuse of HOV lanes around Nashville. Currently there is NO enforcement of HOV rules.
The HOV lanes are a waste of a good lane for everyone else. Not enough people legally use them for them to stay. You have 3 packed lanes and one lane not being used. It does not make sense. We all pay for the roads and you are not letting me use one when I need it the most. And letting electric vehicles use them with only one person is insulting. They use no gas or very little, the gas tax is paying for the roads. I pay more for the roads in taxes and can't use that lane. That needs to be changed.
I have never lived in a state where HOV lanes rules are flouted with no consequence. It is appalling and needs to be changed
Rapid transit would help. Why aren't we investing in commuter rail??????????

well-done; good questions
I found it very irritating in the state of Texas to pay for an EZPass for toll roads. The HOV lanes were difficult to access. Interestingly enough, the paid toll roads were easily accessible.
My survey is probably not valuable because I don't regularly drive on highways. I don't want to see HOV lanes become highways for the rich, hence my opposition to HOT. I do think increased enforcement of HOV rules is really important.
I am from California and we had HOV lanes on majority of the main highways. It was usually a great thing especially during peak hours. Tennessee needs to find a way to section them off as California does without having to pay for them. It would be useless to call them HOV lanes if you are going to allow single drivers in the lanes. I do believe violators need to be fined in some way for it. I travel from Clarksville everyday to come to work at Vanderbilt and there is no HOV lane from that area. Would it be nice, yes especially since I drive in with my sister just about everyday. The bad part is that when an accident happens the interstate is messed up for way to long. That's another that needs to be fixed. But yes, HOV lanes are great as long as they are used for that purpose.
Enforcing minimum speeds on the interstate would do a lot to minimize HOV lane abuse. I would support requiring advanced driver training for interstate usage during rush hour. You should at the minimum be required to understand how to merge, how and when to pass and proper following distance for starters. I would support automatic ticketing of drivers who can't do these things. The problem is distracted and discourteous drivers talking on their cell phone. I will gladly complain about traffic anytime you want me to.
Good survey instrument!
Just have a paid express lane. I suspect that a very high percentage of the legal '10%' in the HOV lane aren't actually carpooling anyway. My wife used to love it when taking our 4 year old to daycare. So she could legally drive in the HOV lane, but that's complete insanity. I can honestly say I have never once in my life met a person who said the HOV lane had any effect on his/her decision to participate or not in carpooling. It's a bunch of self-deluding politicians looking for a quick way to pat themselves on the back while simultaneously not only doing nothing for traffic and the environment but also diverting attention and resources away from things that might actually help.
HOV lanes are useless and a waste of money. Get rid of them.
It is obvious that enforcing HOV lanes in their current format would be more detrimental to the traffic influx than pulling over violators to write a ticket - Rubberneck Rule. Plus it endangers both the offender and the law enforcer. Basically, a lot of money was spent on the placement of signs every few hundred feet as a reminder that these are HOV lanes.
Mid-State Traffic is awful as is. Any of the proposed ideas would just make it that much worse. If you want less traffic then give people a rail system that runs more than 3 times in the morning and 3 times in the afternoon and reaches more people than the 40 miles to the east of Nashville. Another idea is only allow 18 wheelers to drive from certain times of day and keep them out of peak traffic hours.

HOV lanes are used by a lot of single occupancy vehicles all the time, but I don't think it hurts anything. I think the HOV lane is under-utilized by carpooling vehicles so it evens out. It may not seem like it but it's just the general back-up of traffic that keeps traffic in this lane from moving, not because a single driver drives in it.
I do not frequent the interstates listed in this questionnaire. I frequent I-40 , I-385, and I-240 more since I reside in Shelby Co.
volume is very important and under utilization of a HOV lane should be avoided.
Note that my frequency of use is not rated as I would have preferred. I don't drive the route on I-40 regularly, so I would suggest you could add another option to your poll or another question entirely for occasional drivers. Because 'Never' isn't accurate, but it's as close as I could get with my options.
There has been a tremendous amount of money spent on the HOV signs recently. Still, they are of no value if the lane isn't patrolled. Obviously the State Troopers and Police cannot spend a majority of the time patrolling the HOV lane. Also, you could not possible stop and ticket every violator at this point. What I suggest is 'Random' enforcement. Maybe, where each day, a number (i.e. 5) is given to the Troopers by HQ. The troupers would then stop the 5th. vehicle that he/she saw violating the HOV rules. After ticketing the violator, the numbering starts over. The public would not know if they are going to be #5 or not. Would they dare chance it? Just a suggestion. But I agree, it is now out of control. Thank You!!
In the counties I usually travel in do not have HOV lanes, but I think it would be a waste of time and money patrolling these lanes. All residents of Tennessee should have the right to use all lanes because their taxes are paying for them.
HOV lanes do not seem to work in the Nashville area because there is not an acceptable commuter public transportation system in place. I lived in the Washington, DC area for many years and commuters used public transportation because it was widely available to outlying areas and had departures and arrivals scheduled many different times throughout the morning, midday, afternoon, and evening that fit into peoples' schedules. I have checked out using the existing commuter 'express' bus service into downtown Nashville from Sumner County and it would add at least 10 hours every week to my commute. Also, the morning and evening departure and arrival times are too infrequent, and midday departures and arrivals are nonexistent. HOV lanes sound like a good idea, but all lanes should be open to commuters at all time in this area and there should be no fines. Single occupancy vehicle drivers are not offered viable public transportation choices if they live in outlying areas and wish to work downtown. I do not support initiating punitive measures or a toll system for single occupancy vehicle drivers who use the HOV lanes. Let drivers use the lanes as needed.
I'm going to take a leap and say 'that it is obvious that because there is a lack of traffic enforcement by police that traffic rules are rarely practiced on Tennessee roads.'
I think that HOV Lanes should be done away with totally, and all traffic with the exception semi's be allowed to use them without penalty.

We have too many cars for the amount of pavement we have available. Any attempt to enforce the HOV lane would only complicate traffic even worse. I should never have to pay for a HOT lane...that is why I pay taxes.
We need to better restrict trucks use of the inside lanes and build more truck climbing lanes. When two truck get side by side they frequently reduce everyone speed and causes backups for everyone. More traffic congestion causes accident.
I believe a separation of interstates would be a better answer than implementing tolls. The bottle necks of interstate conversions is what I believe to be a contributing issue.
Please provide the reference for the statement. (Recent research shows HOV lanes in Tennessee have a violation rate of nearly 90%.)
I think that HOV lanes are a good idea. It encourages carpooling and having efficient vehicles. However; I think that they are too difficult to enforce. I am not sure how accurate cameras would be but I would assume they would make multiple mistakes a day. Also, policemen do not have the ability to travel across all of the lanes to pull the violator over.
Please educate law enforcement relative to the SmartPass sticker - I have actually been pulled over even though I drive a hybrid and my sticker is prominently displayed.
To enforce the HOV lanes would mean disrupting traffic flow during peak hours. That will NEVER happen.
there is a big mistake by allowing battery operated vehicles passage with one occupant. with their low emission rating, they should be mandated to sit in stop and go traffic since they don't emit pollution. AND the HOV lane is not for daily commutes of police and law enforcement vehicles, lights and audible signal yes. AND HOV should be enforced with more than one LICENSED driver not a baby in a car seat or taking your kids to school. The objective as I understand HOV is to eliminate a vehicle from the road by riding with another person. Under-age riders DON'T eliminate vehicles. I hope this is taken as understanding and not a complaint. There needs to be a consistent use for intended for all parties
I commute at earlier hours than these.
I seldom drive during peak times; however, unless the HOV lane is going to be enforced, I see no reason to keep it. Additionally, the trucks being in the right 2 lanes needs to be enforced. I have seen it with 4 trucks across I-24. Many times I see trucks in the lane next to the HOV lane. My thought is if they're not obeying the signs—why should I?
I typically do not use the HOV lanes during peak hours because I try not to be driving during peak hours. I schedule my life around Nashville traffic. I do ride in the HOV lane alone during peak time if I have my wife's hybrid Escape.
If it found out that HOV or HOT lanes are not necessary then create a dedicated bus lane. Enforcement will the only way to improve these lanes. No one cares or follow the rules of these lanes.
I drive 40 East from White Bride Rd, I am 6 miles from home, I'm not an interest person, normally. thank you

If buses and hov vehicles are only allowed in the HOV lanes the buses might be able to maintain time schedules they have set.
HOV Lanes are not enforced by local PD's.
My answers to this poll are when I worked downtown. I have worked in west Nashville for a couple years now and don't use the interstates at rush hour. I travel local streets as much as possible now.
Hov lanes are a waste of space just like unused Bicycle lanes wasting all the roads around Nashville (make them pay a license fee for using the roads!)!. If you want to enforce some traffic laws let's start with keeping slow moving tractor trailers from using the fast lanes and requiring them not to bunch up in a convoy! you ever try to drive from Memphis to Nashville on I 40? trucks are always 'passing' going up long grades or just riding all bunched up blocking traffic the whole way. maybe explain that the law is slow down.. OR.. move over for stopped emergency vehicles. Not lets jump out in front of faster traffic and cause a pile up in the name of safety! put down your cell phones, stop using emergency message boards for 'clever little gibberish' usually saying keep your eyes on the road while distracting drivers with those very signs! don't run over a fellow motorist while avoiding a squirrel or a piece of tire!! I've got plenty of suggestions.. Former Help truck operator (hit in line of duty 3x..many more near misses!)
All sections of interstate we have HOV Lanes for in the Metro area need more capacity, period. The HOV lanes are under utilized by multiple occupancy vehicles and should be used for more capacity for everyone!
I live west of town in Bellevue. Currently, there are no HOV lanes on the portion of I-40 I currently travel on. Trucks are restricted to the right lane until the White Bridge interchange.
Another option is a report a violator phone number. I have been in a number of cities where the HOV works great but enforcement is key. I would also support the lanes designated as bus lanes only. This would reduce the time added for utilizing public transportation. After all, why take a bus if you are going to be stuck in traffic anyway.
I really like having the HOV lanes.
I live in Mount Juliet and work on Centennial Blvd. off of Briley Parkway on the west side of Nashville. People in Middle TN don't carpool for many reasons. The main reason could be because there is no subway system in Nashville. I can't utilize the Music City Star for that same reason. I can't even get a bus to my office. And we work many different shifts. I only know of one person who lives within two miles of me that works in my building and we don't work the same hours. After 30 years working in the Nashville area at 6 different locations, carpooling has never been an option for me.
Metro Police are told not to enforce HOV violations as it is not a top priority and disrupts traffic flow.
Law endorsement need to enforce the high occupancy lanes by giving tickets.
California uses HOV lanes. They are strictly enforced. The minimum fine is $481. Tennessee HOV lane fine is $50 with minimum enforcement. Which state do you think drivers adhere more respecting HOV lanes?

I think they should just leave the HOV alone. I enjoy riding the HOV lane when coming into Memphis..
Keep in mind that people violating the HOV lane rules alleviates traffic. If HOV lanes are strictly enforced, the interstates will essentially be down a lane and there will be an increase in traffic and traffic-related problems. Increasing capacity for busy areas could be more expensive than the income for enforcing the HOV. Also, I would support using cameras to monitor/fine HOV violators, but instead of a $50 fine, maybe put a point on their driving record instead. This would still deter violators but not anger the public as much.
I've always found it absurd that we have HOV lanes and they are not enforced at all. A drive from my house to work is 34 miles. I should be able to travel that distance in 40-45 minutes. However, since the HOV lane is 'just another lane' it takes me on average an 1:15 (not accounting for a wreck) to travel into Nashville in the morning, and 1:40 to travel home in the afternoon.
HOV lanes are not effective in TN. The safety of police and rubbernecking/'move over' delays to police them are worse than the violations themselves. Remove the HOV and make them general use lanes.
No tolls!
HOV lanes are merely the result of the federal government attempting to hold sway over state DOTs by controlling the purse strings. I consider this situation to be a very base form of exploitation and coercion. Leave our money here; do not send it to Washington for the swamp denizens to drain off their substantial cut and then dribble the scant remainder back to the local governing agencies. Get the federal government out of our lives to the extent possible (and that is a very large extent!).
I provided home email, as I am leaving TDOT this Friday 12/15/17. I began working on this project with Alan Jones early this year from a modeling standpoint. I personally do not own a vehicle nor travel the Interstates to get to work in downtown, as I live in Hillsboro Village and take the bus. I most support HOT lane conversion. As someone who is about to assume a new role at MTA doing scheduling, I very much would like to see these lanes become free-flowing so that we can operate express buses more efficiently and attract more ridership
I would just like to say that I avoid high traffic times and commute to/from work before the HOV restrictions.
Cost of camera, plate identification technologies should be estimated. This question will go along with the location of installation, whether isolated HOV will be separated from other lanes. The study may also consider how this may affect the congestion reduction so that Tennessee may set the FHWA performance goal.
What it REALLY boils down to is the money, isn't it..... No one cared about the HOV lanes when fines were $12.00.
Having all lanes open to all commuters lessens congestion. We do NOT need additional tolls on our roadways.

HOT lanes will just benefit the wealthy who can afford to travel faster. It also makes no sense to have unused capacity in a regulated HOV lane during rush hour...enforcement during rush hour creates worse congestion...the answer is just make HOV lanes another lane of traffic and give the FHWA their HOV money back. Get true transit options like light rail, subway, dedicated bus/trolly lanes, etc.
You have to get law enforcement to enforce the law.
An additional lane should be added to our interstate systems solely for Emergency and/or Military Vehicles in a Civil or National Emergency/Disaster.
Just convert those lanes to regular traffic lanes. High occupancy vehicles should be given no preferential treatment. Nor should bicycles for that matter. If your gonna use the road you should have to keep your vehicle up to the same standards as everyone else. Require bicycles to have brake lights and turn signals. They are nowhere near as safe on the roads as an atv or utv. All vehicles should at the very least have an engine and there should be minimum speed limits on all state routes. Sorry to vent, but maybe somebody will read this that actually has a public safety concern.
I drove with my spouse (legally)in the HOV for years and years with no enforcement of the law, amidst much frustration with violators- when he retired I figured 'what the heck'! :-(
Enforcing the HOV Lanes would be a disaster. Alternate routes for truckers during peak hours would be the easiest fix, but w/e I'm just a lowly engineer.
Local law enforcement does not enforce the HOV lane occupancy rules therefore you end up with a 90% violation rate. If they started enforcing the law then you would get a much lower violation rate.
It would be nice to have them in Knoxville
It seems that usage of I-65 south & north HOV lanes during peak hours does not help much during these high volumes times.
enforce the use of the lanes with cameras and post the names of violators on TDOTs web page
I live in a rural area.
HOV lanes don't reflect the 'reality' of how people get to and from work. Carpooling is a nice idea but not all that implementable on a scale that has a real effect; they are just 'social engineering' with little benefit. HOV lanes just take out roadway capacity that could be used to ease congestion instead of adding to it and generating fines and 90% violations.
I do not travel during peak hours.
Currently ride into work on the Gray Line Commuter Bus from Hendersonville and I see a lot of vehicles with only one person in the HOV Lane.
I don't want to provide my email addy.

HOV lanes make no sense when you have more than one interstate highway running together, especially where the routes criss-cross as I-24 and I-65 do in the Trinity Lane area north of downtown Nashville. HOV lanes may make more sense when located on a straight stretch of a single interstate, but even there stopping vehicles for enforcement is likely to cause more traffic congestion than it solves. Automated enforcement makes the most sense if we are to have HOV lanes. The appropriate fine should be somewhere between $0 and $50, which was not an option in the survey.
I know that other cities do implement this toll system and I think that Nashville and surrounding areas is going to 'have' to adopt something similar. The traffic is gotten incredibly worse (day-by-day), and obviously it is not going to get better...just worse! Thank you.
Since first starting to drive in 1965, in Phoenix, Arizona, I have operated vehicles all over the U.S., including some of the most congested parts of L.A., the Grapevine, the Bay Area, etc. And, I've experienced all sorts of rapid and mass transit in different cities. In all that time I have NEVER seen a HOV lane operate efficiently, and actually found them scarce across the West. Experience has taught me that the old-school method of encouraging faster and longer distance traffic taking the far left lane is by far the best, providing better efficiency with limited impact on the bulk of traffic. While high occupancy traffic is a laudible idea for cost savings and lessening congestion, Mass Transit is FAR more effective for those points. Structurally, HOV lanes can provide very little relief from congestion, because of the limited number of people who can or will take advantage of it. Plus, HOV operators tend to go SLOWER causing a serious hazard of accident by imposing a reverse speed gradient across all lanes of traffic, forcing vehicles to make more lane and speed changes. Alternatively, 'Speed Lanes' (far left lane) have been used since the Interstate system was first launched, with significant effect - primarily because EVERYONE can utilize them, on the fly, if they want or need to, with no restrictions or regulation other than normal traffic patrols - very little maintenance or cost. While I generally have seen regulations to be extremely beneficial, this type of regulation is most often ill conceived because it does not consider how drivers naturally deal with the roads and other drivers - the process is NOT organic, but a misguided Top-Down concept based upon an idealized model. Shoot, for decades the California Highway Patrol would routinely ticket slower drivers if they did not yield the left lanes - and not to excessive speeding mind you, but to those in the vast majority who find a 'road speed' where all can flow best without hindering their traveling neighbors. Slower drivers naturally (usually) tend to occupy the right lanes, because they are more unsure of their path and their abilities, or that they are entering or exiting the roadway. Similarly, long distance traffic or those who prefer a faster speed take the left lanes to experience better flow while not interfering with other traffic. For well over 40 years I have seen both, and can say with no hesitation that HOV lanes have very little real-world effect when compared to Mass Transit and natural lane management. These are not opinions but observations.
Happy to help out.
Plz understand that I don't use HOV lanes during the hours stated on the sign atop the median barrier wall. Outside those hours, I may use them. I feel there is just way too much traffic to support HOV lanes in Nashville. All interstates lead to town & we need the extra lanes for everyone.

Fortunately I do not have to get on the Interstate System during my commute to work; however, I have had to travel from Nashville to points beyond during Rush Hour and it appears to be a waste of resources having an empty lane with traffic backed up in all of the others. Do you really want a State Trooper out writing tickets? This would tie up even more traffic. Shall we spend millions to enforce this? No! We would have to write new legislation then we would end up in litigation every time we turned around. More money down the drain. Not to mention we would end up selling the administration rights to some company that would make millions while the tax payer would be burdened even more.
There are no HOV lanes in my area that affect my daily commute but I do think the violation rate is extremely high and something should be done in place.
The traffic is a nightmare, need to do away with the HOV lanes. 90% are single drivers. Go to express lanes like Atlanta and Chicago use. The left lanes should be used for Franklin and farther south exit only. The problem is mergers. Express lanes would stop that.
If TDOT wants HOV lanes, proper enforcement of the HOV law is key, and the best way to do this is via automated law enforcement. If HOV laws will not be enforced, remove the HOV designation and treat it just like any other lane. Most motorists do anyway.
What we really need is Light Rail, and better Mass Transit overall. HOV lanes are backwards thinking, & toll lanes will A) Result in more people crowding into the other lanes B) Economic Hardship (wages AREN'T rising), and C) ANGRY voters.
The question about the maximum amount I would be willing to pay for HOT lanes needs to have the added option of '$0'. I am grudgingly in favor of changing HOV lanes to HOT lanes—only if they were enforced—but I probably wouldn't pay to use them myself; I'd just be jealous of those who did use them. Also, enforcement would be key to my being 'at peace' with the change. I do have the concern that HOT lanes might lead to greater frustration and possible road rage with other drivers. People don't like to see others pass them when they don't have the option of going into that same lane.
I think we at TDOT would be remiss to start any toll system. Once we start tolling, it will lead to more and we don't need that. My thought is do away with the HOV lane and create a designated merge and exit lane for areas 1mile before and after congested exits to allow traffic to merge safer and more efficiently.
I believe the HOV lanes would be better used as bus only lanes with increased bus services/routes/schedule to help decrease individual car use on the highways.
we do not have HOV lanes where I live and I seldom am in an area that does.
I think with the amount of congestion that we are currently experiencing, all lanes should be available for use at any point during the day. If the percentage of violators (without penalties) and the amount of current congestion are both extremely high, then the lane is not serving a purpose. Ultimately, people are just trying to get to work on time and get home at a decent hour.

In general I understand the need for HOV lanes but I oppose camera enforcement as a rule. The HOT thing sounds interesting, I think that will keep people from ever using the HOV lanes at all. It will increase the amount of time to access the interstate and create greater traffic back up for everyone. Nashville has enough traffic issues. What we really need is another access route to the southeast, greater public transportation in the whole Murfreesboro to Nashville general area, and fewer bottlenecks and hang-ups on the very few paths we have from Rutherford and Williamson counties.
I would also support designating the HOV lanes for buses only. Making public transportation just as fast (or faster) as driving yourself is the key to increasing use.
I have a hybrid Ford Fusion and I always feel guilty about using the HOV lane.
The Hov Lane should be a lane for single occupancy as well as for two or more people and passengers. More People means more cars om the highways. WE need more lanes because more cars on the interstate.
Your first question regarding which interstate is used should have a 'none of the above' option. I never use I65, although in principle it would be a few minutes faster.
I think HOV lanes cause more congestion then they solve. Complete nonsense.
I feel the traffic issue in Nashville is a very hot topic. We need more lanes and not take lanes away. There is no incentive for using the inside lane as an HOV or toll lane because there is no easy way to exit the interstate when ready during peak travel times. If there were easy exit as well as enforcement and it was actually beneficial to use it then sure enforce it. Right now I feel we need to utilize the lane until we get some alternate transit system in place.
We really need lane expansion on 1-75. It has too many vehicles especially during rush hour. There are no trucker lanes climbing White Oak Mountain (between Hamilton & Bradley counties).
My granddad got the money to put in the first hov lane :)
I don't believe we should do away with the HOV lanes or convert to HOT lanes. People that use the HOV lane illegally should get a warning, but by no means be fined for it. It just ties up traffic for that and uses time from our law enforcers that have more importance to their job. Cameras 'NO' and license plate readers 'NO'. I don't see them being honest either.
I tried contacting Megan Barry to complain about the lack of enforcement of the HOV lanes, and she informed me that it was not a metro issue; likewise, the state does not feel that it is theirs to enforce inside Davidson County. Until this jurisdictional issue is addressed, there will be no enforcement of the HOV lanes.
I drive a 15 passenger van and it is very frustrating to have non HOV vehicles in the HOV lanes. I have witnessed 18 wheelers us the HOV lanes as well. The State receives Federal funding for the HOV lanes, it would be helpful if the State would enforce the restrictions and tend to the violators. Thank you.

I believe that HOV and HOT lanes, in Memphis especially, are a waste of a passing lane. Most motorists find it easier to weave through traffic than to depend on a lane to provide for them an alternative to the congestion. I also believe penalizing individuals for this lane change is absurd and will only create more revenue for the state at the expense of those who just desire to get through traffic. Not everyone drives the same speed and because of this there would only be individuals jumping out of the lane to get around motorists that are driving slowly in the same afore mentioned lane. Altogether I see it as a waste since there cannot be proven that these lanes help in any fashion to decrease road congestion and accidents...
The Hot Lane is a good idea. Monitoring the HOV Lanes has a down side of which I witnessed 8-10yrs ago on I-24 westbound and that is traffic will back up because violators switch lanes when they spot law enforcement officers which can cause accidents.
Enforcement of HOV lanes without dedicated exit ramps is not a good plan and invites road rage directed at people trying to get out of the HOV lane ramps to approach an exit.
I favor HOV or HOT lanes only if it can be enforced. It's extremely frustrating to be in the regular travel lanes following the law and seeing all these one-occupant vehicles passing me in the HOV lane.
I feel a little silly voicing my opinion when my city (Chatt) doesn't have HOV lanes, but from what my 'HOV-
I would only support paying for HOT lanes if the enforcement is better than the current HOV lanes.
I think Nashville and surrounding areas should focus on building and expanding infrastructure that can accommodate the DAILY increase of traffic and new gentrified residents that it is promoting. The city should not punish drivers that have to navigate through the outdated infrastructure in rush hour traffic in an admittedly overpopulated city. Fining residents does not reduce the issue. It just creates unnecessary revenue for the city to misuse or apply to some other unnecessary expense that only benefits certain areas.
I think HOV lanes should be eliminated and this lane be open to all drivers.
HOV lanes are very helpful in peak hours to have faster mobility and to help reduce pollution.
I think we should enforce the HOV laws now. I think since they have started, I have only ever seen it enforced one time.
Traffic in Nashville is congested coming in and going out. I suggest removing the HOV lane altogether. We need more lanes for all passengers to get to their destinations in a timely manner. The purposed HOT lane will be an additional expense that I personally can't afford.

I'm in favor of HOT lanes...IF and only IF, no toll booths/centers are installed on roadways & HOT-payment is strictly by stickers or placards on the cars that would have been paid online, mailed-in, or in-person. I'm not in favor of typical toll roads or lanes (with booths for payment, etc.). This question on your survey is missing '1-2 TIMES' as an answer: During peak hours, how often do you typically use the HOV lane each week? ...which is what my answer really was...but I could not answer it accurately due to the survey issue. It would serve the Metro and outlying areas well to have major employers driving large (HOV) on the roadways and employees furnished incentives for riding them two times a week. Employers: HCA, TSU, Vanderbilt, CMS, etc. would fit this model. These HOVs would come from Mt Hermitage, Cool Springs, and Hendersonville, Joelton (or better yet, Clarksville). Drivers would drive their cars to these loading locations and take the HOV via the HOT lane to work. Both the companies and the government would fund these larger vehicles. Another suggestion to the Governor and Mayor (that I find it hard to believe they haven't enforced yet): EVERY governmental office should force employees (those that can) to work from home 2 days a week...so that the road traffic is varied and lessened among days. Some of these simple solutions don't take a brain surgeon. Just put them into place. The Mass Transit plan being discussed/planned will only allow tourists and downtown workers to get around downtown. The starting and ending points of its lines are STILL DOWNTOWN. Nashville's problem is not downtown traffic. It's regional traffic. And until the State of TN revises budgeting and planning to be among regional parties (b/c many of the outlying areas don't have the funds to fund mass transit alongside Metro), you will NOT solve any of the true problems. I live just outside of the city...AND the mass transit plan being put forth will not help me one iota in my daily frustrations with our limited roadways. And that is a sad statement considering how much we'll be paying from our pockets toward it. ☹ REGIONAL. THINK REGIONAL. PLEASE.
The traffic population in Tennessee exceeds the road capacity. While the HOV lane violation rate is high, it is a direct response to the state's inability to handle the (traffic) population. To limit 90% of traffic to non-HOV lanes because the city does not have mass transit, and then to potentially penalize drivers, I think is PREPOSTEROUS!!! Converting HOV lanes to HOT lanes is not the answer. The answer is to expedite mass transit projects. Traffic is horrible and drivers are only trying their best to get from point A to point B in less than approximately 1 hour, which it usually takes to get anywhere (even distances averaging 15 miles or less).
I think that the issue here is that most people do not know they are driving in HOV. Signalization needs to be better displayed!
Mass transit needs to happen. HOV lanes are a good concept, but don't really work.
Tennessee is already one of the highest taxed states in the US; more money (fees) for whom?
I always use HOV lanes as I drive a hybrid vehicle. It is frustrating to see the abuse of these lanes daily without any consequences.
There has to be a better solution.
There are accidents on 65 multiple times per week which shuts down 1-2 lanes in addition to the requirement to get over if a car is pulled over on the side. It makes no sense to have HOV lanes.
Why would commuters with only 1 passenger be penalized for just trying to find a quick way to work on my extremely long route to work. The traffic is really terrible in Nashville TN

I commute from west of town where there are no HOV lanes.
Thank you for the opportunity to voice my opinion.
It would really help if the 'trucks stay in the two right lanes' rule was enforced. The 18 wheelers are slowly up traffic and force people to go into the HOV lane to get around them. Another problem is that many HOV lane users get into the HOV lane, set their cruise control, and forget about the slower traffic keep right rule. One inconsiderate driver doing this can really create a lot of traffic congestion behind him.
I do not drive on interstates at all as part of going to work and going home at the end of the day. I don't know if HOV lanes in TN are open to a Prius (which I drive) with one passenger, as in other states.
I enjoyed the survey and thought that it was a good idea. I don't think the HOV lane is necessary. With the traffic issues Nashville has, the HOV lane is counterproductive to the problem.
I do not frequently travel the interstate system during peak hours, usually during off hours. During the times I have used the interstate during peak hours, I usually see violators. However I think the HOV lane should not be turned into a toll lane, it should be able to be accessed for safety purposes.
HOV lanes simply cause an underutilized lane because almost all drivers during peak hours are single occupancy. Carpooling has not been significantly affected by the availability of HOV lanes.
The real problem is the trucks and slower cars in the leftmost non-HOV lane. With a 70 mph speed limit the HOV lane is a defector passing lane that very often has big pickup trucks and high end sports cars running 80-90+. There is virtually no enforcement as police know there is nowhere to pull over violators during rush hour. I think making the right most lane an express bus lane would be more effective in reducing congestion. enforce semis must use right two lane and slower traffic keep right. Cars with excessive front distance running on the left lanes must move right. One car going 65 in left lane forces many cars to change lanes to pass them. Excessive front distance is three to twenty semi-truck lengths back from car in front.
Lower the ticket amount and increase visibility of officers to stop violators.
The estimations of 90% noncompliance is accurate for 65N in the morning. I travel from OHB or Harding to downtown a few times a week with a member of my household. Most of the cars in the HOV have one person (who is frequently on the phone!)
The HOV lane is best utilized when it is FULL; perhaps include internal combustion engine vehicles with less than 2.0 L displacement in the definition of 'inherently low emission vehicle'. even the 15 year old examples get over 30 MPG.
I believe the HOV lanes are useless. A stricter enforcing would further aggravate the traffic. Drivers should learn how to go with the traffic at peak times. Sometimes people drive on the HOV lanes way slower than the posted speed limit.
Why is there not an HOV lane on I-40 west/east from I-440 to Chatham County?

Where I live does not require interstate travel during peak hours when the HOV lanes are mostly utilized. My responses may not be very useful. I do feel $50-$100 is too high of a fine for HOV lane misuse. I recommend $25 - $50; a similar option was not provided.
I travel to many states that have HOV lanes with front license plates that allows them to see violators (using cameras). Even the purchase of front license plates by Tennesseans to allow them to use the lanes legally would be helpful.
The HOV lanes are not used effectively. Much lane space is available during peak hours. People see that space not in use and then use it. Tolls are not the answer. During not peak hours I see confusion on who may use a HOV lane. There are a high number of wrecks on the Nashville interstate during rush/ high volume hours. the merging traffic situation is awful. There is not adequate use of non-interstate roads during rush hours-maybe educating local public to other routes and travel times could help. Upgrading and widening local primary roads or creating a new primary road would be an alternative. Travelers and tourist also add to your problem. Better info could help for them. Regular updates of GPS systems in this area would help- but they need the most update to date data for their system, which I think is not being done. Maybe TDOT should be proactive in this endeavor with Nashville, Memphis, Chattanooga, Knoxville, Johnson City I-26, etc. In general, HOV lane are frustrating to many drivers whether they have 1 or 4 people in their vehicles.