Final Report

For

# IMPROVING EFFECTIVENESS OF HOV FACILITIES – BEHAVIORAL AND OPERATIONAL CONSIDERATIONS

prepared for

Tennessee Department of Transportation

by

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16. Abstract

This report documents and details the work done on Project RES 2017-01, Improving Effectiveness of HOV Facilities- Operational and Behavioral Considerations. In this project, the problem of the extremely high violation rates in Nashville's HOV lanes is considered. Specifically, the project seeks to: (1) document the current operational conditions on Nashville's HOV lanes, (2) understand the values and perceptions of key stakeholders through focus groups held with legislative and law enforcement officials and through a survey of the general public, (3) quantify the choice behavior of the driving public through analysis of revealed preferences of drivers, (4) perform user equilibrium modeling to explore the sensitivity of mode and lane choice decisions; (5) perform macroscopic simulation using the Cell Transmission Model to solve the Lighthill-Whitham-Richards Partial Differential Equation, coupled with relationships of the speed in the mixed-flow and HOV lanes to the speed of all vehicles, obtained from field data; (6) construct, calibrate, and validate VISSIM models for traffic microsimulation to explore operations on the HOV corridors, and (7) evaluate the effectiveness of various lane management strategies for the HOV corridor.

It was found that in general, people in Middle Tennessee are dissatisfied with the current operational state of Nashville's HOV lanes. Violation rates are very high and do seem to detract from some users' experience of the benefits the HOV lane should be able to provide. However, the public will to enforce HOV lane restrictions in their current form is lacking, as is the ability of the Tennessee Highway Patrol to enforce HOV lane restrictions in any significantly impactful way. Roughly one in four drivers of single occupant vehicles appear to be willing to violate the HOV lanes, but because of the location of the HOV lane in relation to the off ramps make the HOV lane an undesirable option for many travelers.

Operationally, the HOV lanes suffer poor performance even under relatively lighter volumes than the mixed-flow lanes carry. The close correlation between speeds in the HOV lane and the mixed-flow lanes is observed in field speed data. Microsimulation allows the cause of this sympathetic slowdown as a result of vehicles in the HOV lane having insufficient gaps to re-enter the mixed-flow lanes. The late entry into the mixed-flow lane of vehicles exiting the HOV lane results in the enhanced breakdown of both the HOV lane and the mixed-flow lanes in the vicinity of diverge bottlenecks.

The ideal utilization of the HOV lane depends on many factors, but most importantly, whether flow is being controlled by merge or diverge bottlenecks. In general, HOV lanes are over utilized when flow is controlled by diverge bottlenecks but are underutilized when flow is controlled by merge bottlenecks. As flow into Nashville is controlled by both merge and diverge bottlenecks, more vehicles need to be recruited to the HOV lane in order to achieve optimal usage of the highway in the vicinity of the merge bottlenecks, while forcing the re-integration of the vehicles that use the HOV lane into the mixed-flow lanes at desirable locations for the entire corridor. In the peak direction (i.e., out of Nashville), the flow is primarily controlled by diverge bottlenecks. These bottlenecks can be improved by restricting lane changes from the HOV lane in the vicinity of the bottleneck by striping or by barrier separation.

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## LIST OF ACRONYMS & ABBREVIATIONS:

- BPR – Bureau of Public Roads
- BSCL – Basic Speed Classification Length
- BSCR- Basic Speed Classification Report
- GP – General Purpose
- HOT – High Occupancy Toll
- HOV – High Occupancy Vehicle
- MCR – multichannel report
- MF – Mixed-flow
- Pax - Passenger
- SOV – Single Occupancy Vehicle
- TDOT – Tennessee Department of Transportation
- TTI – Time-Travel Index
- VPMPL – vehicles per lane per mile

## GLOSSARY:

- Bureau of Public Roads – formerly under the Department of Commerce, the Bureau of Public Roads' functions are now under the purview of the Federal Highway Administration (FHWA)
- Cell Transmission Model – a popular numerical method proposed to solve the kinematic wave equation and is important for solving macroscopic traffic problems.
- Comparative statics – a methodological concept of economic theory, comparing two or more equilibrium states that results from changes in exogenous variables.
- Decoy effect (*in relation to dominated option)* – the phenomenon whereby consumers will tend to have a specific change in preference between two options when also presented with a third option that is asymmetrically dominated, or when it is inferior in all respects to one option. But when compared with the option, it is inferior in some respects and superior in others. *See pg. 278 of the report.*
- Discretization – concerns the process of transferring continuous functions, models, and equations into discrete counterparts, usually carried out as a first step toward making them suitable for numerical evaluation and implementation on digital computers.
- Fundamental diagram of traffic flow – a visual that gives a relation between the traffic flux (vehicles/hour) and the traffic density (vehicles/km). A macroscopic traffic model involving traffic flux, traffic density and velocity forms the basis of the fundamental diagram. It can be used to predict the capability of a road system or its behavior.
- Heavy enforcement – describes the examination of system operation considering whatever traffic controls, pricing decisions, or combination thereof are necessary to produce a prescribed violation rate.
- K factor – a measure determined using annual average daily traffic counts, converted to peak hour demands for peak and design hour demands and directional splits.
- Method of Characteristics – a technique for solving partial differential equations. It typically applies to first-order equations, although more generally the method of characteristics is valid for any hyperbolic partial differential equation. The method is to reduce a partial differential equation to a family of ordinary differential equations along which the solution can be integrated from some initial data given on a suitable hypersurface.
- Microscopic traffic flow model – a class of scientific models of vehicular traffic dynamics, which simulate single vehicle-driver units, so the dynamic variables of the models represent microscopic properties like the position and velocity of single vehicles. *See Wiedemann 74.*
- Monotonic function – a function between ordered sets that preserves or reverses the given order. This concept first arose in calculus and was later generalized to the more abstract setting of order theory.
- Objective function – in nonlinear programming, the function, expressing given conditions for a system, which one seeks to minimize subject to given constraints

- Policy – any control scheme, be it automated enforcement, enhanced manual enforcement, etc., that reduces the HOV lane violation rate to a prescribed level.
- Space mean speed – the speed based on the average time taken to cross a given distance, found in Lighthill and Whitham.
- Steady state – In systems theory, a system or a process is in a steady state if the variables which define the behavior of the system or the process are unchanging in time. In continuous time, this means that for those properties of the system, the partial derivative with respect to time is zero.
- Unity – Mathematically, the number "one" (1).
- Wiedemann 74 – A type of *microscopic traffic flow model* incorporated into PTV VISSIM.

# EXECUTIVE SUMMARY

This report presents the findings of research undertaken for TDOT's Long Range Planning Division by Lipscomb University's Civil and Environmental Engineering Department. The overarching purpose of this research was to determine the current effectiveness and benefits of the High Occupancy Vehicle (HOV) lanes in Tennessee and make recommendations regarding enhanced effectiveness including analysis of HOV lanes operating under base conditions and operating under variable violation rates. These results were compared with the current operating conditions as well as a case in which the HOV lanes are converted to mixed-flow lanes.

## Study Objectives

Nashville is one of the most rapidly growing cities in the United States. Its citizens are highly automobile-dependent with minimal transit options available to the public. Nashville is sprawling geographically with more and more people living in its suburban areas. HOV lanes can provide carpool and transit operations a major competitive advantage if properly implemented and enforced. However, the I-24 and I-65 corridors under consideration have very high violation rates, and very limited resources to enforce HOV restrictions in dedicated HOV lanes. State officials have estimated that current violation rates in these lanes are as high as 85 to 90 percent in the AM and PM rush hours (Walters, 2014).

This study quantifies the benefits associated with HOV lanes in the I-24 and I-65 corridors, determines key inputs for decision making concerning how the HOV lanes would best serve the traveling public and provides a modeling framework to estimate the potential benefits of removing or adding traffic volume to the HOV lane by enhanced enforcement techniques or conversion of the HOV lane to a High Occupancy Toll (HOT) lane. Our approach was based on a multi-tiered and multidimensional analysis of HOV corridors as a network over which users establish equilibrium flows. As such, it is imperative to understand the system on three levels: (1) how users of the system choose their mode of travel and then select their travel lane (i.e., demand analysis), (2) how the roadway performs as a function of the number of users on the facility (i.e., supply analysis), and (3) equilibration between the supply and demand in the transportation network.

## Analysis of Google Traffic Data on HOV Corridors (Chapter 2)

A careful study of Google Traffic data has provided greater insight about the times of activation and mechanisms of action of the most significant bottlenecks on the Nashville interstate system. This information is important for the validation of traffic microsimulation models.

In general, the PM congestion is more severe than the AM, as the demand appears to be more peaked. In most instances, but not all, the PM hours of HOV lane operation tend to enclose the most congested operations, but in some locations, congestion is heavy at the end of HOV lane hours of operation. If HOV lanes are effective ways of increasing highway passenger capacity, then an extension of HOV lane hours can be justified based on congestion levels on some of the HOV corridors in the PM. Also, the AM demand is distributed over a wider time interval, and in many instances, congestion becomes severe before the HOV lane hours of operation begin. Once again, if HOV lanes are effective ways of increasing passenger throughput, then it is likely sensible to consider an extension of HOV lane hours of operation.

## Analysis of Traffic Data from HOV Corridors (Chapter 3)

Chapter 3 of this report contains an analysis of traffic data obtained from HOV corridors of interest on I-24. This analysis was performed to understand the usage of the HOV lane, the relationship of speeds in the HOV lane to the speeds in the mixed-flow lanes, and the operating characteristics of the mixed-flow lanes.

Analysis of the utilization of the HOV lanes shows that some locations along the HOV lanes, particularly near major active bottlenecks, are carrying up to thirty to forty percent more volume than the average volume per lane. However, in many other locations along the corridor, utilization can be as low as half of the average volume per lane across all lanes of the freeway. Utilization of the HOV lane (or leftmost lane in off-peak hours), expressed as a percentage of the average volume per lane across all lanes as a function of time is shown in Figure 1. The locations where the HOV lane carries the largest share of the traffic volume are typically near busy interchanges closest to the downtown area. In these locations, the HOV lane is the lane least impacted by the formation of the merge or diverge bottleneck at the right-handed entrance or exit, and therefore attracts drivers eager to circumvent the bottleneck. However, at most locations not impacted by bottleneck operations, the HOV lanes are avoided by most drivers.

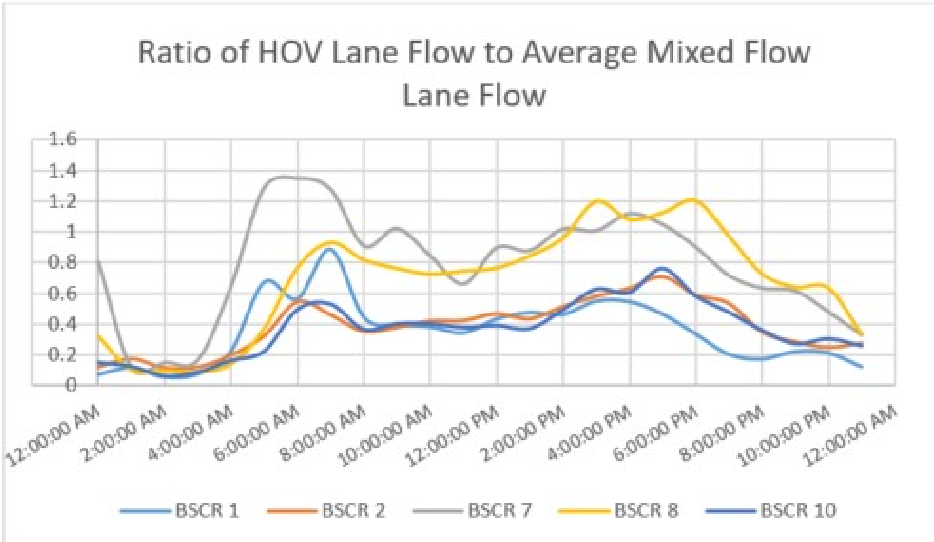



Figure 1 Traffic volume in HOV lane as a percentage of average volume for all lanes

Figure 2 and Figure 3 show a comparison of average speeds in the HOV lane and average speed in the mixed-flow lane when averaged over each hour of the day for a heavily congested and a lightly congested location on the HOV corridor. It can be seen that the speed in the HOV lane is very closely related to the speed in the mixed-flow lanes in both cases but is approximately ten miles per hour faster than the average speed in the mixed-flow lanes at most times of the day.

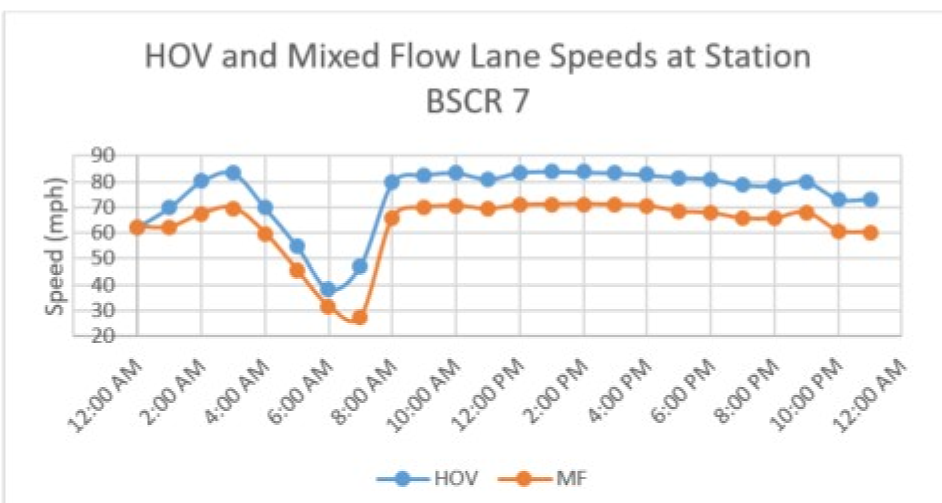



Figure 2 Average speeds in mixed-flow and HOV lanes at station BSCR 7.

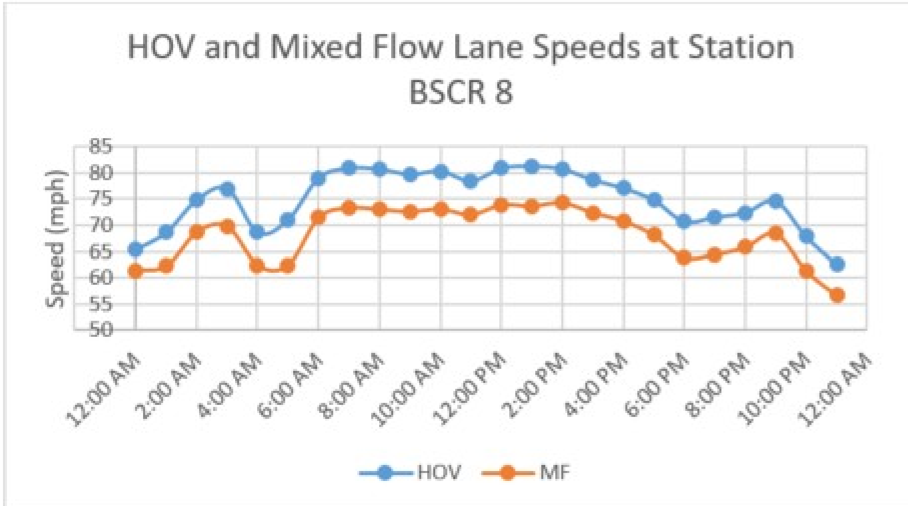



Figure 3 Average speeds in mixed-flow and HOV lanes at station BSCR 8

that the speeds in the HOV lane closely follow speeds in the mixed-flow lanes but are typically higher than in the mixed-flow lanes.

Analysis of hourly traffic count and speed data show that the capacity of the HOV lane tends to be higher than the capacity of the mixed-flow lanes. Figure 4 and Figure 5 show that the maximum hourly volume observed in the mixed-flow lanes is somewhat lower than the maximum hourly volume observed in the HOV lane. However, what can be seen is that as demand exceeds the capacity and traffic moves from an uncongested flow regime to a congested flow regime, there is a more extreme capacity drop observed in the mixed-flow lanes than is observed in the HOV lane. The larger capacity drop in the mixed-flow lanes is likely the result of weaving in the mixed-flow lanes.

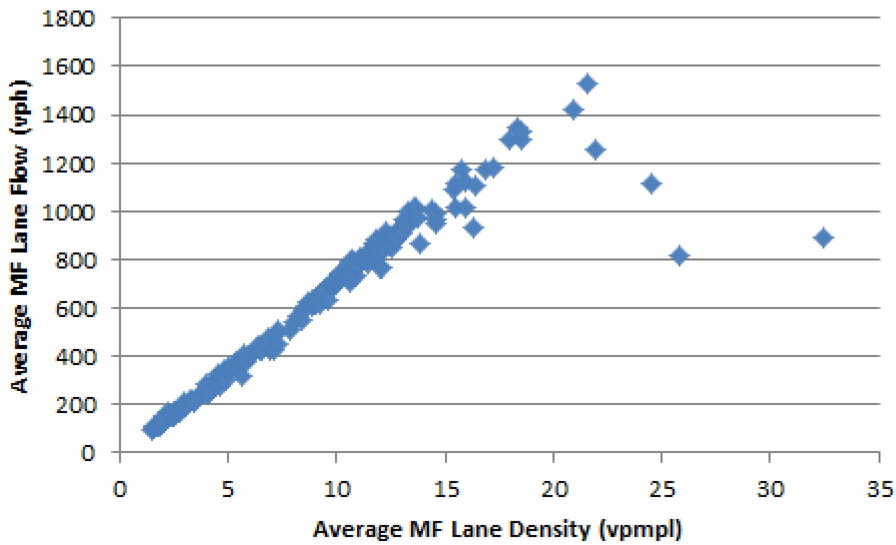



Figure 4 Fundamental diagram constructed based on hourly average flow and density values for all mixed-flow lanes

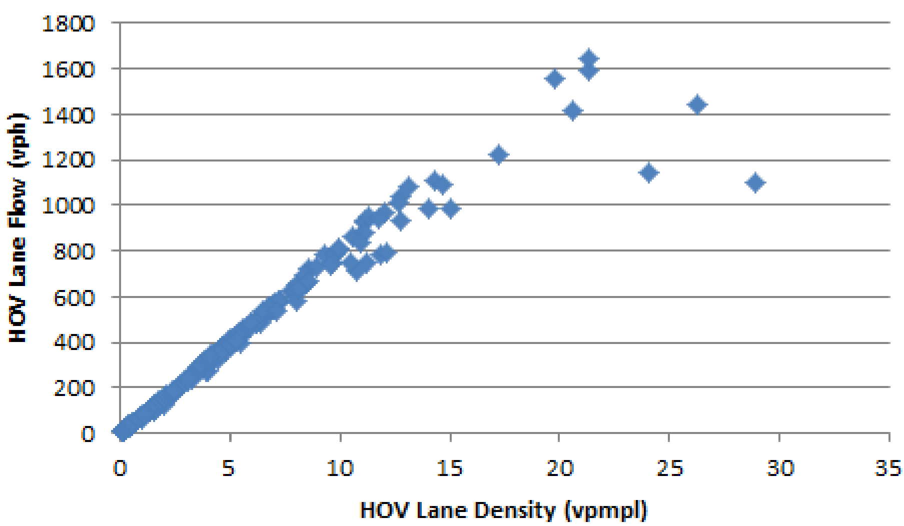



Figure 5 Fundamental diagram constructed based on hourly average flow and density values for HOV lanes

From the analysis of traffic data, it can be seen that the HOV lane is largely underutilized at many locations along the HOV corridor. However, at major bottlenecks, the HOV lane has greater utilization because it is far less affected by weaving. It has also been observed that speeds in the HOV lane are typically closely correlated with the speeds in the mixed-flow lanes. Further, the development of fundamental diagrams of traffic flow shows that there is a greater capacity drop in the mixed-flow lanes than there is in the HOV lane. While vehicles in both the HOV lane and mixed-flow lane may slow their speeds to be able to change lanes, vehicles in the HOV lane do not slow down to create gaps for merging vehicles.

### Outcomes of Legislative and Law Enforcement Focus Group Meetings (Chapter 4)

Chapter 4 contains insights provided from focus groups held with Tennessee state legislators and Tennessee Highway Patrol officers to qualitatively understand the perception of the public about HOV lanes, their effectiveness, and their enforcement. The following points offer an encapsulation of stakeholder attitudes arising from these focus groups:

- Both focus groups noted that violation rates are extremely high, on the order of eighty to ninety percent, for the HOV corridors on I-24 and I-65.
- Both focus groups noted that the HOV lanes are now effectively functioning as a passing lane, but they can also become congested.
- The legislative focus group expressed that they see it as likely that the majority of the public believes that the requirement to operate the HOV lane as an HOV lane at peak demand time forces four lanes of traffic demand into three lanes, significantly worsening congestion.
- Both focus groups believe that current traffic control devices (signage and striping) are not successful in lowering violation rates.
- Both the legislative and law enforcement focus groups felt that speeding in HOV lanes happens on a very regular basis and is a public safety concern.
- The members of the law enforcement focus group believe that pulling over HOV lane violators for only a suspected HOV lane violation is dangerous and disruptive to traffic

flow. The officers felt that manual enforcement operations may well defeat the purpose of having an HOV lane.

- The law enforcement group noted that there is no enforcement possible for many parts of the HOV corridors on I-24 and I-65 because there is no place for law enforcement officers to pull drivers over.
- The legislative and law enforcement focus group members voiced an opinion that the option of automated enforcement likely would not be well received by the public.
- Participants of both focus groups felt that the incentive of saving travel time is not presently sufficient to cause drivers to form new carpools to take advantage of the HOV lane.
- Members of both the legislative and law enforcement focus groups felt that the consequences of an HOV violation must cause enough pain for people to change their behavior if enforcement activities are to be impactful. The members of the focus groups felt that a fine of $50 is not viewed by the public as much of a deterrent to illegal use of the HOV lane, especially when very little enforcement of the lane restrictions is possible.
- It was perceived by both the legislative and law enforcement focus groups that enforcing HOV lane restrictions will undoubtedly cause increasing dissatisfaction of the driving public, as the focus group participants think that the public believes that the majority of drivers will experience longer commutes as a result of heavy enforcement.
- While many constituents of areas surrounding Nashville view the HOV lane as an attempt to force four lanes of traffic into three lanes, many of the driving public are also irritated by HOV lane violators. Hence there will likely be a mixed reaction to any attempt to increase enforcement activities.

The results of the focus group meetings have indicated that there is significant public opposition to the enforcement of HOV lanes because the drivers of single-occupant vehicles find it impractical to form carpools, and also believe that enforcing HOV lane restrictions will lead to longer commute times. (This may or may not be the actual operational result of such enforcement actions.) From the opinions expressed in the focus groups, it is clear that some of the public does not believe the HOV lane is beneficial to travel conditions in the corridor or perhaps to the public overall. This outcome of the focus groups shapes the objectives of the remainder of the study. In the following research activities, it is desired to obtain a better understanding of to what extent the public shares the attitudes expressed by the focus group participants and to understand whether the perception of highway operations held by the public is descriptive of how HOV corridors operate. By developing a fuller understanding of how the corridor operates, suggestions and recommendations for improving operations on the corridor can be formulated.

### Outcomes of Public Survey (Chapter 5)

It is important to understand the attitudes of the public about the use of the HOV lanes and their motivations for obeying or disobeying regulations surrounding their use, as the public likely has mixed opinions about the HOV lanes. Chapter 5 presents the results of a survey of the public undertaken by the Lipscomb University psychology department. The survey instrument contained items covering basic demographics, qualifying questions, knowledge of HOV lane restrictions, compliance and noncompliance, respondents' value of time, responses to increases in fines, factors motivating or preventing carpooling, and aggressive driving behaviors. The following paragraphs summarize the major findings of the survey.

The commuter survey was administered to 476 individuals. The demographic data indicates a reasonably diverse population was achieved. This is especially true for household size, age, and income. However, approximately three-fourths of the respondents were female, and nine-tenths of the respondents were white. The vast majority of respondents are aware of what HOV lanes are and of the restrictions associated with them. However, approximately three-quarters of the respondents self-reported having violated the HOV lane use restrictions, citing frustration with traffic conditions as the primary reason for violating.

While a significant number of respondents self-reported violating HOV lane use restrictions, they reported violating infrequently and primarily to avoid slower moving traffic. This report should be of obvious concern for operations on the HOV corridors because this suggests an important mechanism for breakdown of the entire freeway's performance at diverge bottlenecks. If most drivers choose to change lanes leftward to use the HOV lane, those using the HOV lane to circumvent the queue may ultimately need to force their way back into the queue to make their exit. These lane changes can be disruptive, dropping the capacity of the bottleneck.

Participants have varying opinions concerning carpooling. A large number of respondents felt that carpooling is not a possibility, and nothing can be done to make it more appealing. However, others would consider convenience and facilities would make carpooling a more appealing choice. Some individuals could likely be swayed by monetary incentives to carpool. Some might be willing to consider carpooling with more flexibility in work schedules. Finally, some feel discouraged by the lack of enforcement of HOV lane restrictions. Most individuals need a time savings benefit of 10 to 30 minutes to make either carpooling or use of a service like Uber or Lyft a desirable option.

According to the response of users, the general public is very resistant to paying to travel in the HOV lane as a single-occupant vehicle, and a toll of as much as $1.00 would likely deter many from traveling in the HOV lane. The median valuation of time savings from the HOV lane appears to be on the order of $4.00 per hour. A modestly tolled express lane would likely be able to keep traffic in the HOV lane to low enough levels to prevent deterioration of the HOV lane, as well as the negative consequences to the mixed-flow lanes resulting from a too-heavily-traveled HOV lane.

Although most respondents would not participate in a peer reporting program similar to the HERO program implemented in Seattle WA, a significant number of individuals would be willing to participate. The primary reasons for wanting to participate in such a program include respect for the law, a desire to place a check on unsafe driving behaviors, a belief that people should not prosper from breaking the rules, frustration with a perceived lack of enforcement, and desire to be helpful and improve traffic conditions for society as a whole. Those averse to participating cited the desire not to be a “snitch”, the fear of distracted driving, the desire not to do the government’s job for the government, a general lack of concern or interest regarding HOV violations, a belief that the HOV lanes should not be used as such, an unwillingness to take the time to report, a belief that such actions violate the spirit, if not the letter, of our nation’s constitutional protections, the desire to not be reported when the respondent violates the HOV lane restrictions, a concern that people lie, a concern that people may be punished on flimsy evidence, and concern that people may abuse the system to maliciously and possibly falsely report drivers who have angered the one reporting.

Although Tennessee’s HOV corridors are not open to drivers of single-occupant vehicles during peak hours, some managed lanes operate as high occupancy and tolled access (HOT) lanes, and the study included items to elicit the response of drivers to tolled access and their sensitivity to pricing. It is clear from the high violation rates that a significant portion of the traveling public is willing to use the HOV lanes when driving single-occupant vehicles. The data in Figure 6 show the willingness of drivers to pay a toll to travel in the HOV lane to save 15 minutes of travel time.

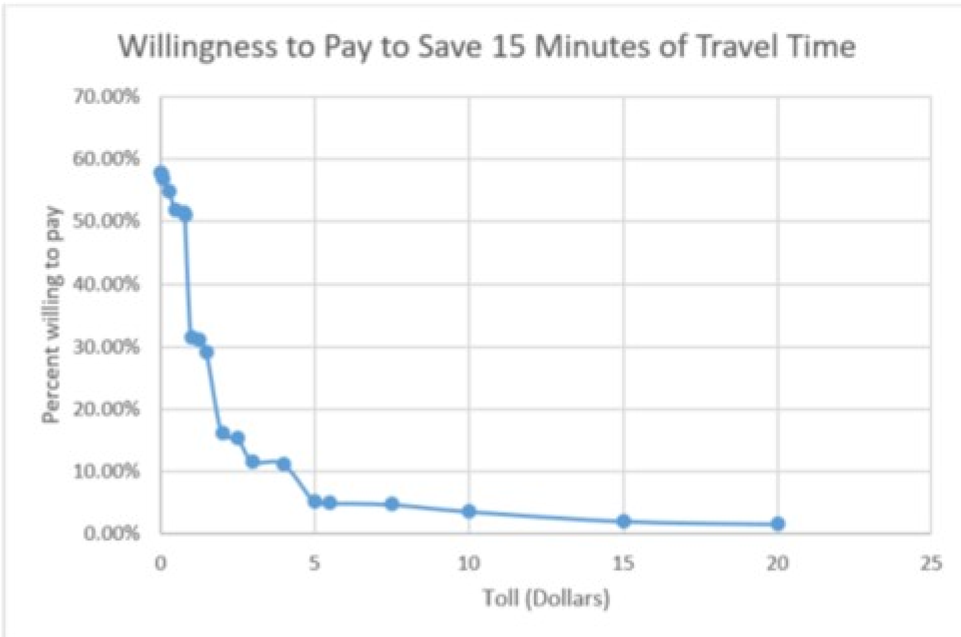



Figure 6 Willingness of respondents to pay to save 15 minutes of travel time by using HOV lane

Using this data, a logit model to predict the probability of a user choosing to pay a toll to use the HOV lane was estimated and is shown as Eq. (1). If the HOT lane is priced at *f* and saves *t* minutes, then the price can be expressed as a price per 15 minutes. By reinterpreting the price *p* as a price per 15 minutes, the probability of a single-occupancy vehicle driver choosing to use the HOT lane gave a cost of *f* dollars and a travel time savings of *t* minutes can be estimated as

$$P(HOT|f,t) = \frac{e^{-1.097 - 0.06875 * f * \frac{15}{t}}}{1 + e^{-1.097 - 0.06875 * f * \frac{15}{t}}} \tag{1}$$

## Analysis of Revealed Preference Data and Stochastic User Equilibrium Model Development (Chapter 6)

While the study undertaken in Chapter 5 provided insight into the stated preferences of drivers, it did not provide evidence of how users of the HOV corridor make decisions about carpooling or lane choice. In Chapter 6, revealed preference data, collected in 2012 by Southern Traffic Systems, was used to study and model how people make these choices. Further, by examining the choice behaviors of thousands of users during peak time, additional insights about the operation of the HOV corridors were generated. In Chapter 6, revealed preference data obtained from a 2012 study of the Nashville HOV corridors in which the number of SOV's and HOV's in the mixed-flow and HOV lane was analyzed to better understand how drivers make choices.

In the analysis of revealed preferences of users, three important findings emerged. First, as can be seen from the data in Figure 7 depicting the relationship between HOV adoption and the travel time index for the mixed-flow lanes (defined as the ratio of the free flow speed to the actual speed in the mixed-flow lanes), congestion in the mixed-flow lane has little or no effect on an individual's decision to carpool. While the data does support a mild positive association between willingness to carpool and the travel time index, the $R^2$ associated with this correlation is so small that it appears that time savings from the usage of the HOV lane do not appear to be a significant factor in the decision of travelers to form carpools. This result is in close agreement with the results of the public survey which indicates that most of the traveling public is unwilling to change their travel behaviors due to travel time savings available to carpools through the use of the HOV lane.

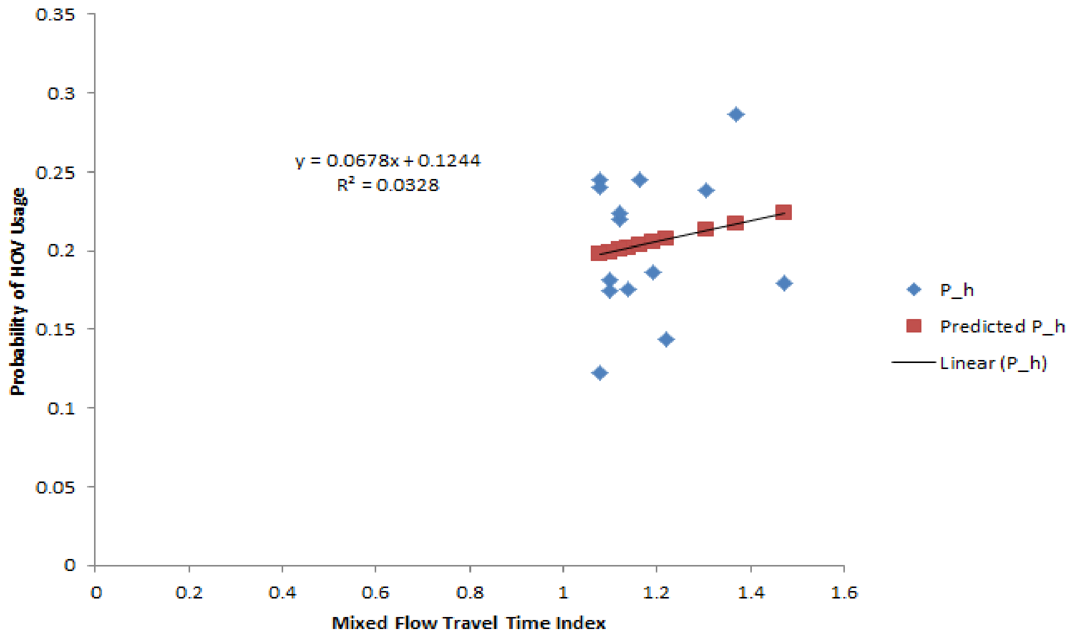



Figure 7 Probability of HOV usage versus mixed-flow travel time index

Second, heavy congestion on the freeway caused many legal HOV lane users to avoid using the HOV lane. The relationship between legal HOV lane usage rates and congestion in the mixed-flow lanes as expressed by the travel time index is shown in Figure 8.

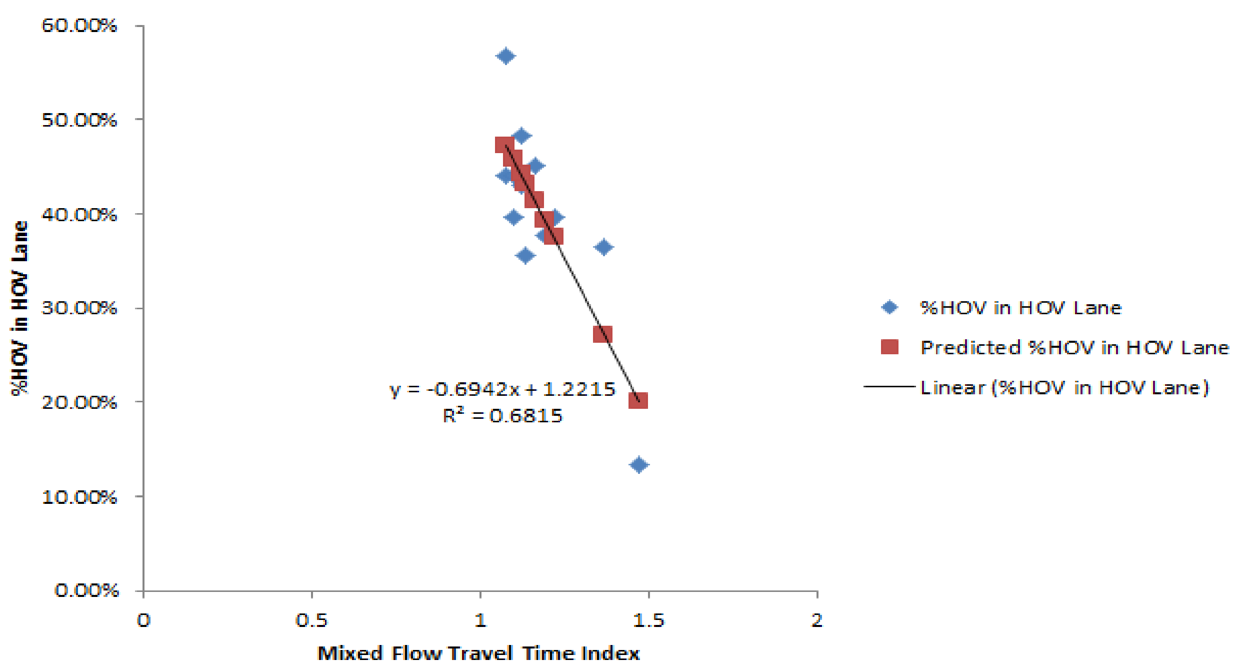



Figure 8 Percent of HOV using HOV lane versus mixed-flow travel time index

Third, the willingness of single-occupant vehicles to violate HOV lane restrictions increases with congestion in the mixed-flow lanes. This is shown by the data in Figure 9.

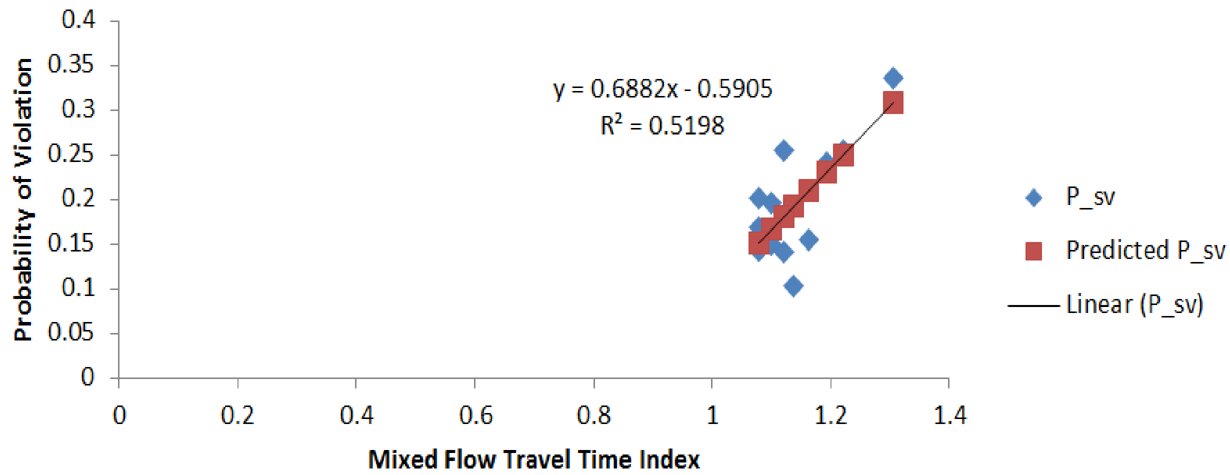



Figure 9 Probability of SOV violation versus mixed-flow travel time index

Chapter 6 seeks to investigate the implications of the revealed preference behaviors of drivers by performing comparative statics studies to determine how equilibrium flows change as a result of changes in demand. Discrete choice models, estimated from the data available in the 2012 Southern Traffic Systems study, form the basis of demand estimation in a stochastic user equilibrium model formulated to determine mode and lane choices.

In modeling the network performance, it was assumed that the flows in the mixed-flow lane and the HOV lane do not interfere with one another and that the corridor can be represented as a network of the configuration shown in Figure 10. Each lane in the network has a performance function that determines travel time as a function of the demand flow rate. These functions are shown for HOV and mixed-flow lanes in Figure 11.

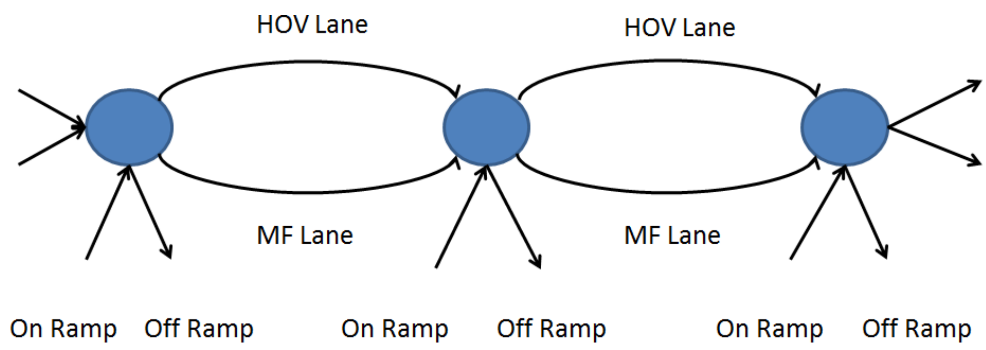



Figure 10 Conceptual network structure for stochastic user equilibrium analysis

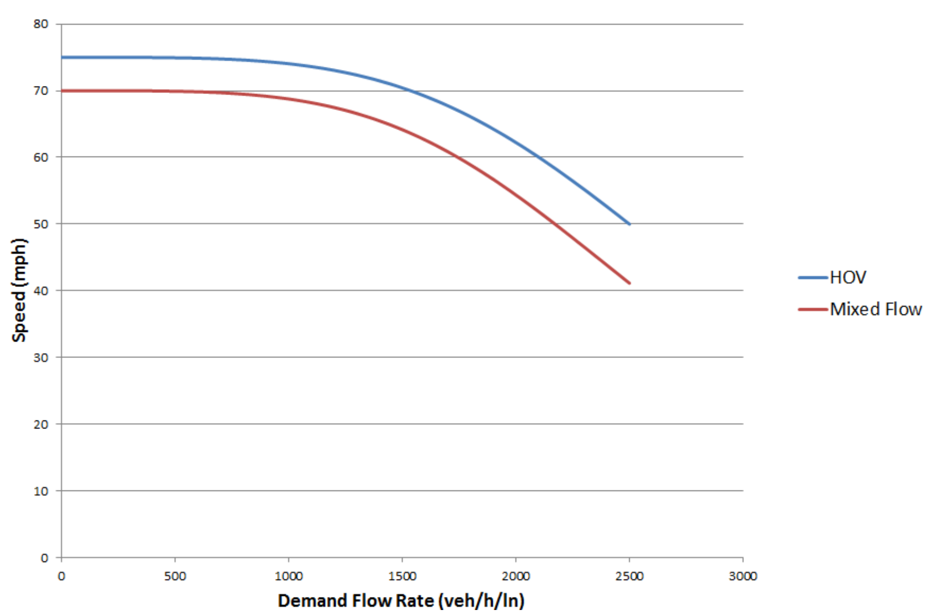



Figure 11 Performance functions for HOV and mixed-flow lanes

The discrete choice models estimated based on counts of HOV and Single Occupancy Vehicle (SOV) in the HOV and mixed-flow lanes were solved simultaneously with the performance functions at varying levels of passenger demand to determine equilibrium HOV and SOV flows in each lane and to determine the corresponding travel speeds. Though it seems counterintuitive that increasing proportions HOV users would choose not to use the HOV lane during highly congested times, equilibrium models solved over a range of total volumes of passengers yield results that closely match field data which indicates that the HOV lane is the last lane to fill with traffic volume. Figure 12 shows the predicted volume of vehicles in the HOV lane as a function of total volume for a section with three mixed-flow lanes. Figure 13 shows the actual usage of the HOV lane as a function of total volume on a heavily traveled segment of I-65 with three mixed-flow lanes and an HOV lane. There is close agreement in the general trends of the data, with a strong upward concavity to the trendlines.

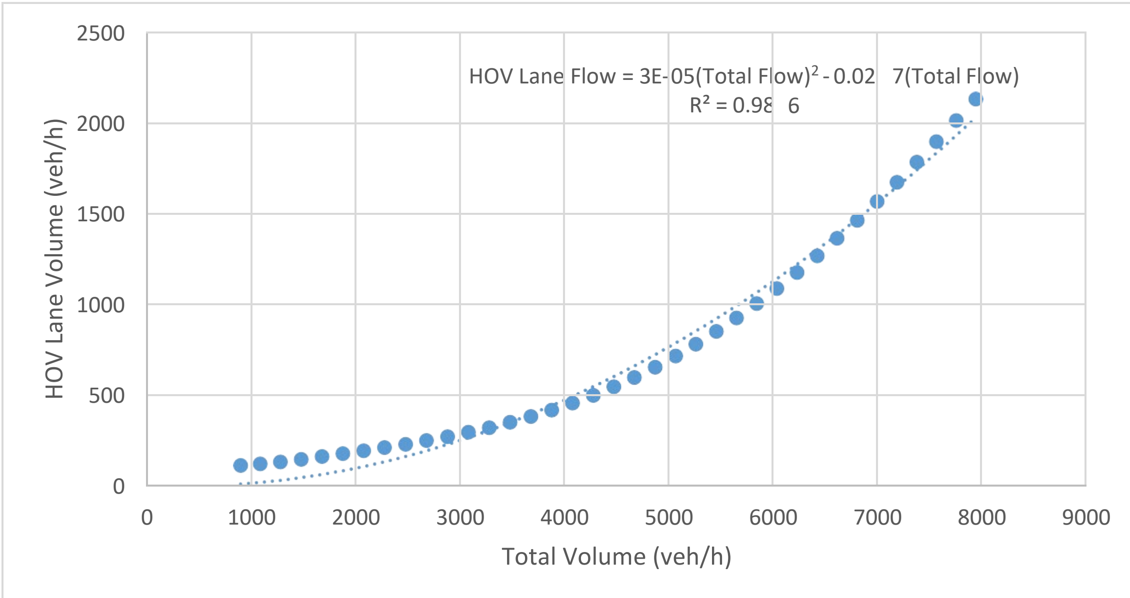



Figure 12 Predicted utilization of HOV lane as a function of the total volume

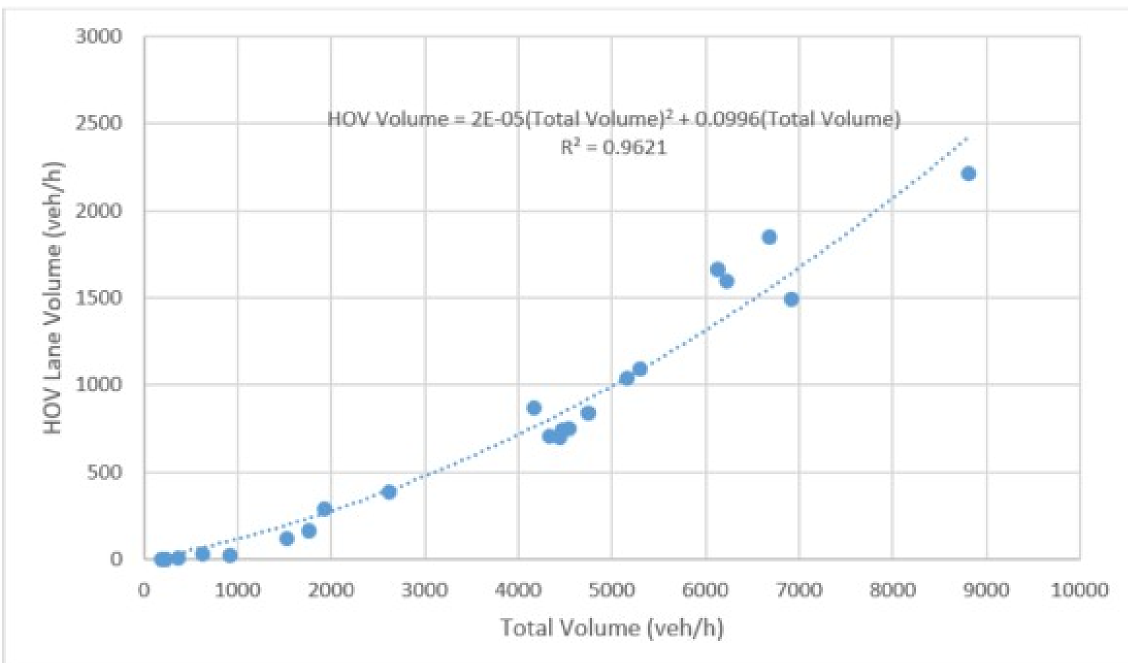



Figure 13 Actual utilization of HOV lane as a function of the total volume

## Equilibrium Studies on the I-65 and I-24 Corridors (Chapter 7)

Chapter 7 extends the analytical work done in Chapter 6 to explore the implications of doing nothing, heavily enforcing the HOV lane restrictions (via toll measures or otherwise) such that the violation rate is held to ten percent and reverting the lane to a mixed-flow lane for the I-24 HOV corridor and the I-65 corridor south of Nashville. The analysis is performed under base year and future (design) year scenarios. The results of the analyses for the I-65 HOV corridor south of Nashville are shown in Table 1. The results of the analyses for the I-24 corridor are shown in Table 2. Note that for the lane reversion case, statistics related to HOV lane usage and violation rates are not applicable, as the HOV lane restriction is no longer enforced and traffic is assumed to load equally into all four lanes.

The results of the equilibrium modeling suggest that reversion of the HOV lane to a mixed-flow lane will likely reduce overall delay and may reduce some classifications of emissions relative to the do-nothing scenario, but it will happen at the expense of losing a rapid way for carpoolers, emergency vehicles, and transit/paratransit vehicles to traverse the HOV corridor.

Given the likely inelasticity of demand for driving SOVs with respect to overall congestion or conditions in the HOV lane, it is likely that removal of flow from the HOV lane could result in very large increases in both vehicular delay and emissions, although it would be difficult to quantify exactly how large the emissions and delay increases would be without resorting to traffic microsimulation. The results of the equilibrium model also suggest that removal of traffic from the HOV lane could lead to a paradox in which more people seem to be willing to carpool, perhaps as a social response to having to drive daily in heavy traffic, but the heavy traffic will make the use of the HOV lane undesirable. Therefore, many travelers may form carpools but reject the HOV lanes intended to incentivize carpooling.

Table 1 Summary of Analysis Results For I-65 HOV Corridor

| | Do Nothing (Peak) | Lane Reversion (Peak) | Heavy Enforcement (Peak) | Do Nothing (DHV) | Lane Reversion (DHV) | Heavy Enforcement (DHV) |
|---|---|---|---|---|---|---|
| Peak Hour HC Emissions (g/hr) | 20376 | 20211 | 25799 | 36227 | 29302 | 43800 |
| Peak Hour CO Emissions (g/hr) | 264412 | 268331 | 314934 | 415486 | 371673 | 427439 |
| Peak Hour NOx Emissions (g/hr) | 33718 | 33884 | 36407 | 48402 | 43481 | 50604 |
| HOV Corridor Free Flow Trip Time (min) | 23.9 | -- | 23.9 | 23.9 | -- | 23.9 |
| HOV Corridor Trip Time (min) | 29.3 | -- | 23.9 | 51.0 | -- | 23.9 |
| MF Corridor Free Flow Trip Time (min) | 25.6 | 25.6 | 25.6 | 25.6 | 25.6 | 25.6 |
| MF Corridor Trip Time (min) | 30.9 | 31.8 | 49.1 | 52.5 | 44.6 | 77.4 |
| Total Corridor Delay (veh-min/hr) | 53905 | 62425 | 213306 | 328823 | 214687 | 505993 |
| Average Violation Rate | 81.6% | -- | 10.00% | 83.92% | -- | 10.00% |
| Percentage HOV in Traffic Stream | 23.0% | 22.16% | 29.41% | 21.35% | 27.73% | 40.04% |
| Percentage of HOVs in HOV Lane | 29.5% | -- | 6.60% | 29.40% | -- | 2.71% |

Table 2 Summary of Analysis Results for I-24 HOV Corridor

| | Do Nothing (Peak) | Lane Reversion (Peak) | Heavy Enforcement (Peak) | Do Nothing (DHV) | Lane Reversion (DHV) | Heavy Enforcement (DHV) |
|---|---|---|---|---|---|---|
| Peak Hour HC Emissions (g/hr) | 28707 | 28559 | 31739 | 35903 | 36314 | 64323 |
| Peak Hour CO Emissions (g/hr) | 343476 | 342882 | 381997 | 440288 | 445542 | 591769 |
| Peak Hour NOx Emissions (g/hr) | 55237 | 55651 | 56422 | 67058 | 67230 | 93094 |
| HOV Corridor Free Flow Trip Time (min) | 35.0 | N/A | 35.0 | 35.0 | N/A | 35.0 |
| HOV Corridor Trip Time (min) | 40.4 | N/A | 35.0 | 48.2 | N/A | 35.0 |
| Mixed-flow Corridor Free Flow Trip Time (min) | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 |
| MF Corridor Trip Time (min) | 43.3 | 43.6 | 60.2 | 54.7 | 55.3 | 108.6 |
| Total Corridor Delay (veh-min/hr) | 55607 | 59761 | 201026 | 178717 | 192488 | 673455 |
| Average Violation Rate | 82.5% | N/A | 10.0% | 90.2% | N/A | 10.0% |
| Percentage of HOV in Traffic Stream | 21.4% | 21.6% | 27.6% | 25.6% | 26.0% | 31.3% |
| Percentage of HOV in HOV Lane | 29.4% | N/A | 9.5% | 14.1% | N/A | 10.3% |

Given the agreement of the baseline user equilibrium model with field data, the conclusions are likely valid for times of day and locations of the HOV corridors that are not under heavy congestion, though the models themselves have significant limitations and modeling assumptions that must be investigated when congestion becomes heavier. It should be noted that the Bureau of Public Roads (BPR) performance functions are only valid for mildly to moderately congested states of traffic. While transportation planners are likely to use these models for instances where demand exceeds the capacity for simple planning studies, there is no operational reason why these models should be considered valid when demand nears or exceeds capacity.

Moreover, there is an assumption underlying these stochastic user equilibrium models that the freeway under consideration is homogeneous with regard to its speed-flow-density relationships. As freeways become excessively congested, this is rarely the case near the causes of the bottlenecks that govern delay on the freeway. A full understanding of operations must include analysis of flow and density along the highway, necessitating either macroscopic modeling of the corridor, as presented in Chapter 8, or microscopic modeling, as presented in Chapter 9.

If the assumptions underlying the stochastic equilibrium models are invalid, the conclusions of this modeling framework could be wrong or even misleading. This is particularly true at merge or diverge bottlenecks where poor queue discipline can lead to a breakdown of the facility. Nonetheless, these models are of significant value because they explain how many in the public may perceive changes to the corridor, whether or not the supply functions assumed in the analysis are realistic and can be extrapolated beyond the point at which demand exceeds capacity, or whether or not weaving maneuvers make the network representation of Figure 10 an appropriate representation of the system.

## Macrosimulation Studies (Chapter 8)

Macrosimulation was performed by using the Cell Transmission Model (CTM) to solve the LWR PDE for several reasons. First, the CTM is capable of simulating the behavior of traffic when demands on the facility exceed the capacity of the facility. Second, analysis using the CTM allows for investigation into the homogeneity of the highway and to see where (if anywhere) key operational parameters in the fundamental diagram change when compared with traffic data. Third, when traffic is simulated in VISSIM, the results of the CTM are useful in assessing the reasonableness of the results obtained from VISSIM.

In this chapter, only the southbound corridor of I-65 south of Nashville was considered. This is because calibration studies were performed in VISSIM to adjust the parameters of the Wiedemann74 model on a single corridor such that the calibrated model was a reasonable starting point for the investigation of the five other corridors.

Figure 14 shows the results of the CTM simulation for a situation in which the fundamental diagram is homogeneous. (Occupancy is used for the elevation of the surface plot and is proportional to density. Higher occupancy corresponds to higher traffic density.) Note that there is a major bottleneck near Interchange 79 (Armory Drive) where there is a lane drop. This bottleneck regulates the discharge of the vehicles down the rest of the corridor, and the simulation indicates that the rest of the corridor would operate at or near capacity for most of the rest of its length. However, analysis of Google Traffic data indicates the presence of congestion near the bottlenecks. The presence of these bottlenecks indicates that the capacity of the Interstate in these locations is less than the capacity of the immediately upstream section. Figure 15 shows the results of the CTM simulation where the diverge sections have been subjected to a one percent drop in capacity. Note the densification of traffic near the bottlenecks in Figure 15.

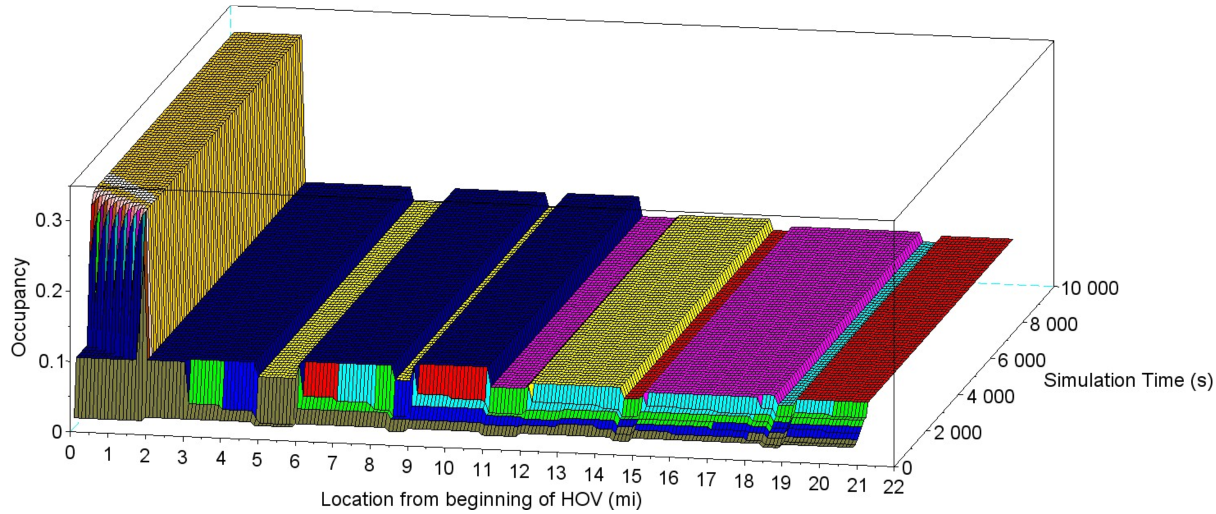



Figure 14 CTM results under the assumption of a homogeneous fundamental diagram

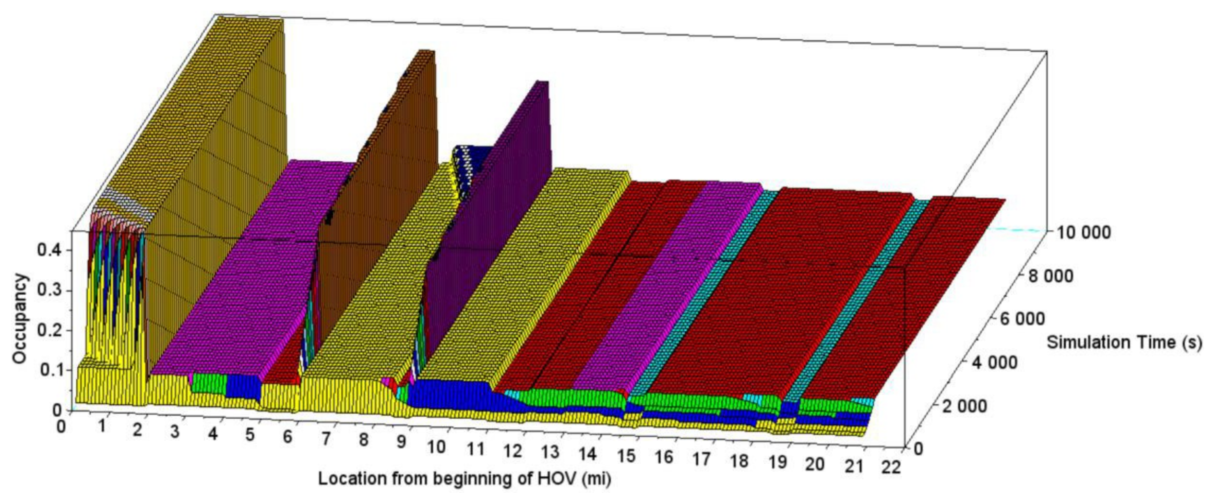



Figure 15 CTM results under the assumption of one percent capacity drop at diverge nodes

It is well known that traffic flow is relatively unstable near the top of the fundamental diagram and that as traffic moves from the unqueued state the capacity can often drop significantly. This drop is on the order of three to ten percent for many facilities. However, the behavior of a facility near capacity is very difficult to quantify precisely in constructing a mathematical model to represent the fundamental diagram. It should be noted that only a one percent drop in the capacity of a weaving section was sufficient to significantly alter the solution of the LWR PDE in the vicinity of the bottlenecks. For this reason, managing weaving traffic carefully is crucial to avoiding the capacity drop phenomenon to the greatest extent possible. Managing this capacity drop is key to alleviating many of the conditions responsible for causing the bottlenecks that likely drive most of the HOV lane violations.

### Microsimulation Studies (Chapters 9, 10, and 11)

While it should be suspected that weaving has a significant impact on operations, only direct observation of traffic video or traffic microsimulation can provide insights into the mechanics of the breakdown. To gain a deeper understanding of operations on each of the six HOV corridors on I-65 and I-24 in Nashville, microsimulation analysis was performed in VISSIM. Each corridor was simulated for a two-hour time window, and outputs are based on the second hour of the simulation, allowing for ample warmup time for the network.

In the models, various classes of users were established, including heavy goods vehicles, single-occupant vehicles, violators, and high occupancy vehicles. Only violators and high occupancy vehicles were allowed to enter the HOV lane, and heavy goods vehicles were prohibited from using the leftmost two lanes when the facility had four or more lanes including the HOV lane.

By varying the composition of each class of vehicles in the traffic stream, it was possible to construct scenarios that reflect the current state of operations on the interstate corridors and to vary compositions of vehicle classes to allow more vehicles into the HOV lane (by making all SOVs part of the violator class) or restrict more vehicles from using the HOV lane. For each facility, six different analyses were performed, including do-nothing, lane reversion, and heavy enforcement actions for the base year and future demands, which were assumed to be twenty percent greater than the base year demands.

For all six corridors, significant frictive slowing of the HOV lane occurs not primarily because of traffic density in the HOV lane, but rather because of the need to make lane changes to exit the HOV lane. This problem is exacerbated by the provision of continuous access and egress from the HOV lane. The allowance of continuous access and egress from the HOV lanes will limit the ability of the HOV lane to perform well under heavy congestion.

On all corridors, delay on the corridor is primarily caused by bottlenecks, which are typically caused by necessary weaving at the exits and entrances. Diverge bottlenecks are improved by reducing the number of vehicles who are weaving over short distances from the leftmost lanes and by drivers going through the bottleneck traveling in the leftmost lanes. Merge bottlenecks are improved by traffic on the mainline moving leftward, thereby providing gaps for entering vehicles to join the traffic stream and increasing bottleneck throughput. Specific results and observations for each corridor are presented in the following subsections.

### Southbound I-65 South of Nashville

Simulation results for the southbound I-65 corridor are summarized in Table 3. Beyond Exit 79 (Armory Drive), the southbound corridor of I-65 south of Nashville is overwhelmingly controlled by diverging bottlenecks. The best ways to improve operations at these diverge bottlenecks is to: (1) encourage traffic exiting the freeway at exits beyond the bottleneck to use the leftward lanes, and (2) prevent traffic from the leftmost lanes from moving rightward too late. Improvements in queue discipline that could come from a heavily enforced HOV lane could save the typical SOV driver more time than the reversion of the HOV lane to a mixed-flow lane.

Under current operational regulations, the HOV lane on the southbound corridor of I-65 south of Nashville is currently overutilized. This might not be the case if double solid white lines were used to promote access and egress from the HOV lane to occur in desirable locations, but without these modifications, the conflicts of vehicles exiting the HOV lane with vehicles in the leftmost mixed-flow lanes cause a significant slowing of traffic in the HOV lane.

Table 3 Corridor Performance Metrics for VISSIM Simulation of the Southbound I-65 South of Nashville (Preferred Outcomes in Green)

| Metric | BYDN | BYLR | BYHE | FYDN | FYLR | FYHE |
|---|---|---|---|---|---|---|
| Corridor All Vehicles Travel Time (min) | 40.4 | 46.2 | 37.7 | 47.6 | 46.2 | 46.2 |
| Corridor Trip Time for SOV (min) | 44.4 | 46.9 | 38.1 | 52.4 | 46.9 | 46.9 |
| Corridor Trip Time for HGV (min) | 49.2 | 52.9 | 43.8 | 59.9 | 52.9 | 52.9 |
| Corridor Trip Time for HOV (min) | 22.9 | N/A | 20.7 | 25.8 | N/A | 23.4 |
| Total CO2 Emissions (g/hr) | 782992 | 694199 | 681278 | 958814 | 1001220 | 890348 |
| Total NOX Emissions (g/hr) | 152342 | 135066 | 132552 | 186550 | 194801 | 173229 |
| Total VOC Emissions (g/hr) | 181468 | 160877 | 157893 | 222214 | 232042 | 206347 |
| Total Fuel Consumption (gal/hr) | 11202 | 9931 | 9746 | 13717 | 14324 | 12737 |

### Northbound I-65 South of Nashville

Microsimulation results for the northbound I-65 corridor south of Nashville are shown in Table 4. The northbound I-65 HOV corridor south of Nashville has some important operational differences from the southbound corridor south of Nashville due to the distribution of the influx along the corridor. Downtown Nashville serves as a major trip attractor in the AM direction and a major trip producer in the PM direction and the distribution of the influx in the AM direction results in a system that is governed by a combination of merge and diverge bottlenecks distributed over approximately ten to fifteen miles from Franklin to downtown Nashville. The feature along the corridor responsible for the greatest generation of delay is the merge bottleneck that occurs immediately after the entrance ramp of Interchange 74 (Old Hickory Boulevard). At this point, there is a heavy volume being carried in the main lanes, and there are initially two auxiliary lanes of traffic that merge into the freeway.

When policy options are compared concerning operational and environmental metrics for the performance of the corridor as a whole, it becomes clear that for this corridor, as it was for the southbound corridor, a heavy enforcement strategy which allows the HOV lane to be used by a smaller number of users could be the best strategy under current demands, but the advantages could also ultimately erode in future years as larger volumes of traffic must merge at freeway entrances and gaps need to be created for the merging vehicles by allowing more drivers to use the HOV lane.

This corridor is lengthy, carrying a very large traffic volume, and is governed by both merge and diverge bottlenecks. However, the presence of major merges of traffic into very heavy traffic closer to downtown tends to make operations of the northbound direction significantly different from the southbound due to the prevalence of a very significant merge bottleneck unlike any found on the southbound corridor. As a result, in future years it may be the case that the HOV lane would be underutilized in the heavy enforcement scenario. If too much volume is removed from the HOV lane and placed in the mixed-flow lane, the merge bottleneck could be made so severe it negates the benefits to the HOV lane in terms of overall metrics of system performance.

The most important challenges facing this corridor are: (1) getting exiting vehicles out of the leftmost lanes early enough to avoid causing operational problems at diverge bottlenecks, (2) getting vehicles leftward at merge bottlenecks to allow for enough gaps for merging vehicles to join the traffic stream, and (3) incentivizing through traffic to stay in the leftward lanes until time for an orderly exit. Solving the aforementioned operational challenges will likely require operational improvements preventing lane changes out of the HOV lanes at times that are too late to avoid degrading diverge bottlenecks. If sufficient demand cannot be attracted to the HOV lanes under operational improvements from barrier separation and/or double solid white line indicators, the corridor could benefit operationally from a HOT lane conversion to allow those desiring to use the current HOV lane to have legal access to the lane.

Table 4 Corridor Metrics of Performance for VISSIM Simulation of Northbound I-65 South of Nashville (Preferred Outcomes in Green)

| Metric | BYDN | BYLR | BYHE | FYDN | FYLR | FYHE |
|---|---|---|---|---|---|---|
| Corridor All Vehicles Travel Time (min) | 25.9 | 26.4 | 25.6 | 37.9 | 40.9 | 40.5 |
| Corridor Trip Time for SOV (min) | 26.4 | 26.2 | 25.6 | 39.8 | 40.7 | 41.1 |
| Corridor Trip Time for HGV (min) | 29.8 | 29.0 | 28.7 | 43.1 | 45.5 | 43.7 |
| Corridor Trip Time for HOV (min) | 23.3 | N/A | 21.9 | 31.8 | N/A | 30.3 |
| Total CO2 Emissions (g/hr) | 394422 | 391643 | 375751 | 595911 | 620733 | 582562 |
| Total NOX Emissions (g/hr) | 76740 | 76200 | 73108 | 115943 | 120772 | 113345 |
| Total VOC Emissions (g/hr) | 91411 | 90767 | 87084 | 138108 | 143861 | 135014 |
| Total Fuel Consumption (gal/hr) | 5643 | 5603 | 5376 | 8525 | 8880 | 8334 |

### Northbound I-65 North of Nashville

A summary of the results of the microsimulation of the northbound I-65 corridor north of Nashville is shown in Table 5. The HOV lane on this corridor north of Nashville is the only facility that Tennessee cannot certify as meeting minimum performance standards for HOV lanes. This failure is caused by a major bottleneck at the Vietnam Veterans Boulevard exit near the end of the HOV corridor. Typically, the activation of the bottleneck at the Vietnam Veterans Boulevard exit creates a backward wave of traffic operating at near-standstill speeds. This ultimately extends back up the I-65 corridor to the beginning of the HOV corridor at MM 90. The HOV lane has slowed in sympathy with the mixed-flow lanes to the point that TDOT is now no longer able to certify to FHWA that the HOV lane meets minimum performance standards of a better than 45 mi/h operating speed with better than 90 percent reliability. The slowing of the HOV lane to speeds below that required of HOV facilities is a result of the poor configuration of the egress from the HOV lane before the Vietnam Veterans Boulevard exit.

The inability to prevent late lane changes out of the HOV lane by drivers using the HOV lane as a queue jump from the beginning of the corridor to Vietnam Veterans Boulevard causes additional stress to an otherwise major diverge, creating a significant bottleneck with a backward queueing wave that leaves most of I-65 operating at nearly standstill conditions through most of the period of peak demand. As drivers in the HOV lane attempt to exit, they both further break down operations in the mixed-flow lanes and delay other drivers in the HOV lane. These operational conditions can be visualized by considering the dense spacing of vehicles in the HOV lane in Figure 16.

If considering options from among those considered in this study, there is no single dominant alternative as there was for the I-65 corridor south of Nashville. However, if heavy enforcement were implemented, travel times for both the single-occupant vehicles and the high occupancy vehicles would decrease. This is despite an increase in the average travel time, which currently is the best under the do-nothing scenario because violators who are going through the bottleneck on the I-65 side can leverage the HOV lane to bypass the bottleneck. However, under a heavy enforcement scenario, those who stand to gain the most are the honest SOV operators. Those who stand to lose the most are the HOV violators.

With design improvements to control lane changes to more desirable locations, a HOT lane concept could provide the maximal benefit, as there are likely many drivers who are willing to pay to save half an hour of travel time if they knew that they could bypass the Vietnam Veterans Boulevard exit. Getting these drivers to take the HOV/HOT lane could create significant improvements to the operations of this corridor as they are taking the lane straight through the bottleneck and increasing bottleneck throughput. Lane reversion would decrease delays but would also increase emissions on the corridor due to the stop-and-go nature of traffic. A lane reversion would also lose all benefits of having an uncongested route and would not provide as much benefit as a well-enforced HOT lane.

In the author's opinion, the best solution for the northbound I-65 corridor north of Nashville is a combination of operational improvements to manage access and egress to the HOV lane and the conversion of the HOV lane to a HOT lane, as the HOT lane has enforcement mechanisms built into the design and concept of operations.

Figure 16 Queue formation in HOV lane due to vehicles exiting from the HOV lane. Note the yellow ellipse showing a region of congested vehicles where some have slowed to attempt a last-second lane change.

Table 5 Corridor Performance Metrics for VISSIM Simulation of the Northbound I-65 Corridor North of Nashville (Preferred Outcomes in Green)

| Metric | BYDN | BYLR | BYHE | FYDN | FYLR | FYHE |
|---|---|---|---|---|---|---|
| Corridor All Vehicles Travel Time (min) | 39.8 | 47.4 | 44.6 | 44.0 | 55.1 | 47.4 |
| Corridor Trip Time for SOV (min) | 55.2 | 47.4 | 49.3 | 61.6 | 55.0 | 52.0 |
| Corridor Trip Time for HGV (min) | 55.3 | 48.0 | 49.8 | 61.2 | 56.7 | 53.4 |
| Corridor Trip Time for HOV (min) | 10.9 | N/A | 5.2 | 12.3 | N/A | 5.4 |
| Total CO2 Emissions (g/hr) | 916329 | 1073588 | 1022544 | 1041827 | 1358958 | 1102764 |
| Total NOX Emissions (g/hr) | 178284 | 208881 | 198950 | 202702 | 264404 | 214558 |
| Total VOC Emissions (g/hr) | 212368 | 248814 | 236984 | 241453 | 314952 | 255576 |
| Total Fuel Consumption (gal/hr) | 13109 | 15359 | 14629 | 14905 | 19441 | 15776 |

### Southbound I-65 North of Nashville

This downtown Nashville-bound corridor has very different operational challenges from the northbound corridor, as well as any other corridor under consideration. The corridor has significant downstream flow control at the end as the bottleneck caused by the merge of I-24 and I-65 can result in extremely slow conditions that can spill back into the corridor. However, when downstream bottlenecks do not interfere with the operation of the HOV corridor, the corridor is primarily controlled by diverge bottlenecks.

Microsimulation results are summarized in Table 6. From these results, it can be seen that enforcing HOV lane restrictions does not serve the interests of either operational efficiency or enhancement of environmental quality. The HOV lane reversion to a mixed-flow lane would provide the best operational outcomes for the facility. However, HOT lanes could be used to gain almost as favorable an operational scenario while preserving a minimally congested alternative and providing significant air quality enhancement over a simple lane reversion.

Table 6 Corridor Performance Metrics for VISSIM Simulation of the Southbound I-65 North of Nashville (Preferred Outcomes in Green)

| Metric | BYDN | BYLR | BYHE | FYDN | FYLR | FYHE |
|---|---|---|---|---|---|---|
| Corridor Trip Time for SOV (min) | 19.7 | 15.5 | 25.7 | 28.2 | 23.5 | 37.9 |
| Corridor Trip Time for HGV (min) | 20.4 | 16.6 | 27.9 | 30.1 | 24.7 | 41.2 |
| Corridor Trip Time for HOV (min) | 7.6 | N/A | 7.0 | 8.5 | N/A | 6.8 |
| Total CO2 Emissions (g/hr) | 196661 | 225914 | 244827 | 241805 | 302545 | 365943 |
| Total NOX Emissions (g/hr) | 38263 | 43955 | 47634 | 47046 | 58864 | 71199 |
| Total VOC Emissions (g/hr) | 45578 | 52358 | 56741 | 56041 | 70118 | 84811 |
| Total Fuel Consumption (gal/hr) | 2813 | 3232 | 3503 | 3459 | 4328 | 5235 |

## Eastbound I-24

Microsimulation results for the eastbound corridor of I-24 are summarized in Table 7. The eastbound corridor of I-24 is overwhelmingly controlled by diverge bottlenecks. The best way to improve operations at these diverge bottleneck is to: (1) encourage traffic exiting the freeway at exits beyond the bottleneck to use the leftward lanes, and (2) prevent traffic from the leftmost lanes from moving rightward too late. Improvements in queue discipline that could come from a heavily enforced HOV lane could save the typical SOV driver more time than the reversion of the HOV lane to a mixed-flow lane.

Under current operational regulations, the HOV lane on the eastbound corridor of I-24 is currently overutilized. This might not be the case if these HOV lanes were barrier separated, or if double solid white lines were used to promote access and egress from the HOV lane to occur in desirable locations, but without these modifications, the conflicts of vehicles exiting the HOV lane with vehicles in the leftmost mixed-flow lanes cause a significant slowing of traffic in the HOV lane and contribute to bottleneck formation in the mixed-flow lanes.

Enforcing the HOV lane restrictions in an automated manner through the use of tolling and a HOT lane regulatory framework would likely improve every aspect of the corridor's performance for all users and reduce emissions and fuel consumption, while simultaneously opening access to the HOT lane to the entire driving public. Pricing controls could give TDOT the ability to manage the number of individuals using the HOV lane by controlling the pricing, allowing for the operation to vary from nearly HOV-only to a full lane reversion.

Table 7 Corridor Performance Metrics for VISSIM Simulation of the Eastbound I-24 Corridor (Preferred Outcomes in Green)

| Metric | BYDN | BYLR | BYHE | FYDN | FYLR | FYHE |
|---|---|---|---|---|---|---|
| Corridor All Vehicles Travel Time (min) | 41.1 | 45.1 | 37.7 | 43.4 | 50.6 | 43.3 |
| Corridor Trip Time for SOV (min) | 46.8 | 44.7 | 38.8 | 51.1 | 50.1 | 44.7 |
| Corridor Trip Time for HGV (min) | 50.0 | 48.3 | 42.1 | 52.5 | 55.3 | 47.8 |
| Corridor Trip Time for HOV (min) | 21.7 | N/A | 19.4 | 24.0 | N/A | 19.7 |
| Total CO2 Emissions (g/hr) | 871907 | 1066842 | 717935 | 1040549 | 1175423 | 820636 |
| Total NOX Emissions (g/hr) | 169641 | 207569 | 139684 | 202453 | 228695 | 159666 |
| Total VOC Emissions (g/hr) | 202073 | 247251 | 166388 | 241157 | 272416 | 190190 |
| Total Fuel Consumption (gal/hr) | 12474 | 15262 | 10271 | 14886 | 16816 | 11740 |

## Westbound I-24

Microsimulation results for the westbound corridor of I-24 are summarized in Table 8. The westbound I-24 HOV corridor is a lengthy corridor, carrying a very large traffic volume, and is governed by both merge bottlenecks and diverge bottlenecks. The most important challenges facing this corridor are: (1) getting exiting vehicles out of the leftmost lanes early enough to avoid causing operational problems at diverge bottlenecks, (2) getting vehicles leftward at merge bottlenecks to allow for enough gaps for merging vehicles to join the traffic stream, and (3) incentivizing through traffic to stay in the leftward lanes until time for an orderly exit. Solving the aforementioned operational challenges will likely require operational improvements preventing lane changes out of the HOV lanes at times that are too late to avoid degrading diverge bottlenecks. Lane reversion could provide significant operational benefit, but with significant environmental costs and the loss of an uncongested route through the corridor. The HOT lane concept could provide significant operational benefits to the corridor while reducing emissions over the lane reversion scenario.

The most impactful thing that could be done to the HOV corridor to improve the performance of the corridor overall is to introduce significant segments of double solid white line, or a pair of double solid white lines with reflectors between them to discourage weaving in undesirable locations and protect the HOV lane from frictive slowing at the bottlenecks. The HOV facilities on I-5 in Seattle currently use both types of demarcations to help control weaving from the HOV lane. While this type of lane demarcation may not prevent all undesirable weaving volume near diverge bottlenecks, it could provide drivers with guidance about when to make their lane changes and significantly reduce weaving problems. At these locations, it is not as problematic for drivers to violate restrictions to join the traffic in the HOV lane, but it is far more disruptive for a vehicle to exit the HOV lane so late that it must disrupt flow in three or more mixed-flow lanes to exit the facility.

Table 8 Corridor Performance Metrics for VISSIM Simulation of the Westbound I-24 Corridor (Preferred Outcomes in Green)

| Metric | BYDN | BYLR | BYHE | FYDN | FYLR | FYHE |
|---|---|---|---|---|---|---|
| Corridor All Vehicles Travel Time (min) | 41.54 | 39.77 | 46.26 | 49.87 | 58.69 | 58.26 |
| Corridor Trip Time for SOV (min) | 49.94 | 39.34 | 49.41 | 63.49 | 58.29 | 62.84 |
| Corridor Trip Time for HGV (min) | 51.73 | 46.18 | 52.92 | 65.39 | 63.96 | 65.83 |
| Corridor Trip Time for HOV (min) | 25.72 | N/A | 22.89 | 28.69 | N/A | 24.33 |
| Total CO2 Emissions (g/hr) | 676047 | 743376 | 620460 | 1041827 | 1358958 | 1102764 |
| Total NOX Emissions (g/hr) | 131534 | 144634 | 120719 | 202702 | 264404 | 214558 |
| Total VOC Emissions (g/hr) | 156680 | 172285 | 143798 | 241453 | 314952 | 255576 |
| Total Fuel Consumption (gal/hr) | 9672 | 10635 | 8876 | 14905 | 19441 | 15776 |

## Discussion, Conclusions, and Recommendations

This study has pursued the issue of understanding the reasons for the high violation rates on Nashville's HOV corridors from a wide variety of perspectives. In this study, public opinion and attitudes toward HOV lanes have been better understood through focus groups and public opinion surveys. This has been necessary because the traffic patterns observed on the HOV corridors are largely the results of individuals seeking to minimize their travel disutility- money, time, and other sources of discomfort (complicated maneuvers, lane changes, etc.). Hence it was necessary to evaluate how drivers make choices through the qualitative survey.

From the public survey, it was learned that the HOV lanes do not have much impact on whether drivers choose to carpool. We learned that the travel time saved by the use of the HOV lane is valued little by drivers when asked what they would be willing to pay to use the HOV lane. We also learned that most drivers do not prefer to be in the HOV lane and that the HOV lane serves as a passing lane, as those who admit to HOV violation do not spend most of their time on the highway in the HOV lane and that it is used only because of dissatisfaction with the progression of traffic. Various aspects of data compiled from other sources support these conclusions.

User choice is also impacted by the performance of the facilities available, and equilibrium flows cannot be determined without understanding the performance of facilities and capturing them in a mathematical or computational model. There are many models available for estimating facility performance, ranging from simple BPR formulae to the Lighthill-Whitham-Richards Partial Differential Equation (LWR PDE) to traffic microsimulation. Each level of increasing detail has been used to better understand and evaluate the reasonableness of predictions made by simpler models.

Equilibrium traffic flows have been determined under light traffic using discrete choice models estimated based on vehicle counts found for mixed-flow and HOV lanes. This is a standard practice in transportation planning models where user equilibrium is to be determined. These models are typically valid for uncongested traffic but are sometimes extrapolated in practice in traffic assignment algorithms. In these models, traffic slowing happens because the progression of traffic becomes increasingly dictated by those with the slowest desired speeds.

In the equilibrium model for lane choice, the links on the network are not assumed to impact the performance of other links. Further, the BPR formula typically requires an assumption of homogeneity for the facility. The results of equilibrium analysis imply that HOV lane reversion is unequivocally the best option for facilities when the aforementioned assumptions are valid, and indeed, the HOV lane restrictions do not apply in off-peak periods. It should also be noted that when legislators say that their constituents describe the HOV lanes as serving to “force four lanes of traffic into three,” it is clear that the public generally makes these aforementioned assumptions in forming their opinion about what will happen as a result of HOV lane policy changes. Hence, it was necessary to test the validity of the assumptions made in the stochastic user equilibrium models.

After solving the user equilibrium models, the same general trend of drivers avoiding the HOV lane until the mixed-flow lanes fill was observed in the field data as well. When traffic can freely change lanes between the HOV and mixed-flow lanes, there is good reason to have confidence in the predictions of the user equilibrium analysis concerning the implications of user equilibrium models.

Unfortunately, BPR formulae and network modeling assumptions fall apart when demand exceeds capacity at some location on the freeway and the performance of a part of the corridor is governed by bottlenecks. At this point, the assumption of independence of performance of the

HOV lane and the mixed-flow lanes is simply no longer valid. The remainder of the project clarified to what extent the assumptions behind the equilibrium models are valid.

The first assumption to be investigated was the assumption of homogeneity of the corridor. In investigating the southbound I-65 corridor south of Nashville, the LWR PDE was solved by the cell transmission model under assumptions of homogeneity about the fundamental diagram. The solution led to a result where there would be a primary bottleneck at Exit 78 with capacity discharge south of Exit 78, diminishing as drivers exit the facility at downstream exits. However, from the observation of typical traffic patterns available in Google Maps, it is clear that secondary bottlenecks form downstream of the primary bottleneck, notably at Exits 74, 71, and 68.

The formation of these bottlenecks clearly shows the inhomogeneity of the facility, and minor reductions in the capacity of the fundamental diagram for cells in the CTM simulation led to an observation of bottleneck formation. This is evidence that the freeway performance is not homogeneous in space, likely due to the weaving in the vicinity of the exits. While previous studies have noted that a capacity drop on the order of three to ten percent exists as traffic moves from a queued to an unqueued state on the fundamental diagram, a capacity drop of only one percent produced significant bottlenecks with high densification of traffic in the vicinity of the diverge bottlenecks and a match to the behaviors observed in the peak hour. The elimination of weaving volumes from the HOV lane in the vicinity of exits represent significant potential for improving operations near diverge bottlenecks.

While it should be suspected that weaving has a significant impact on operations, only direct observation of traffic video or traffic microsimulation can provide insights into the mechanics of the breakdown. In this project, the mechanisms of breakdown could beobserved for the HOV corridors on I-24 and I-65 under various assumptions about restrictions on vehicle classes allowed to use the HOV lane and their relative prevalence in the composition of the traffic stream. This process of experimentation allowed the impacts of such simple policy decisions like doing nothing, reverting the HOV lanes to mixed-flow lanes, or removing violators by enforcing HOV restrictions more heavily, to be considered for each corridor given estimates of the current and future demand. Further, these models can be modified for future study to determine what the optimal mix of vehicle classes should be.

Microsimulation of the southbound corridor of I-65 south of Nashville found that there were locations where the HOV lane slowed in sympathy with the mixed-flow traffic. This is because vehicles exiting the facility from the HOV lane must merge back into the mixed-flow lane. Restriction of traffic in the HOV lane tended to improve conditions by reducing weaving volumes. However, when simulating the northbound direction, the largest problems with traffic flow arose from the merge of vehicles entering the interstate into a stream of traffic flowing at or near capacity. In cases where the flow is controlled by merge bottlenecks, it is important to improving system performance to achieve maximal throughput through the leftmost lanes to provide a maximal number of gaps for merging vehicles. ***In general, the most significant bottlenecks on the outbound facilities are diverge bottlenecks while the most significant bottlenecks on inbound facilities are merge bottlenecks.*** Similar trends were observed for the I-24 corridor and the I-65 corridor north of Nashville.

***The results of microsimulation make it clear that there is no simple policy solution that can improve operations on the HOV corridors.*** Strategies that may improve conditions on one corridor may make conditions worse on other corridors. However, the insights gained from microsimulation also provide insights about how to solve some of the operational problems faced along these corridors. Solutions should be tailored based on how the flow is controlled, whether by upstream volume (uncongested flow), diverge bottleneck, or merge bottlenecks. In general, solutions should be pursued for the relevant operational case as follows:

**(1) Uncongested Flow:** HOV lane enforcement is counterproductive to achieving the best operational results for the facility. Removal of HOV lane restrictions should be considered in these times and at these locations, but barrier separation and/or striping to reduce the weaving volume near bottlenecks may be helpful for overall traffic operations.

**(2) Mixed-flow Controlled by Diverge Bottlenecks:** If possible, weaving from the HOV lane in the vicinity of exits should be limited to maximize throughput of the HOV lane and to prevent the breakdown of the mixed-flow lanes.

**(3) Mixed-flow Controlled by Merge Bottlenecks:** If possible, achieve maximal throughput in the HOV and leftmost lanes to increase bottleneck capacity. Ramp metering may be effective as well in preventing the breakdown of the bottleneck, but any ramp metering solution should be tailored carefully to the facility.

The research results lay out a path forward for improving the corridor. First, egress from the HOV lane should be controlled so that weaving occurs in locations more favorable to the operation of the mixed-flow and HOV lanes. Second, the HOV lane needs always operate at uncongested conditions and reasonably full to maximize bottleneck throughput. Perhaps significant improvements to the HOV lane resulting from improved egress management will attract more carpoolers to the HOV lane, but since the HOV lanes are not the primary motivation behind carpooling decisions, it is uncertain that the HOV demand for the HOV lane is going to be sufficient for optimal operations. Third, while target HOV lane volumes could be achieved by tolerating violations of the HOV lane, the use of a HOT lane with variable tolls could provide a solution to the problem where the SOV flow necessary to improve operating conditions is not legal under the HOV lane framework. The HOT concept also provides some extent of automated enforcement via toll collection, a degree of basic fairness as those who seek to utilize the benefit of the HOV lane pay more of the social cost of using the HOV lane, and a practical price-based mechanism by which to control the flow of vehicles into the lane.

# Chapter 1 Introduction

## 1.1 Research Motivation

This report presents the findings of research undertaken for TDOT's Long Range Planning Division by Lipscomb University's Civil and Environmental Engineering Department. The overarching purpose of this research was to determine the current effectiveness and benefits of the High Occupancy Vehicle (HOV) lanes in Tennessee and make recommendations regarding enhanced effectiveness, including analysis of HOV lanes operating under base conditions, operating under variable violation rates. These results were compared with the current operating conditions as well as a case in which the HOV lanes are converted to mixed-flow lanes.

As TDOT considers the implementation of more aggressive enforcement for HOV lanes, it is unclear what benefits will result from the enhanced enforcement strategies, as well as what enforcement goals should be. This uncertainty stems from a lack of knowledge of how HOV lane demand will change as a result of shifts in volume on the interstate corridors where HOV lanes exist.

HOV lanes have been implemented throughout North America as a way to maximize the person-carrying capacity of a facility by offering travel-time savings as well as more reliable and predictable travel times. HOV lanes in several states, including New Jersey, California, and Virginia, have recently come under fire for what is termed the "empty lane syndrome," or perceived underutilization. Two HOV facilities in New Jersey, I-80 and I-287, were decommissioned in November 1998 under political pressure. In these particular cases, the facilities lacked some of the fundamental design and operational characteristics common to successful HOV lanes, and local users deemed the lanes wasteful (Poppe et al, 1994; MnDOT, 2002; California Legislative Analyst's Office, 2000). However, under the right circumstances, other implementations of HOV lanes are effective at increasing average vehicle occupancy and improving throughput, including HOV lanes constructed and operated for the Salt Lake City Winter Olympics in 2002.

Nashville is one of the most rapidly growing cities in the United States. Its citizens are highly automobile-dependent with minimal transit options available to the public. Nashville is sprawling geographically with more and more people living in its suburban areas. HOV lanes can provide transit operations a major competitive advantage if properly implemented and enforced. Nashville also has significant air quality problems which could be reduced with the many advantages that are provided by HOV lanes, including the elimination of vehicle trips through the implementation of carpooling, as well as making transit a more viable option. If implemented as a High-Occupancy and Toll (HOT) lane, these managed lanes could provide incentives for buyers to purchase hybrid or electric vehicles, provide a source of revenue for infrastructure projects, and provide benefits to the general population if travelers choose to switch to carpooling or to transit (e.g., a Metropolitan Transit Authority bus providing rapid access to downtown) to take advantage of the managed lane's benefits.

It is perceived by the general public that the I-24 and I-65 corridors under consideration in this proposal have very high violation rates, and ~~that~~ law enforcement has very limited resources to enforce HOV restrictions in dedicated HOV lanes. State officials have estimated that current violation rates in these lanes are as high as 85 to 90 percent in the AM and PM rush hours (Walters, 2014). This present study seeks to quantify the benefits associated with HOV lanes in the aforementioned corridors, determine whether the HOV lanes would better serve the traveling public by conversion to mixed-flow lanes, and estimate the potential benefits of improved enforcement.

As Nashville has grown at a very rapid rate, it is important to examine the impacts of growth as well as driver behavior upon the performance of its HOV corridors. Future innovations including automated vehicles and technology-assisted enforcement need to be studied. Since HOV/HOT lanes are capable of providing either significant benefits or creating significant burdens, depending upon the extent to which they are properly utilized by the driving public, it is becoming critically important for Nashville's development to determine the current benefits and burdens of the current state of operations. It is also very important to understand what benefits could be derived if enforcement is improved and whether the attitude of the population being served by such lanes is supportive enough of HOV lanes to make enforcement and/or education and awareness programs cost-effective.

To provide better guidance for enforcement goals in HOV corridors, a comprehensive systems analysis perspective is needed, including (1) an understanding of public attitudes about HOV lanes, current regulation, and enforcement in general, (2) supply, demand, and equilibrium modeling to understand how carpool demand will shift as a result of enhanced enforcement, (3) air quality models to determine air quality impacts of enhanced enforcement, and (4) traffic microsimulation models to inform the macroscopic modeling and equilibrium process, as well as to validate its results.

## 1.2 General Approach

Our approach was based on a multi-tiered approach to the analysis of HOV corridors as a network over which users establish equilibrium flows. As such, it is imperative to understand the system on three levels: (1) how users of the system choose their mode of travel and then select their travel lane (i.e., demand analysis), (2) how the roadway performs as a function of the number of users on the facility (i.e., supply analysis), and (3) equilibration between the supply and demand in the transportation network.

The general framework for the proposed research is shown in Figure 1-1. User equilibrium is the result of the interaction of demand for travel by each of several mode choices (carpool, toll lane in SOV, mixed-flow lane, etc.) and the performance of the road facility and the drivers upon it. The overall goal of the framework is to determine what the equilibrium states will be for the HOV corridors as a result of policy (i.e., control scheme that reduces HOV lane violation rates to a prescribed level) changes to the network and to choose a policy or policies that will induce the most favorable equilibrium states.

Determination of equilibrium states requires both an accurate understanding of the travel demand behavior of those who will use the network as well as the performance features of the network. To understand the preferences of the network, the project team was assisted by Professors Jake Morris and Paul Turner of Lipscomb University's psychology department and the psychology department's students to design and administer appropriate surveys to elicit preference data from individuals who travel in the four HOV corridors. The data collected from these surveys was analyzed using econometric techniques such as multinomial logit modeling to determine the mode choice preferences of users in the network.

Supply analysis was performed in three distinct ways, each of increasing fidelity. First, the performance of the system was captured using closed-form equations fitted to the field data to determine travel times in each lane as a function of flow volume in each lane. Second, traffic was simulated by macroscopic modeling techniques based on continuum models of traffic flow. Third, microsimulation models were constructed in VISSIM to represent the behavior of the system. These models were calibrated to and validated against field data collected on the HOV corridors.

Equilibrium was determined by solving the supply and demand functions simultaneously. Parametric studies were performed to simulate the impacts of enhanced enforcement upon the HOV corridor, allowing for the study of impacts of operational and policy changes upon user delay, air quality, and potential revenue for scenarios under consideration. Equilibrium studies can be very useful when demand is less than the capacity for the facilities under consideration. However, when demand exceeds supply, the limitations of the link performance models preclude accurate modeling with simple, closed-form expressions. Traffic microsimulation becomes a necessary tool to understand the complexities of traffic flow on the HOV corridors, particularly around the bottlenecks caused by weaving movements at the entrance and exit ramps. Models of each of the six HOV corridors on Interstates 65 and 24 were constructed in VISSIM and validated against field data collected by TDOT, mobile sensing data available in Google Traffic, and the predictions of the Lighthill-Whitham-Richards Partial Differential Equation (LWR PDE), a well-accepted continuum model for traffic flow based on conservation laws.

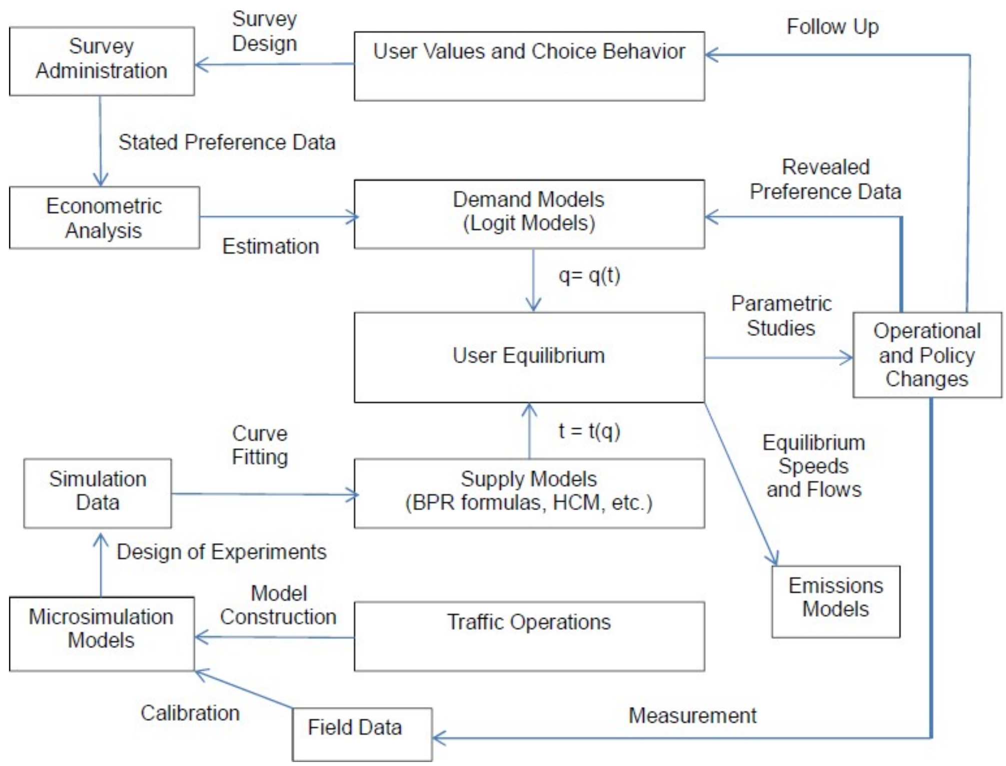



Figure 1-1 Framework for HOV Lane Research

## 1.3 Research Objectives:

In support of these overall objectives, the project involved the following tasks, each of which were briefly discussed in the executive summary, and in more detail in the final report:

1. Collection and assembly of data necessary to evaluate the current operational state of HOV corridors in Nashville.
2. Design and administration of surveys of the public and key stakeholders regarding HOV attitudes and perceptions, reasons for high violation rates, and to obtain stated preference data about mode choice.
3. Estimation of demand models for carpool and tolled access to managed lanes in Nashville.
4. Estimation of simple supply equations for HOV and mixed-flow lanes in Nashville.

5. Computation of equilibrium lane utilization for lanes in Nashville's HOV corridors.
6. Modeling of delay, emissions, and revenue rates for Nashville HOV corridors and estimate the impacts of policy changes upon delay, emission, and revenues.
7. Construction of microsimulation models in VISSIM for HOV corridors in Nashville.
8. Validation of conclusions of equilibrium models using both the LWR PDE and VISSIM simulations.
9. Formation of conclusions and suggestions to improve operations on the HOV lanes.

Research objective 1 provides the data necessary to accomplish all further research objectives, as highway performance data is necessary to build performance models for equilibration and revealed preference data is necessary to estimate models of mode and lane choice. Research objective 2 provides insights to better understand why drivers make the choices they make concerning carpooling and observing lane restrictions. When taken together, objectives 3-6 allow for the study of the sensitivity of equilibria to various changes in operational conditions, including decisions such as removal of violators from the HOV lane through enforcement and/or pricing or reversion of the lanes, and to also evaluate environmental conditions. When travel demand exceeds capacity at bottlenecks, research objectives 7 and 8 will allow for a more complete analysis and greater insight about root causes of operational problems.

## 1.4 Organization of Report

The remainder of this report is organized as follows:

Chapter 2 details the typical conditions found on the I-65 and I-24 corridors, leveraging data available on Google Maps. In this chapter, bottlenecks and their typical times of activation are identified. This information will be vital in assessing the validity of microsimulation models. Appendix O contains schedules of interchanges, entrances, exits for reference.

Chapter 3 provides an analysis of traffic data, provided by TDOT, measuring speeds and volumes of traffic at various locations on the I-65 and I-24 corridors at different times of the day. Relationships between the speed in the HOV lane and the speed in the mixed-flow lanes are investigated. Correlation equations between the speed in the HOV lanes and the mixed-flow lanes are estimated. Fundamental diagrams of traffic flow are constructed.

Chapter 4 contains insights provided from focus groups held with Tennessee state legislators and Tennessee Highway Patrol officers to qualitatively understand the perception of the public about HOV lanes, their effectiveness, and their enforcement.

Chapter 5 provides the results of the survey of the public undertaken by the Lipscomb University psychology department. The survey instrument contains items covering basic demographics, qualifying questions, knowledge of HOV lane restrictions, compliance and noncompliance, respondents' value of time, responses to increases in fines, factors motivating or preventing carpooling, and aggressive driving behaviors.

Chapter 6 contains the fundamental analyses required to develop a stochastic user equilibrium model to explore comparative statics on a basic segment of an HOV corridor. In Section 6.1, an analysis of revealed preferences of drivers from traffic counts in the HOV and mixed-flow lanes that have been used by previous researchers to estimate violation rates in the HOV lane. This section provides estimates of the probability of a driver choosing to carpool, conditioned on the travel time index in the mixed-flow lanes; of the probability of HOVs choosing to use the HOV lane, conditioned on the travel time index on the mixed-flow lanes; and the probability of a SOV choosing to violate HOV lane restrictions, conditioned on the travel time index in the mixed-flow lanes. Section 6.2 constructs simplistic supply functions based on the Bureau of Public Roads (BPR) formulas for lane speeds as a function of link flow based on highway performance data. Section 6.3 describes the development of simple air quality models that can be used in an equilibrium analysis of an idealized HOV corridor. Section 6.4 investigates the interaction of supply and demand modeling for a simple HOV facility.

Chapter 7 extends the analytical work done in Chapter 6 to explore the implications of doing nothing, heavily enforcing the HOV lane restrictions (via toll measures or otherwise) and reverting the lane to a mixed-flow lane for the Interstate 24 HOV corridor and the I-65 corridor south of Nashville. The analysis is performed under base year and future (design) year scenarios.

Chapter 8 develops a macroscopic model of traffic flow for the I-65 corridor south of Nashville. Using the fundamental diagram and the correlation equations relating the speed in the HOV and mixed-flow lanes to the speed of all vehicles, which were both developed in Chapter 3, the LWR PDE is solved by the Cell Transmission Model. Speeds in the mixed-flow lanes and the HOV lane are then inferred from the single 1-D solution to the LWR PDE.

Chapter 9 details the process of development for VISSIM models. This chapter details the network construction process. Data sources used in the construction of the model inputs are documented, and the calibration process for various model parameters is explained. The model outputs are compared with mobile sensing data and field data. The Cell Transmission Model developed in Chapter 8 is refined considering the insights gained from the VISSIM modeling process. The process is implemented for the southbound Interstate 65 HOV corridor south of Nashville.

Chapter 10 details the process of scenario construction and evaluation for VISSIM models. Six scenarios are constructed. For both base year and future year demands, the model is evaluated for three different vehicle compositions, reflecting a do-nothing scenario, lane reversion scenario, and a heavy enforcement scenario. Major results for the southbound I-65 HOV corridor south of Nashville are displayed and discussed.

Chapter 11 provides system-level analysis results from VISSIM models developed for all six HOV corridors in Middle Tennessee. Insights regarding system performance are inferred from the numerical results and major features of the remaining corridor simulations are shown.

Chapter 12 provides a discussion and synthesis of the major conclusions and results of the study and provides recommendations for possible improvements to the HOV corridors under study. This chapter also discusses future research needs for these corridors.

# Chapter 2 Analysis of Traffic conditions in AM and PM Peak on I-65 and I-24 using Google Traffic Data

Using data collected at multiple points along both corridors, times of bottleneck activation and spans of upstream influence have been identified to assist in performance modeling. In this chapter, we present the findings of our study of traffic conditions on Nashville's traffic corridors. We begin our discussion of data analysis with a discussion of data assembled from Google Maps showing activation and propagation of bottlenecks. We continue our discussion with volume profiles obtained from data collected by TDOT. In the following discussions, the map direction denotes whether the interstate facility is located to the north, south, east, or west of Nashville, and the AM/PM designation indicates the time of day at which the peak flow is occurring (toward downtown in AM and away from downtown in PM).

## 2.1 Southbound I-65 South of Nashville

At approximately 4:00 PM, when HOV lane policies come into effect for the PM hours, the volume of traffic originating from downtown starts to overwhelm the capacity of the inner loop and I-440, and numerous bottlenecks have activated at major interchanges, as shown in Figure 2-1. Merge bottlenecks start to activate at the I-440 and Armory Drive interchange at approximately 4:45, as shown in Figure 2-2. These bottlenecks start to cause densification of the traffic stream with queues propagating back toward downtown, and with demand peaking from downtown, I-65 operates in a heavily queued state shortly thereafter. Further downstream, operations approach capacity and remain at or near capacity until traffic volumes decrease after 6:00, with much of South I-65 operating at capacity at 6:00, when the current HOV lane hours end, as shown in Figure 2-3 and Figure 2-4. These images are based on a time-average of speed data taken in the early months of 2018 using a formula proprietary to Google.

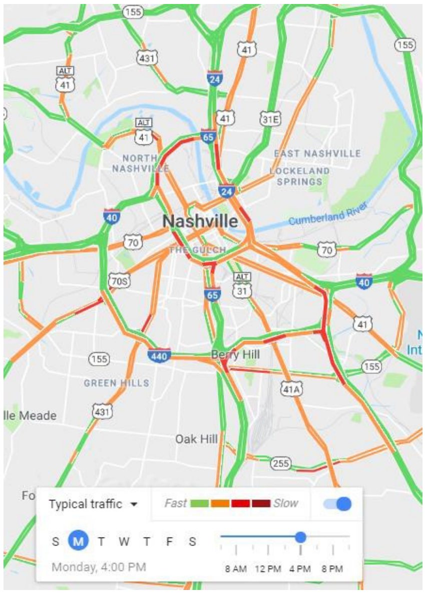



Figure 2-1 Typical beginning of heavy congestion near downtown Nashville at 4:00 PM. (image from Google Maps)

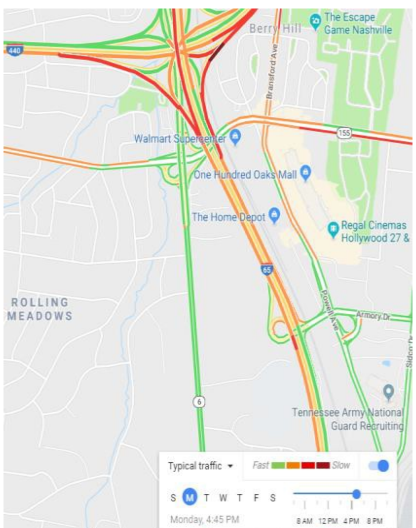



Figure 2-2 Typical bottleneck activation at approximately 4:45 near I-440 interchange and Armory Drive interchange on South I-65 (image from Google Maps)

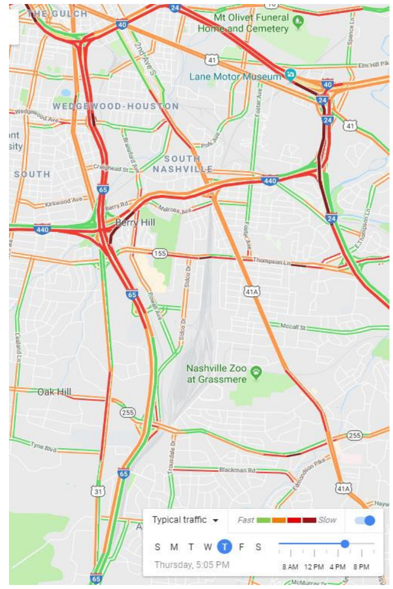



Figure 2-3 Typical weekday heavy congestion on South I-65 at 5:05 PM (image from Google Maps)

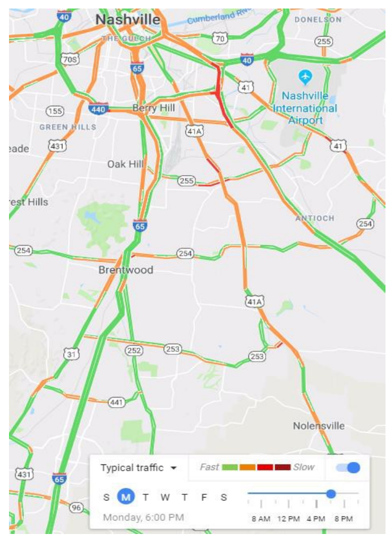



Figure 2-4 Operations at or near capacity on much of South I-65 at 6:00 PM (image from Google Maps)

## 2.2 Northbound I-65 South of Nashville

During AM hours, the congestion on northbound I-65 south of Nashville is typically more moderate than other interstates near Nashville. However, the segment of I-65 near Concord Road begins to operate near capacity as early as 6:40 AM as shown in Figure 2-5, and a bottleneck typically begins to activate at the Interstate 440 interchange at approximately 7:00 AM, as shown in Figure 2-6. At 7:40, a merging bottleneck typically activates at Old Hickory Boulevard, as shown in Figure 2-7. At about the same time, a merge bottleneck activates at the Concord Road interchange, shown in Figure 2-9. By 8:00 AM, the Interstate 440 interchange is overwhelmed, and traffic densifies, as shown in Figure 2-8. However, by 8:30 congestion begins to dissipate, and by 9:00 AM traffic is typically free flowing or at capacity, as shown in Figure 2-10.

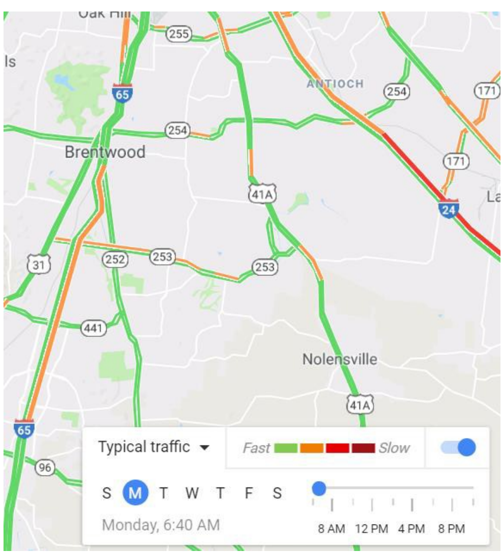



Figure 2-5 South I-65 reaching capacity in the vicinity of Concord Road at approximately 6:40 AM (image from Google Maps)

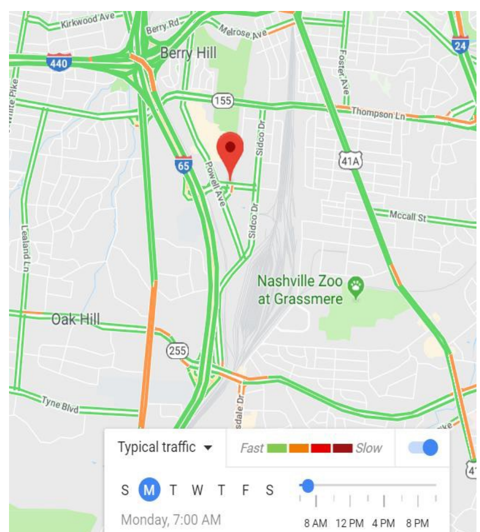



Figure 2-6 Typical activation of the bottleneck at I-440 interchange on northbound South I-65 (image from Google Maps)

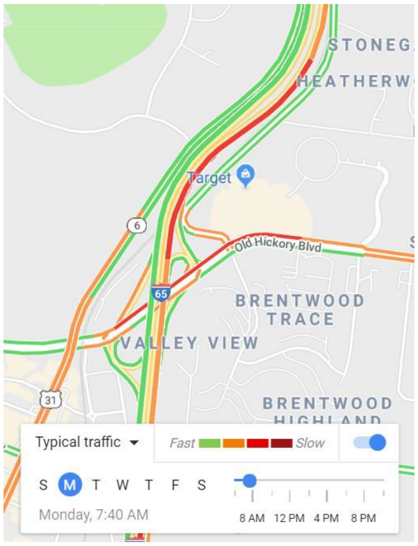



Figure 2-7 Bottleneck activation at approximately 7:40 AM on Northbound I-65 at Old Hickory Boulevard Interchange (image from Google Maps)

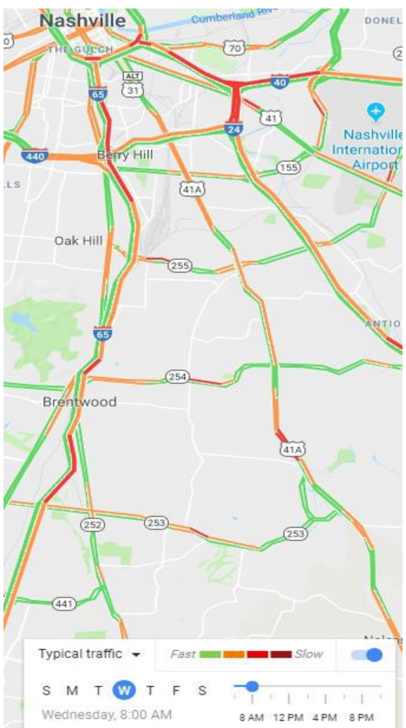



Figure 2-8 Typical peak AM congestion on South I-65 (image from Google Maps)

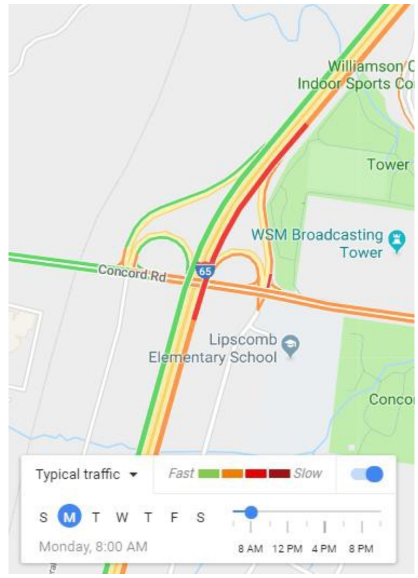



Figure 2-9 Activation of Merge Bottleneck on Northbound I-65 Concord Road (image from Google Maps)

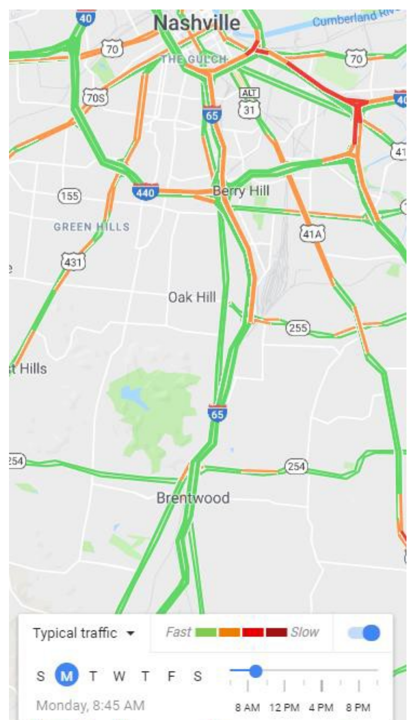



Figure 2-10 Typical dissipation of congestion by 9:00 AM on South I-65 (image from Google Maps)

## 2.3 Northbound I-65 North of Nashville

From the observation of Google Maps data for a typical Monday at 3:40 PM, a merge bottleneck activates on I-65 North after the Long Hollow Pike, as shown in Figure 2-11. A diverge bottleneck also activates at or near 4:00 at the TN 368/ Vietnam Veterans Boulevard exit as shown in Figure 2-12. These two bottlenecks cause I-65 to flow at or near the bottleneck capacity, as queuing waves form and slow the progression of traffic elsewhere on I-65 North (Figure 2-12). Traffic densifies rapidly thereafter (Figure 2-13), with the congestion remaining heavy until after the hours of HOV lane operation end at 6:00 PM (Figure 2-14). Congestion is typically dissipated by 6:30 PM (Figure 2-15).

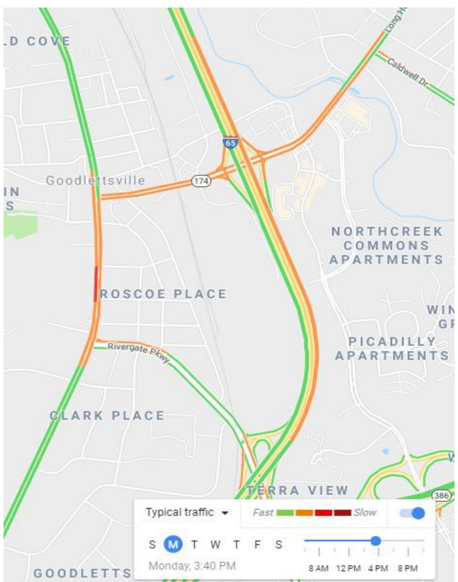



Figure 2-11 Typical merge bottleneck activation on I-65 North at Long Hollow Park Exit (image from Google Maps)

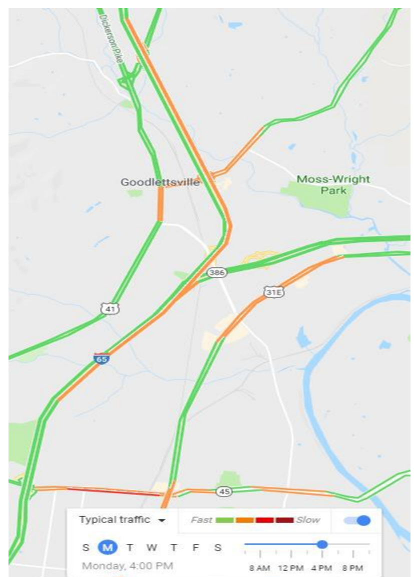



Figure 2-12 Diverge bottleneck activation at Vietnam Veterans Boulevard Exit on North I-65 (image from Google Maps)

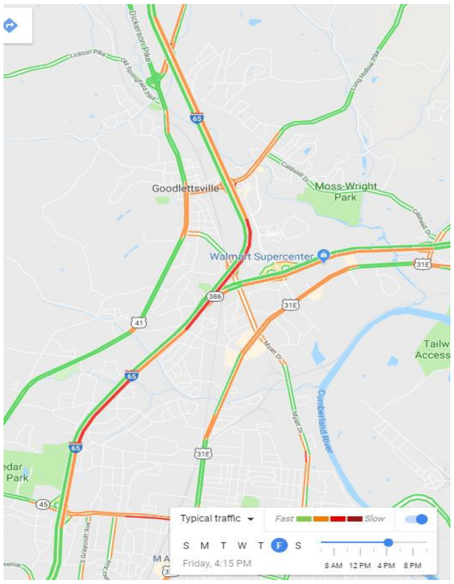



Figure 2-13 PM Queue propagation and traffic densification on Northbound I-65 North of Nashville (image from Google Maps)

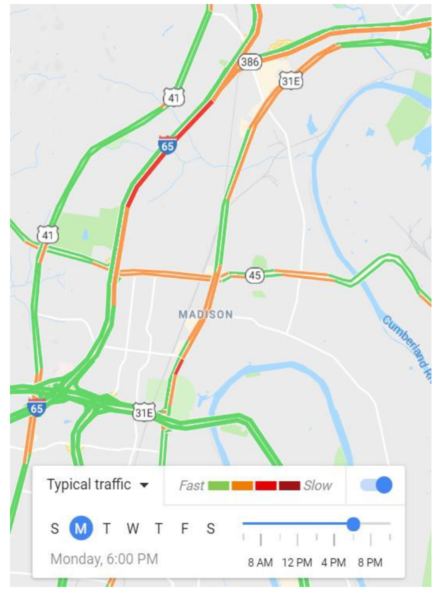



Figure 2-14 Typical heavy congestion on Northbound I-65 North of Nashville at 6:00 PM (image from Google Maps)

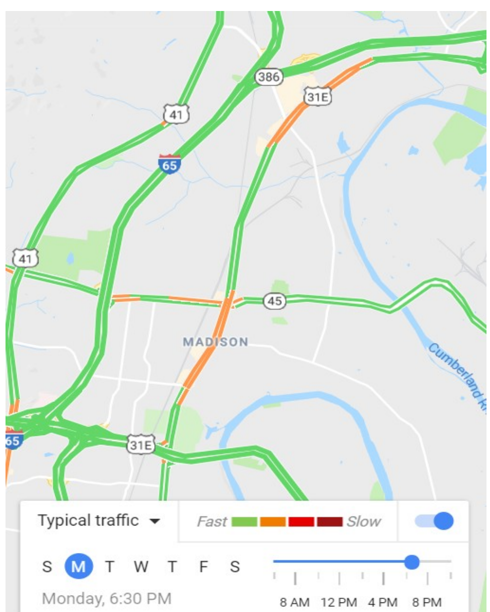



Figure 2-15 Typical Dissipation of Congestion on North I-65 at 6:30 PM (image from Google Maps)

## 2.4 Southbound I-65 North of Nashville

Bottleneck activation typically begins at approximately 6:00 AM at the divergence ofI-24 and I-65, as shown in Figure 2-16. Queues typically propagate backward with the facility operating at or near capacity until queues pass the Trinity Lane interchange and, ultimately, the merge of I-24 and I-65. Traffic begins to densify near the merge of I-24 and I-65 as the interchange becomes saturated and discharges at capacity. This discharge tends to overwhelm the interchanges downstream as the morning progresses, and the drop in capacity at the merge bottleneck after activation causes heavy congestion on both I-24 and I-65 before the merge, as shown in Figure 2-17 and Figure 2-18. The bottleneck is no longer active at approximately 9:15, shortly after the end of HOV lane hours, as shown in Figure 2-19.

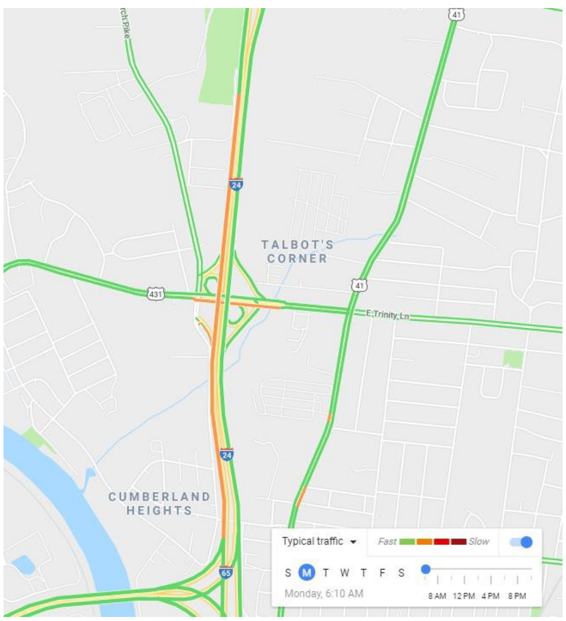



Figure 2-16 Typical AM bottleneck activation (image from Google Maps)

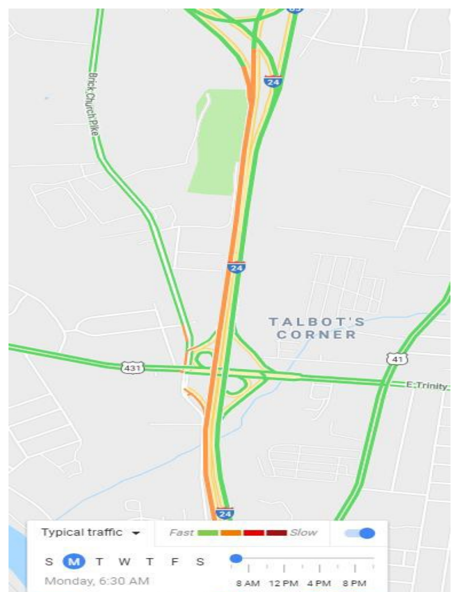



Figure 2-17 Typical queue propagation at 6:30 AM on North I-65 (image from Google Maps)

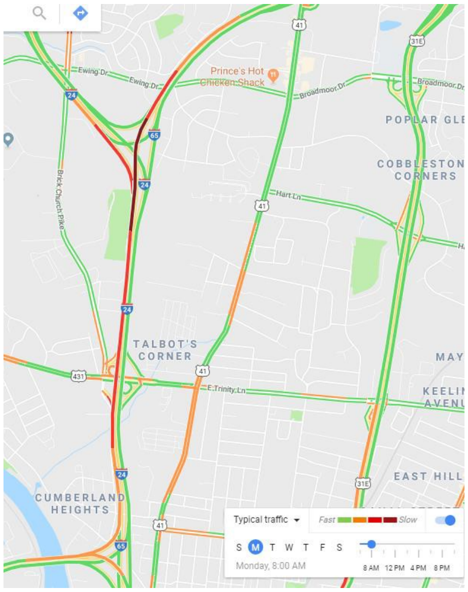



Figure 2-18 Typical traffic densification at bottleneck at 8:00 AM on I-65 and merge bottleneck activation at the junction of North I-65 and I-24 (image from Google Maps)

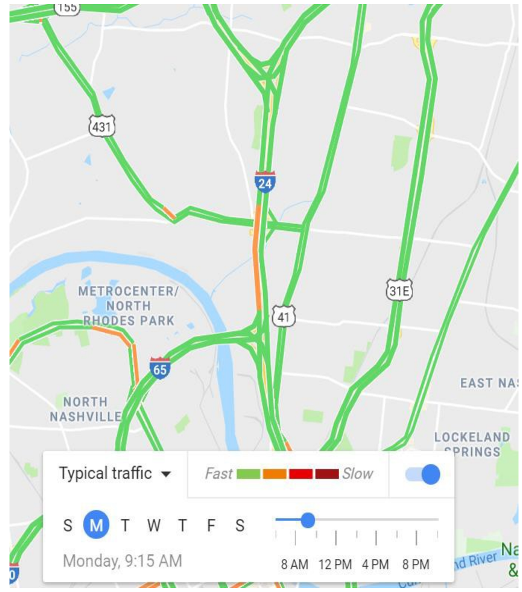



Figure 2-19 Dissipation of Bottleneck Congestion shortly after 9:00 AM on I-65 North of Nashville. (image from Google Maps)

## 2.5 Eastbound I-24

By 3:30 PM, traffic from I-440, I40, and Thompson Lane starts to back traffic up into Nashville, forming the most significant traffic bottleneck in the entirety of Nashville's interstate system, as shown in Figure 2-20. Traffic becomes heavily densified and this bottleneck stays active until after 6:30 PM, sending a capacity discharge down I-24. Figure 2-21 shows the intensity of the bottleneck at 5:15 PM. This bottleneck leaves most of the rest of the I-24 corridor operating at capacity for the majority of the HOV lane hours of operation.

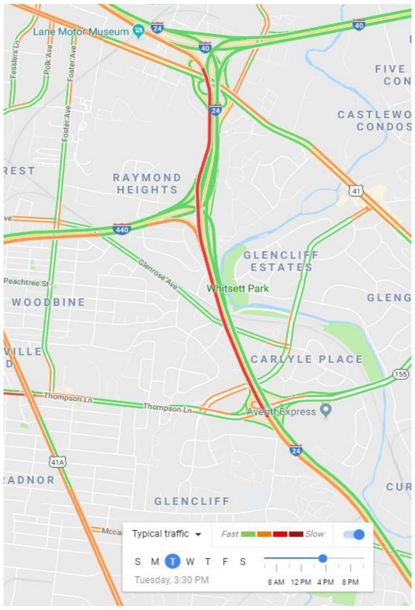



Figure 2-20 Bottleneck activation near Thompson Lane interchange on I-24 at about 3:30 PM (image from Google Maps)

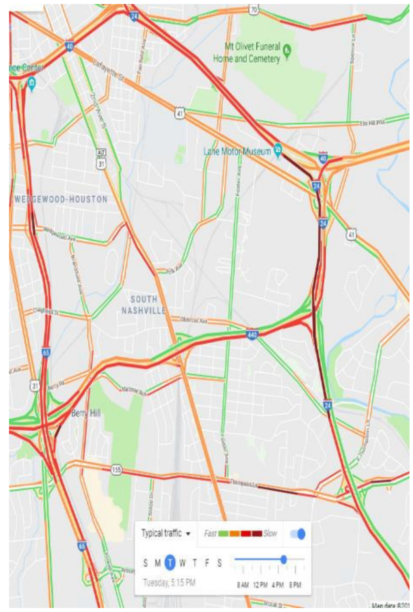



Figure 2-21 Typical bottleneck intensity near the start of the I-24 HOV corridor at 5:15 PM (image from Google Maps)

## 2.6 Westbound I-24

I-24 reaches capacity earlier than the other corridors and has the most severe congestion. I-24 experiences delays at the Waldron Road and Sam Ridley Parkway interchanges, with traffic having reached a queued state by 6:30 AM, as shown in Figure 2-22. By 7:00 AM, congestion typically dissipates at these interchanges, and bottlenecks activate at Bell Road at about 7:00 AM, as shown in Figure 2-23. At about 7:50 a bottleneck activates at Thompson Lane, as shown in Figure 2-24. By 7:30 AM, a bottleneck also typically activates at the merge of I-24 and I-40, which stays active until a few minutes after 9:00, as shown in Figure 2-25. (Though this is outside the I-24 HOV lane corridor, it is one of the most severe bottlenecks on the interstate highways around Nashville, and queueing from this bottleneck affects operations in the HOV corridor). Along most of the I-24 corridor, heavy congestion has dissipated by 9:00 AM and I-24 is typically operating at or near capacity, with many sections freely flowing, as shown in Figure 2-26, when HOV lane hours end.

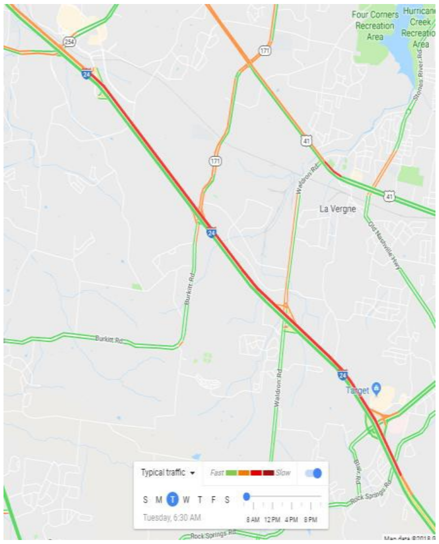



Figure 2-22 Bottleneck activation on I-24 at Sam Ridley Parkway and Waldron Road interchanges. (image from Google Maps)

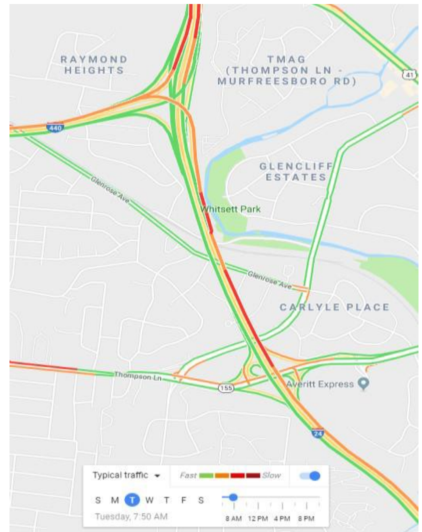



Figure 2-24 Typical bottleneck activation at 7:50 AM on I-24 at the Thompson Lane interchange (image from Google Maps)

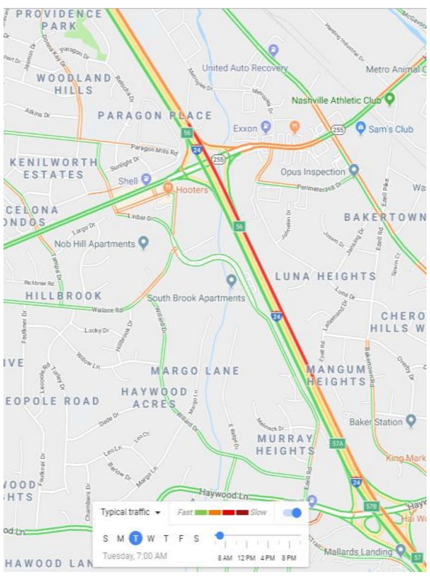



Figure 2-23 Typical bottleneck activation at Bell Road at 7:00 AM on I-24 (image from Google Maps)

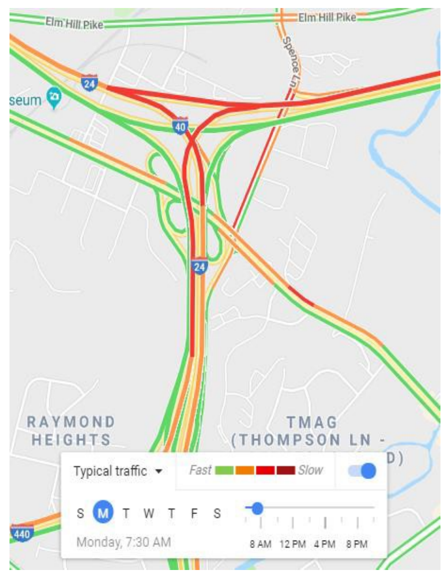



Figure 2-25 Typical bottleneck activation at 7:30 AM at the merge of I-24 and I-40 (image from Google Maps)

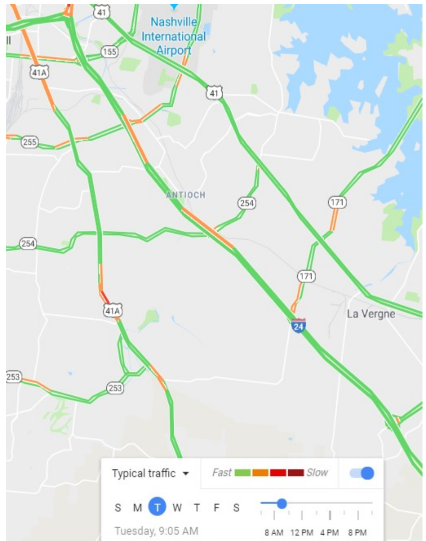



Figure 2-26 Typical states of traffic on I-24 corridor at end of AM HOV lane operational hours (image from Google Maps)

## 2.7 Conclusions

This chapter has intended to present the basic patterns seen along the HOV corridor with the purpose of understanding how the corridors function. This information is crucial to have in the construction of reasonable traffic microsimulation models for the HOV corridors. Careful observation of Google Traffic data has allowed for greater insight about the times of activation and mechanisms of action of the most significant bottlenecks on the Nashville interstate system.

In general, the PM congestion is more severe than the AM, as the demand appears to be more peaked. In most instances, but not all, the PM hours of HOV lane operation tend to enclose the most congested operations, but in some locations, congestion is heavy at the end of HOV lane hours of operation. If HOV lanes are effective ways of increasing highway passenger capacity, then an extension of HOV lane hours might could be justified on specific corridors based on congestion levels on some of the HOV corridors in the PM. However, this extension should be based on operational analysis and not solely upon identification of times of peak congestion.

For the outbound routes in the PM, it is typical for a large bottleneck to occur near the beginning of the HOV corridors, as seen in Figure 2-3, Figure 2-13, and Figure 2-20. While these appear to be the dominant features controlling the outbound routes, and the significant feature controlling Northbound I-65 north of Nashville, on the longer corridors these are far from the only bottlenecks that are responsible for the creation of congestion and delay. Bottlenecks also form downstream of these bottlenecks on Southbound I-65 south of Nashville and Eastbound I-24.

Traffic patterns for the inbound routes under peak AM demand are somewhat different from the outbound routes. Several bottlenecks appear to be merge bottlenecks on the inbound facilities, such as the notable merge bottleneck on I-65 at the entrances of Interchanges 71 and 74, shown in Figure 2-9 and Figure 2-7, respectively. However, there are also significant diverge bottlenecks on the inbound corridors as well. While it is not possible to quantify the performance of the facilities from analysis of Google Traffic data as shown on Google Maps, this review of data has shown some of the key features of facilities in this study that must be replicated by later modeling efforts. The remaining chapters in this report sought to understand why these behaviors were observed and how best to distribute traffic volumes across lanes to manage congestion on the corridor.

# Chapter 3 Analysis of Volume and Speed Profiles for Facilities Using Field Data

In this chapter, traffic data provided by TDOT, measuring speeds and volumes of traffic at various locations on the I-24 corridor at different times of the day is analyzed to develop a deeper understanding of traffic operations on the I-24 corridor. All data were collected by TDOT on November 6 and 7, 2017 using automated traffic counting stations located at various counting stations along the corridor. Each station produced several automated reports detailing traffic counts, vehicle speeds, and vehicle lengths. These are termed the basic speed classification report (BSCR), basic length classification report (BLCR) and multichannel report (MCR). Locations of the traffic counting devices used in collecting the data for the BSCR's used in this section are shown in Figure 3-1. Throughout the chapter, reporting locations will simply be associated with the name "BSCR #", where the # represents a report number associated with Figure 3-1.

Using the data collected in the BSCR's, this chapter presents data and analysis that will help with understanding the nature of operations on the relationships between the speed in the HOV lane and the speed in the mixed-flow lanes. Correlation equations between the speed in the HOV lanes and the mixed-flow lanes are estimated. Fundamental diagrams of traffic flow are constructed.

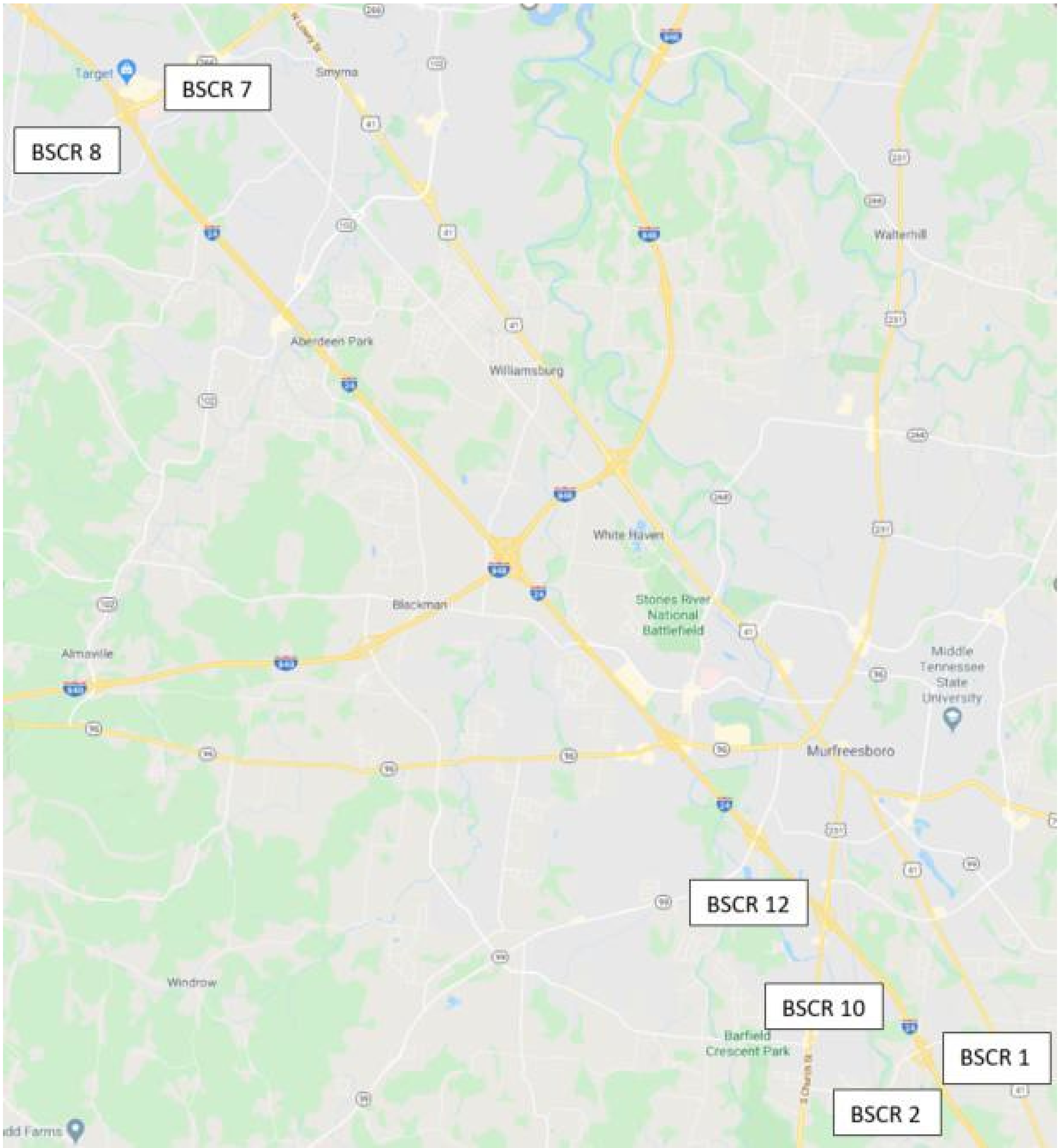



Figure 3-1 Location of traffic data collection points

## 3.1 Temporal Distribution of Traffic Volume

A review of typical traffic conditions from Google Maps shows that the HOV lane hours of operation are well placed around the PM peak hours, but that the AM peak is likely flatter.

Volume and speed studies were performed by TDOT in 2016, and selected data from the study was shared with the research team. In general, the profile of these studies tends to align with the observations for typical traffic obtained from Google Traffic. Virtually all segments show an AM peak and a PM peak, with one peak typically significantly larger than the other, as one would expect based on the directionality of the flow. However, in most instances, the AM peak is flatter than the PM peak. Figure 3-2 shows hourly HOV lane volumes at various locations on I-24 and I-65.

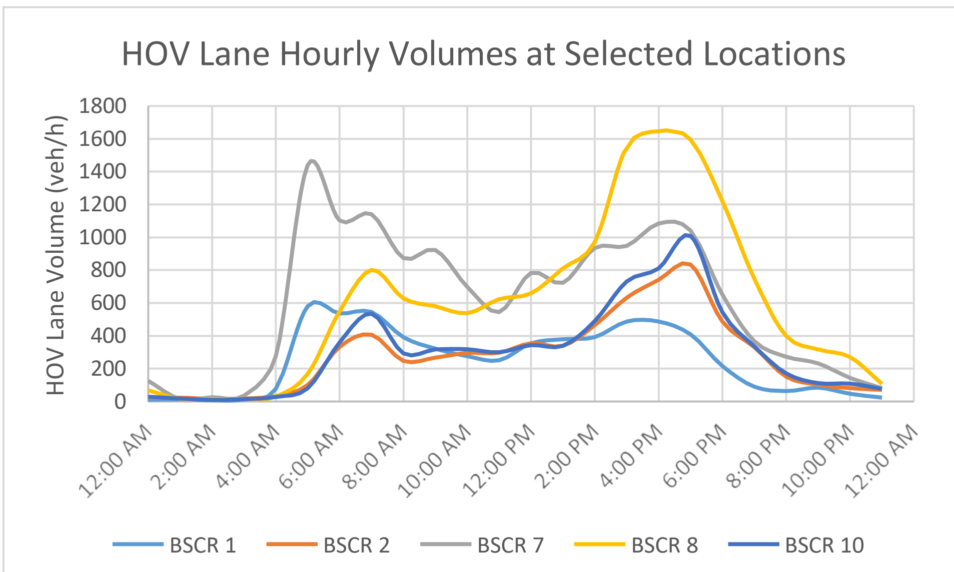



Figure 3-2 Hourly HOV lane volumes at selected locations on I-24 and I-65

In most of these profiles, it should be noted that the observed flows in the HOV lane are far less than the lane capacity, given in the Highway Capacity Manual (2010) as 2400 passenger cars per hour per lane over the peak 15 minutes of demand. Traffic starts to slow at somewhere between 1200 and 1450 passenger cars per hour per lane, so in some instances, it can be inferred that the HOV lane will operate at a speed less than the free-flow speed. This observation begs the question of whether some of these lanes are underutilized, or if there is a reason why the peak flows are markedly less than the approximate capacity of 2400 vehicles per hour.

If the violation rate was near the national average of 10 percent, it would be clear that the HOV lanes are transporting between approximately 900 and 3300 passengers per hour at peak demand. However, as violation rates are typically in the 60 to 90 percent range, the passenger throughput is far lower. These HOV lane flows suggest significant underutilization of the HOV lanes in Nashville. Figure 3-3 shows a comparison of the HOV lane flow with the flow in the average mixed-flow lane at the same locations shown in Figure 3-2. In peak times it can be seen that the vehicular flows in the HOV lane are higher than the average vehicular flows in mixed-flow lanes at higher levels of congestion, but at lower levels of congestion, the HOV lanes are not preferred lanes of travel.

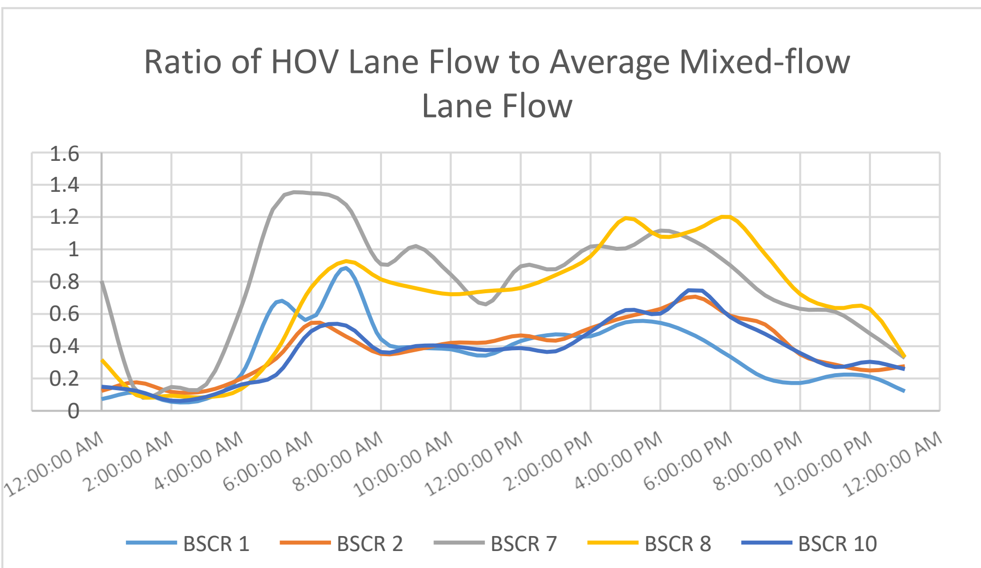



Figure 3-3 HOV lane volume as a percentage of average volume in mixed-flow lanes at selected locations with three mixed-flow lanes on I-65 and I-24

The utilization of the HOV lane is highest at the most congested locations along the corridors. At the most congested locations, the HOV lane is carrying significantly more vehicles than the average mixed-flow lane is carrying. Careful analysis of the trends shown in Figure 3-2 and Figure 3-3 leads to the following hypothesis. *Under light traffic conditions, the HOV lanes are not preferable for most drivers. However, as traffic becomes more heavily congested, it is the congestion that causes drivers to desire to use the HOV lane. As the HOV lane is a faster-moving lane, and the mixed-flow lanes are either in a queued state of traffic or approaching a queued state, the HOV lane can (and does) carry a greater flow of drivers than the mixed-flow lane.*

To more carefully investigate the relationships between the volumes carried by the HOV lane and the mixed-flow lanes, Figure 3-4 and Figure 3-5 show the HOV lane flow and the average mixed-flow lane flow for two locations. In Figure 3-4, these flows are shown for a relatively low volume location. At all times, it can be seen that the flow in the HOV lane is much less than the flow in an average mixed-flow lane. However, in Figure 3-5, which shows flows at a more congested location, the flow in the HOV lane is lower than the flow in a typical mixed-flow lane during off-peak hours. This is not the case during peak demand, as volumes increase in the mixed-flow lane, the flows in the HOV lane exceed the flows in the average mixed-flow lane.

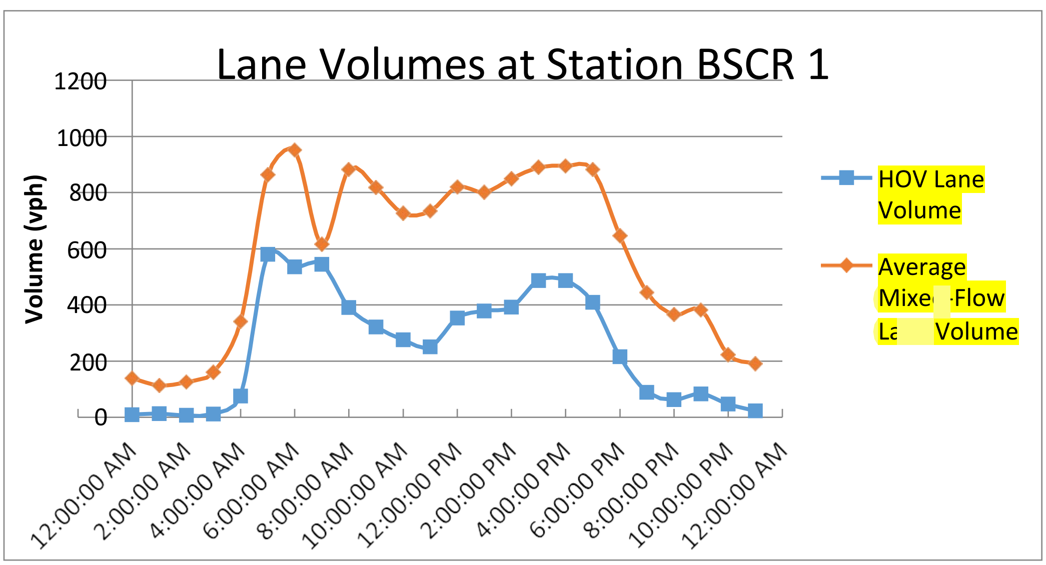



Figure 3-4 Lane Volumes at Station BSCR 1

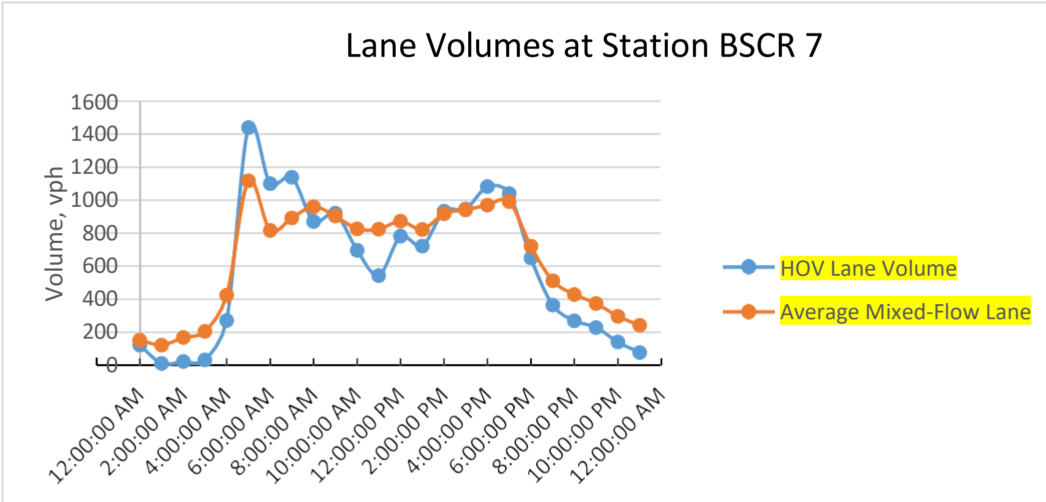



Figure 3-5 Lane Volumes at Station BSCR 7

## 3.2 Relationship Between Speeds in Mixed-flow and HOV Lane

It can be seen from Figure 3-6 through Figure 3-8 that there is a high degree of correlation between the average speed of vehicles in the HOV lane and the average speed of vehicles in the mixed-flow lane. It is also the case that the average speed of the vehicles in the HOV and mixed-flow lane is related to the average speed of all vehicles on the highway. Regression analysis has been performed on hourly speed data collected in 2016 on I-65 and I-24 HOV corridors. Conditions in the mixed-flow lane and HOV lane can be estimated from the speed of all vehicles on the highway. This can also be inferred from real-time traffic data sources or solved for using the LWR PDE, which helps us understand the relationships between speeds and the mixed-flow lanes and speeds in the HOV lane.

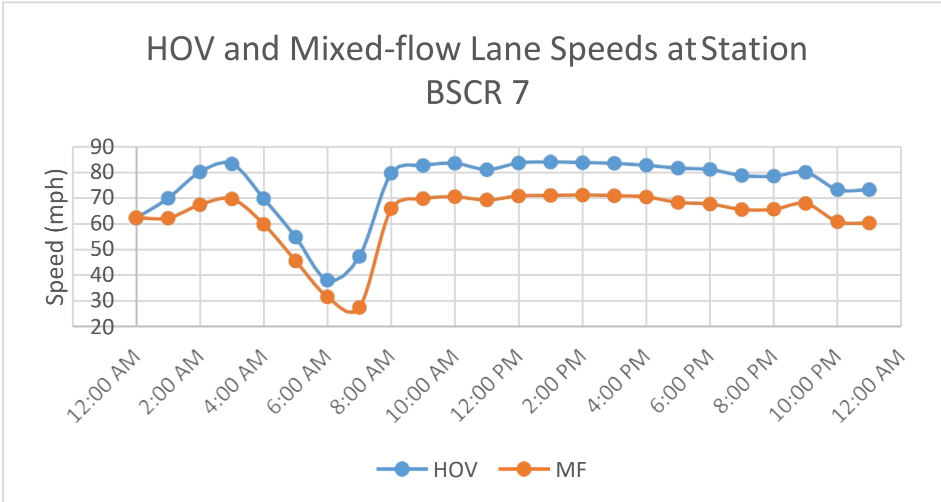



Figure 3-6 Average speeds in mixed-flow and HOV lanes at station BSCR 7.

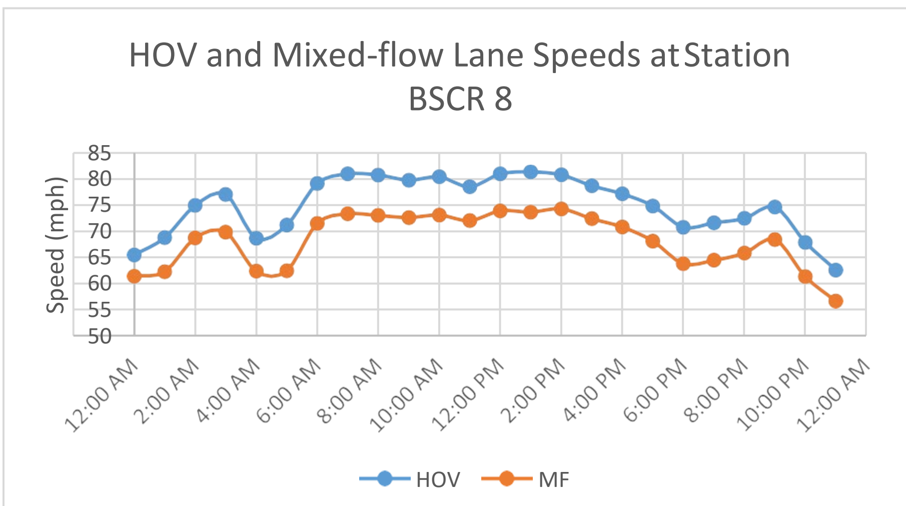



Figure 3-7 Average speeds in mixed-flow and HOV lanes at station BSCR 8

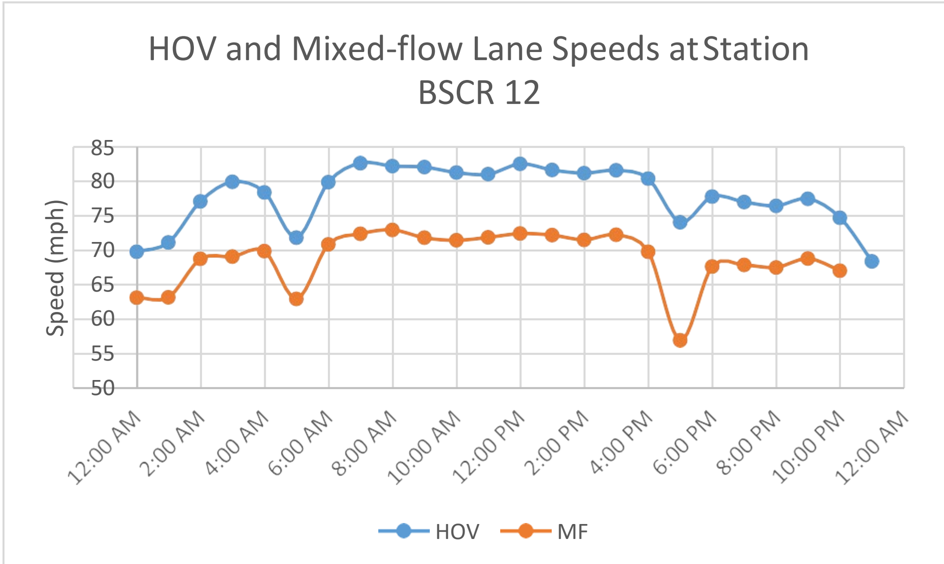



Figure 3-8 Average speeds in mixed-flow and HOV lanes at station BSCR 12

The relationship between the speeds in the HOV and mixed-flow lanes have also been investigated quantitatively. The regression results in Table 3-1 shows that the average speed of all vehicles in the HOV lane is closely related to the average speed for all vehicles (coefficient = 0.999) but on average is about 7 miles per hour faster than the mixed-flow lane speed (intercept = 7.02). The variability in the difference has a standard deviation of 2.61 miles per hour. The regression equation has an $R^2$ value of 0.799, indicating a strong degree of correlation between the speed in the HOV lane and the speed of all vehicles on the facility and the F-statistic value of 0.000 shows that the model is highly statistically significant. All regression model significance tests indicate that both the model and all parameters are statistically significant ($t \geq 3$).

Table 3-1 HOV Lane Average Speed vs. All Lanes Average Speed

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.894 |
| R Square | 0.799 |
| Adjusted R Square | 0.798 |
| Standard Error | 2.610 |
| Observations | 240 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 6454.304 | 6454.304 | 947.220 | 0.000 |
| Residual | 238 | 1621.718 | 6.814 | | |
| Total | 239 | 8076.021 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* |
|---|---|---|---|---|
| Intercept | 7.206 | 2.255 | 3.196 | 0.002 |
| All Lanes Avg. Spd. | 0.999 | 0.032 | 30.777 | 0.000 |

The regression results in Table 3-2 show the relationship between mixed-flow lane speed and the average speed of all vehicles. As most vehicles are in the mixed-flow lane, it is unsurprising that the speed is very closely related to the average speed of all vehicles (coefficient = 1.006). As expected, the average speed of all vehicles in the mixed-flow lane is slightly slower than the speed of all vehicles (intercept = -1.442). The $R^2$ value of 0.973 shows that the linear model is a very good fit to the data, and the F-statistic value of 0.000 shows that the model is highly statistically significant. Parameter estimates are somewhat to highly significant, with the intercept having a t- stat magnitude of 1.92 and the regression slope having a t-statistic over 93.

Table 3-2 Mixed-flow Lane Average Speed vs. All Lanes Average Speed

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.987 |
| R Square | 0.973 |
| Adjusted R Square | 0.973 |
| Standard Error | 0.869 |
| Observations | 240 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 6554.256 | 6554.256 | 8671.128 | 0.000 |
| Residual | 238 | 179.897 | 0.756 | | |
| Total | 239 | 6734.153 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* |
|---|---|---|---|---|
| Intercept | -1.442 | 0.751 | -1.920 | 0.056 |
| All Lanes Avg. Spd. | 1.006 | 0.011 | 93.119 | 0.000 |

The regression results in Table 3-3 show the relationship between the HOV lane speed and the mixed-flow lane average speed over the same hour. As expected, there is a strong correlation between the HOV lane speed and the average mixed-flow lane speed, but not as strong a correlation as in the previous two regression models (where the response was indirectly used in calculating the regressors). Nonetheless, an $R^2$ of 0.708 was obtained, showing a strong degree of correlation between the HOV lane average speed and the mixed-flow lane average speed.

Table 3-3 HOV Lane Average Speed vs. Mixed-flow Lane Average Speed

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.841 |
| R Square | 0.708 |
| Adjusted R Square | 0.706 |
| Standard Error | 3.150 |
| Observations | 240 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 5713.903 | 5713.903 | 575.716 | 0.000 |
| Residual | 238 | 2362.118 | 9.925 | | |
| Total | 239 | 8076.021 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* |
|---|---|---|---|---|
| Intercept | 13.501 | 2.630 | 5.133 | 0.000 |
| MF Avg. Spd. | 0.921 | 0.038 | 23.994 | 0.000 |

The regression results in Table 3-4 show the relationship between the HOV lane speed and the mixed-flow speed when the average speed of all vehicles is less than 70 miles per hour (116 observations total). This instance represents the case where congestion is beginning to occur. While there are not many excessively congested data points in the data set, there are enough to make some inferences about how traffic divides itself between the HOV and mixed-flow lanes. These insights will be valuable in determining how traffic is likely to split in congested conditions and provide a target for user equilibrium studies under saturated traffic flows. As one might expect, traffic conditions are much more unstable under these conditions, and the $R^2$ value dropped significantly to 0.602. However, the model suggests that there is a reasonable degree of correlation between the HOV lane speed and the mixed-flow lane speed.

Table 3-4 HOV Lane Average Speed vs. Mixed-flow Lane Average Speed for Congested Conditions

TABLE 4: HOV SPEED VS MF LANE SPEED FOR CONGESTED CONDITIONS

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.776 |
| R Square | 0.602 |
| Adjusted R Square | 0.598 |
| Standard Error | 3.877 |
| Observations | 116 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 2590.192 | 2590.192 | 172.283 | 0.000 |
| Residual | 114 | 1713.935 | 15.035 | | |
| Total | 115 | 4304.127 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* |
|---|---|---|---|---|
| Intercept | 20.293 | 4.000 | 5.073 | 0.000 |
| MF Lane Avg. Spd. | 0.804 | 0.061 | 13.126 | 0.000 |

## 3.3 Fundamental Diagram Development

By using hourly traffic count and speed data obtained by TDOT, the research team was able to develop fundamental diagrams of traffic flow for the HOV and mixed-flow lanes along the HOV corridor. It should be noted, however, that the flows are based on hourly flows and the densities were calculated through the use of the time-mean speed. The use of hourly flow data will likely obscure the capacity of the highway segments, but the true capacity would be obtained from dividing the estimated capacity by the peak hour factor. The time and space mean speeds are typically closely related and would not create large errors in the fundamental diagram. Figure 3-9 contains the fundamental diagram for mixed-flow lanes and Figure 3-10 contains the fundamental diagram for the HOV lanes.

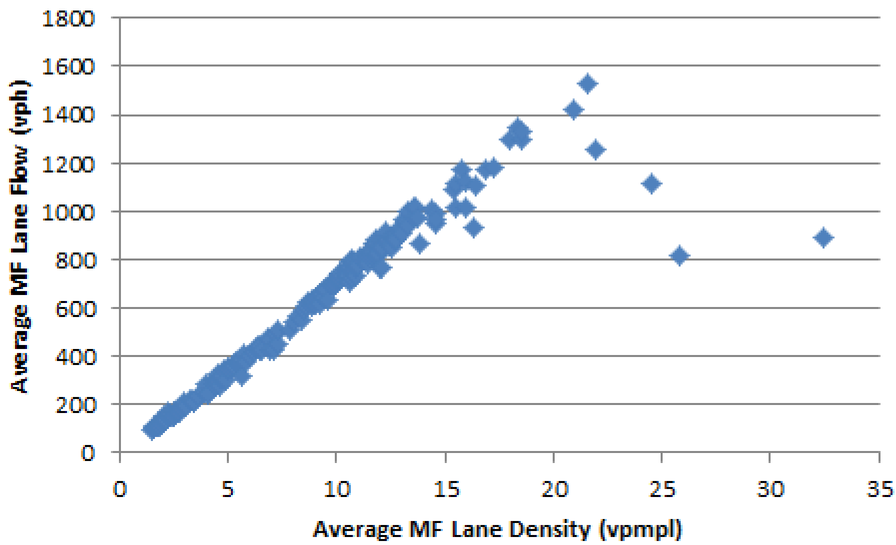



Figure 3-9 Fundamental diagram constructed based on hourly average flow and density values for all mixed-flow lanes

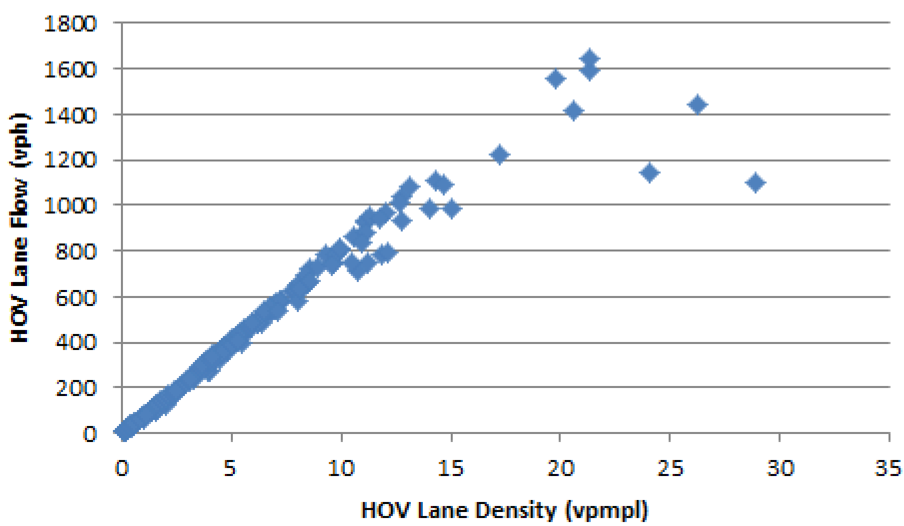



Figure 3-10 Fundamental diagram constructed based on hourly average flow and density values for HOV lanes

The examination of the fundamental diagram tends to strongly support the use of the Newell-Daganzo triangular model for the fundamental diagram. This is advantageous, as the entire curve is summarized by specifying three parameters (e.g., free-flow speed, capacity, and jam density / backward wave speed). As one might expect, the presence of only passenger cars in the HOV lane, as well as the lack of left-hand exits, tends to cause the HOV lanes to operate at a higher vehicular capacity. This is reflected in the plots in Figure 3-9 and Figure 3-10. From an assumption of a peak hour factor of 0.90, the capacity of the HOV lane is estimated to be approximately 1850 vehicles per hour and the capacity of the mixed-flow lane will be estimated as approximately 1700 vehicles per hour.

One great advantage of the Bureau of Public Roads link performance function is that it can be extended to calculate average travel times when demand for a facility exceeds capacity. If the performance function is used to determine travel times or speeds as a function of demand rates, the service rate can be then back-calculated from a speed-flow curve generated from the fundamental diagram. Link performance functions can then be calibrated to create a queueing module that can estimate queueing delay when the corridor becomes oversaturated with demand. Microsimulation will be used for this purpose later in the project.

# Chapter 4 Outcomes of Focus Group Meetings with State Legislators and Tennessee Highway Patrol Officers

This chapter provides insights from focus groups held with Tennessee state legislators and Tennessee Highway Patrol officers to qualitatively understand the perception of the public about HOV lanes, their effectiveness, and their enforcement.

## 4.1 Legislative Focus Group

Our goals were to determine key stakeholders' purposes/objectives of using HOV lanes and their current assessment and perceptions. Specifically, we interviewed, under the condition of anonymity, a panel of House and Senate members with interest in transportation, as well as representatives of those affected by HOV lanes, especially those representing Davidson, Williamson, Maury, and Rutherford Counties. The following were general themes that emerged from the focus group held on Tuesday, March 27, 2018.

The following points summarize the legislative focus group's perspective on the current state of HOV lanes in Tennessee:

- HOV lanes are not being used properly by the public.
- HOV lanes are now effectively functioning as a passing lane, but it gets jammed up just as bad and is sometimes slower.
- The requirement to operate the HOV lane as an HOV lane at peak demand time forces four lanes of traffic demand into three lanes.
- Current signage enhancements and striping markings enhancements are not changing any drivers' habits or lowering violation rates.

- HOV lanes are not currently effective.
- Speeding in HOV lanes happens on a very regular basis and is a public safety concern.

Legislators participating in the focus group expressed the following views on the objectives for having HOV lanes:

- Legislators want shorter commute times for their constituents.
- Legislators view time lost on the highways as a significant financial loss to their constituents.
- Create more carpooling to have fewer cars on the road.
- Legislators want to create as many ways as possible to reduce the need for people to travel through the corridors at peak time.
- Some of the focus groups see the value of having HOV lanes if for no otherreason than having the potential to create reasonably clear separate infrastructure for high-capacity transit in the future.

The focus group expressed the following views on patrolling the HOV lanes:

- Legislators do not want to place law enforcement officers in unnecessarily risky situations. Because manual enforcement activities for HOV lane violations can be hazardous to undertake, the lawmakers felt hesitant to introduce laws or policy directives requiring additional manual enforcement.
- The panel felt that, as is the case of speed limits, drivers will not abide by HOV lane restrictions until they are enforced.

- Automated enforcement can be suspect but could be tested to see if the system can take a photo of the front and back of the car.

Legislators were very much interested in developing different types of appropriate solutions to congestion in HOV corridors and misuse of HOV lanes. They expressed few if any aversions to ~~cost~~-effective ways to increase the capacity of the transportation system in Middle Tennessee. In particular, the following ideas were put forward to create improved traffic conditions:

- Construction of elevated platforms or other appropriate infrastructure facilities for transit vehicles and other high occupancy vehicles.
- Using HOV lanes as an incentive for the others in other lanes
- Incentivizing travel at different times of day
- Encouraging telework solutions.
- Operating public transportation vehicles, including automated vehicle trains, through a well-enforced HOV corridor.
- Finding ways to facilitate carpooling, like “slug lines” that form in Northern Virginia and Washington D.C. metropolitan areas to share tolls and enable HOV corridor access.

There was also a discussion of House Bill 446. The bill seeks to raise the fine for HOV lane violations and post signage of the increased fine for the HOV lane violation. While the consensus of the legislative group favored moving as much traffic as possible from the three mixed-flow lanes into the HOV lane and recognized little value to improving operations would likely be gained by performing more than the minimal required enforcement, the committee also acknowledged their obligations to the Federal Highway Administration to be good stewards.

There will be little opportunity to implement certain improvements that can allow HOV lanes to operate as intended if Tennessee does not show itself to be a good steward of Federal investments in the HOV lane.

## 4.2 Law Enforcement Focus Group

On June 25, 2018, the Lipscomb research team arranged a focus group with several senior Tennessee Highway Patrol officers who provided significant insight into how traffic regulations are enforced in the HOV corridors, particularly those along I-24 and I-65. The team followed a set of questions that had been approved by the Lipscomb University Institutional Research Board. A summary of major points raised by the officers follows, along with each of the questions asked the focus group, is presented here. Our questions are in ***bold italics***. The officers' responses were summarized in normal font. Great care has been exercised to protect anonymity of the participants.

***What are your current perceptions of the HOV lanes?***

While the group of law enforcement officers declined to make statements of opinion about public policy and maintained neutrality and impartiality, the officers did confirm that the violation rate is high along the I-24 and I-65 HOV corridors. The officers also confirmed that HOV lane enforcement is a very low priority in comparison with the enforcement of those traffic regulations that have been shown through research and experience to prevent fatal crashes. As such, the primary enforcement objectives of THP are focused upon the four areas of:

- Impaired driving
- Hazardous moving violations
- Distracted driving
- Safety belts

While the number of citations written by THP for HOV lane violations was confirmed to have increased significantly in 2017 as opposed to 2016, there is little evidence to suggest that HOV lane enforcement as a primary objective of THP will save any lives. Further, enforcement of HOV regulations in heavy traffic is one of the most dangerous tasks THP could be asked to do. There is no place on the left-hand side of the road to make a traffic stop safely and pulling the driver over requires that the officer and the driver move across three lanes of heavy traffic. The risk of creating another much more hazardous situation on the roadway is very significant, and the act of pulling a driver over will almost certainly disrupt the flow of traffic. The officers noted that there is a much greater likelihood of a Highway Patrol officer dying by being struck by a vehicle than there is that the Highway Patrol officer dying by being shot.

Given that the enforcement of a typical HOV lane offense is both risky and causes negative impacts on traffic operations, enforcement of HOV lane restrictions defeats the purpose ofhaving an HOV lane, as an HOV lane should be used to improve traffic operations and reduce pollution in heavily traveled corridors. The risks and negative impacts of HOV enforcement activities on these corridors, especially in those locations where there are few satisfactory places to stop drivers, make it a wise decision to not stop drivers for HOV violations. Further, an HOV lane violation is a class C misdemeanor and carries a fifty-dollar fine, the penalty imposed upon drivers is unlikely to deter drivers from violating these laws. It was the consensus of the officers that a low priority being placed on enforcement and a low penalty being imposed upon offenders has led to a situation where the HOV lanes, as operated today, are not very effective in achieving the goals for which they were introduced. HOV was created to help alleviate pollution and manage congestion, therefore, where it started is completely different than where it is today.

***How do you currently enforce the HOV lanes?***

The officers made it very clear that enforcement of HOV lanes is a no-win situation and places lives, property, and traffic operations at risk. The officers explained that the decision to pull someone over is made on a risk-reward basis. If traffic is moving well, a THP officer does not want to impair the progression of traffic. When officers pull individuals over for HOV violations, they pull the driver to the right. Drivers pulling themselves off the roadway to the left creates a very dangerous situation, especially when a concrete median barrier is located very near the left-hand side of the pavement. Officers typically do HOV lane enforcement when there is ample room to pull a driver over to the right.

***How many tickets have you given in the last month? 6 months? 1 year?***

THP issued 604 citations for HOV lane violations statewide in 2017, up from 244 in 2016. Of all tickets issued, the majority are issued for not wearing seat belts. Less than 1% of tickets are HOV lane violation; they used to be in the miscellaneous category. There is an assumption that the majority of citations for HOV lane violations are issued in Rutherford County because there is more room for THP to operate on the side of the interstate in this area when pulling drivers over.

***What would need to change to make enforcement easier for you? Or to make it more worth your time and attention?***

The THP officers believe that current hours of operation show that the lane restrictions are not important. It needs to be enforced 24 hours a day, 7 days a week. Allowing officers to enforce the HOV lane restrictions in off-peak time would allow them many more and safer opportunities to cite drivers, eventually leading to a greater deal of public respect for the HOV lane restrictions.

***What changes need to be made to make the HOV lanes more beneficial or successful?***

The officers noted that information about the fine for HOV violation was removed from the signs. Perhaps warning drivers of a fine on HOV lane signage will deter people from violating. However, since the fine is only $50 for an HOV lane violation and the odds of being issued a citation are very small, the officers felt that it may be wise that drivers do not know what the fine is. *(Note: The officers were incorrect in their statement that the fine amount is not posted on signage. The fine of $50 is posted on HOV lane signage on all corridors.)*

***Any other comments or recommendations for the improvement of the HOV lane usage and enforcement?***

In closing, the officers noted the following:

- There is the option of going the technology and camera route, but it will not likely be well received by the public.
- Pulling people over for HOV lane violation is simply not safe for anyone involved.
- If the HOV lanes are to be kept, then there needs to be stronger enforcement and a higher penalty to make them function as originally intended. The incentive of arriving at destinations sooner by use of the HOV lane is not sufficient to induce a significant shift in carpooling behavior.
- The consequences of an HOV violation must cause enough pain for people to change their behavior. If we do enforce it for the short-term, it is going to cause more of an issue. If the commute is, say, 15 minutes more, then people might consider changing by asking others to ride with them.

# Chapter 5 Analysis of Stated Preferences of Drivers- User Survey Results

## 5.1 Introduction

The Lipscomb team has designed and administered a survey of the driving public as a major component of this research project. In particular, we have included additional demographic items, including income, vehicle ownership and types, and household composition. We have also included items to elicit where the users most often enter and exit the roadways. The current survey includes demographic items, items to determine whether the user drives on interstates with HOV corridors in peak hours, items to determine whether the user has used HOV lanes and reasons why or why the participant doesn't use them, items to determine the knowledge of regulations regarding HOV lanes, items regarding compliance behavior and reasons for compliance or noncompliance, items to elicit users' value of travel time, and items to elicit the aggressiveness of the drivers. There are three forms of the survey that the team has used, with only changes in numerical parameters in a few question stems.

The survey instrument was approved by Lipscomb University's Institutional Review Board, and the survey was launched using REDCap for survey administration and data collection. The team elected to distribute links electronically in four phases to date, with the second and fourth phases receiving the second of the three forms. There were 476 total responses. 184 total participants completed the first of the three forms. 108 respondents completed the second form, and 184 total participants completed the third form. A complete collection of survey questions and a tabulation of their results is presented in Appendix K.

## 5.2 Demographic Data

The first series of questions in the survey collected demographic data about the participants in the survey. Questions were asked to determine the age, gender, and race of the participants; the number of people and drivers in the participant's household; and education level and household income for the participant. Data were also collected about the number of miles driven to work, miles driven on the interstate, and hours participants spend in their car.

A large number of respondents fell in the 20-29 age group. However, the survey was distributed to several area churches, and there is a significant degree of diversity in the responses concerning age. The respondents to the survey were 76.7% female. The reason for this discrepancy is not well understood, though the distribution of the survey at Lipscomb University may have contributed to the gender imbalance, as Lipscomb has more female students than male students. Caucasian/white people make up nearly 90 percent of the survey respondents. This may result in an oversampling bias toward Caucasian people and results from the distribution of the survey to students at Lipscomb University, as well as the distribution of the survey to predominantly white churches.

Although the survey instrument was distributed at Lipscomb University (among other places), great care was taken not to oversample undergraduate students and to include as many graduate students and faculty as possible. As a result, only a minority of respondents reports having only one member of their household. This does point to the survey participants' spanning a fairly diverse spectrum of households in terms of size. Figure 5-1 shows a histogram of the household size.

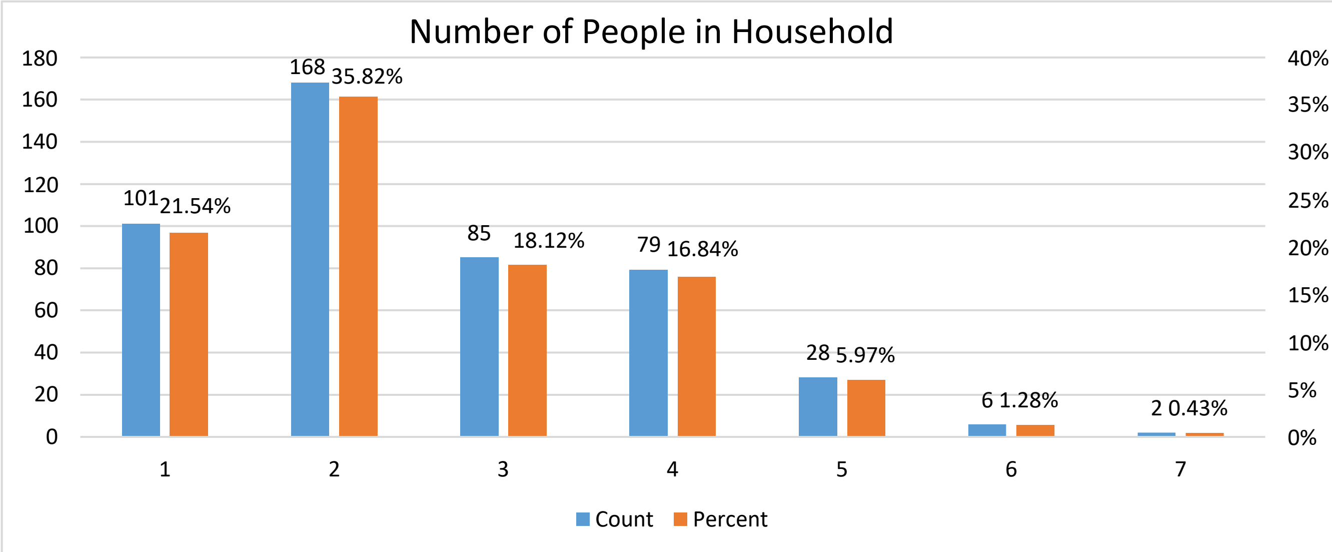



Figure 5-1 Number of people in the respondent’s household

A vast majority of households report having more than one driver, with 52% of respondents having two drivers in their household. Figure 5-2 shows a histogram of the responses to this question.

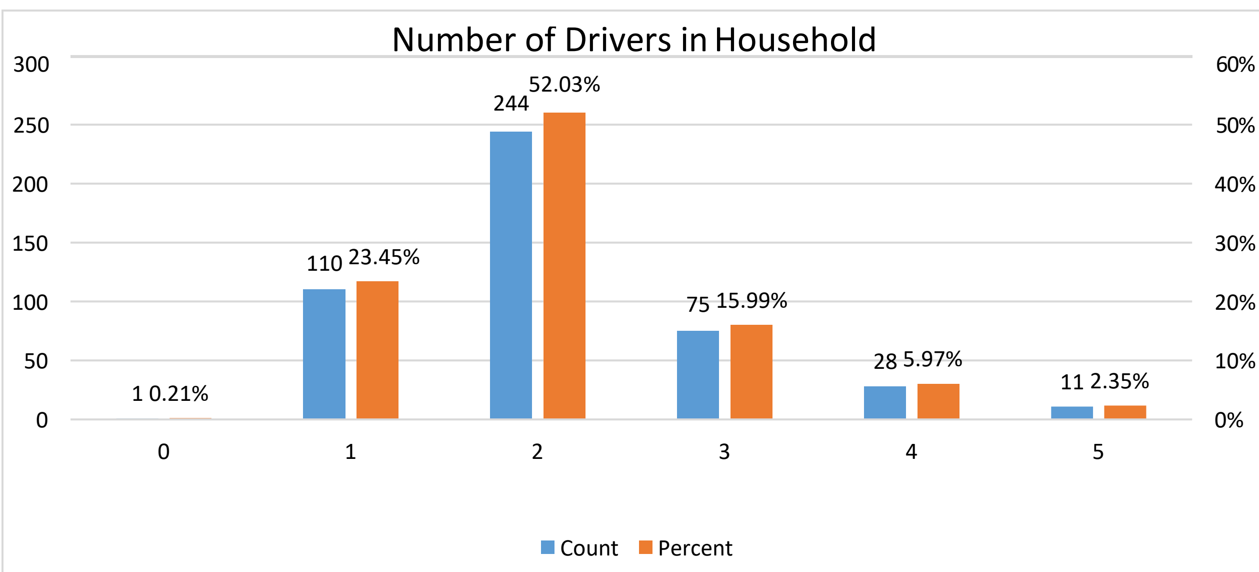



Figure 5-2 Number of drivers in the respondent’s household

The majority of people (67.1%) completing the survey have completed a bachelor's degree. A significant number have completed only high school or achieved a GED. A small minority of people have completed a professional degree and no respondents report having completed a doctoral degree. This distribution shows that the survey was not widely distributed to traditional undergraduates, though the survey was administered to many graduate and commuter students as well as university staff. A significant number of respondents also came from churches in the area where many of the members are college graduates.

The survey was successfully administered to households with a wide array of household income levels. This is very beneficial as the sample population will reflect a wide variety of economic conditions. As it is desired to understand the impact of fines and tolls on the driving population, this level of diversity is highly desirable in the sample. The distribution of the respondents' household income is shown in Figure 5-3.

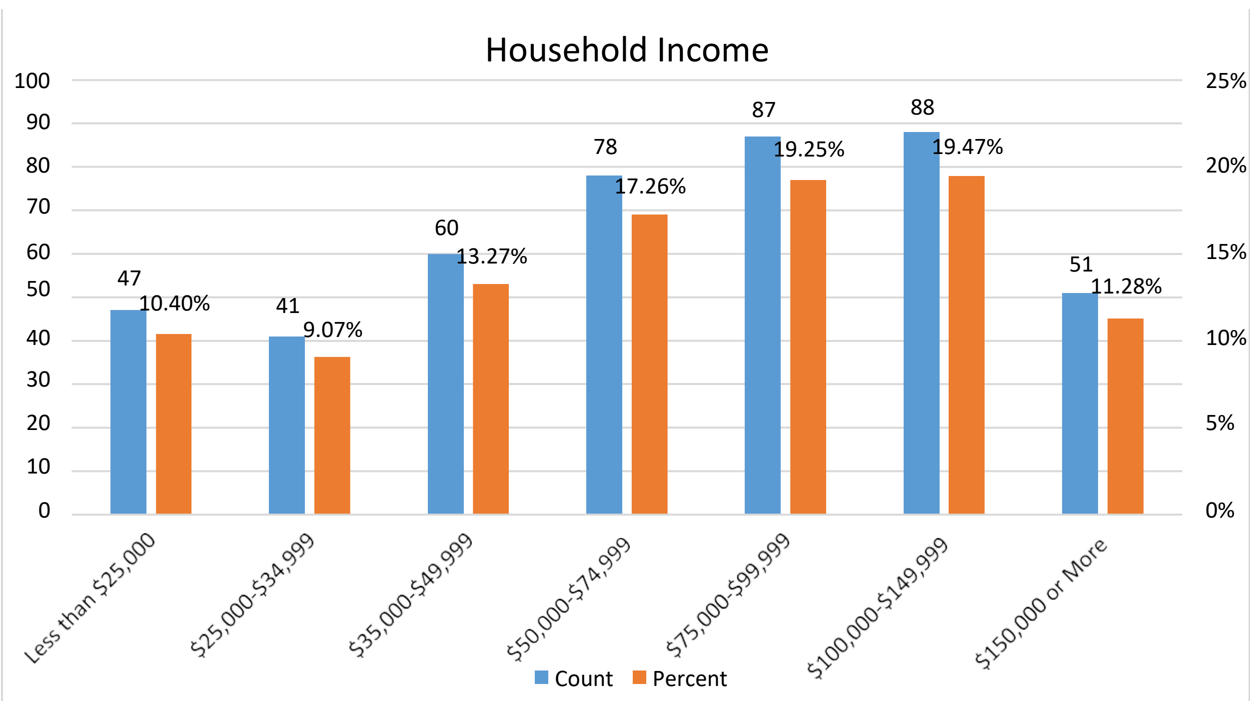



Figure 5-3 Distribution of participants' household income

The greatest number of respondents report a round trip commute of between 11 and 25 miles. A histogram of the distribution of round-trip distance to work or school is shown in Figure 5-4.

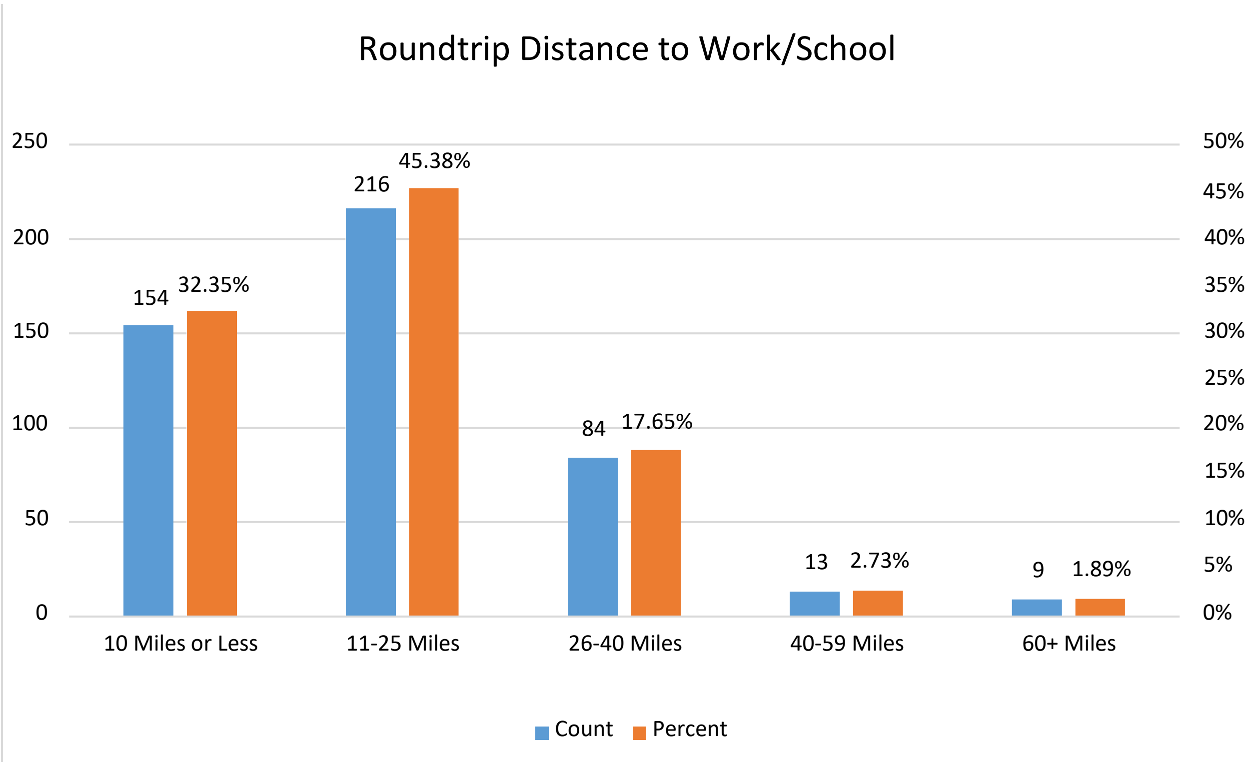



Figure 5-4 Distribution of roundtrip distance to work/school.

The distribution of interstate miles driven by users is shown in Figure 5-5. The data appears bimodal, with one mode in the 0 to 4-mile bin and another in the 10 to 19-mile bin. The majority of respondents reported spending 1-3 hours per day in their vehicle. Properly functioning HOV facilities can offer meaningful time savings to the majority of travelers.

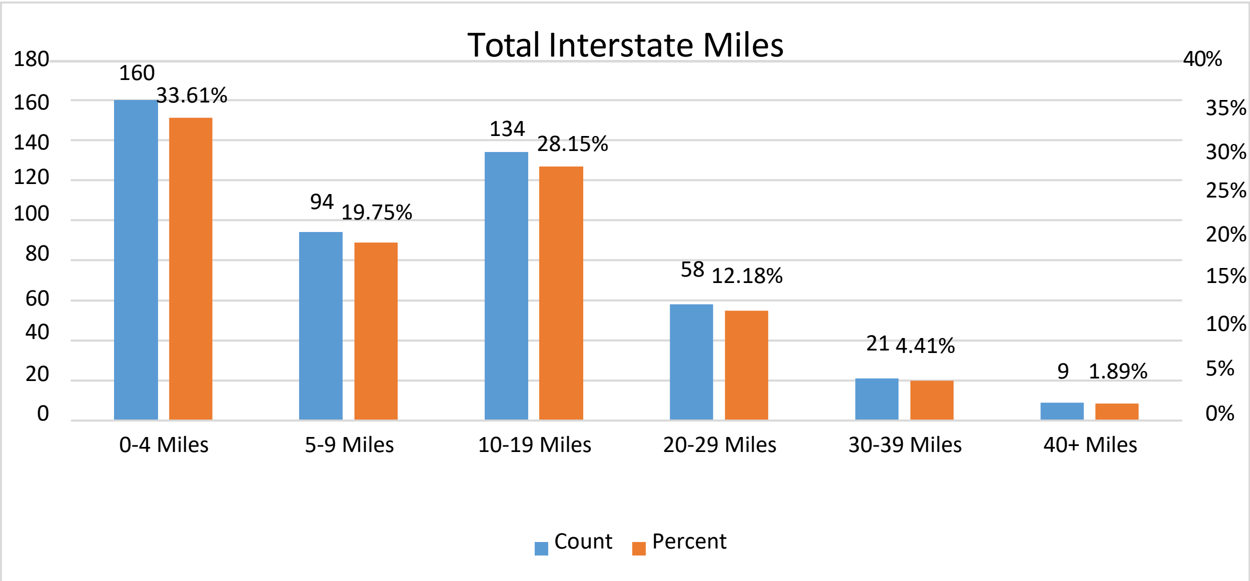



Figure 5-5 Total interstate miles

Only a small number of participants in the survey drive a hybrid or electric vehicle, with the majority driving a vehicle with a gasoline-powered engine. The vast majority of survey respondents own their primary vehicle. Only 23.9 percent of respondents report having only one vehicle in their household. Only two respondents did not report owning a vehicle.

## 5.3 Qualifiers

Another series of questions were asked to determine whether the respondents frequently travel on I-65, I-24, or both and whether the users travel during peak time. The vast majority of respondents use either I-24, I-65, or both regularly, meaning that the majority of respondents have relevant knowledge and experience with these facilities and make travel behavior decisions that this study wishes to further understand. Over three-quarters of the respondents drive during rush hour. As the HOV restrictions are only applicable during rush hour, the majority of respondents use the facilities in question.

## 5.4 Knowledge of HOV lanes

A series of questions judging knowledge about HOV lanes were included to elicit the extent to which users of the facilities are aware of the HOV lane rules of operation. The vast majority of respondents (94.3%) know what an HOV lane is. Hence, the vast majority of self-reported violations are done with the knowledge of the HOV restrictions. Not only do most respondents know what an HOV lane is, the overwhelming majority of respondents (92%) recall seeing HOV regulatory signage. However, only 60 of 476 respondents correctly identified the vehicles considered to be inherently low emission vehicles. This result shows that there is a need to better inform the public of the requirements for legal use of the HOV lanes. Some single-occupant vehicles may legitimately be unaware that they are not legally permitted to use the HOV lanes.

## 5.5 Usage of HOV Lane

The next series of questions were intended to assess whether the participants use the HOV lane, why they do or do not use the HOV lane, when the participants most desire to use the HOV lane, whether they violate HOV lane restrictions, and why they choose to obey or violate the restrictions.

Most (83%) participants report having used the HOV lane. Approximately half of those who report using the HOV lane self-report using the lane at least once a week, with the demand for the use of the lane highest in peak times. Of those who do not use HOV lanes, most of them report reasons for obeying the restrictions stemming from an innate desire to follow the law. The possibility of enforcement and penalties also is a significant motivator for some. However, weaving conditions do not seem to deter individuals from using the HOV lane.

While nearly three-quarters of people admit to having at some point violated the HOV lane rules, and approximately one-third of respondents who report using the HOV lane admit to at least sometimes violating HOV lane use rules, about three-quarters of respondents also admit to doing so under ten percent of the time. This suggests that the HOV lane serves and functions as a passing lane. Natural lane management would place drivers in the rightmost lane unless the lane is moving too slowly, and the drivers move leftward where the pace in the leftward lane is higher than the pace in the rightward lane. The responses, therefore, convey that HOV lane usage is not preferred by most drivers unless the facility is so congested that acceptable speeds cannot be maintained in the mixed-flow lanes. At that point, drivers will tend to use the HOV lane to circumvent localized congestion on the freeway.

The most important reasons for non-compliance cited amongst those who sometimes, often, or always violate HOV restrictions stem from frustration with traffic conditions. These individuals are often frustrated with conditions in the mixed-flow lanes (and maybe more inclined to violate when they are in a hurry) and choose to violate out of dissatisfaction with progression in the mixed-flow lanes. Many of these respondents believe that they are not likely to be caught and punished for their violation. A few respondents report violating the HOV regulations because they disagree with the rules, and a few respondents also claim a lack of understanding or a lack of knowledge of the rules. As for overall public attitudes about the effectiveness of HOV lanes in addressing environmental problems, relatively few cite this cynicism as a motivation for violating HOV lane use regulations.

The improvement most essential to reducing violation rates among those who report sometimes, often, or always violating HOV lane restrictions is an abatement of congested conditions in the mixed-flow lanes. Some frequent violators may be deterred by stronger enforcement and fines, as well as clearer rules and punishments, but the frequent violators in this study have identified delays in the mixed-flow lanes as the primary motivator for violating HOV restrictions.

## 5.6 Value of Time

The next series of questions were posed to participants to elicit their valuation of travel time. This knowledge of stated preference is useful in understanding how users of the HOV corridor are likely to respond should the HOV lane be opened to single-occupant vehicles via tolled access. An item was also included to assess the drivers' willingness to violate usage rules as a function of fines. A further item was also included to ask drivers what time savings would be required to entice them to violate the HOV lane restrictions.

### 5.6.1 Willingness to Pay

Question 28 in the survey was formulated to assess the willingness of survey respondents to pay to use the HOV lane if they knew how much time it would save them. This item was included to judge how users perceive the value of the time savings afforded by the HOV lane. It was stated as:

28. **Assuming that you are driving as a single-occupancy vehicle, you could save 15 minutes by traveling in the HOV lane on your morning commute. What dollar amount of a toll would you be willing to pay to drive legally in the HOV lane? (open-ended)**

This question was intentionally posed as an open-ended question. Some individuals did not answer the question using a simple dollar amount, and their responses are removed from the data. This information is recast as a percentage willing to pay the toll to save 15 minutes in Figure 5-6.

From the plot in Figure 5-6, we can see that the median user is willing to pay less than a dollar to save 15 minutes of travel time. Hence the median valuation of time saved by the HOV lane is less than four dollars per hour.

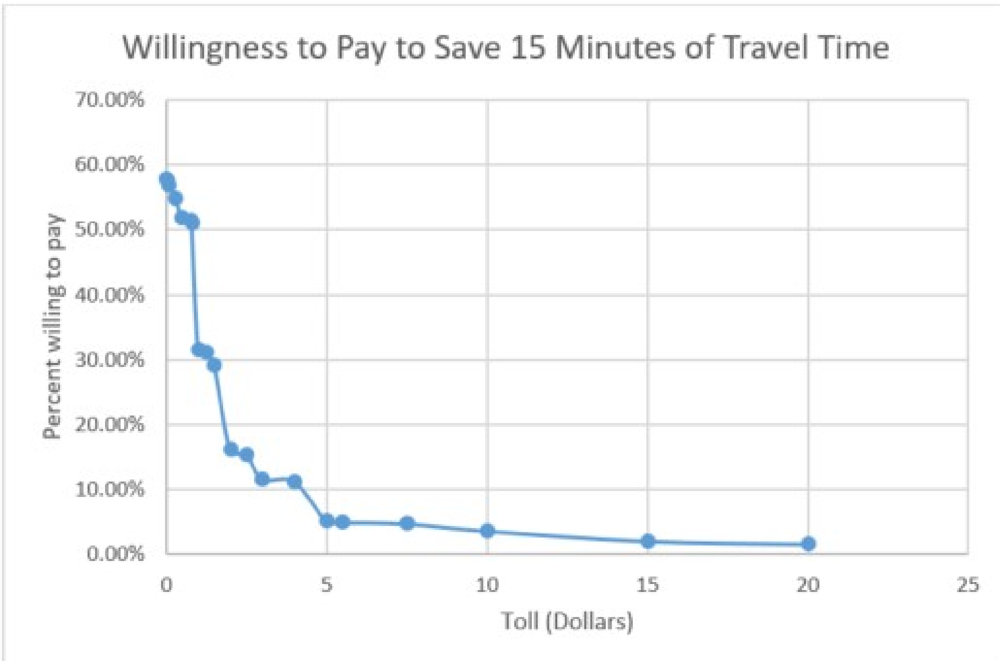



Figure 5-6 Willingness to pay to save 15 minutes of travel time

From the data collected for question survey question 28, a very simple model will be presented for estimation of the probability of a single occupant vehicle electing to travel in the HOV lane. Question 28 asked respondents how much they would be willing to pay to save 15 minutes of travel time by using the HOV lane. By considering the proportion π of those willing to pay to use the HOV lane at various prices, *p*, we will formulate a logistic regression model of the form,

$$\pi(p) = \frac{e^{a+bp}}{1+e^{a+bp}} \tag{5-1}$$

where a and b are constants. The model can be estimated using linear regression techniques if the model is expressed in the form,

$$ln\left(\frac{\pi(p)}{1-\pi(p)}\right) = a + bp \tag{5-2}$$

The HOT lane would become more favorable with a more strongly positive value of $a$, and it is expected that $b$ should be negative as the probability of individuals being willing to pay to use the HOT lane should decrease with increasing prices. The coefficients $a$ and $b$ can be estimated using linear regression and are shown in Table 5-1. This model can be expressed as,

$$P(HOT|Price) = \frac{e^{-1.097-0.06875*Price}}{1+e^{-1.097-0.06875*Price}} \tag{5-3}$$

Because the intercept for the HOV alternative is negative, this model shows that the HOT lane is not preferred by most survey respondents. As expected, the sign of the price coefficient is negative. Both intercepts are statistically significant. The $R^2$ for the model is 0.65, indicating a reasonable degree of fit, and the significance F-value is 1.895E-6, indicating that the model provides a high degree of explanatory power.

Table 5-1 Logit Parameter Estimation for Lane Choice Model

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.807 |
| R Square | 0.651 |
| Adjusted R Square | 0.635 |
| Standard Error | 1.167 |
| Observations | 24.000 |

| ANOVA | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 55.970 | 55.970 | 41.080 | 1.895E-06 |
| Residual | 22 | 29.974 | 1.362 | | |
| Total | 23 | 85.944 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* |
|---|---|---|---|---|
| Intercept | -1.097 | 0.278 | -3.945 | 0.001 |
| Price | -0.06875 | 0.011 | -6.409 | 0.000 |

This result can be generalized if the value of time is constant. If the HOV lane is priced at *f* and saves *t* minutes, then the price in the prior logistic regression can be recast as a price per 15 minutes of time savings. By reinterpreting the price p as a price per 15 minutes, the probability of a single-occupancy vehicle driver choosing to use the HOV lane, given a cost of f dollars and a travel time savings of *t* minutes can be estimated as,

$$P(HOV|f,t) = \frac{e^{-1.097-0.06875*f*\frac{15}{t}}}{1+e^{-1.097-0.06875*f*\frac{15}{t}}} \tag{5-4}$$

Based on the results of this logistic regression model, if the travel time savings are held at constant at 15 minutes, the prediction of those willing to use the HOV lanes at various price points is shown in Figure 5-7. At a price of zero, approximately 25 percent of single-occupant vehicles would be willing to use the HOV lane. This result compares well with the results of VISSIM model calibration, which indicates that under current conditions approximately one in four single-occupant vehicles is willing to violate the HOV lane restrictions. Since current enforcement is relatively ineffective and is perceived by the public to be ineffective, this is a reasonable prediction for the number of drivers who would be willing to use the HOV lane if it was to be untolled. Further, as the highway reaches capacity, it is also sensible that traffic would distribute itself across four lanes in a nearly equal fashion. Hence, the intercept parameter is very reasonable, as the predictions of the model are well aligned with the results of the calibration of other models and field data.

The sensitivity to tolling is another important parameter for study and is a parameter that would ultimately be updated as any tolling algorithm is implemented and revealed preference data becomes available. Figure 5-7 shows the sensitivity of lane choice by travel time savings as a function of the toll in dollars. Each curve is representative of user choice for fixed time savings.

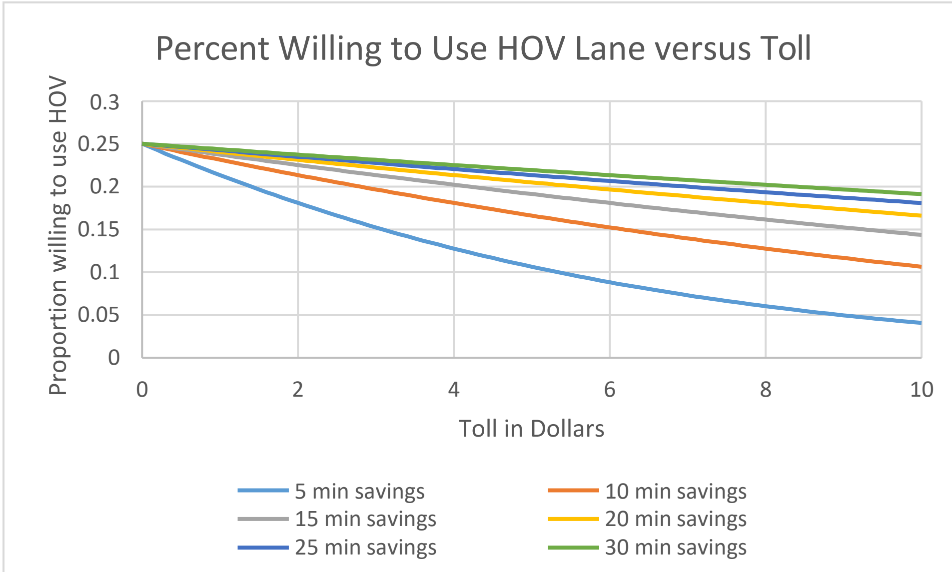



Figure 5-7 Percent willing to use HOV lane versus toll.

Analysis of survey data from Question 28 has provided a useful model to estimate the probability of a given lane choice for specified time savings and tolls. Although the implementation of tolled access is beyond the scope of this project, VISSIM does allow for the use of dynamic traffic assignment with tolled access to the managed lanes if coefficients for a logit model of the specification are provided. Hence, the estimation activity provides a reasonable starting point for future work in studies involving the response of the public to the introduction of a HOT lane.

However, there are some significant limitations to this analysis. First, and perhaps most importantly, this question was posed to determine how the public tends to value time saved from the use of the HOV lanes. This stated preference survey does not have the sample sizes used in studies such as the Bay Area Transportation Study or the Chicago Area Transportation Study. Further, the range of parameters in the questions posed by the survey does not cover a broad enough range to know how the public would respond to a wider decision space of tolls and time savings. Finally, it would be ideal to include demographic parameters in the model to be able to understand the sensitivity of a broader range of demographic groups, including economically disadvantaged protected classes in a full-scale model that could be used to justify the creation of a HOT lane. However, given the time and objectives of this particular study, this work is best saved for a later study more tailored to the integration of a broader set of planning models to determine the impacts of policy changes to the HOV lanes to various segments of the general public.

### 5.6.2 Sensitivity to Fines

Question 29 was used to gauge the sensitivity of individuals to increases in fines. It is stated as:

**29. Assuming that you are driving as a single-occupancy vehicle, if the fine for driving in an HOV lane is <$50, $100, $500> and enforcement is done automatically, how many minutes in time savings that would be required before you'd be willing to violate the HOV lane rules? (open-ended)**

A plot of the percentage of individuals willing to violate the HOV lane rules as a function of travel time savings is shown in Figure 5-8. The population was divided into subgroups by using different forms of the survey instrument. It is remarkable how similar the curves are under a $50 fine, $100 fine, and $500 fine, ***even if enforcement is automated***. The stated preference data seem to suggest that a significant increase in the fine alone may not change driver behavior much in the HOV corridor.


Figure 5-8 Percent willing to violate vs. travel time savings

**30. Assuming that you are driving as a single-occupancy vehicle, if the toll for driving in an HOV lane is $1 and enforcement is done <automatically, manually by police>, how many minutes in time savings that you would require before being willing to pay the toll to use the HOV lane? (open-ended)**

Different forms of this survey question were used with this survey. In one administration of the survey, this item was presented with the enforcement being done manually, while in the other administration the enforcement is to be automated. The reason why this item is included in the survey is to gauge the public's willingness to pay to avoid delay. In this item, the travel time equivalent of one dollar is to be determined. To process the data from this open-ended question, only responses presenting a positive monetary amount were considered to be valid.

The nature of how the facility is enforced had virtually no impact on how the public values time. The distribution is almost identical across both groups. What is also interesting is that question 30 revealed that a toll of approximately 80 cents would be sufficient to deter half of the driving public from using the HOV lane if the HOV lane promised 15 minutes of travel time savings. In this question, 63 percent of users are willing to pay $1.00 to save 15 minutes of travel time. From the results of these two items, it is reasonable to assume that a $1.00 toll would deter approximately two-thirds of the public from using the HOV lane if tolled access were provided and the use of the HOV lane offered a 15-minute travel time savings. Figure 5-9 shows the willingness of the respondents to pay a $1.00 toll to save a certain amount of time by using the HOV lane.

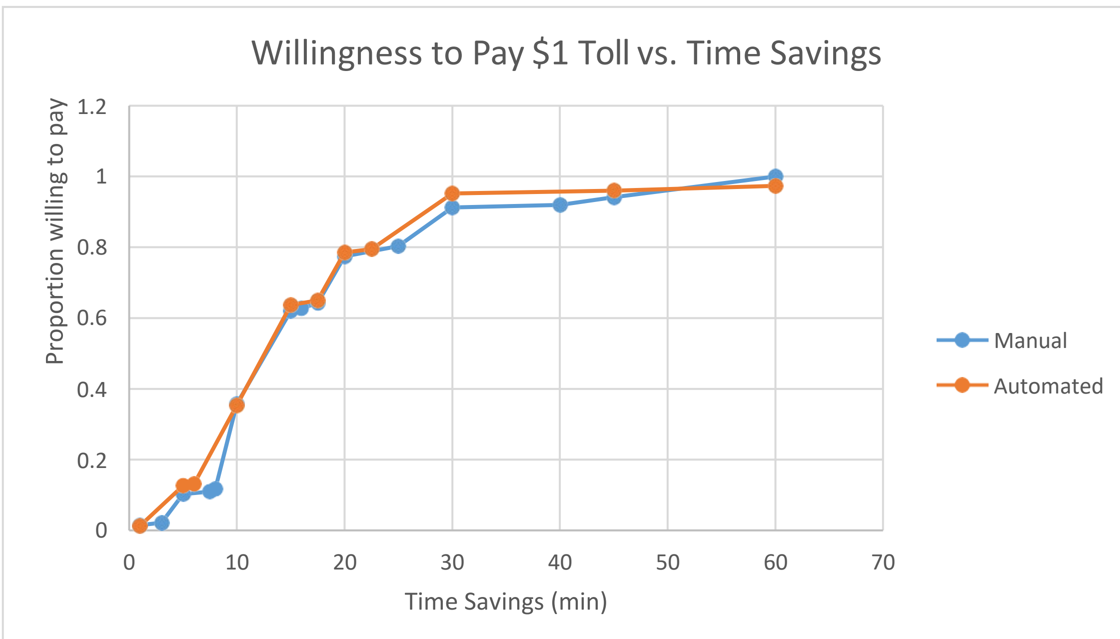



Figure 5-9 Willingness to pay $1 toll vs. travel time savings

## 5.7 Carpooling Habits and Motives

The next series of questions were asked to better understand the motivating factors behind the participants' mode choice decisions. Specifically, it is desired to determine the extent to which access to HOV lanes motivates the decision to carpool and to use eco-friendly modes of transportation. It is also desired to understand what would make the participants more likely to desire to carpool. As Lyft and Uber are making it easier for others to form carpools, a question has been asked to determine the conditions, particularly concerning travel time savings, that would motivate the participants to choose a service of this nature.

The survey response indicates that the use of the HOV lane will not likely be a deciding factor in the travel behavior of the majority of the public. Nearly seventy percent of respondents indicate a low probability that they would carpool or use eco-friendly transportation options to take advantage of HOV lanes. Only about fifteen percent of the respondents indicate that they are or would with a high probability consider carpooling or using an eco-friendly transportation option just to use the HOV lane.

While access to the HOV lane may not be a primary factor driving mode choice, and while many single-occupancy vehicle drivers either cannot or will not carpool, about thirty-five percent of respondents did note that access to the HOV lane would be a motivating factor to carpool (when considered along with other benefits, such as the savings of vehicle miles of travel and fuel expense).

When asked how much time savings would motivate the respondent to form a carpool if the HOV lanes were enforced and violators caught and fined, only 154 of the 476 respondents indicated that they would be motivated to carpool at all. As can be seen from Figure 5-10, a small number of respondents indicated that they would be willing to carpool for minimal travel time savings. This shows that for some individuals that carpooling has significant benefits beyond travel time savings for these users. The majority of those willing to carpool indicate that 10 to 30 minutes of time savings would be sufficient to motivate carpooling.

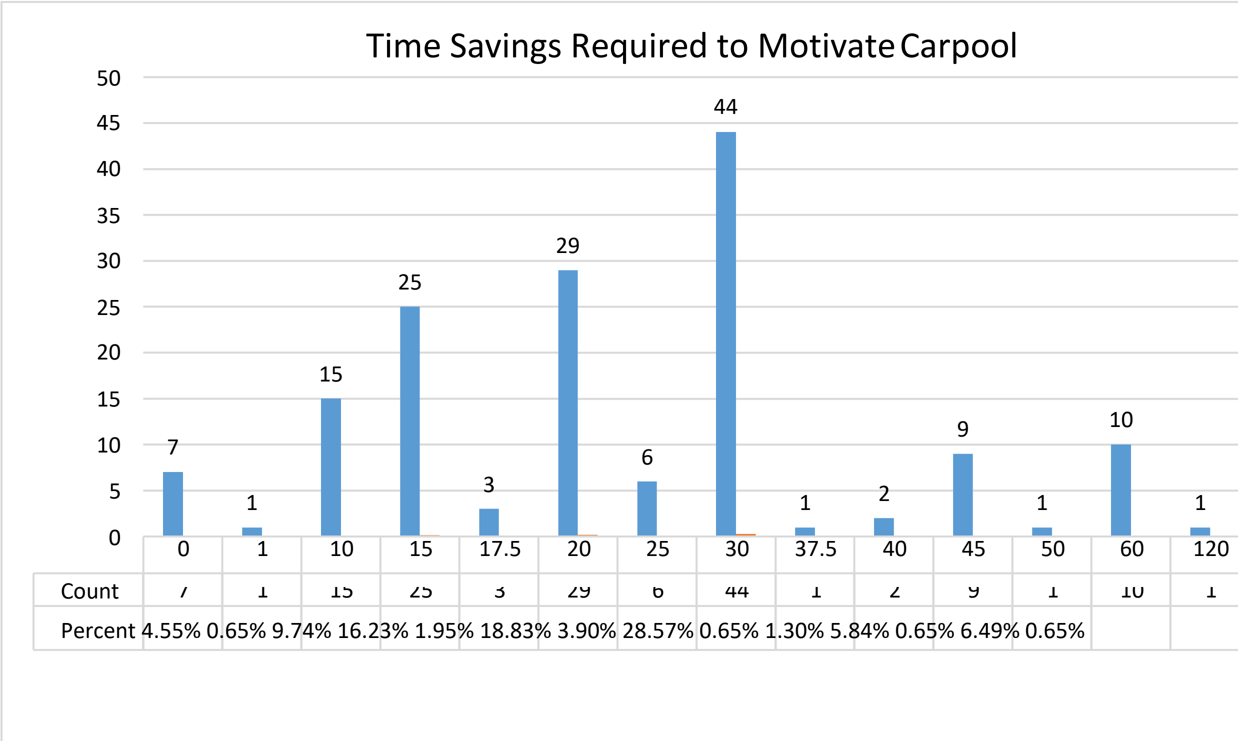



Figure 5-10 Time savings required to motivate carpool

Participants were asked what could be done to make carpooling a more enticing option. The answers to this question are shown in Appendix L. The answers provided by the participants revolved around the following themes:

- Those who feel that carpooling is not a possibility, and nothing can be done to make it more appealing.
- Those who want more convenience and facilities to enable ridesharing and carpooling.
- Those who could be swayed by monetary incentives to carpool.
- Those who would be more willing to consider carpooling with flexibility in work schedules.
- Those who desire better enforcement for HOV lanes.

There were 269 of 476 respondents who indicated a willingness to use a Lyft or Uber service to take advantage of travel time savings that could be afforded by HOV lanes. In general, the distribution of travel times necessary to motivate the use of Lyft or Uber is very close to that required to form a carpool, though Lyft and Uber are more accessible to a wider segment of the population than those who can carpool. A histogram of user responses to the question of how much time savings would be necessary to motivate the use of Lyft or Uber is shown in Figure 5-11.

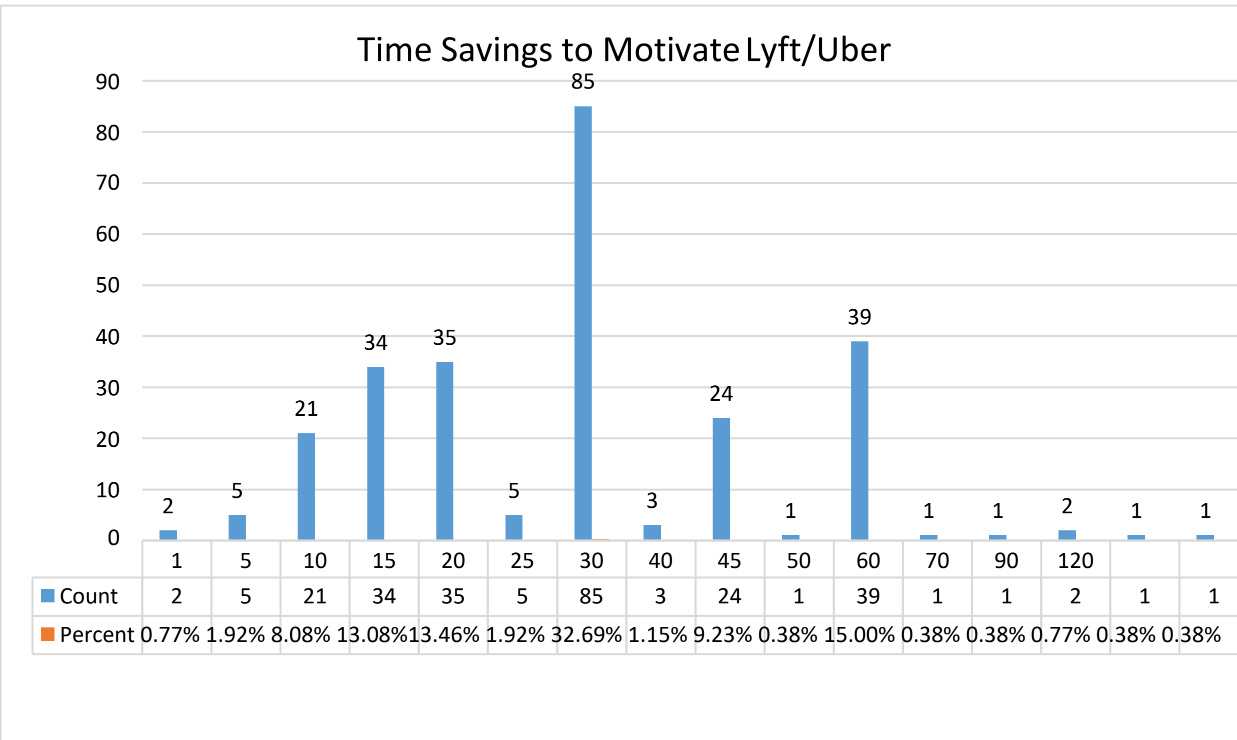



Figure 5-11 Time savings required to motivate Lyft or Uber use

### 5.8 Peer Enforcement

Questions were included in the survey to determine the willingness of drivers to participate in a peer enforcement program similar to the HERO program in Seattle, WA. The answers to these questions are aggregated in Appendix M. While the respondents overwhelmingly reported they would not be willing to participate in a peer-reported enforcement system for HOV lane usage, there is a contingent of people who are willing to do so, and in numbers great enough to identify a significant number of HOV lane violators. The primary reasons cited by the study participants for wanting to participate in such a program include:

- Respect for the law
- A desire to place a check on unsafe driving behaviors
- A belief that people should not prosper from breaking the rules
- Frustration with a perceived lack of enforcement
- A desire to be helpful and improve traffic conditions for society as a whole

There was a much larger number of individuals who were averse to participating in a peer reporting system. Their responses are included in Appendix N. The major themes in the responses include:

- The desire not to be a “snitch”
- The fear of distracted driving. (However, in many cases there would be a passenger who could call and not the driver).
- The desire not to do the government’s job for the government
- A general lack of concern or interest regarding HOV violations
- A belief that the HOV lanes should not be used as such
- An unwillingness to take the time to report

- A belief that such actions violate the spirit, if not the letter, of our nation's constitutional protections
- The desire to not be reported when the respondent violates the HOV lane restrictions
- A concern that people lie
- Concern that people may be punished on flimsy evidence
- Concern that people may abuse the system to maliciously and possibly falsely report drivers who have angered the one reporting

## 5.9 Driver Aggressiveness

The following series of questions (questions 40-45) have been included in the survey instrument to help understand the level of aggression of the participants' driving habits. These questions are scored on a six-point scale and added together for a cumulative driver aggressiveness score, with the scale as follows:

- 1 = never
- 2 = hardly at all
- 3 = occasionally
- 4 = often
- 5 = quite frequently
- 6 = nearly all the time

The battery of questions includes the following:

- When another driver angers you while on the road, you attempted to get revenge on them.
- You stick your tongue out or make faces at drivers that annoy you or make you mad.
- You take chances and run through red lights.
- When another driver angers you while on the road, you shout verbal insults towards them, even if they cannot hear you.
- When another driver angers you while on the road, you follow very close (tailgate) or otherwise try to scare them.
- While driving, you fail to notice signs or other cars, misjudge other's speed, etc.

Figure 5-12 shows a histogram of the overall aggressiveness index for participants in the study. The aggressiveness index follows a primarily unimodal distribution centered near 13 (average = 13.6, median = 13) that displays a rightward skewness.

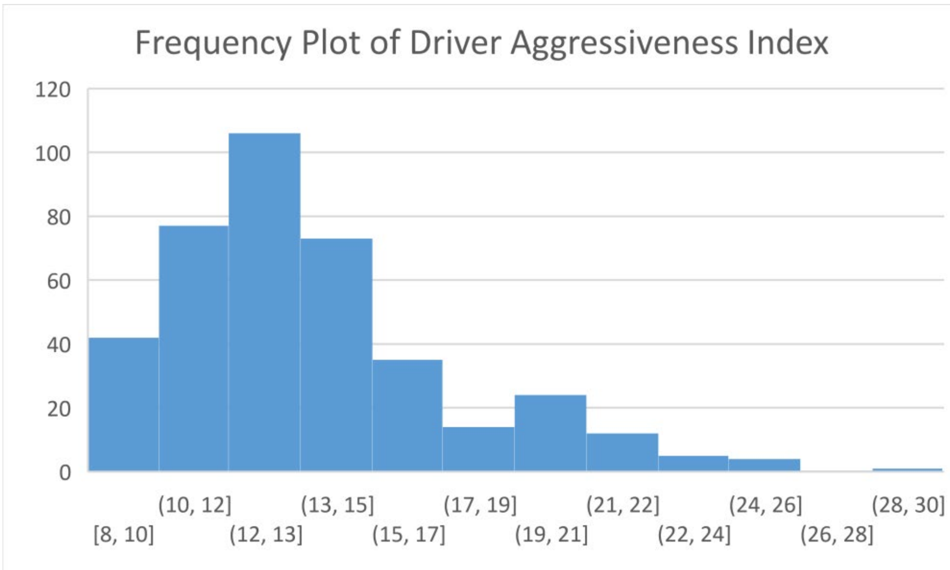



Figure 5-12 Frequency plot of driver aggressiveness index

A contingency table was constructed to examine the relationship between willingness to violate HOV lane restrictions. Respondents who reported that they violate the HOV lane restrictions sometimes, often, or always were classified as HOV lane violators, whereas those responding that they never or rarely violate the HOV lane restrictions are classified as non-violators. As the average driver aggressiveness index (as calculated by the sum of all point values for responses to the driver aggressiveness was 13.6, drivers scoring over 14 were classified as more aggressive drivers and drivers scoring 13 or fewer were classified as less aggressive drivers. The contingency table is as follows:

Table 5-2 Contingency Table for Driver Agressiveness and Violator Status

| | Violator | Not Violator | Total |
|---|---|---|---|
| Aggressive | 75 | 93 | 168 |
| Not Aggressive | 71 | 154 | 225 |
| Total | 146 | 247 | 393 |

The use of the $\chi^2$ test showed that the table had a $\chi^2$ value of 7.0556 with one degree of freedom, for a significance value of 0.007902. This result indicates that these two factors are not statistically independent. There is a strong positive association between the respondents' self-reported status as an aggressive driver and the self-reported status as an HOV lane violator.

## 5.10 Summary and Conclusions

As a major component of the overall program of research, a survey has been administered to 476 members of the driving public. This survey has captured responses on a wide range of topics related to the public perception of the HOV lanes on the I-65 and I-24 corridors. Specifically, the survey has provided insight into the level of knowledge that the traveling public has of HOV lanes and their policies, why drivers choose to violate or obey, how frequently they choose to violate, how the public values the travel time savings afforded by the HOV lane, attitudes toward enforcement, and the opportunity to investigate the relationship between HOV lane violation and driver aggression.

The demographic data obtained within the survey indicates a reasonably diverse population has been reached. This is especially true concerning household size, age, and income. However, approximately three-fourths of the respondents were female, and nine-tenths of the respondents were white.

The survey also found that the vast majority of respondents travel on the HOV corridors of I-65 and I-24. The vast majority of respondents are aware of what HOV lanes are and of the restrictions are, although there was considerable confusion concerning what constitutes an inherently low emission vehicle. However, approximately three-quarters of the respondents self-reported having violated the HOV lane use restrictions, citing frustration with traffic conditions as the primary reason for violating.

While a significant number of respondents self-report that they violate HOV lane use restrictions, they report violating infrequently and primarily to avoid queues at bottlenecks. This report should be of obvious concern for operations on the HOV corridors because this suggests an important mechanism for breakdown of the entire freeway's performance at diverge bottlenecks. If the most aggressive of drivers choose to change lanes leftward to use the HOV lane, especially if the diverge bottleneck is activated and a queue extends back significantly from the bottleneck, those using the HOV lane to circumvent the queue may ultimately need to force their way back into the queue to make their exit. These lane changes can be disruptive, dropping the capacity of the bottleneck. As delays are caused by bottlenecks, when the capacity of the bottleneck drops, delays can increase for all users. While this is an unfortunate outcome resulting from congestion in mixed-flow lanes, if this is happening, controlling the locations of weaving with the HOV lane can potentially lead to improvement of the facility.

Participants have varying opinions about carpooling. A large number of respondents felt that carpooling is not a possibility, and nothing can be done to make it more appealing. However, others would consider convenience and facilities would make carpooling a more appealing choice. Some individuals could likely be swayed by monetary incentives to carpool. Some might be willing to consider carpooling with more flexibility in work schedules. Finally, some feel discouraged by the lack of enforcement of HOV lane restrictions. Most individuals need a time savings benefit of 10 to 30 minutes to make either carpooling or use of a service like Uber or Lyft a desirable option.

According to the response of users, the general public is very resistant to paying to travel in the HOV lane as a single-occupant vehicle, and a toll of as much as $1.00 would likely deter many from traveling in the HOV lane. The median valuation of time savings from the HOV lane appears to be on the order of $4.00 per hour. A modestly tolled express lane would likely be able to keep traffic in the HOV lane to low enough levels to prevent deterioration of the HOV lane, as well as the negative consequences to the mixed-flow lanes resulting from a heavily traveled HOV lane.

Although most respondents would not participate in a peer reporting program similar to the HERO program implemented in Seattle WA, a significant number of individuals (15 percent indicated yes, and about one in three respondents indicated yes or maybe) would be willing to participate. The primary reasons for wanting to participate in such a program include respect for the law, a desire to place a check on unsafe driving behaviors, a belief that people should not prosper from breaking the rules, frustration with a perceived lack of enforcement, and desire to be helpful and improve traffic conditions for society as a whole. Those averse to participating cited the desire not to be a “snitch”, the fear of distracted driving, the desire not to do the government’s job for the government, a general lack of concern or interest regarding HOV violations, a belief that the HOV lanes should not be used as such, an unwillingness to take the time to report, a belief that such actions violate the spirit of our nation’s Constitutional protections, the desire to not be reported when the respondent violates the HOV lane restrictions, a concern that people lie, a concern that people may be punished on flimsy evidence, and concern that people may abuse the system to maliciously and possibly falsely report drivers who have angered the one reporting.

By relating the responses on the questions about how often a respondent violates to their responses on the driver aggressiveness behavioral questionnaire, a contingency analysis was able to conclude that driver aggression and HOV lane violator status are not statistically independent. A larger than expected proportion of HOV lane violators are also more aggressive drivers, and a larger than expected proportion of non-violators are also less aggressive drivers.

This survey is particularly useful for two reasons. First, it has been useful in diagnosing operational problems faced by the HOV corridors. Recalling that bottlenecks appear near most merge and diverge bottlenecks on the corridor, the drivers who regularly violate the HOV lane restrictions have expressed that they are frustrated with the progression of traffic and choose to violate, though they also tend to report violating less than ten percent of the time. This revelation from the drivers corresponds with the traffic data shown in Figure 3.2 that show that, at the most heavily trafficked interchanges, the HOV lane carries a very large volume relative to the other lanes.

Second, the study is useful because it has identified practical and behavioral action levers for TDOT to use to control conditions on the corridor, as well as ineffective levers. While manual enforcement is not a practical strategy for reduction of the number of HOV lane violators along most of the corridor, tolled access to the HOV lane could be an effective way of controlling the distribution of traffic across the lanes. Secondly, TDOT could adopt a program similar to the HERO program in Seattle, WA, where there is a significant proportion of the public who would be willing to report HOV lane violators.

Finally, it should be noted that while the survey provided a reasonably clear view of the opinion of the public in many areas, and while it did effectively point to the use of pricing controls as an effective strategy for removing excess vehicles from the HOV lane without requiring manual enforcement operations, the present study has limitations that would preclude the results from justifying the implementation of a HOT lane. The sample size is limiting, and the questions did not span the full space of items that would ultimately be desirable in determining user choice. For instance, a wider range of commute times and tolls should be presented to a wider range of people in a shorter and simpler survey instrument. Future studies should focus on reaching more minority protected classes and economically disadvantaged individuals to capture the sensitivities of various demographic groups.

# Chapter 6 Supply and Demand Analysis of HOV Corridors: Modeling and Insights

This chapter contains the fundamental analyses required to develop a stochastic user equilibrium model for a general HOV corridor. The stochastic user equilibrium model is used to explore comparative statics on a basic segment of an HOV corridor. In Section 6.1, an analysis of revealed preferences of drivers from traffic counts in the HOV and mixed-flow lanes is presented. This section provides estimates of the probability of a driver choosing to carpool, conditioned on the travel time index in the mixed-flow lanes; of the probability of HOVs choosing to use the HOV lane, conditioned on the travel time index on the mixed-flow lanes; and the probability of an SOV choosing to violate HOV lane restrictions, conditioned on the travel time index in the mixed-flow lanes. Section 6.2 constructs simplistic supply functions based on the Bureau of Public Roads formulas for lane speeds as a function of link flow based on highway performance data. Section 6.3 describes the development of simple air quality models that can be used in an equilibrium analysis of an idealized HOV corridor. Section 6.4 investigates the interaction of supply and demand modeling for a simple HOV facility. Section 6.5 makes a comparison of model predictions and field data observed regarding the number of vehicles choosing to use the HOV lane as a function of the total vehicular volume.

## 6.1 Demand Analysis for HOV Lanes Using Revealed Preference Data

In 2012, TDOT obtained extensive data regarding HOV violation rates from a study performed by Southern Traffic Services in July through August 2012. This study focused on operating characteristics of every HOV corridor in the state of Tennessee. As part of that study, operating speeds, mixed-flow and HOV lane volumes, numbers of HOV and SOV drivers, numbers of legal HOV lane users and violators, numbers of SOV and HOV users in the HOV lane, and numbers of total people were recorded. Given the extensive revealed preference data available from this study, the objective of this section is to mine it to determine what information and insights can be gained about operations on the HOV corridors. In most instances, the traffic was split as approximately 78% mixed-flow lane users, 4% legal HOV lane users, and 18% HOV lane violators. The expanded objective of this analysis was to determine what factors lead to increases or decreases away from these baseline values.

In pursuing the studies in this section and the following section focused on the development of user equilibrium models in the next section, we have used an abstract representation of the network as shown in Figure 6-1.

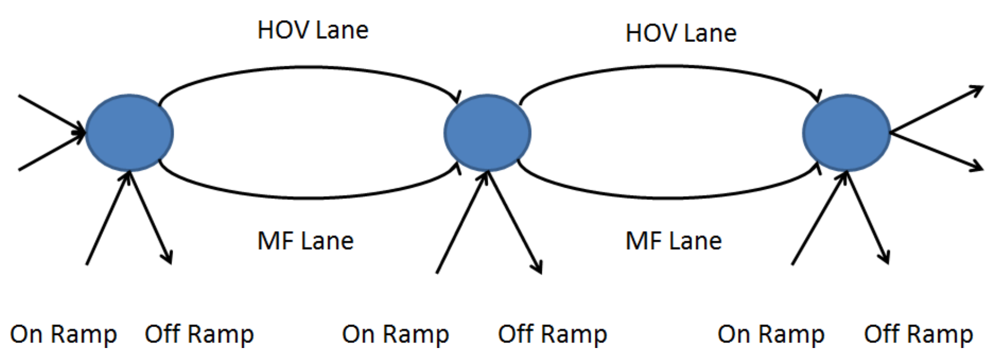



Figure 6-1 Abstract representation of HOV corridor

In our approach to the modeling of user choice, we assume that users make two decisions sequentially. First, they must choose whether to travel by HOV or SOV and then they must choose the link, mixed-flow or HOV lane, they will take between interchanges. It is also assumed that all SOV users who wish to use the HOV lane can do so, but in the future, pricing or enforcement activities may deter at least a fraction of the willing violators from using the HOV lane. Our demand modeling process utilized probability (P) equation estimations of the following form:

$$P(HOV) = f(Travel\,Time\ Index\ on\ \ MF\ Lanes) \tag{6-1}$$

$$P(HOV\ in\ HOV\ Lane) = \ P(HOV) * P(HOV\ Lane \mid HOV) \tag{6-2}$$

$$P(HOV\ Lane \mid HOV) = \ f(Travel\,Time\ Index\ on\ MF\ Lane) \tag{6-3}$$

$$P(HOV\ in\ MF\ Lane) = \ P(HOV) * (1 - P(HOV\ Lane \mid HOV) \tag{6-4}$$

$$P(SOV) = 1\ - P(HOV) \tag{6-5}$$

$$P(Violator\ Class\ Membership) = P(SOV) * f(Travel\,Time\ Index\ on\ MF\ Lanes) \tag{6-6}$$

In these equations, the travel time index (TTI) is defined as the posted speed limit divided by the average speed of vehicles on the mixed-flow lane. These models require three separate equations to be estimated, one for the probability of HOV usage, a second for the probability of an HOV using the HOV lane, and a third for estimating the probability of an SOV user being willing to violate HOV policy. Data for the 14 observations of the 2012 Southern Traffic Systems study were graphically analyzed. Outliers were removed, and it was found that linear regression would be an appropriate tool to use to model the probabilities of user choice as a function of the travel time index on the mixed-flow lanes.

Figure 6-2 shows that the probability of a user choosing the HOV mode varies in a relatively linear fashion with the mixed-flow lane TTI. The higher the TTI on the mixed-flow lane, the greater the degree of congestion, which would be expected to make the choice of the HOV mode of travel more attractive to a traveler. This trend is seen from the data in Figure 6-2, although the $R^2$ value of the linear model fit to the data shows that the level of congestion accounts for only a very small amount of variance in the probability of HOV usage. Hence, it can be inferred that congestion is not a significant motivating factor for carpooling. This lack of correlation shows that the intention of HOV lanes is not having a direct effect on drivers. This general lack of effect has also been confirmed through the survey respondents' answers to questions regarding the effectiveness of the time savings afforded by the HOV lanes influencing their decisions regarding carpooling. While some locations have lower violation rates than others, most travelers' decisions about carpooling are driven by issues of convenience, and many drivers do not have a practical carpooling alternative due to the lack of proximity to coworkers or others sharing a similar destination.

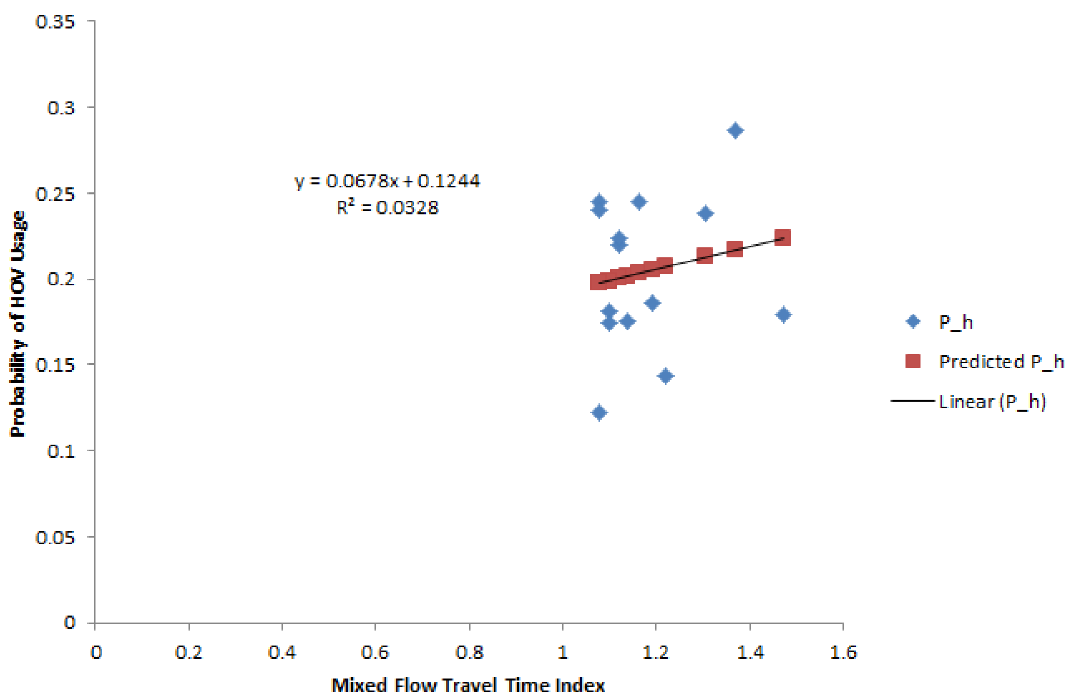



Figure 6-2 Probability of carpooling vs. mixed-flow travel time index

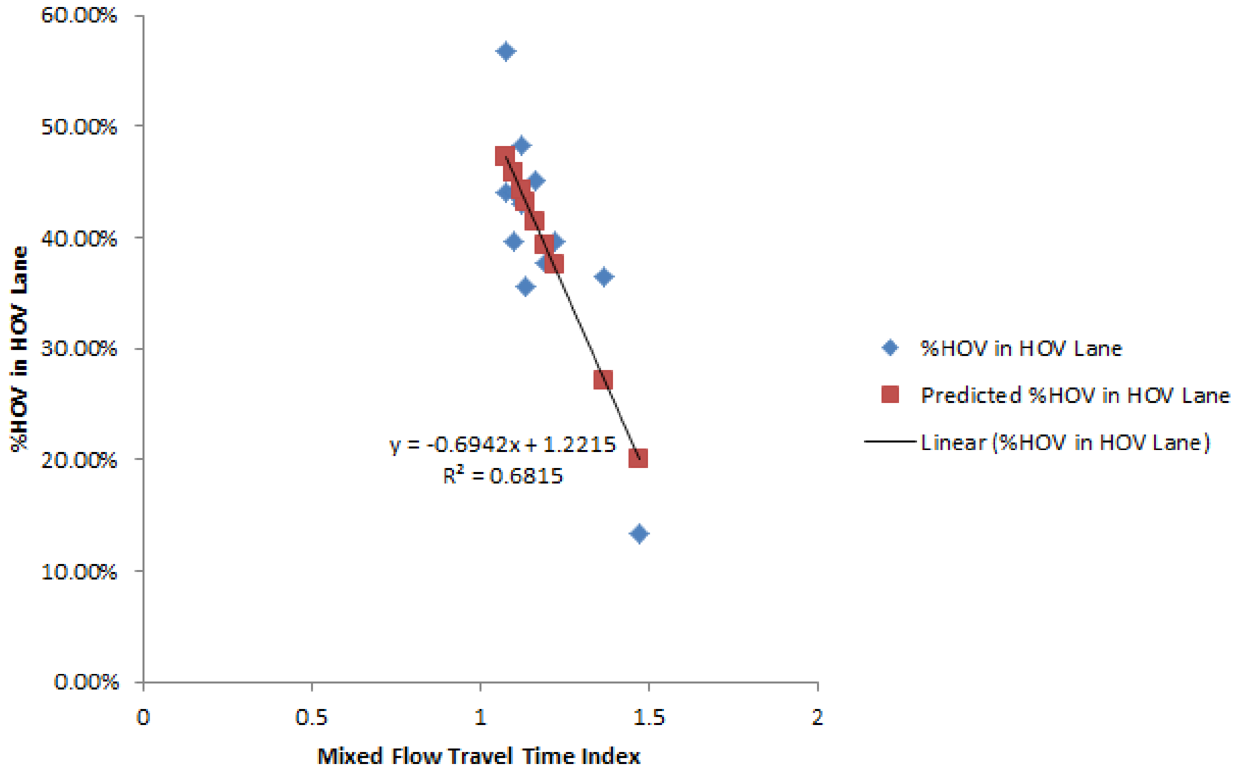



Figure 6-3 Percent of HOV's using HOV lanes as a function of mixed-flow travel time index

Figure 6-3 shows the percentage of HOV's using HOV lanes as a function of the mixed flow travel time index. This result is counterintuitive, as one might expect that increased delays on mixed-flow lanes would make the HOV lane more attractive. However, the examination of revealed preference data shows that this is not the case on the HOV lanes in Tennessee. Onemust consider, however, that the HOV lanes in the Nashville and Memphis corridors are in the far left lane, with right-hand exits. It is reasonable to expect that the difficulty in making the requisite lane changes to enter the HOV lane, the need to slow down from a higher speed to safely re-enter the mixed-flow lane, and the need to cross several mixed-flow lanes to exit the highway make the HOV lane a much less attractive option under heavy congestion.

It would be reasonable to expect that in areas where a high percentage of HOV users use the HOV lane, the congestion in the mixed-flow lanes would be less. However, the ineffectiveness of enforcement of HOV regulations means that traffic will assign itself to lanes in accordance with the desired speeds of the drivers, as a significant proportion of SOVs will enter the HOV lane under highly congested conditions. Further, as HOVs only comprise 18% of the overall traffic stream, and a reasonable proportion of these drivers are satisfied with the speed in their lane of travel or need to exit the facility at an upcoming exit, the effect of a fraction of HOVs entering the HOV lane will be small in comparison to the effect of a similar proportion of SOVs. Hence it is reasonable to expect that the behavior of the SOV class (comprising approximately 80 percent of the traffic stream) is the primary driver of the performance of the system and that the behavior of the HOV class can be viewed as somewhat reactionary. The reassignment of traffic would certainly be expected to alleviate some of the congestion in the mixed-flow lanes, but the data suggest that HOV lane utilization rates drop for HOVs and increase for SOVs as congestion increases. Nonetheless, the revealed preference behaviors of HOVs indicate that the HOV lane is not preferred as congestion in the mixed-flow lanes increases. While higher HOV lane utilization by HOV's may make use of the lane more attractive to other HOV's, each driver is autonomous and makes lane usage decisions that result in the best individual outcome. The analysis of the Southern Traffic Systems data shows that under heavy traffic the HOV lane is not a preferred alternative for many HOVs.

Figure 6-4 shows the percent of drivers willing to violate the HOV lane restrictions as a function of the mixed-flow travel time index. Though the data point with the highest travel time index exerts a great deal of influence on the slope of the regression line, note that the tendency to violate increases sharply with increases in the travel time index. This is an intuitive result, as it is reasonable that aggressive and motivated drivers would take a greater risk to save a larger amount of time.

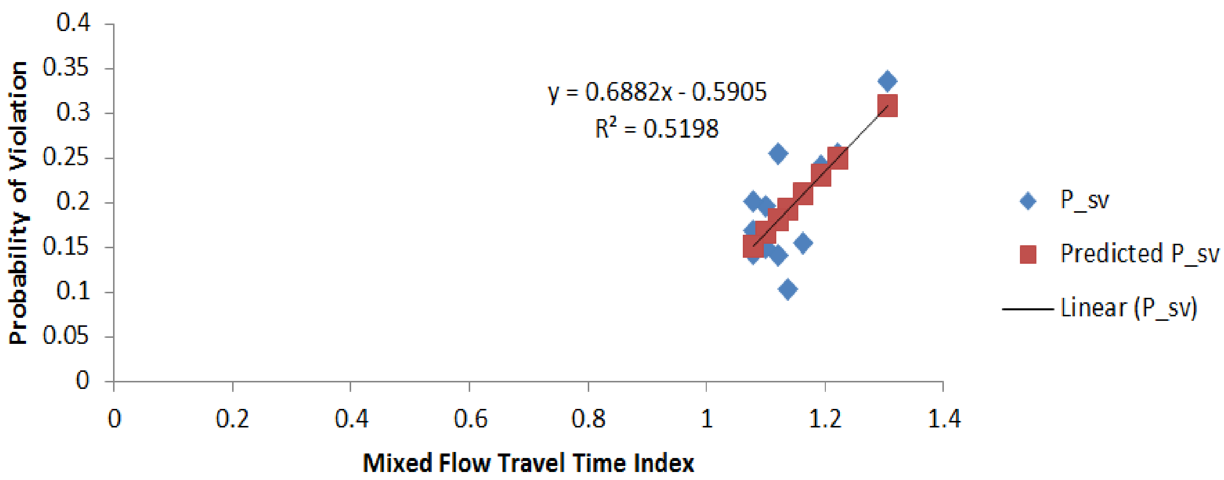



Figure 6-4 Probability of SOV violating HOV lane restrictions vs. mixed-flow travel time index

## 6.2 Highway Link Performance Estimation

In this section, we will seek to estimate performance functions for each lane of the highway at various points along the HOV corridor. We will use the basic approach developed by the Bureau of Public Roads (BPR), giving the travel time in terms of volume-to-capacity ratio as,

$$t(q) = t_0 + a\left(\frac{v}{c}\right)^b \tag{6-7}$$

$v$

$t(q)$ = (unit) travel time for the facility as a function of flow volume $v$

$t_0$ = free flow (unit) travel time

$c$ = facility capacity

$a, b$ = calibration constants

For the sake of illustration, we will use the BPR coefficients of $a = 0.15$ and $b = 4.0$. Based on the fundamental diagrams shown in Figure 3-9 and Figure 3-10, we will take the capacity of the HOV lane as 1850 vehicles per hour and the capacity of the mixed-flow lanes as 1700 vehicles per hour. We will also assume a free-flow speed of 75 miles per hour for the HOV lane and 70 miles per hour for the mixed-flow lanes. Theoretical speed-flow curves are shown for demand flows ranging from 0 to 2500 vehicles per hour in Figure 6-5. It should be noted that demand flows can exceed capacity, so it should not be expected that the links will be able to carry 2500 vehicles per hour. If demand flows exceed the capacity of the lane, then queueing models and microsimulation will become necessary to validate the parts of the curve where demand exceeds capacity.

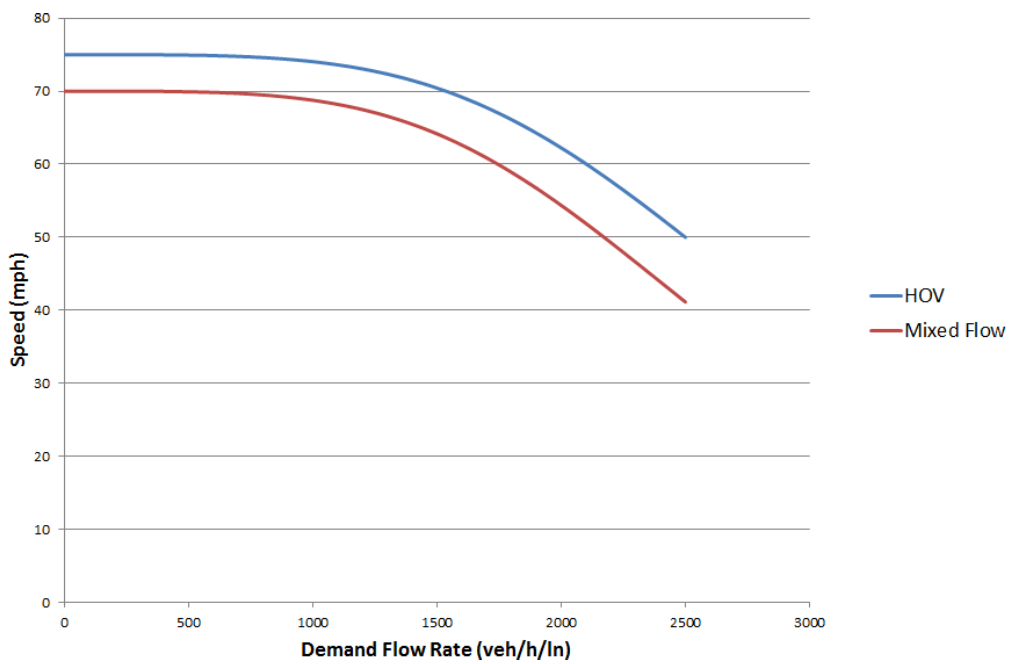



Figure 6-5 Speed-flow curves for HOV and mixed-flow lanes using BPR formula

For comparison, plots of speed and flow data collected by TDOT for the I-65 and I-24 corridors are shown in Figure 6-6 and Figure 6-7. These figures contain data from all 24 hours of operation of the interstate, not exclusively HOV hours of operation. However, HOV lane volumes are relatively light in non-peak hours and consist of passenger cars only, so it is expected that the operations would be similar for the HOV lane, regardless of how many passengers are in the vehicle.

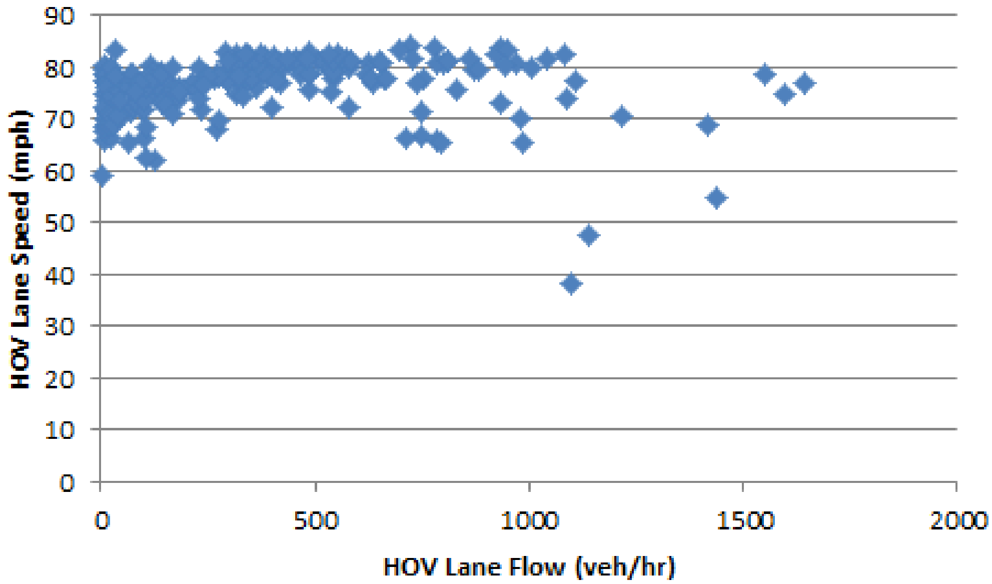



Figure 6-6 Speed-flow data for HOV Lane

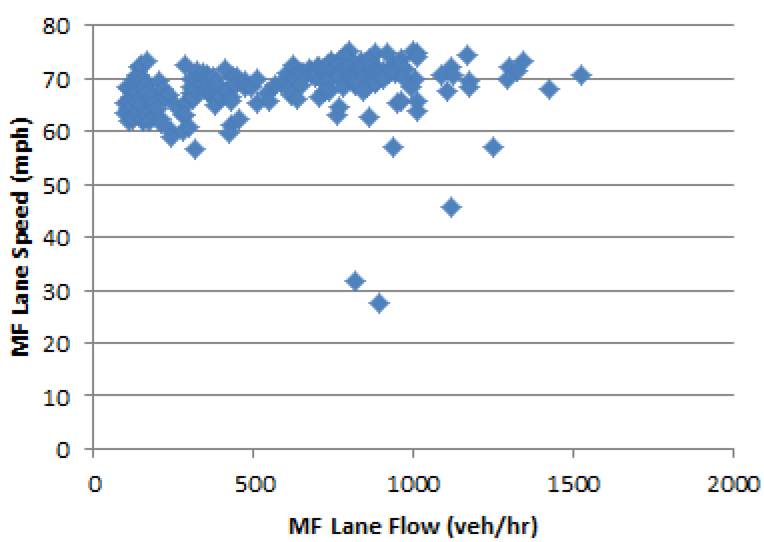



Figure 6-7 Speed-flow data for mixed-flow lane

From observations of the speed-flow data in Figure 6-6 and Figure 6-7, it is clear that the free flow speed is higher in the HOV lane than it is in the mixed-flow lane. Slight deterioration of speed starts to occur at about 750 vehicles per hour in both cases. However, the HOV lane appears to be capable of sustaining near-free flow speeds at somewhat higher volumes than the mixed-flow lanes, and the capacity of the HOV lane is somewhat higher than the capacity of the mixed-flow lane. The analysis of this data supports that the speed-flow curves are reasonable. However, it should be noted that after demand exceeds capacity, the flow rates drop as traffic densifies. This is not reflected in the BPR formula.

A careful analysis of the plots in Figure 6-6 and Figure 6-7 allows for some important observations. First, as volume varies from negligible to 600 vehicles per hour, there is a significant shift in the HOV lane speeds, as the distribution of speeds tightens at a higher mean value. Part of the distribution's width may come from the fact that drivers tend to drive more cautiously at night when the volumes are low. However, HOV lanes start to see more drivers with speeds above 80 mph when volumes exceed 300 vph in the HOV lane. This is coupled with a decrease in the number of drivers exceeding a speed of 70 mph in the mixed-flow lanes from volumes of 300 to 800. This indicates that some of the most aggressive drivers on the roadway may start to switch lanes into the HOV lane once vehicular volumes begin to approach those for Level of Service B (approximately 770 passenger cars per hour per lane in unqueued traffic conditions, according to the Highway Capacity Manual (Transportation Research Board, 2016)).

From this observation, it seems that HOV enforcement may not be best accomplished by making the HOV lane violation the primary offense for which a law enforcement officer would stop a motorist. It may prove more effective to enforce speeding violations more aggressively in the HOV lane and to ticket the HOV lane violation as a secondary violation. While it is unproven whether the tendency to speed is coupled with the tendency to violate HOV lane regulations, it is clear that those who speed excessively also tend to have less respect for traffic regulations in general, and there may be a significant correlation between the two. Further, since it is more difficult for a law enforcement official to detect an HOV lane violation, enforcement of speed limits would limit the payoff for a driver who wants to use the HOV lane to speed and would decrease the incentive for violation of HOV lanes overall.

It may be the case that simply enforcing the speed limit in the HOV lane with automated enforcement technology may drop the violation rates significantly for HOV lanes. Presumably, by limiting the reward an HOV lane violator can expect to have from the violation, the likelihood of a driver choosing to violate the HOV lane restrictions may be significantly reduced. However, the importance of enforcing speeding laws is important for more than just controlling violation rates in the HOV lanes. Recalling that there is a correlation between driver aggressiveness and willingness to violate HOV lane restrictions, there are significant possibilities for improving public safety, as well as the possibility of improving operations by reducing the number of crashes on the corridor. Controlling the discrepancy between speeds in the HOV lane and mixed-flow lane reduces the chances of collisions between vehicles changing lanes and drivers in the HOV lane.

## 6.3 Air Quality Model Development

To capture the impact of travel speeds and volumes upon air quality, a modeling approach based upon the FREQ model, a model developed to estimate emissions for various components of air pollution by the State of California Air Resources Board Emissions Inventory Section (ARB-EIS) (Maldonado, 1991), was implemented. The FREQ freeway simulation model includes the prediction of air quality as well as traffic performance. The air quality predictions include hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen ($NO_x$) as a function of predicted traffic intensity and performance, vehicle fleet year, ambient temperature, and vehicle classification. The air quality predictions are made for each section of the freeway and for each time interval based on traffic performance predictions and aggregated for the entire freeway study section over the study duration. FREQ is a macroscopic freeway simulation model that is based on a supply-demand framework. It analyzes traffic performance over the length of a directional study area and for a given length of time. The freeway study area is divided into subsections with subsection boundaries being established at any location where there is a change in demand (on-ramp and off-ramps) and /or a change in capacity (e.g., lane drops/adds, significant changes in grade). The simulation time is comprised of up to twenty-four equal-length time slices.

In 1991 a UC Berkeley research project sponsored by FHWA and Caltrans was conducted to improve the emission estimates in the FREQ model as described in FREQ10 Modification: Emission Factors, Gasoline Consumption, and Growth Factors (Ostrom, et al, 2001). In consultation with Caltrans and the State of California ARB-EIS, a set of twelve emission rate tables were developed and incorporated into FREQ. The emission rates for HC, CO, and $NO_x$ were provided by ARB-EIS from their EMFAC7E computer model, which is described in Methodology to Calculate Emission Factors for On-Road Motor Vehicles, for seven distinct years (1990 through 2020 in five-year increments) and four temperatures (55, 65, 85, or 95 degrees Fahrenheit). In this task, we will use the data tables from the FREQ10 model to determine vehicle emissions as a function of flow, average speed, and traffic mix. Emissions rates based on FREQ10 can be found in a very simple lookup form in May, et al (2007) given the speed of vehicles in a segment, allowing for easy computation of emissions on a roadway segment if the average speed of vehicles on the highway is known.

Analysis of the emissions tables has shown that sixth-degree polynomials could faithfully reproduce emissions rates provided in May, et al. (2007), but would be mathematically smoothed functions for use in optimization studies. The data underlying the development of the air quality model is presented in Appendix B of this report. In every case, the models fit the data extremely well, with very smooth curves and R-square values at or very near unity. Selected regression analysis results (slopes and $R^2$ values) are shown for the air quality models used in this project are found in Appendix C of this report.

Example curves are shown in Figure 6-8 through Figure 6-11, and a complete set of curves for the 2020 vehicular fleet compositions for every combination of pollutant class (total hydrocarbons, carbon monoxide, and nitrogen oxides), every vehicle class (automobile, gas truck, and diesel truck), and each temperature (55 F, 65 F, 75 F, and 85 F) are presented in Appendix D. Most curves have shapes similar to those in Figure 6-8 through Figure 6-10, though a few are monotonically decreasing or increasing. Such a curve is shown in Figure 6-11. However, it is important to note that since the minima happen at different speeds, and some curves are monotonically decreasing, decreasing average speeds from the speed limit does not necessarily imply that all air pollution constituents will decrease accordingly.

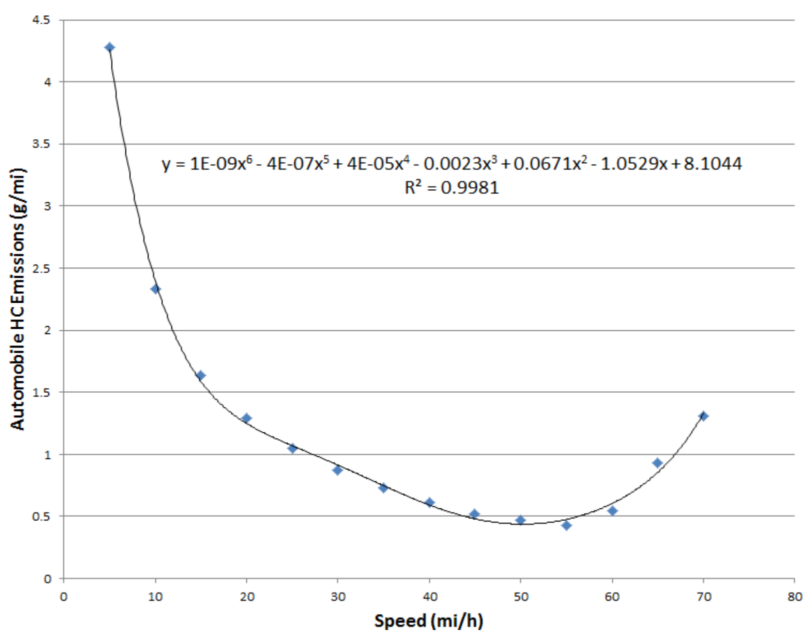



Figure 6-8 Automobile hydrocarbon emissions vs. vehicle speed

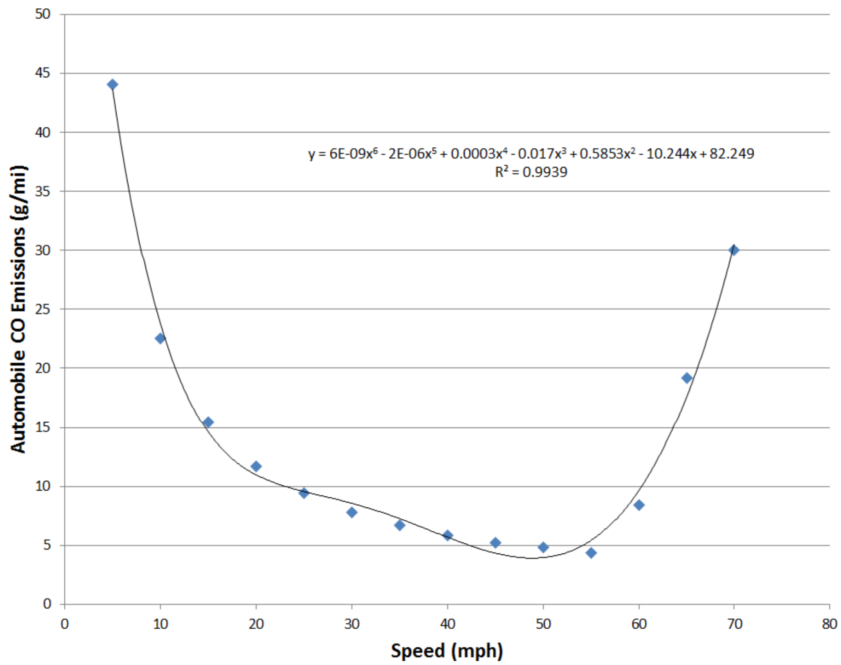



Figure 6-9 Automobile carbon monoxide emissions vs. vehicle speed

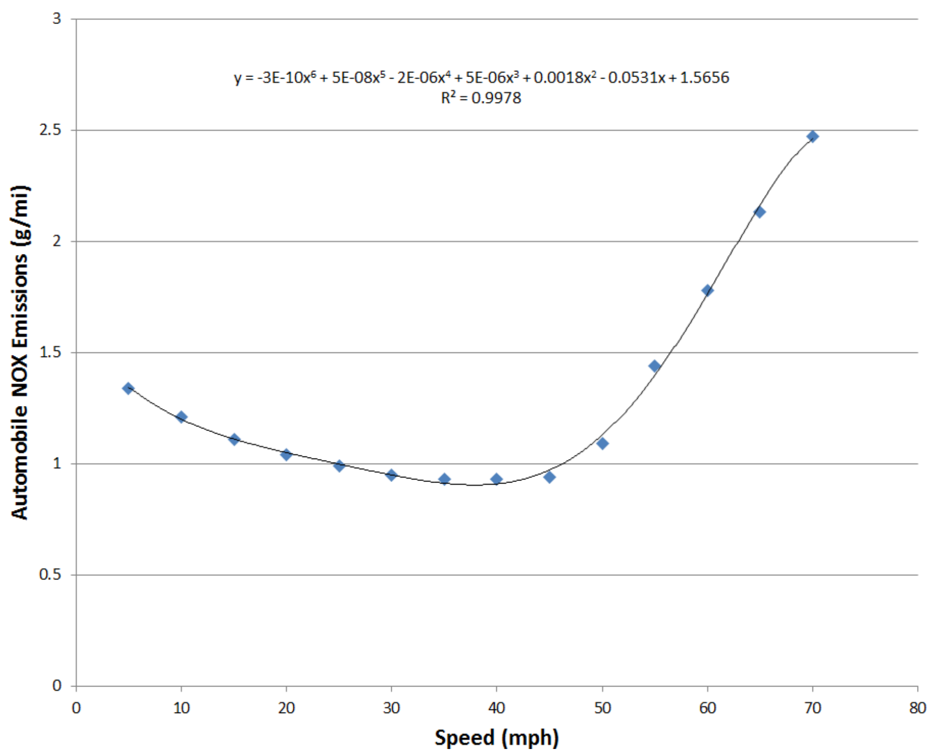



Figure 6-10 Automobile nitrogen oxide emissions vs. vehicle speed

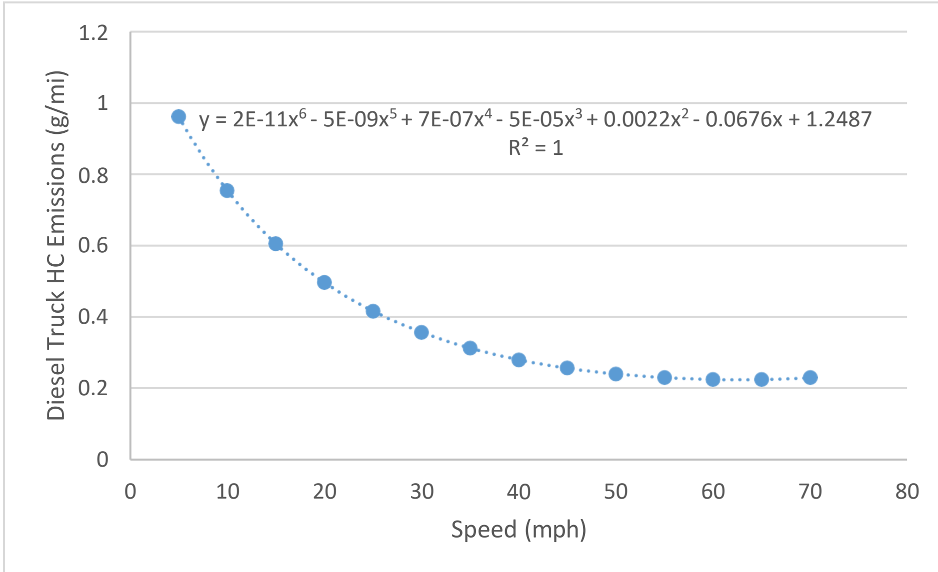



Figure 6-11 Monotonically decreasing emissions curve

## 6.4 Stochastic User Equilibrium Modeling for Basic Segments

In this section, we will break the HOV corridors into a network of nodes and links, with the HOV lane and the General Purpose (GP) lanes modeled as two separate links between regularly spaced nodes along the corridor, consistent with the approach to network modeling proposed in section 6.1 of this report. In this section, we were interested only in comparative statics in the context of the performance of a basic freeway section, but later, nodes will be placed wherever there is a significant change in flow and at other intervals along the corridor as appropriate to develop corridor models upon the principles developed in this section. Stochastic User Equilibrium will be determined for the general case by the following mathematical programming problem to determine a vector of travel times $\boldsymbol{t}$ for each lane and a set of passenger flows $\boldsymbol{q}$ indexed by lane group $i$ and vehicle class $j$ (e.g., single occupancy, carpool, transit):

$$\min \sum_{i=1}^{N_{lanes}} \left(t_i - t_i(\boldsymbol{q})\right)^2 + \sum_{j=1}^{N_{classes}} \sum_{i=1}^{N_{lane\ groups}} \left(q_{ij} - q_{ij}(\boldsymbol{t})\right)^2 \tag{6-8}$$

$$w.r.t.\ \ \boldsymbol{t}, \boldsymbol{q}$$

$$where:$$

$$v_i = \sum_{j=1}^{N_{classes}} \frac{q_{ij}}{vehicle\ occupancy\ for\ class\ j} \quad \forall\, i\ \in I\ lanes \tag{6-9}$$

$$t_i = t_{0i} + a_i \left(\frac{v_i}{c_i}\right)^{b_i} \quad \forall\, i\ \in I\ lanes \tag{6-10}$$

$$q_{ij} = Q_j * P(lane\ group\ is\ chosen \mid \boldsymbol{t}, other\ discrete\ choice\ model\ inputs) \tag{6-11}$$

$$Q_j = Passenger\ Demand * P(class\ j\ is\ chosen \mid \boldsymbol{t}, class\ k\ attributes) \tag{6-12}$$

The objective function in Eq. (6-8) enforces consistency between the travel time decision variables $\boldsymbol{t}$ and the travel times $\boldsymbol{t}_i(\boldsymbol{q})$ predicted by facility performance functions, as well as consistency between the decision variable flows. Eq. (6-9) aggregates flow by vehicle class into link flows. Eq. (6-10) is the link performance function. Eqs. (6-11) and (6-12) are implemented by using the discrete choice models determined in section 6.1 to reflect mode choice behavior.

A spreadsheet has been written in Microsoft Excel to solve the mathematical programming problem formulated in Eqs. (6-8) - (6-12). The program is solved by assuming a mixed-flow travel time index and a total passenger flow. SOV and HOV vehicular flows are determined using the discrete choice models developed in section 6.1. Actual travel time indices are calculated for the mixed-flow and HOV lanes. The Excel solver is used to minimize the discrepancy between the assumed and actual travel time index for the mixed-flow lane.

A case study was done for a typical four lane interstate segment (three lanes plus HOV in the same direction) for demand flows ranging from 1000 passengers per hour to 9000 passengers per hour, assuming no enhancements to HOV lane enforcement are made. The results of the case study are shown in Figure 6-12 through Figure 6-15. These results are provided to give a degree of verification to assess the reasonableness of the overall equilibrium modeling approach.

Figure 6-12 provides a graph of the HOV and SOV splits in terms of vehicles per hour. An average HOV occupancy of 2.1 is assumed. Note that while the SOV volume displays a slight downward curve, the shape of the SOV plot is essentially linear. This indicates that the demand modeling process indicates that users are not swayed in terms of their mode choice by the difference in operating speeds that an HOV lane provides. This result is as expected from our previous demand modeling efforts. While mode share should change slightly as congestion increases, mode shares stay relatively fixed, and the results of the stochastic user equilibrium models are in agreement with this trend.

Figure 6-13 shows volume to capacity ratios for the mixed-flow and HOV lanes, as well as for the facility as a whole. The v/c ratio for the entire facility is calculated as the total number of vehicles divided by the capacity of all lanes. As expected, at lower volumes the HOV lane is perceived as an inferior mode of travel and carries a significantly lower mode share, often less than half of the volume of mixed-flow lanes. This corresponds to observed data shown in Figure 3-3, where the HOV lane carries less than half of the mixed-flow lane volume at lower levels of congestion. However, also per the data shown in Figure 3-3, the v/c ratios become closer across the HOV and mixed-flow lanes at higher levels of congestion.

Figure 6-14 and Figure 6-15 shows the composition of the traffic in the HOV lane as a function of the total volume on the segment. These figures indicate that violation rates of HOV lanes on lesser congested HOV corridors are near 60 percent and increase to well over 80 percent as congestion increases. These violation rates are very comparable with those observed in the Southern Traffic Systems study.

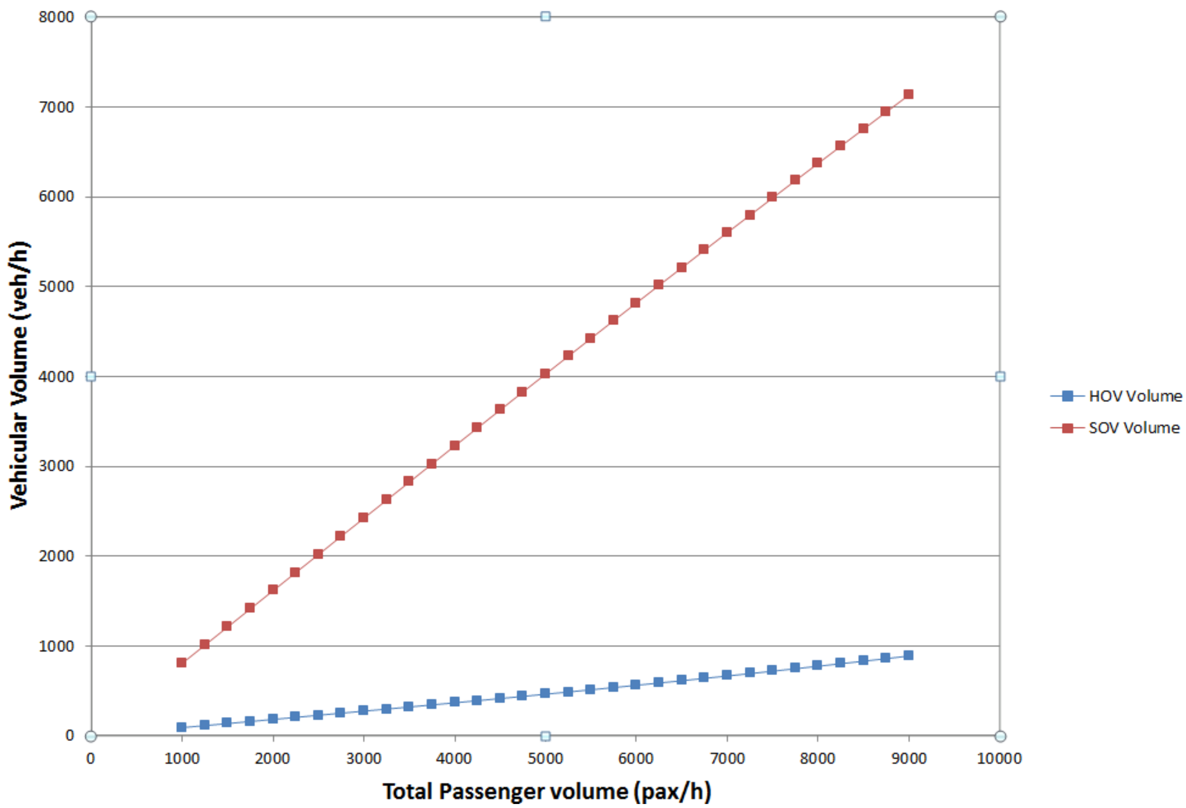



Figure 6-12 Equilibrium HOV and SOV mode splits as a function of total passenger demand

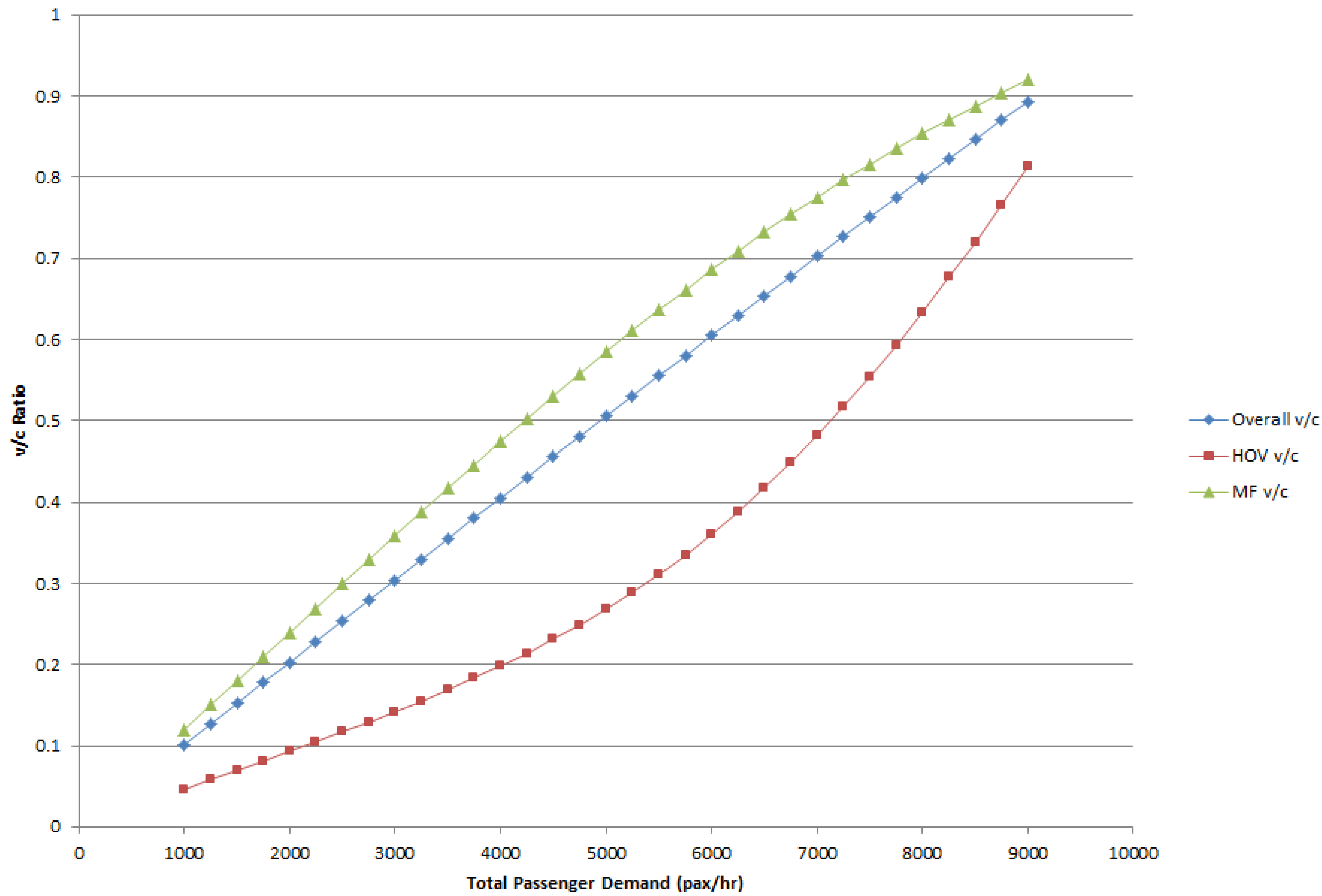



Figure 6-13 Equilibrium volume-to-capacity ratio for HOV, mixed-flow, and overall facility

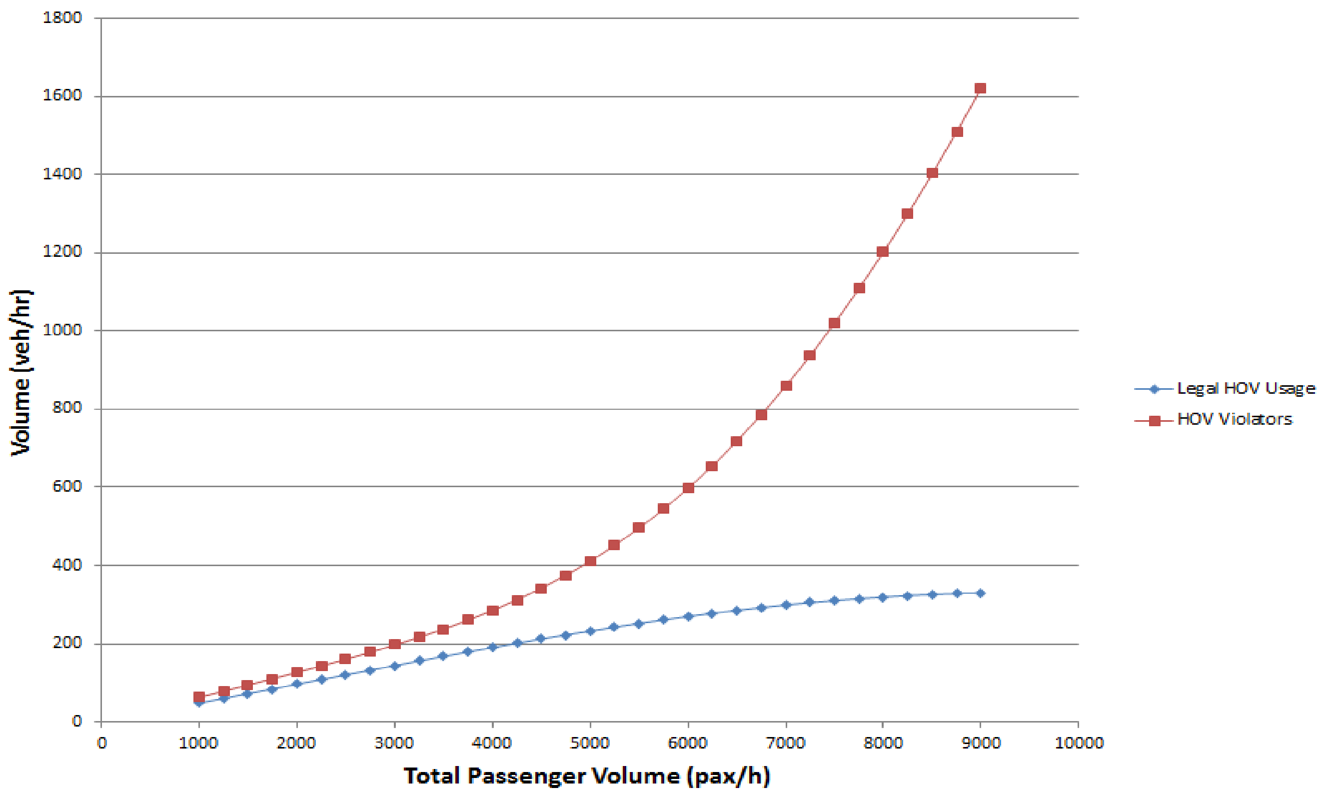



Figure 6-14 Equilibrium legal HOV lane users and HOV lane violators vs. total passenger volume

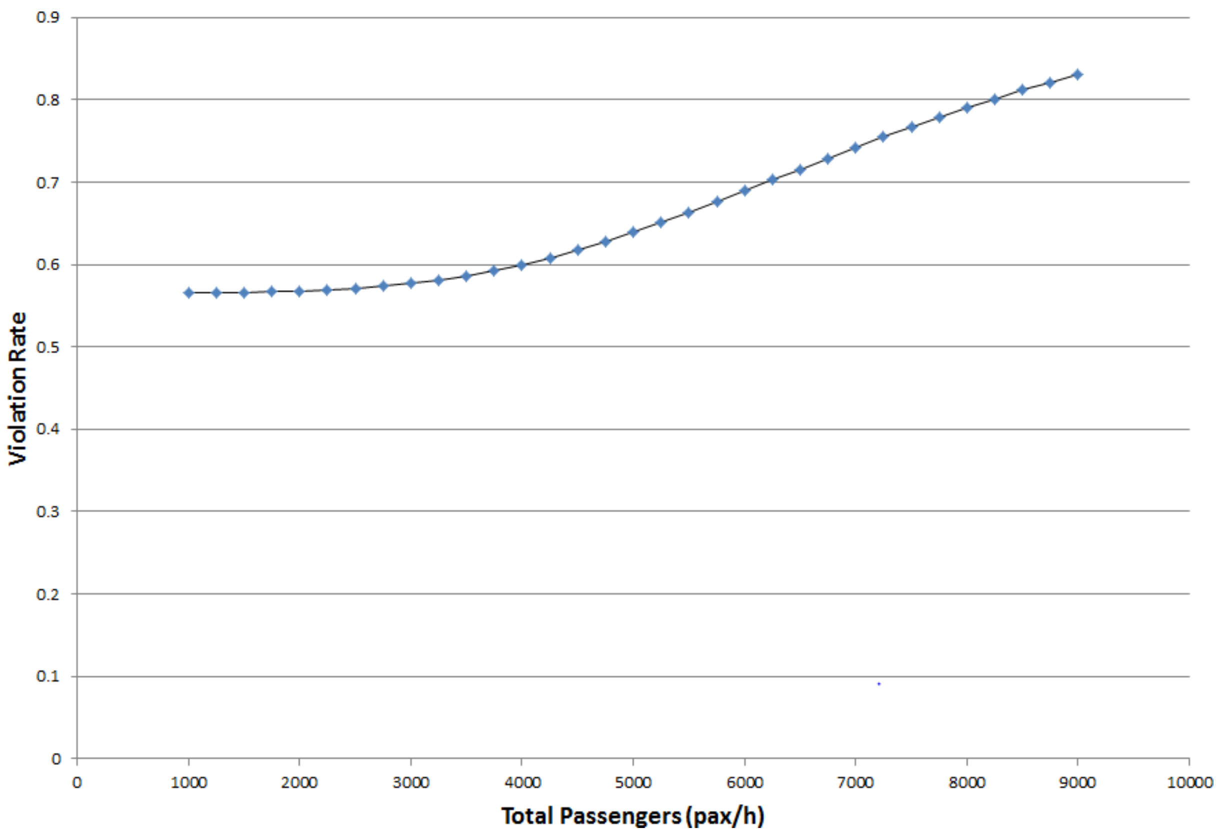



Figure 6-15 Equilibrium violation rates vs. total passenger volume

Figure 6-16 through Figure 6-18 shows the total emissions for hydrocarbons, carbon monoxide, and nitrogen oxides in grams per mile per hour for the facility. These figures are included to illustrate how the stochastic user equilibrium model is applied to obtain results for analysis on the impacts of air quality. Note that the plot of total hydrocarbon emissions vs. total passenger demand in Figure 6-16 shows that air quality is often improved overall at higher demand levels if the congestion results in a more efficient operating speed than the free flow speed for most of the engines on the roadway. Figure 6-17 and Figure 6-18 show similar trends with carbon monoxide emissions and nitrogen oxide emissions, respectively, but with peak values at different magnitudes.

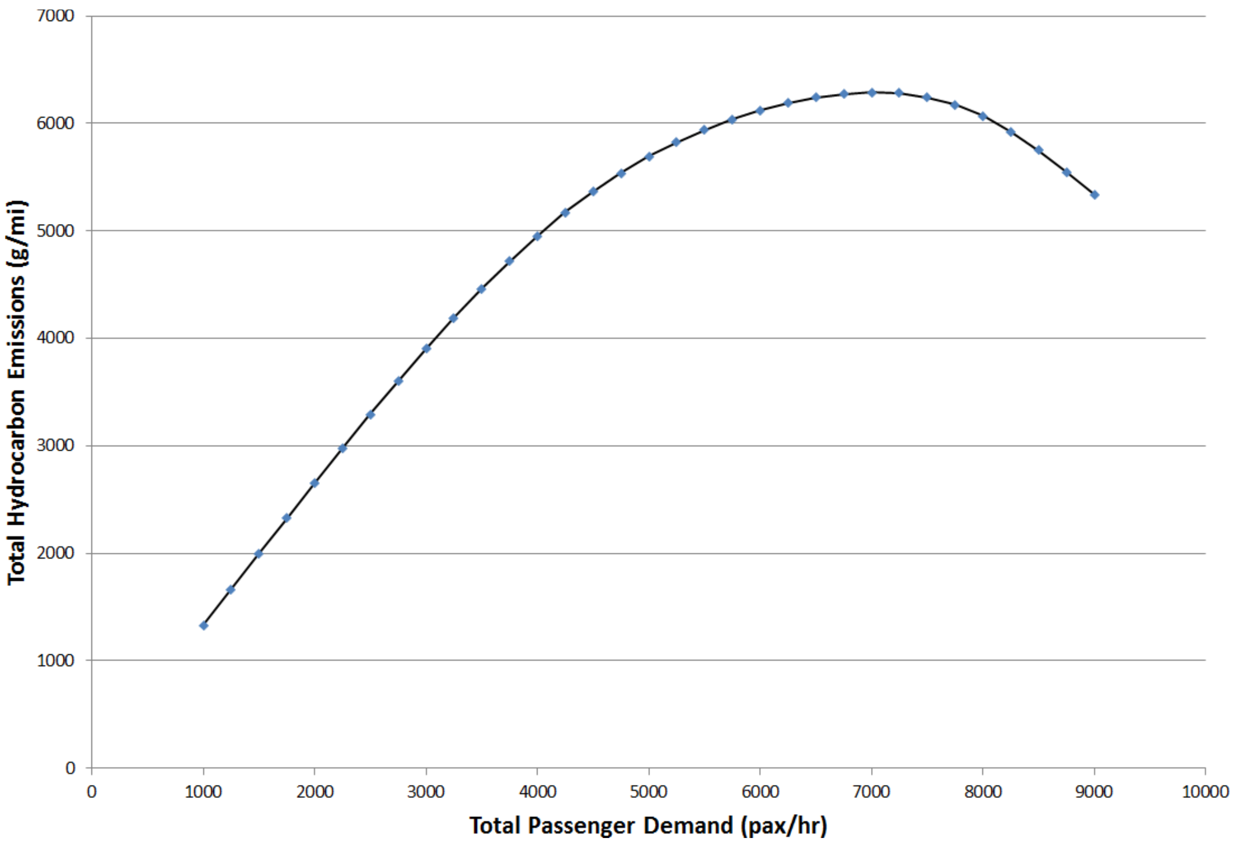



Figure 6-16 Total hourly hydrocarbon emissions vs total passenger demand

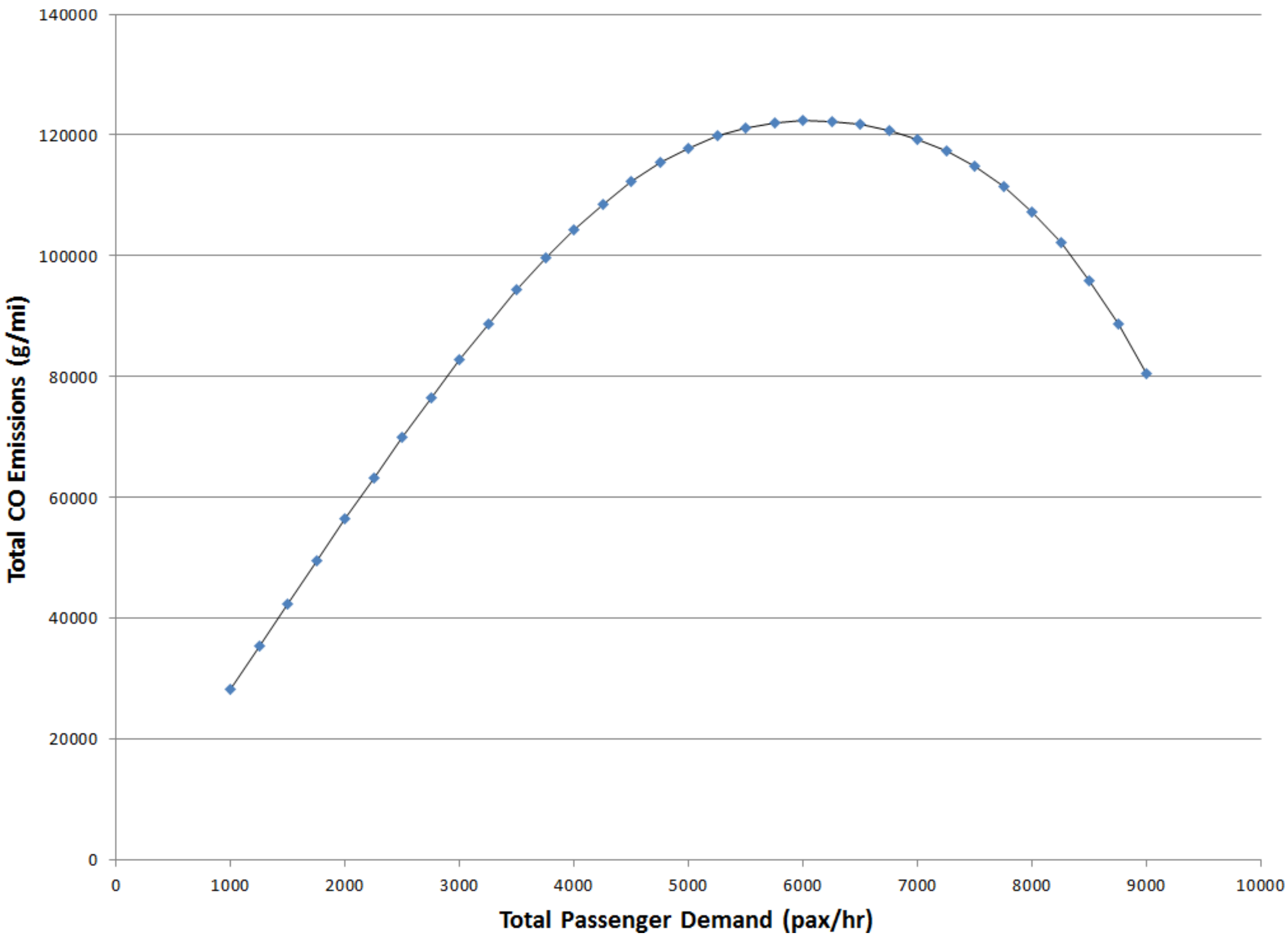



Figure 6-17 Total hourly carbon monoxide emissions vs. total passenger demand

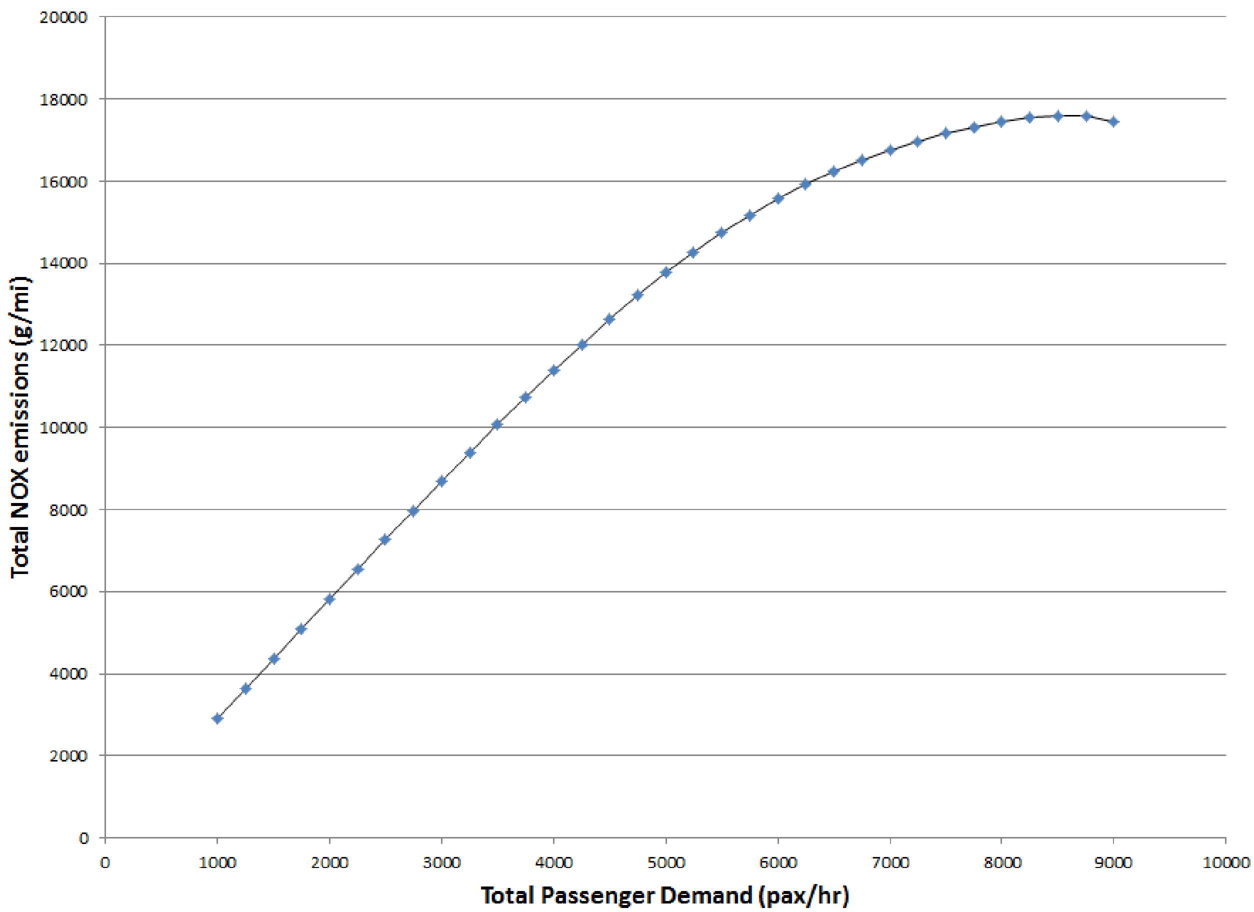



Figure 6-18 Total hourly nitrogen oxide emissions vs. total passenger demand

A modification was made to the Excel spreadsheet model to allow for the stochastic user equilibrium modeling approach to include the impacts of enhancements to law enforcement activities. In the computational model, it is assumed that a target violation rate is to be maintained through appropriate enforcement activities. As a result of enforcement activities, some willing violators under choice model estimation conditions would be deterred from entering the HOV lane. In the updated model, a variable was added to allow only fractional assignment of the SOV violator class to the HOV lane. Stochastic user equilibrium was imposed via use of the Excel Solver by varying the travel time index on the mixed-flow lanes as well as the fraction of violator class members who use the HOV lane, and solving for both of these parameters by (1) setting the assumed mixed-flow travel time index equal to computed mixed-flow travel time index, and (2) setting the computed violation rate equal to the target violation rate.

Results of a parametric sweep of target violation rates are shown in Figure 6-19. In particular, speeds on the HOV and mixed-flow lanes are plotted as a function of the HOV violation rate. From the plot of speeds as a function of violation rate, it can be seen that it is desirable for operational purposes for the violation rate to be more than 70 percent, no matter whether the single- occupancy vehicles are allowed to enter by toll, by driving an inherently low emission vehicle, or by violation of law.

According to the analysis shown in Figure 6-19, having a significant violation rate can be beneficial for all travelers. Under the present assumptions, there is no degradation of the HOV lane performance until there is a violation rate of approximately 70 percent. There are also likely practical benefits to having a significant violation rate. First, by having SOVs use the HOV lane, traffic moves out of more slowly moving mixed-flow lanes, improving their performance without degrading the HOV lane. Second, by moving out of the mixed-flow lane, the violators have made weaving near entrances and exits to the interstate significantly easier for drivers in the left-hand lane. This analysis may indicate that reversion of the HOV lane to a mixed-flow lane could be the best solution to the operational problems on the corridor, but a more detailed study on the operations of the freeway near bottlenecks should be done to evaluate the validity of the link performance functions, especially when demand nears or exceeds capacity.

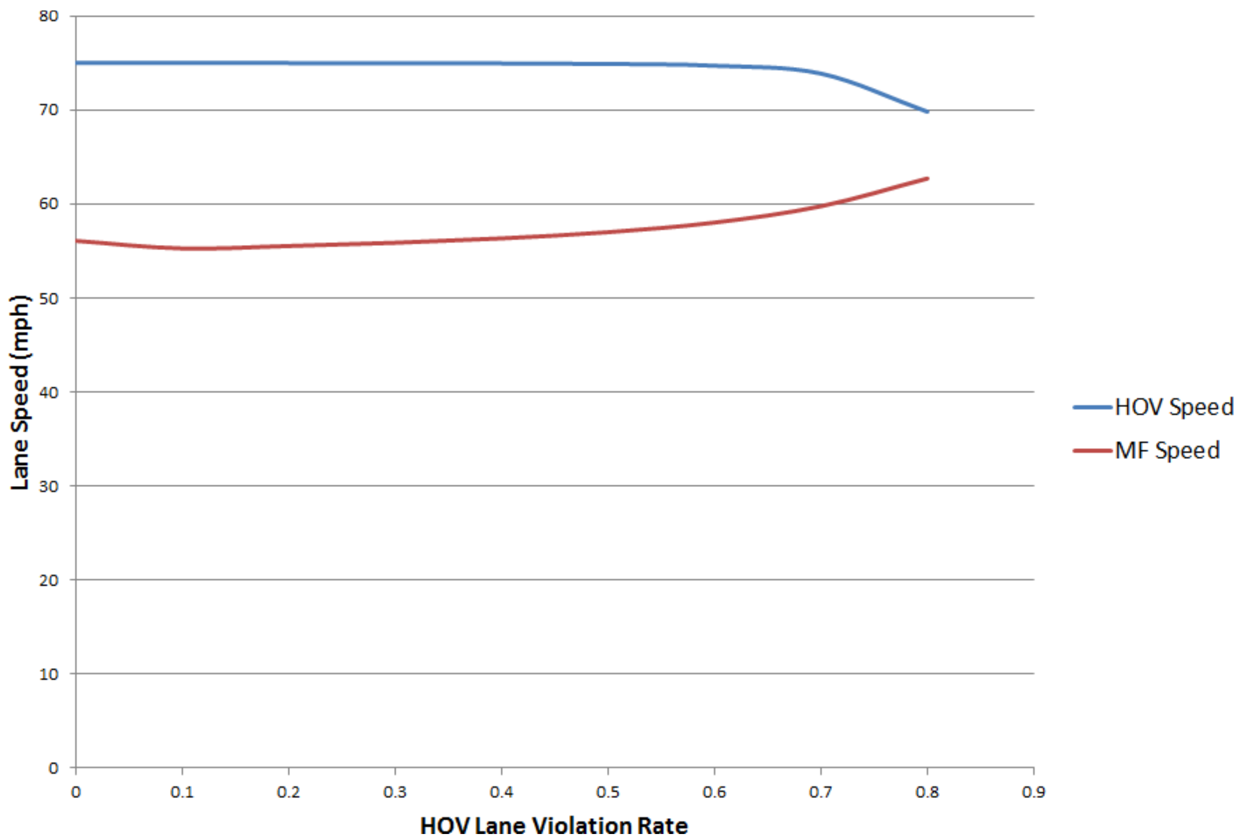



Figure 6-19 Projected average HOV and mixed-flow lane speeds vs. HOV lane violation rate

## 6.5 Verification and Validation of Equilibrium Modeling for Basic Sections

The purpose of this section is to verify and validate the predictions of the stochastic user equilibrium modeling effort and to discuss the merits and limitations of this approach. The discrete choice models, estimated based on counts of HOV and SOV in the HOV and mixed-flow lanes, were solved simultaneously with the performance functions at varying levels of passenger demand to determine equilibrium HOV and SOV flows in each lane and to determine the corresponding travel speeds. Though it seems counterintuitive that increasing proportions HOV's would choose not to use the HOV lane during highly congested times, equilibrium models solved over a range of total volumes of passengers yield results that closely match field data that indicates that the HOV lane is the last lane to fill with traffic volume.

Figure 6-20 shows the predicted volume of vehicles in the HOV lane as a function of total volume for a section with three mixed-flow lanes. Figure 6-21 shows the actual usage of the HOV lane as a function of total volume on a heavily traveled segment of eastbound I-24 at Sam Ridley Parkway with three mixed-flow lanes and an HOV lane. There is close agreement in the general trends of the data, with a strong upward concavity to the trendlines.

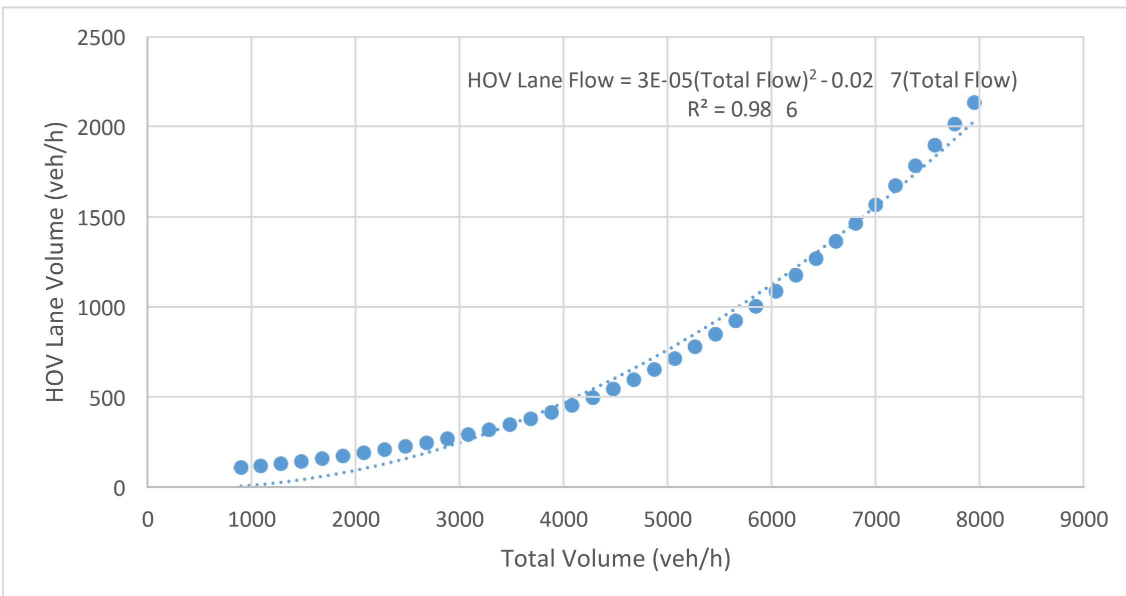



Figure 6-20 Predicted utilization of HOV lane as a function of the total volume

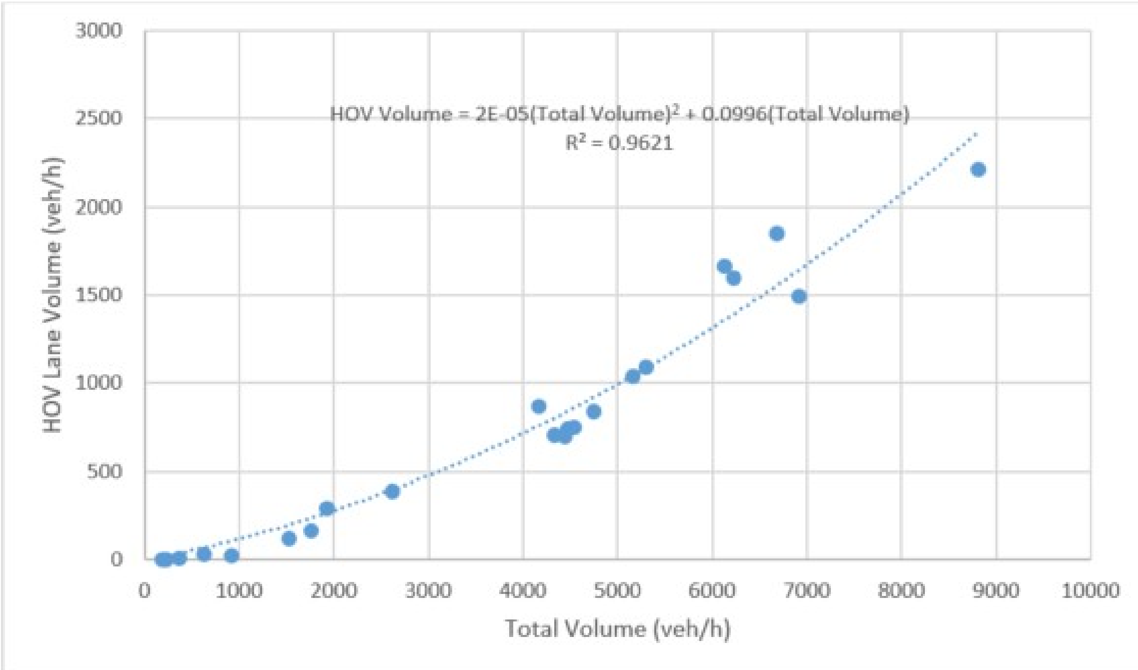



Figure 6-21 Actual utilization of HOV lane as a function of the total volume

Based on these predictions and the comparison with field data, it can be concluded that a relatively simple user equilibrium modeling approach can predict the lane choice preferences for the public in the aggregate with a reasonable degree of accuracy. While the reasons for HOVs avoiding the HOV lane at times of significant congestion in the mixed-flow lanes are not fully understood, the models estimated based on the Southern Traffic Systems study data have provided accurate predictions that match vehicle count data obtained by TDOT at a later time. Given the alignment between the predicted and observed HOV utilization, there is a good reason for confidence in the model for the operational regimes under which the models were estimated and for which the link performance models are valid.

*It should be noted that there are significant limitations to the extrapolation of the model beyond the conditions over which these models were developed. Should the demand exceed capacity, the BPR formulas are not necessarily accurate predictors for speeds on the freeway. Under this circumstance, it is also possible that traffic conditions in one lane may be impacted by conditions in adjacent lanes. For these reasons, more sophisticated models of freeway performance, such as the LWR PDE or traffic microsimulation should be used, and the use of these types of models can serve as an important verification for the results obtained from stochastic user equilibrium.*

As this comparison of predicted and actual lane flows for demand volumes significantly less than capacity has developed confidence in the model predictions, it can be concluded that as long as traffic can freely make lane changes, there is little social benefit to be gained from enforcing HOV restrictions when traffic volumes do not approach or exceed capacity. However, it may be difficult to draw any further inference at this point.

Chapter 7 will focus on the use of stochastic user equilibrium modeling for the I-65 corridor south on Nashville and the I-24 corridor. Chapter 8 will focus on the verification of stochastic user equilibrium modeling for the I-65 southbound corridor using the LWR PDE as a more accurate and detailed predictor of the evolution of speed and density over time on the freeway. Chapters 9-11 focus on the use of traffic microsimulation for verification and validation, as well as for the generation of operational level insights impossible to gain through the use of the stochastic user equilibrium approach taken in Chapters 6 and 7.

# Chapter 7 Stochastic User Equilibrium Analysis of HOV Corridors on I-65 South of Nashville and I-24

Chapter 7 extends the analytical work done in Chapter 6 to explore the implications of doing nothing, heavily enforcing the HOV lane restrictions (via toll measures or otherwise), and reverting the lane to a mixed-flow lane for the I-24 HOV corridor and the I-65 corridor south of Nashville. Analysis is performed under base year and future (design) year scenarios.

## 7.1 Model Implementation and Equations

### 7.1.1 User Inputs

The implementation of the model in Excel requires that the user specify certain inputs for analysis. These inputs include:

- A segment ID
- A segment length
- A truck fraction
- HOV and Mixed-Flow (MF) lane free-flow speeds
- HOV and MF capacities (Note that these are not the same as absolute maximum rates of flow a segment can sustain but represent calibration parameters in a vehicle delay function.)
- HOV average occupancy
- HOV and MF vehicular delay function parameters alpha and beta
- The number of mixed-flow lanes for the segment under consideration
- Target violation rates (if an enforcement study is to be performed with the spreadsheet).

For user convenience, the cells that require these inputs are shaded orange as shown in Figure 7-1. Note that the model is implementable for multiple segments simultaneously,

| | | | | |
|---|---|---|---|---|
| 1 | | | | |
| 2 | Segment ID | 1 | 2 | 3 |
| 3 | Segment Length | 0.28 | 3.27 | 1.333 |
| 4 | Truck Fraction | 0.07 | 0.07 | 0.07 |
| 5 | Fraction of Trucks that are Gas Trucks | 0.5 | 0.5 | 0.5 |
| 6 | HOV FFS | 75 | 75 | 75 |
| 7 | FFS | 70 | 70 | 70 |
| 8 | Total Pax | 14592.2205 | 14259.245 | 12732.7816 |
| 9 | HOV Capacity | 1857 | 1857 | 1857 |
| 10 | MF Capacity | 1722 | 1722 | 1722 |
| 11 | HOV alpha | 0.32 | 0.32 | 0.32 |
| 12 | HOV beta | 8.4 | 8.4 | 8.4 |
| 13 | MF alpha | 0.263 | 0.263 | 0.263 |
| 14 | MF beta | 6.869 | 6.869 | 6.869 |
| 15 | Assumed TTIMF | 3.378855069 | 2.901419157 | 2.111408911 |
| 16 | P(V\|S) | 0.999 | 1 | 0.820396776 |

Figure 7-1 Example stochastic user equilibrium model inputs

### 7.1.2 Solver Variables

In addition to the user-defined inputs, there are also variables that the user must manipulate, either manually or through the Excel Solver. These include the assumed travel time index for the mixed-flow lanes and the percentage of willing violators who can use the HOV lane. Cells where the Solver is able to manipulate inputs are highlighted in a soft yellow color as shown in Figure 7-1.

### 7.1.3 User Choice Modeling and Vehicle Volume Calculations

Figure 7-2 shows the implementation of user choice modeling. In rows 16-19 of the spreadsheet, choice models are implemented to determine the probability of a user choosing a single-occupancy vehicle (SOV) or a high occupancy vehicle (HOV). The analysis is based on the following Excel equations:

$$P(HOV) = MEDIAN(0.001, 0.999, -0.59051 + 0.69418 * Assumed\ TTIMF) \quad (7\text{-}1)$$

$$P(SOV) = 1 - P(HOV) \quad (7\text{-}2)$$

Choice models for determining the probability that an SOV user is a willing violator, P(V|S), and the probability that an HOV uses the HOV lane, P(H|H) are implemented via the following formulas:

$$P(V|S) = MEDIAN(0.001, 0.999, 0.124419 + 0.067754 * Assumed\ TTIMF) \quad (7\text{-}3)$$

$$P(H|H) = MEDIAN(0.001,\ 0.999,\ 1.2215 - 0.69418 * Assumed\ TTIMF) \quad (7\text{-}4)$$

By bounding the P(V|S) and P(H|H) functions to fall between 0.001 and 0.999, many convergence difficulties are resolved within the spreadsheet model. With the user choices defined using Eqs. (7-1) - (7-4), traffic can be assigned to HOV and MF lanes in the segment using the following equations:

$$HOV\ Pax\ Flow\ Rate\ = Total\ Pax * P(HOV) \quad (7\text{-}5)$$

$$HOV\ Vehicular\ Flow\ Rate = \frac{HOV\ Pax\ Flow\ Rate}{HOV\ Occupancy} \quad (7\text{-}6)$$

$$HOV\ Volume\ in\ HOV\ Lane\ = HOV\ Vehicular\ Flow\ Rate * P(H|H) \quad (7\text{-}7)$$

$$SOV\ Volume\ = Total\ Pax * P(SOV) \quad (7\text{-}8)$$

$$SOV\ Violators\ = SOV\ Volume * P(V|S) \quad (7\text{-}9)$$

$$SOV\ Violators\ in\ HOV\ = SOV\ Violators * \%\ SOV\ Violators\ in\ HOV \quad (7\text{-}10)$$

$$SOV\ Violators\ in\ MF\ = SOV\ Violators - SOV\ Violators\ in\ HOV \quad (7\text{-}11)$$

$$SOV\ in\ MF\ = SOV\ Volume - SOV\ Violators\ in\ HOV \quad (7\text{-}12)$$

$$MF\ Vehicular\ Flow\ Rate = $$
$$SOV\ Volume\ in\ MF + HOV\ Vehicular\ FLow\ Rate - HOV\ Volume\ in\ HOV\ Lane \quad (7\text{-}13)$$

$$MF\ Lane\ Flow = \frac{MF\ Vehicular\ Flow\ \ Rate}{Number\ of\ Mixed\ Flow\ Lanes} \quad (7\text{-}14)$$

$$HOV\ Lane\ Flow\ = HOV\ Volume\ in\ HOV +\ SOV\ Violators\ in\ HOV \quad (7\text{-}15)$$

| | | |
|---|---|---|
| 15 | Assumed TTIMF | 3.378855069 |
| 16 | P(V\|S) | 0.999 |
| 17 | P(HOV) | 0.353349946 |
| 18 | P(SOV) | 0.646650054 |
| 19 | P(H\|H) | 0.001 |
| 20 | HOV Occupancy | 2.1 |
| 21 | HOV Pax Flow Rate | 5156.16033 |
| 22 | HOV Vehicle Flow Rate | 2455.314443 |
| 23 | HOV Volume in HOV Lane | 2.455314443 |
| 24 | SOV Volume | 9436.06017 |
| 25 | SOV Violators | 9426.62411 |
| 26 | Percent SOV Violators in HOV | 0.254343427 |
| 27 | SOV Violators in HOV | 2397.599883 |
| 28 | SOV Violators in MF | 7029.024227 |
| 29 | SOV in Mixed Flow | 7038.460287 |
| 30 | Mixed Flow Vehicular Flow Rate | 9491.319416 |
| 31 | Mixed Flow Lanes | 4 |
| 32 | Mixed Flow Lane Vehicular Flow Rate | 2372.829854 |

Figure 7-2 User choice modeling and traffic assignment in stochastic user equilibrium model

As shown in Figure 7-2, the majority of calculation cells involving intermediate calculations are shown with a grey background and orange font. However, since the HOV and MF lane flows are critical outputs, these flows are given a blue background to make them easily identifiable.

### 7.1.4 Link Performance Modeling

After determining the lane flow rates, vehicle delay functions based upon a calibrated form of the Bureau of Public Roads vehicular delay functions by Mtoi and Moses (2014) were selected for performance modeling. The functions estimated in Mtoi and Moses (2014) were based upon a very large dataset collected by the Florida Department of Transportation, including data points which were collected under operational conditions at or near the maximal discharge capacity of the highway segments. Further Mtoi and Moses fit a wide variety of functional forms and found the best agreement with a modified BPR functional form. For these reasons, the vehicular delay functions used give us travel speeds as a function of volume to capacity ratio $x$ for the MF lane as

$$V_{HOV} = \frac{V_{f,HOV}}{1+\alpha_{HOV}(x)^{\beta_{HOV}}} \tag{7-16}$$

$$V_{MF} = \frac{V_{f,MF}}{1+\alpha_{MF}(x)^{\beta_{MF}}} \tag{7-17}$$

Based on the results of Mtoi and Moses (2014) we used parameters for α of 0.320 and 0.263 for the HOV and MF lanes, respectively. We used β as 8.4 and 6.89 for the HOV and MF lanes, respectively. The capacity estimates of 1857 and 1722 vehicles per hour per lane for the HOV and MF lanes show very good agreement with the data obtained by TDOT on the I-24 and I-65 HOV corridors, and as nominal capacities for the BPR formula. Based on data obtained from TDOT in the I-65 and I-24 HOV corridors, free-flow speeds of 75 mph for the HOV lane and 70 for the MF lane were used. As these are very important outputs, the cells are shown in Figure 7-3 with a green background. Travel time indices are computed using the formula

$$TTI = \frac{V_f}{V} \tag{7-18}$$

Where $V_f$ is the free-flow speed and $V$ is the actual speed of traffic flow.

A violation rate is computed for the section using the formula

$$Violation\ Rate = \frac{SOV\ Violators\ in\ HOV}{HOV\ Lane\ Flow} \tag{7-19}$$

As violation rates are a primary motivator for this study, the violation rate cell has a pink background as shown in Figure 7-3.

Equilibrium analysis requires that the travel time assumptions and actual travel times agree when the solution algorithm selected for the problem comes to convergence. This consistency is achieved at convergence by minimizing the squared residuals between the assumed and actual MF travel time index. Row 41 computes the squared difference in the mixed-flow travel time indices. Likewise, an enforcement study considers the impacts of reducing violation rates. In performing such a study, it is necessary to add a violation rate constraint when determining equilibrium flows. This is done by specifying a target violation rate and calculating the squared residual for the violation rate. The residual is calculated as the square of the difference between the calculated and target violation rates. Analyses for multiple segments can be solved together by minimizing the sum of squared residuals for the TTI, the violation rate, or the sum of all squared residuals. As shown in Figure 7-3, residuals are presented with black font on a gray background.

A variety of other outputs for analysis of the sections are given with several volume to capacity ratios. In these ratios, it is assumed that capacity is reached at a maximal discharge of 2400 vehicles per hour per lane. The following equations are implemented in rows 42 through 46:

$$Total\ Flow\ in\ All\ Lanes\ = Total\ SOV\ Volume + Total\ HOV\ Volume \tag{7-20}$$

$$Total\ Capacity = 2400 * Total\ Number\ \ of\ Lanes \tag{7-21}$$

$$Overall\frac{v}{c} = \frac{Total\ Flow\ in\ All Lanes}{Total\ Capacity} \tag{7-22}$$

$$HOV\frac{v}{c} = \frac{HOV\ Lane\ Flow}{2400} \tag{7-23}$$

$$MF\frac{v}{c} = \frac{MF\ Lane\ Flow}{2400} \tag{7-24}$$

These equations are useful in giving the analyst some insight to which flow is oversaturated. It should also be noted that these ratios can exceed unity in the implementation of the spreadsheet. However, if they do exceed unity it is certain that a bottleneck has activated and that traffic is moving in a queued state.

| | | |
|---|---|---|
| 32 | Mixed Flow Lane Vehicular Flow Rate | 2372.829854 |
| 33 | Mixed Flow Average Speed | 20.71767 |
| 34 | Mixed Flow TTI | 3.378758326 |
| 35 | HOV Lane Flow | 2400.055197 |
| 36 | HOV Lane Speed | 19.94413728 |
| 37 | HOV Lane Violation Rate | 0.998976976 |
| 38 | Target Violation Rate | 0 |
| 39 | SSResid VR | 0.997954998 |
| 40 | HOV Lane TTI | 3.760503599 |
| 41 | SSResid TTI | 9.35915E-09 |
| 42 | Total Vehicles in All Lanes | 11891.37461 |
| 43 | Total Capacity | 12000 |
| 44 | Overall v/c | 0.990947884 |
| 45 | HOV v/c | 1.000022999 |
| 46 | MF v/c | 0.988679106 |

Figure 7-3 Link performance modeling and metrics in stochastic user equilibrium model

The delay for both the HOV lane and the MF lanes are calculated using the following equations:

$$Free\ Flow\ Trip\ Time\ (\text{minutes}) = \frac{Segment\ Length\ (mi)*60}{Free\ Flow\ Speed\ (mph)} \tag{7-25}$$

$$Trip\ Time\ (\text{minutes}) = \frac{Segment\ Length\ (mi)*60}{Travel\ Speed\ (mph)} \tag{7-26}$$

$$Delay\ Per\ Vehicle\ = Trip\ Time - Free\ Flow\ Trip\ Time \tag{7-27}$$

$$Total\ Delay\ \left(\frac{veh*min}{hr}\right) = Delay\ Per\ Vehicle\ (\text{minutes}) * Flow\ \left(\frac{veh}{hr}\right) \tag{7-28}$$

These equations are implemented in rows 52-59 of the spreadsheet. As these are highly important outputs they are placed in bright yellow cells with black font, as shown in Figure 7-4.

| | | |
|---|---|---|
| 52 | HOV FFTT (min) | 0.224 |
| 53 | HOV TT (min) | 0.842352806 |
| 54 | HOV Delay Per Vehicle (min) | 0.618352806 |
| 55 | HOV Total Delay (veh-min/hr) | 1484.080866 |
| 56 | MF FFTT (min) | 0.24 |
| 57 | MF TT (min) | 0.810901998 |
| 58 | MF Delay Per Vehicle (min) | 0.570901998 |
| 59 | MF Total Delay (veh-min/hr) | 5418.61322 |

Figure 7-4 Delay computation in stochastic user equilibrium model

### 7.1.5 Air Quality Model Implementation

Air Quality model implementation requires the calculation of automobiles in the mixed-flow lanes and the HOV lane, as well as the number of gas and diesel trucks. These values are computed based on the vehicular flows determined from the process of solving demand models and user equilibrium models simultaneously, along with the use of the truck fraction as well as the percentage of trucks that are gas trucks. It is assumed that there are no trucks in the HOV lane. These values are calculated by the spreadsheet and stored in rows 47 through 51 as shown in Figure 7-5.

| | | |
|---|---|---|
| 46 | MF v/c | 0.988679106 |
| 47 | Total Autos | 11058.97839 |
| 48 | Total Trucks | 832.3962229 |
| 49 | Total Gas Trucks | 416.1981114 |
| 50 | Total Diesel Trucks | 416.1981114 |
| 51 | Autos in MF | 8658.923193 |
| 52 | HOV FFTT (min) | 0.224 |

Figure 7-5 Traffic volume computations to support air quality model

As all pollution models require evaluation of a sixth-degree polynomial in the speed of the vehicle, an intercept and coefficients for all six powers of the speed are computed in rows 62 through 68 in the spreadsheet as shown in Figure 7-6. Note that one is used for the intercept, since the SUMPRODUCT function will be used to evaluate the polynomial.

| | | |
|---|---|---|
| 61 | HOV V. | |
| 62 | Int | 1 |
| 63 | v | 19.94413728 |
| 64 | v^2 | 397.7686116 |
| 65 | v^3 | 7933.151794 |
| 66 | v^4 | 158219.8684 |
| 67 | v^5 | 3155558.775 |
| 68 | v^6 | 62934897.39 |

Figure 7-6 Velocity computations to support air quality model

The coefficients required to estimate each pollutant in each month are stored in a table in the spreadsheet as shown in Figure 7-7 to provide the other vector to be used as an argument to the SUMPRODUCT function.

EMISSIONS MODEL COEFFICIENTS

| X | Y | Z | AA | AB | AC | AD | AE |
|---|---|---|---|---|---|---|---|
| | Multiplier | Total Hydrocarbons | | | Carbon Monoxide | | |
| | | Autos | Gas Trucks | Diesel Trucks | Autos | Gas trucks | Diesel Tr |
| January | Intercept | 6.087E-01 | 1.334E+00 | 1.249E+00 | 2.790E+00 | 6.938E+00 | 6.843E- |
| | v | -5.029E-02 | -1.154E-01 | -6.761E-02 | -8.338E-02 | -4.079E-01 | -5.609E |
| | $v^2$ | 2.137E-03 | 5.132E-03 | 2.238E-03 | 1.991E-03 | 1.633E-02 | 2.506E- |
| | $v^3$ | -5.062E-05 | -1.306E-04 | -4.835E-05 | -3.311E-05 | -4.033E-04 | -6.713E |
| | $v^4$ | 6.583E-07 | 1.888E-06 | 6.720E-07 | 3.518E-07 | 5.868E-06 | 1.076E- |
| | $v^5$ | -4.117E-09 | -1.403E-08 | -5.319E-09 | -2.147E-09 | -4.529E-08 | -9.396E |
| | $v^6$ | 8.820E-12 | 4.088E-11 | 1.818E-11 | 9.274E-12 | 1.469E-10 | 3.462E- |
| February | Intercept | 6.087E-01 | 1.334E+00 | 1.249E+00 | 2.790E+00 | 6.938E+00 | 6.843E- |
| | v | -5.029E-02 | -1.154E-01 | -6.761E-02 | -8.338E-02 | -4.079E-01 | -5.609E |
| | $v^2$ | 2.137E-03 | 5.132E-03 | 2.238E-03 | 1.991E-03 | 1.633E-02 | 2.506E- |
| | $v^3$ | -5.062E-05 | -1.306E-04 | -4.835E-05 | -3.311E-05 | -4.033E-04 | -6.713E |
| | $v^4$ | 6.583E-07 | 1.888E-06 | 6.720E-07 | 3.518E-07 | 5.868E-06 | 1.076E- |
| | $v^5$ | -4.117E-09 | -1.403E-08 | -5.319E-09 | -2.147E-09 | -4.529E-08 | -9.396E |
| | $v^6$ | 8.820E-12 | 4.088E-11 | 1.818E-11 | 9.274E-12 | 1.469E-10 | 3.462E- |
| March | Intercept | 6.157E-01 | 1.353E+00 | 1.249E+00 | 2.747E+00 | 6.989E+00 | 6.843E- |
| | v | -5.136E-02 | -1.168E-01 | -6.761E-02 | -8.120E-02 | -4.150E-01 | -5.609E |
| | $v^2$ | 2.195E-03 | 5.169E-03 | 2.238E-03 | 1.928E-03 | 1.679E-02 | 2.506E- |
| | $v^3$ | -5.205E-05 | -1.307E-04 | -4.835E-05 | -3.248E-05 | -4.209E-04 | -6.713E |
| | $v^4$ | 6.727E-07 | 1.871E-06 | 6.720E-07 | 3.567E-07 | 6.254E-06 | 1.076E- |
| | $v^5$ | -4.131E-09 | -1.374E-08 | -5.319E-09 | -2.282E-09 | -4.970E-08 | -9.396E |

Figure 7-7 Emissions model coefficients

Evaluation of the air quality model begins with finding the pollution rates for automobiles in the HOV lane, automobiles in the mixed-flow lanes, gas trucks, and diesel trucks, respectively. This is done in rows 70 through 245 in the spreadsheet, with an example section shown in Figure 7-8.

| | | | |
|---|---|---|---|
| 232 | | | |
| 233 | **MFL Diesel Truck ON** | | |
| 234 | (1)January | 1.661009796 | 1.414 |
| 235 | (2)February | 1.661009796 | 1.414 |
| 236 | (3)March | 1.661009796 | 1.414 |
| 237 | (4)April | 1.661009796 | 1.414 |
| 238 | (5)May | 1.661009796 | 1.414 |
| 239 | (6)June | 1.661009796 | 1.414 |
| 240 | (7)July | 1.661009796 | 1.414 |
| 241 | (8)August | 1.661009796 | 1.414 |
| 242 | (9)September | 1.661009796 | 1.414 |
| 243 | (10)October | 1.661009796 | 1.414 |
| 244 | (11)November | 1.661009796 | 1.414 |
| 245 | (12)December | 1.661009796 | 1.414 |
| 246 | | | |

Figure 7-8 Emissions rate computations

Once the vehicle outputs are computed, they are aggregated into a peak hour monthly total for determination of the annual pollution contributed from the peak hour's traffic operations in rows 247-428 using the formula

$$Peak\ Hour\ Total\ Pollution = Rate * Traffic\ Volume * Segment\ Length \quad (7\text{-}29)$$

The monthly peak hour total pollution values are averaged in rows 430-438 as shown in Figure 7-9.

| | | | |
|---|---|---|---|
| 429 | **Hydrocarbon Summary** | | |
| 430 | Total HOV Auto | 107.5239395 | |
| 431 | Total MFL Autu | 372.6791289 | |
| 432 | Total Gas Truck | 36.05095113 | |
| 433 | Total Diesel Truck | 56.3334234 | |
| 434 | **Total HC Emissions** | **572.5874429** | |
| 435 | | | |
| 436 | **Carbon Monoxide Summary** | | |
| 437 | Total HOV Auto | 1348.51907 | |
| 438 | Total MFL Autu | 4792.020321 | |
| 439 | Total Gas Truck | 378.3400727 | |
| 440 | Total Diesel Truck | 193.5665593 | |
| 441 | **Total CO Emissions** | **6712.446022** | |
| 442 | | | |
| 443 | **Nox Summary** | | |
| 444 | Total HOV Auto | 99.16942889 | |
| 445 | Total MFL Autu | 352.676675 | |
| 446 | Total Gas Truck | 42.73200562 | |
| 447 | Total Diesel Truck | 193.5665593 | |
| 448 | **Total Nox Emissions** | **688.1446688** | |
| 449 | | | |
| 450 | | | |

Figure 7-9 Summary of annual average peak hour emissions for individual sections

### 7.1.6 Batch Analysis Features

In our spreadsheet, calculations for a single segment are performed in a single column of the spreadsheet. This is advantageous as the column can be copied and multiple segments can be analyzed in the same sheet. The squared residuals can be added across all segments for the TTI and violation rate. Combining both squared residuals into an overall sum of squared residuals to be minimized allows for the computation of stochastic user equilibrium subject to constraints on violation rate. In spreadsheets organized to solve for equilibrium over the I-24 and I-65 HOV Corridors, the residuals are summed and used as optimization objectives as shown in Figure 7-10. For convenience, the residuals are placed near the top of the spreadsheet.

| P | Q | R | S | |
|---|---|---|---|---|
| | | | | |
| 15 | | OPTIMIZATION RESIDUALS | | |
| 2.85 | | | | |
| 0.07 | | SSResid TTI | | |
| 0.5 | | 6.26739E-05 | | Total HOV |
| 75 | | SSResid VR | | Total MFL |
| 70 | | 90.33983603 | | Total Gas |
| 14592.2205 | | Total SSR | | Total Dies |
| 1857 | | 90.33989871 | | **Total HC Er** |
| 1722 | | | | |
| 0.32 | | | | |
| 8.4 | | | | Total HOV |
| 0.263 | | | | Total MFL |

Figure 7-10 Sum of squared residuals for use in batch equilibrium analysis

A results summary for the entire analysis is provided in the spreadsheet to account for the most important delay and emissions results. This is shown in Figure 7-11. In this summary the emissions results are presented as annual average peak hour emissions levels in grams per hour. Trip times across the entire corridor are computed, and delay is computed for all vehicles on the entire corridor. Vehicle-miles of travel are computed for both the HOV lane and the MF lanes, as is the fraction of the traffic stream composed of HOV's and the percentage HOV's that use the HOV lane.

| T | V | W | X |
|---|---|---|---|
| TION RESIDUALS | **CORRIDOR ANALYSIS SUMMARY** | | |
| | **Hydrocarbon Summary (Annual Average Peak Hour Emissions)** | | |
| 4.75029E-09 | Total HOV Auto | 6773.467379 | g/hr |
| | Total MFL Auto | 21452.64575 | g/hr |
| 1.17324E-17 | Total Gas Truck | 3891.854332 | g/hr |
| | Total Diesel Truck | 6364.94332 | g/hr |
| 4.75029E-09 | **Total HC Emissions** | 32273.89902 | g/hr |
| | **Carbon Monoxide Summary (Annual Average Peak Hour Emissions)** | | |
| | Total HOV Auto | 6623.661944 | g/hr |
| | Total MFL Auto | 303182.4762 | g/hr |
| | Total Gas Truck | 51059.35541 | g/hr |
| | Total Diesel Truck | 24055.14779 | g/hr |
| | **Total CO Emissions** | 384920.6413 | g/hr |
| | **NOx Summary (Annual Average Peak Hour Emissions)** | | |
| | Total HOV Auto | 532.1586752 | g/hr |
| | Total MFL Auto | 24908.29757 | g/hr |
| | Total Gas Truck | 7430.116551 | g/hr |
| | Total Diesel Truck | 24055.14779 | g/hr |
| | **Total Nox Emissions** | 56925.72059 | g/hr |
| | **Corridor Delay Statistics** | | |
| | HOV Corridor FFTT | 34.968 | min |
| | HOV Corridor TT | 34.96800008 | min |
| | MF Corridor FFTT | 37.46571429 | min |
| | MF Corridor TT | 61.02534204 | min |
| | Total Corridor Delay | 209663.9412 | veh-min/hr |

Figure 7-11 Corridor level results summary in stochastic user equilibrium

## 7.2 Model Scenarios and Solution Strategies

The spreadsheet model is solved using Microsoft Excel through the use of the Excel Solver. Three different types of analyses have been implemented using Excel Solver in different ways. First, user equilibrium using baseline assumptions is implemented. Second, the impacts of reverting the HOV lane to a mixed-flow lane are studied. Third, the impacts of heavy enforcement are studied. Details of the implementation of the spreadsheet model for each of the three analysis cases are given in the following subsections.

### 7.2.1 User Equilibrium Analysis (Do Nothing Case)

In general, user equilibrium analysis should be considered the “do nothing” case, as this case seeks to determine the lane choice behavior of users with no enhancement strategies given their revealed preference behaviors as expressed through models of the users’ choices. This model converges well and produces reasonable results when demands are significantly undersaturated. However, when flows approach the saturation rate, unreasonable results can be produced. For instance, the demand for the HOV lane in equilibrium solution can become so high that the lane would not be able to operate with speeds greater than 5 miles per hour. For this reason, an additional constraint is added to the model requiring that the speed in the HOV lane be greater than or equal to the speed in the MF lane. The program to be solved is stated as

$$\begin{gathered} \min \sum (TTI_{MF} - Assumed\ TTI_{MF})^2 \\ w.r.t.\ Assumed\ TTI_{MF} \\ s.t.\ V_{HOV} \geq V_{MF} \\ Assumed\ TTI_{MF} \geq 1 \end{gathered} \tag{7-30}$$

This is implemented for the I-65 analysis case in Excel Solver using the input shown in Figure 7-12.

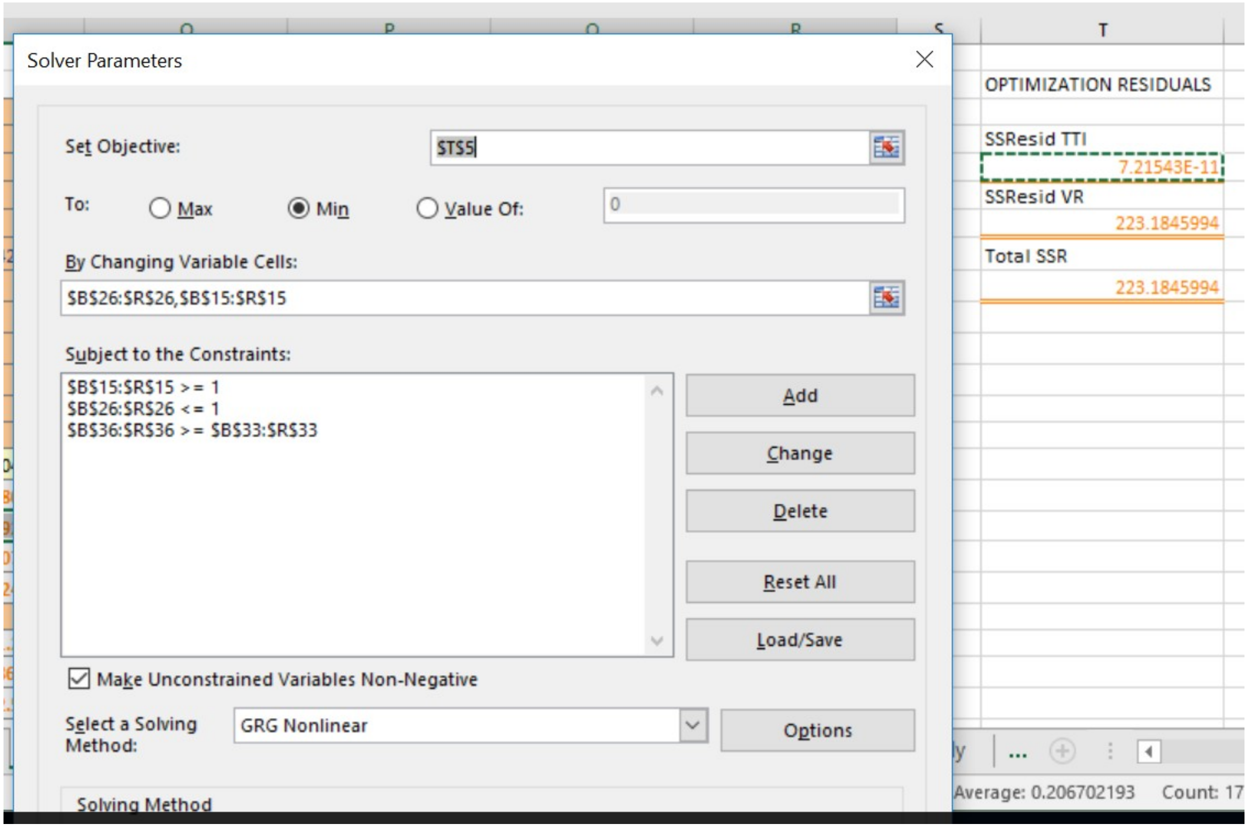



Figure 7-12 Solver dialogue box for determining stochastic user equilibrium

### 7.2.2 Lane Reversion Analysis

This study differs from user equilibrium analysis in that it is assumed that the vehicle delay functions are the same for all lanes and that the traffic will be equally distributed across all lanes. Excel Solver is used to solve the mode choice analysis, which requires an assumption of the mixed-flow lane travel time index. Given the mixed-flow travel time index, the probabilities of users choosing HOV and SOV modes are calculated, and the flows are directly determined in rows 32 and 35 of the spreadsheet. Hence Excel Solver is used to solve the following optimization problem:

$$\min \sum (TTI_{MF} - Assumed\ TTI_{MF})^2$$

$$w.r.t.\ Assumed\ TTI_{MF}, Percent\ Violators\ in\ HOV\ Lane \qquad (7\text{-}31)$$

$$s.t.\ Assumed\ TTI_{MF} \geq 1$$

$$0 \leq Percent\ Violators\ in\ HOV\ Lane \leq 1$$

This optimization problem is implemented in the Excel Solver for the I-24 corridor using the dialogue box shown in Figure 7-13.

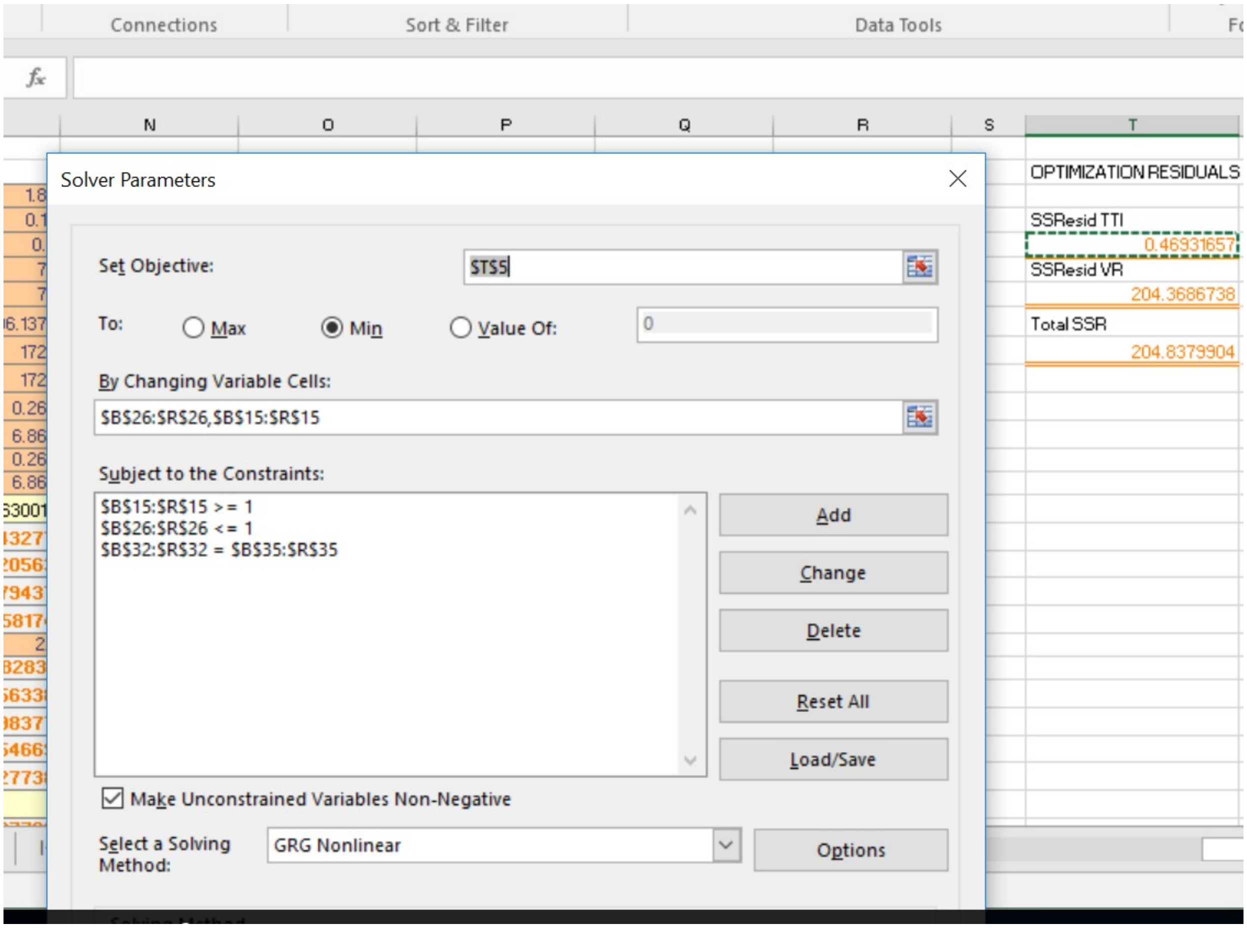



Figure 7-13 Solver dialogue box for solving lane reversion analysis

### 7.2.3 Enforcement Studies

The spreadsheet model for user equilibrium analysis is useful in computing equilibrium under a given level of enforcement effort. This is specified in the optimization model by placing a constraint on the violation rate. This is implemented in Excel by allowing the analyst to define a target rate and calculating the sum of squared residuals of the violation rate. The sum of squared residuals for travel time index and violation rate are added to determine the total sum of squared residuals, with respect to the assumed mixed-flow travel time index and the percent of willing violators that will use the HOV lane under new enforcement conditions. Hence, the approach is to convert this constraint to a term in the objective function. This is expressed mathematically as

$$\min \sum \{ (TTI_{MF} - Assumed\ TTI_{MF})^2 + (VR - Target\ VR)^2 \}$$

$$w.r.t.\ Assumed\ TTI_{MF}, Percent\ Violators\ using\ HOV \qquad (7\text{-}32)$$

$$s.t.\ Assumed\ TTI_{MF} \geq 1$$

$$0 \leq Percent\ Violators\ using\ HOV \leq 1$$

The Solver dialogue box implementation of this optimization problem is shown in Figure 7-14. This problem could also be solved by removing the sum of squared violation rate errors from the objective function and enforcing the match between the actual and target violation rate as an equality constraint.

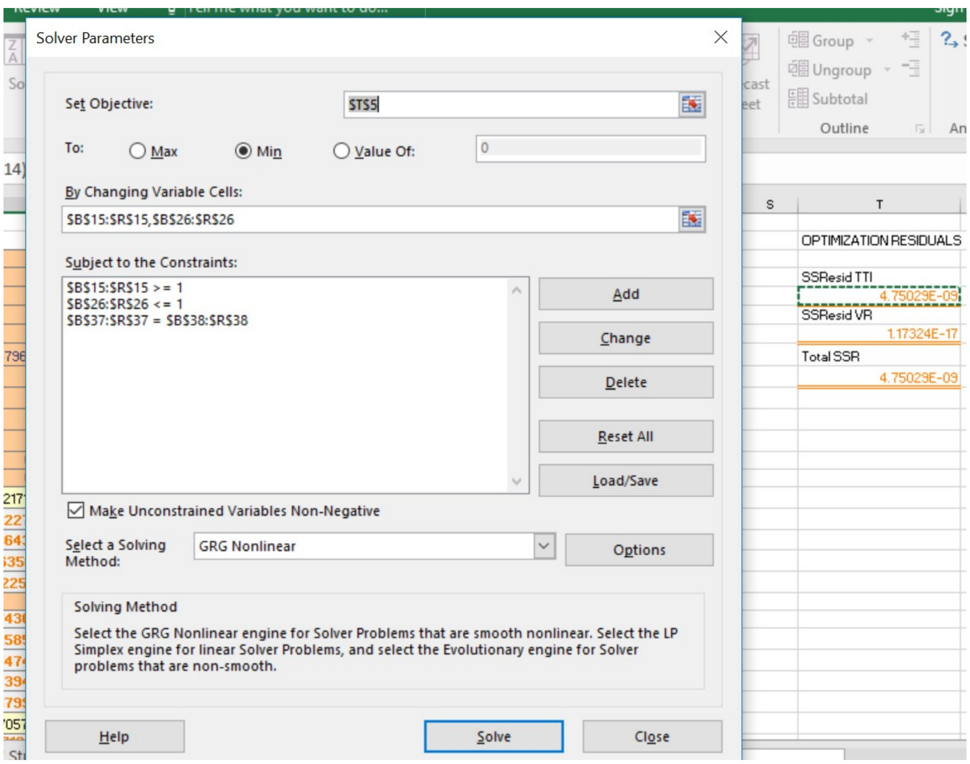



Figure 7-14 Implementation of violation rate constrained equilibrium study

## 7.3 I-24 and I-65 Analysis Results

The models described in sections 7.1 and 7.2 of this report have been implemented for the HOV corridors on both I-24 and I-65. Six analyses have been performed for each corridor, including a do-nothing scenario, a lane reversion scenario, and a heavy enforcement scenario under peak and future design hour volumes. The do-nothing scenario was implemented by using the techniques described in Section 7.2.1. The lane reversion scenario was evaluated using the techniques presented in Section 7.2.2. The heavy enforcement study used the techniques in Section 7.2.3, assuming a violation rate of ten percent.

Volumes through the segment are determined using annual average daily traffic counts, converted to peak hour demands by use of K factors for peak and design hour demands and directional splits. An average vehicle occupancy of 1.1 is assumed to determine the passenger loading on each segment. The number of mixed-flow lanes for analysis purposes is assumed to be at least three but is taken as four whenever the current vehicular throughput exceeds 10,000 vehicles.

Analysis inputs for segments on the I-65 and I-24 corridors are defined in Table 7-1 and Table 7-2, respectively. These tables include beginning and ending log miles, segment lengths, the assumed number of mixed-flow lanes, truck proportions, assumed future design hour passenger loading, and current peak hour passenger loading.

A summary of equilibrium modeling results is provided in Table 7-3 and Table 7-4 for the I-65 and I-24 corridors. These tables include outputs of annual average peak hour hydrocarbon, carbon monoxide, and nitrogen oxide emissions; HOV and mixed-flow lane free-flow trip times and congested trip times over the entire corridor; total corridor delay; corridor average violation rates (where applicable); percentages of HOV in the overall traffic stream across the entire corridor; and percentages of HOV in the HOV lane across the entire corridor. Corridor average violation rate is calculated as the average of all segment violation rates weighted by the flow of all vehicles in the HOV lane. Corridor average percentage HOV in the traffic stream is calculated by computing an average of the probability of a user choosing the HOV mode, weighted by the total number of vehicles on the segment. Corridor average percentage HOV in HOV lane is determined by taking an average of the probability of an HOV using the HOV lane, weighted by the flow of HOV in the segment.

Results in Table 7-3 and Table 7-4 are shown for the following six cases: (1) do nothing under current peak hour volumes, (2) lane reversion under current peak hour volumes, (3) heavy enforcement under current peak hour volumes, (4) do nothing under future design hour volumes, (5) lane reversion under future design hour volumes, and (6) heavy enforcement under future design hour volumes.

An examination of results shown in Table 7-3 shows that under both current and future peak demands, heavy enforcement of the HOV lane results in both dramatically increased delays and significantly increased emissions of all categories of air pollutants. However, it is not always clear whether the reversion of a lane will result in operational or environmental benefits over doing nothing. At current peak demands on I-65, there does not appear to be much advantage in reverting the current HOV lanes to mixed-flow lanes. However, under a future demand scenario with heavier traffic, the equilibrium analysis indicates that there is a greater benefit to lane reversion as excess traffic in the mixed-flow lanes utilizes the capacity of the current HOV lane.

When comparing the do nothing and lane reversion scenarios, there is a tradeoff in the delay increase encountered by those in the HOV lane and the delay reduction experienced by those in the mixed-flow lanes as traffic shifts more fully into the HOV lane. As such, it is not possible to characterize one operational strategy as superior to the other, and under current violation rates and volumes, there is not much difference in the equilibria achieved under either case. However, given what is known of driver choice behaviors, it is unlikely that conditions will be favorable for the HOV lane to be heavily utilized by either SOVs or HOVs if strong enforcement is performed.

Table 7-4 shows similar findings for the I-24 corridor to those shown in Table 7-3 for the I-65 corridor. Under both current peak and future design hourly volume traffic loadings, it was found that the do-nothing scenario appears to be slightly preferable to the lane reversion scenario, although there is not much difference in the outcomes of lane reversion and doing nothing for a given level of demand. However, the results of the analysis show that delays in the mixed-flow lane become exceptionally large and air pollution increases significantly under the heavy enforcement scenario.

It should be noted that in the do-nothing case, the equilibrium assignment was not always such that the HOV lane maintained a higher speed than the mixed-flow lane. Often the result left the HOV lane moving at a near crawl pace while the mixed-flow lanes moved at thirty to forty miles per hour faster. This result would, of course, be unreasonable, and it can be seen that drivers do not make lane choices that could result in that kind of lane assignment. Near the urban core, the do-nothing assignment relied upon equating speeds in HOV and mixed-flow lanes. This assumption could lead to an overstatement of the traffic flows in the HOV lanes, as the speed in the HOV lane is almost always 7 to 10 miles per hour faster than the speed in the mixed-flow lanes. Nonetheless, high volumes in the HOV lanes are often observed, and some segments of the HOV corridor do operate at or near capacity at peak time.

Table 7-5 and Table 7-6 show the model predicted HOV lane volumes. Note that in the heavy enforcement circumstance the HOV lanes are effectively unutilized. This is somewhat unrealistic, as the HOV lane is likely an attractive choice for freeway users traveling long distances in the corridor and is likely a more attractive choice as the mixed-flow lanes become increasingly congested. The predicted volumes show one particular weakness of the modeling approach. The models of user choice assume that the willingness of users to choose the HOV lane is based on the level of traffic in the mixed-flow lanes. This is the result of the difficulty of entrance and exit to the HOV lane under heavy traffic. These difficulties of access and egress are not likely to dissuade long-distance commuters from taking the HOV lane.

Nonetheless, if it can be assumed that drivers are relatively willing to change lanes when they have the opportunity to drive at faster speeds, there is a very important insight to be had from the analysis. Removing HOV lane violators from HOV lanes has the potential to make use of the HOV lane less attractive to legal HOV lane users because of the added difficulty in accessing the leftmost lane given right-hand entrance and exit ramps.

The existence of HOV lanes on an "honor system" provides for enough holes in the mixed-flow lanes for vehicles to enter and exit. The HOV lanes operate at faster overall speeds because most drivers respect the HOV lane restrictions or otherwise find the HOV lane undesirable due to the difficulty in access and egress. While there are a significant number of violators in the HOV lane, speed data collected in the HOV corridor shows that the current flow of violators does not seriously erode the performance of the HOV lane relative to the mixed-flow lanes in most instances. (This may not be the case under heavier future demands, however.) However, when the violators leave their mixed-flow lanes to join the HOV lane traffic flow, they help make lane changes easier to make for those who are in the HOV lane by providing more acceptable gaps for weaving maneuvers in the mixed-flow lanes and thus make the HOV lanes more attractive to legal HOV users.

Table 7-7 through Table 7-10 shows the predicted speeds for the mixed-flow lanes and the HOV lane for current and future demands on the I-65 and I-24 corridors. As expected, speeds are significantly slower when traffic volumes are heavier near the urban core. Further, the heavy enforcement analysis case results in the slowest average travel speeds through the corridors by far.

Table 7-11 and Table 7-12 show the predicted HOV mode shares under each of the scenarios. It should be noted that the current baseline HOV mode share is on the order of 20 percent. In the most congested segments in the heavy enforcement scenario, the model predicts a 40 percent HOV share. This is the result of significant extrapolation of choice models to a range well beyond that which has been observed in the data available from the 2012 Parsons-Brinckerhoff study of HOV lanes in Tennessee. It is unclear how many drivers would be willing to form carpools under the more extreme conditions considered here. This would mean that the delay and emissions results could be optimistic when as many as 40% of all vehicles are HOVs. Further analysis will consider these limitations of the model.

Table 7-1 I-65 Analysis Inputs

| Segment | County | Beg LM | End LM | Segment Length | Mixed -flow Lanes | Truck Proportion | Design Hour Pax | Peak Hour Pax |
|---|---|---|---|---|---|---|---|---|
| 1 | DAVIDSON | 0 | 0.28 | 0.28 | 4 | 0.07 | 14592 | 12347 |
| 2 | DAVIDSON | 0.28 | 3.55 | 3.27 | 4 | 0.07 | 14259 | 11667 |
| 3 | DAVIDSON | 3.55 | 4.883 | 1.333 | 4 | 0.07 | 12733 | 10418 |
| 4 | DAVIDSON | 4.883 | 5.99 | 1.107 | 4 | 0.07 | 15032 | 12299 |
| 5 | DAVIDSON | 5.99 | 7.29 | 1.3 | 3 | 0.06 | 10356 | 8473 |
| 6 | DAVIDSON | 7.29 | 8.44 | 1.15 | 3 | 0.06 | 9058 | 7411 |
| 7 | WILLIAMSON | 0 | 0.155 | 0.155 | 3 | 0.28 | 2121 | 1649 |
| 8 | WILLIAMSON | 0.155 | 4.82 | 4.665 | 3 | 0.16 | 3639 | 2831 |
| 9 | WILLIAMSON | 4.82 | 8.77 | 3.95 | 3 | 0.15 | 4004 | 3114 |
| 10 | WILLIAMSON | 8.77 | 12.58 | 3.81 | 3 | 0.13 | 5497 | 4398 |
| 11 | WILLIAMSON | 12.58 | 13.97 | 1.39 | 3 | 0.11 | 7246 | 5929 |
| 12 | WILLIAMSON | 13.97 | 14.94 | 0.97 | 3 | 0.11 | 7528 | 6159 |
| 13 | WILLIAMSON | 14.94 | 16.29 | 1.35 | 3 | 0.09 | 9157 | 7492 |
| 14 | WILLIAMSON | 16.29 | 18.53 | 2.24 | 4 | 0.07 | 12299 | 10063 |
| 15 | WILLIAMSON | 18.53 | 21.38 | 2.85 | 4 | 0.07 | 14592 | 12347 |

Table 7-2 I-24 Analysis Inputs

| Segment | County | Beg LM | End LM | Length | Truck Proportion | Mixed -flow Lanes | DHV pax | PHV pax |
|---|---|---|---|---|---|---|---|---|
| 1 | DAVIDSON | 17.2 | 18.2 | 1 | 0.15 | 4 | 13336 | 11114 |
| 2 | DAVIDSON | 18.2 | 20.24 | 2.04 | 0.14 | 4 | 15176 | 12647 |
| 3 | DAVIDSON | 20.24 | 21.545 | 1.305 | 0.14 | 4 | 14984 | 12487 |
| 4 | DAVIDSON | 21.545 | 23.93 | 2.385 | 0.15 | 4 | 13079 | 10899 |
| 5 | DAVIDSON | 23.93 | 24.62 | 0.69 | 0.15 | 4 | 12528 | 10440 |
| 6 | DAVIDSON | 24.62 | 27.62 | 3 | 0.16 | 3 | 9337 | 7262 |
| 7 | RUTHERFORD | 0 | 1.235 | 1.235 | 0.17 | 3 | 8864 | 6894 |
| 8 | RUTHERFORD | 1.235 | 3.222 | 1.987 | 0.17 | 3 | 8857 | 6888 |
| 9 | RUTHERFORD | 3.222 | 6.8 | 3.578 | 0.2 | 4 | 11884 | 10399 |
| 10 | RUTHERFORD | 6.8 | 11.47 | 4.67 | 0.13 | 4 | 10925 | 9559 |
| 11 | RUTHERFORD | 11.47 | 13.03 | 1.56 | 0.12 | 3 | 6980 | 5429 |
| 12 | RUTHERFORD | 13.03 | 14.88 | 1.85 | 0.13 | 3 | 6166 | 4796 |
| 13 | RUTHERFORD | 14.88 | 16.71 | 1.83 | 0.14 | 3 | 5419 | 4215 |
| 14 | RUTHERFORD | 16.71 | 18.18 | 1.47 | 0.16 | 3 | 4793 | 3728 |
| 15 | RUTHERFORD | 18.18 | 20.49 | 2.31 | 0.27 | 3 | 2900 | 2256 |
| 16 | RUTHERFORD | 20.49 | 25.73 | 5.24 | 0.32 | 3 | 2327 | 1810 |
| 17 | RUTHERFORD | 25.73 | 33.29 | 7.56 | 0.36 | 3 | 2423 | 1884 |

Table 7-3 Summary Of Analysis Results For I-65 HOV Corridor

| | Do Nothing (Peak) | Lane Reversion (Peak) | Heavy Enforcement (Peak) | Do Nothing (DHV) | Lane Reversion (DHV) | Heavy Enforcement (DHV) |
|---|---|---|---|---|---|---|
| Peak Hour HC Emissions (g/hr) | 20376 | 20211 | 25799 | 36227 | 29302 | 43800 |
| Peak Hour CO Emissions (g/hr) | 264412 | 268331 | 314934 | 415486 | 371673 | 427439 |
| Peak Hour NOx Emissions (g/hr) | 33718 | 33884 | 36407 | 48402 | 43481 | 50604 |
| HOV Corridor Free Flow Trip Time (min) | 23.9 | -- | 23.9 | 23.9 | -- | 23.9 |
| HOV Corridor Trip Time (min) | 29.3 | -- | 23.9 | 51.0 | -- | 23.9 |
| MF Corridor Free Flow Trip Time (min) | 25.6 | 25.6 | 25.6 | 25.6 | 25.6 | 25.6 |
| MF Corridor Trip Time (min) | 30.9 | 31.8 | 49.1 | 52.5 | 44.6 | 77.4 |
| Total Corridor Delay (veh-min/hr) | 53905 | 62425 | 213306 | 328823 | 214687 | 505993 |
| Average Violation Rate | 81.6% | -- | 10.00% | 83.92% | -- | 10.00% |
| Percentage HOV in Traffic Stream | 23.0% | 22.16% | 29.41% | 21.35% | 27.73% | 40.04% |
| Percentage of HOV's in HOV Lane | 29.5% | -- | 6.60% | 29.40% | -- | 2.71% |

Table 7-4 Summary of Analysis Results for I-24 HOV Corridor

| | Do Nothing (Peak) | Lane Reversion (Peak) | Heavy Enforcement (Peak) | Do Nothing (DHV) | Lane Reversion (DHV) | Heavy Enforcement (DHV) |
|---|---|---|---|---|---|---|
| Peak Hour HC Emissions (g/hr) | 28707 | 28559 | 31739 | 35903 | 36314 | 64323 |
| Peak Hour CO Emissions (g/hr) | 343476 | 342882 | 381997 | 440288 | 445542 | 591769 |
| Peak Hour NOx Emissions (g/hr) | 55237 | 55651 | 56422 | 67058 | 67230 | 93094 |
| HOV Corridor Free Flow Trip Time (min) | 35.0 | -- | 35.0 | 35.0 | -- | 35.0 |
| HOV Corridor Trip Time (min) | 40.4 | -- | 35.0 | 48.2 | -- | 35.0 |
| Mixed-flow Corridor Free Flow Trip Time (min) | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 |
| MF Corridor Trip Time (min) | 43.3 | 43.6 | 60.2 | 54.7 | 55.3 | 108.6 |
| Total Corridor Delay (veh-min/hr) | 55607 | 59761 | 201026 | 178717 | 192488 | 673455 |
| Average Violation Rate | 82.5% | -- | 10.0% | 90.2% | -- | 10.0% |
| Percentage of HOV in Traffic Stream | 21.4% | 21.6% | 27.6% | 25.6% | 26.0% | 31.3% |
| Percentage of HOV in HOV Lane | 29.4% | -- | 9.5% | 14.1% | -- | 10.3% |

Table 7-5 Predicted I-65 Corridor HOV Lane Volumes

| Segment | Do Nothing (Peak) | Lane Reversion (Peak) | Heavy Enforcement (Peak) | Do Nothing (DHV) | Lane Reversion (DHV) | Heavy Enforcement (DHV) |
|---|---|---|---|---|---|---|
| 1 | 2246 | 2124 | 3 | 2581 | 2376 | 4 |
| 2 | 2252 | 2049 | 2 | 2729 | 2370 | 4 |
| 3 | 2039 | 1854 | 2 | 2445 | 2196 | 3 |
| 4 | 1728 | 2138 | 2 | 2875 | 2442 | 4 |
| 5 | 1992 | 1882 | 1 | 2463 | 2222 | 3 |
| 6 | 1402 | 1659 | 2 | 2173 | 1997 | 2 |
| 7 | 183 | 371 | 88 | 236 | 477 | 114 |
| 8 | 315 | 636 | 152 | 406 | 818 | 195 |
| 9 | 346 | 700 | 167 | 450 | 900 | 214 |
| 10 | 501 | 989 | 233 | 694 | 1235 | 276 |
| 11 | 805 | 1332 | 279 | 1319 | 1623 | 8 |
| 12 | 876 | 1383 | 273 | 1460 | 1684 | 1 |
| 13 | 1440 | 1676 | 1 | 2194 | 2016 | 2 |
| 14 | 1960 | 1795 | 1 | 2365 | 2138 | 2 |
| 15 | 2374 | 2145 | 2 | 2792 | 2402 | 4 |

Table 7-6 Predicted I-24 Corridor HOV Lane Volumes

| Segment | Do Nothing (Current Peak) | Lane Reversion (Current Peak) | Heavy Enforcement (Current Peak) | Do Nothing (DHV) | Lane Reversion (DHV) | Heavy Enforcement (DHV) |
|---|---|---|---|---|---|---|
| 1 | 2036 | 1950 | 2 | 2245 | 2245 | 3 |
| 2 | 2363 | 2184 | 3 | 2400 | 2454 | 3 |
| 3 | 2341 | 2163 | 3 | 2400 | 2438 | 3 |
| 4 | 2108 | 1931 | 2 | 2400 | 2239 | 2 |
| 5 | 2039 | 1857 | 2 | 2258 | 2169 | 2 |
| 6 | 1327 | 1627 | 1 | 2215 | 2049 | 124 |
| 7 | 1157 | 1546 | 179 | 2126 | 1960 | 241 |
| 8 | 1154 | 1545 | 180 | 2125 | 1958 | 242 |
| 9 | 2033 | 1851 | 1 | 2255 | 2080 | 82 |
| 10 | 1706 | 1710 | 82 | 2112 | 1935 | 327 |
| 11 | 678 | 1220 | 274 | 1195 | 1565 | 345 |
| 12 | 560 | 1078 | 252 | 878 | 1385 | 319 |
| 13 | 477 | 948 | 224 | 676 | 1218 | 285 |
| 14 | 417 | 838 | 199 | 559 | 1077 | 254 |
| 15 | 250 | 507 | 121 | 322 | 652 | 154 |
| 16 | 201 | 407 | 97 | 258 | 523 | 124 |
| 17 | 209 | 424 | 101 | 269 | 545 | 129 |

Table 7-7 Predicted I-65 Corridor Travel Speeds at Current Peak Conditions

| Segment | Do Nothing MF Lane Speed | Do Nothing HOV Lane Speed | Lane Reversion Speed | Heavy Enforcement MF Lane Speed | Heavy Enforcement HOV Lane Speed |
|---|---|---|---|---|---|
| 1 | 29.1 | 29.1 | 33.2 | 17.6 | 75.0 |
| 2 | 44.1 | 44.1 | 43.7 | 22.3 | 75.0 |
| 3 | 56.9 | 56.9 | 55.1 | 31.9 | 75.0 |
| 4 | 69.2 | 69.2 | 37.9 | 19.0 | 75.0 |
| 5 | 55.3 | 59.4 | 53.6 | 24.7 | 75.0 |
| 6 | 60.2 | 73.8 | 63.0 | 36.8 | 75.0 |
| 7 | 70.0 | 75.0 | 70.0 | 70.0 | 75.0 |
| 8 | 70.0 | 75.0 | 70.0 | 70.0 | 75.0 |
| 9 | 70.0 | 75.0 | 70.0 | 70.0 | 75.0 |
| 10 | 69.6 | 75.0 | 69.9 | 69.2 | 75.0 |
| 11 | 66.6 | 75.0 | 68.7 | 62.5 | 75.0 |
| 12 | 65.8 | 75.0 | 68.2 | 60.1 | 75.0 |
| 13 | 59.8 | 73.6 | 62.4 | 36.3 | 75.0 |
| 14 | 59.5 | 60.9 | 57.9 | 35.5 | 75.0 |
| 15 | 36.2 | 36.2 | 37.5 | 18.7 | 75.0 |

Table 7-8 Predicted I-24 Corridor Travel Speeds at Current Peak Conditions

| Segment | Do Nothing MF Lane Speed | Do Nothing HOV Lane Speed | Lane Reversion Speed | Heavy Enforcement MF Lane Speed | Heavy Enforcement HOV Lane Speed |
|---|---|---|---|---|---|
| 1 | 44.3 | 44.3 | 43.3 | 23.7 | 75.0 |
| 2 | 37.0 | 37.0 | 34.9 | 17.5 | 75.0 |
| 3 | 38.4 | 38.4 | 36.2 | 18.1 | 75.0 |
| 4 | 53.1 | 53.1 | 50.9 | 27.7 | 75.0 |
| 5 | 56.9 | 56.9 | 54.9 | 31.7 | 75.0 |
| 6 | 60.9 | 74.2 | 63.9 | 39.7 | 75.0 |
| 7 | 62.6 | 74.7 | 65.8 | 48.5 | 75.0 |
| 8 | 62.6 | 74.8 | 65.9 | 48.7 | 75.0 |
| 9 | 57.3 | 57.3 | 55.3 | 32.1 | 75.0 |
| 10 | 61.3 | 69.7 | 61.3 | 42.2 | 75.0 |
| 11 | 68.1 | 75.0 | 69.3 | 66.1 | 75.0 |
| 12 | 69.2 | 75.0 | 69.8 | 68.5 | 75.0 |
| 13 | 69.7 | 75.0 | 69.9 | 69.5 | 75.0 |
| 14 | 69.9 | 75.0 | 70.0 | 69.8 | 75.0 |
| 15 | 70.0 | 75.0 | 70.0 | 70.0 | 75.0 |
| 16 | 70.0 | 75.0 | 70.0 | 70.0 | 75.0 |
| 17 | 70.0 | 75.0 | 70.0 | 70.0 | 75.0 |

Table 7-9 Predicted I-65 Corridor Travel Speeds at Future DHV Conditions

| Segment | Do Nothing MF Lane Speed | Do Nothing HOV Lane Speed | Lane Reversion Speed | Heavy Enforcement MF Lane Speed | Heavy Enforcement HOV Lane Speed |
|---|---|---|---|---|---|
| 1 | 29.1 | 12.3 | 20.6 | 11.6 | 75.0 |
| 2 | 44.1 | 17.6 | 23.9 | 12.5 | 75.0 |
| 3 | 56.9 | 31.9 | 34.2 | 17.0 | 75.0 |
| 4 | 69.2 | 12.6 | 20.3 | 11.1 | 75.0 |
| 5 | 55.3 | 30.8 | 32.5 | 13.6 | 75.0 |
| 6 | 60.2 | 49.1 | 47.0 | 19.9 | 75.0 |
| 7 | 70.0 | 75.0 | 70.0 | 70.0 | 75.0 |
| 8 | 70.0 | 75.0 | 70.0 | 69.8 | 75.0 |
| 9 | 70.0 | 75.0 | 69.9 | 69.6 | 75.0 |
| 10 | 69.6 | 75.0 | 69.3 | 65.7 | 75.0 |
| 11 | 66.6 | 74.3 | 64.0 | 40.0 | 75.0 |
| 12 | 65.8 | 73.4 | 62.2 | 35.7 | 75.0 |
| 13 | 59.8 | 47.8 | 45.8 | 19.2 | 75.0 |
| 14 | 59.5 | 36.8 | 37.9 | 18.8 | 75.0 |
| 15 | 36.2 | 15.3 | 22.2 | 11.9 | 75.0 |

Table 7-10 Predicted I-24 Corridor Travel Speeds at Future DHV Conditions

| Segment | Do Nothing MF Lane Speed | Do Nothing HOV Lane Speed | Lane Reversion Speed | Heavy Enforcement MF Lane Speed | Heavy Enforcement HOV Lane Speed |
|---|---|---|---|---|---|
| 1 | 26.7 | 29.1 | 26.7 | 14.5 | 75.0 |
| 2 | 19.4 | 34.6 | 19.7 | 13.0 | 75.0 |
| 3 | 20.3 | 34.6 | 20.5 | 12.6 | 75.0 |
| 4 | 33.2 | 34.6 | 31.5 | 11.9 | 75.0 |
| 5 | 36.9 | 43.7 | 35.9 | 11.9 | 75.0 |
| 6 | 46.5 | 46.5 | 43.7 | 11.1 | 75.0 |
| 7 | 52.0 | 52.0 | 49.2 | 16.4 | 75.0 |
| 8 | 52.1 | 52.1 | 49.3 | 16.5 | 75.0 |
| 9 | 43.9 | 43.9 | 41.7 | 14.6 | 75.0 |
| 10 | 52.8 | 52.8 | 50.7 | 25.7 | 75.0 |
| 11 | 62.2 | 74.7 | 65.4 | 48.6 | 75.0 |
| 12 | 65.7 | 75.0 | 68.2 | 60.2 | 75.0 |
| 13 | 68.1 | 75.0 | 69.3 | 66.2 | 75.0 |
| 14 | 69.2 | 75.0 | 69.8 | 68.5 | 75.0 |
| 15 | 70.0 | 75.0 | 70.0 | 70.0 | 75.0 |
| 16 | 70.0 | 75.0 | 70.0 | 70.0 | 75.0 |
| 17 | 70.0 | 75.0 | 70.0 | 70.0 | 75.0 |

Table 7-11 Predicted I-65 Corridor HOV Mode Share

| Segment | Do Nothing (Current Peak) | Lane Reversion (Current Peak) | Heavy Enforcement (Current Peak) | Do Nothing (DHV) | Lane Reversion (DHV) | Heavy Enforcement (DHV) |
|---|---|---|---|---|---|---|
| 1 | 20% | 27% | 39% | 20% | 35% | 52% |
| 2 | 20% | 23% | 34% | 20% | 32% | 49% |
| 3 | 20% | 21% | 27% | 20% | 26% | 40% |
| 4 | 86% | 25% | 37% | 20% | 36% | 54% |
| 5 | 21% | 21% | 32% | 21% | 27% | 47% |
| 6 | 20% | 20% | 24% | 21% | 23% | 36% |
| 7 | 19% | 19% | 19% | 19% | 19% | 19% |
| 8 | 19% | 19% | 19% | 19% | 19% | 19% |
| 9 | 19% | 19% | 19% | 19% | 19% | 19% |
| 10 | 19% | 19% | 19% | 19% | 19% | 20% |
| 11 | 20% | 19% | 20% | 20% | 20% | 24% |
| 12 | 20% | 19% | 20% | 20% | 20% | 26% |
| 13 | 20% | 20% | 26% | 21% | 23% | 37% |
| 14 | 20% | 21% | 26% | 20% | 25% | 37% |
| 15 | 20% | 25% | 38% | 20% | 34% | 52% |

Table 7-12 Predicted I-24 Corridor HOV Mode Share

| Segment | Do Nothing (Current Peak) | Lane Reversion (Current Peak) | Heavy Enforcement (Current Peak) | Do Nothing (DHV) | Lane Reversion (DHV) | Heavy Enforcement (DHV) |
|---|---|---|---|---|---|---|
| 1 | 23% | 23% | 32% | 30% | 30% | 45% |
| 2 | 25% | 26% | 40% | 37% | 37% | 59% |
| 3 | 25% | 26% | 39% | 36% | 36% | 56% |
| 4 | 21% | 22% | 30% | 27% | 28% | 36% |
| 5 | 21% | 21% | 27% | 25% | 26% | 29% |
| 6 | 20% | 20% | 24% | 23% | 23% | 23% |
| 7 | 20% | 20% | 22% | 22% | 22% | 22% |
| 8 | 20% | 20% | 22% | 22% | 22% | 22% |
| 9 | 21% | 21% | 27% | 23% | 24% | 24% |
| 10 | 20% | 20% | 24% | 21% | 22% | 22% |
| 11 | 19% | 19% | 20% | 20% | 20% | 20% |
| 12 | 19% | 19% | 19% | 20% | 19% | 19% |
| 13 | 19% | 19% | 19% | 19% | 19% | 19% |
| 14 | 19% | 19% | 19% | 19% | 19% | 19% |
| 15 | 19% | 19% | 19% | 19% | 19% | 19% |
| 16 | 19% | 19% | 19% | 19% | 19% | 19% |
| 17 | 19% | 19% | 19% | 19% | 19% | 19% |

# Chapter 8 Development of Cell Transmission Models to Predict Conditions on I-65 Corridor

## 8.1 Introduction

During the past four decades, many traffic simulation software programs have been developed to address oversaturation in traffic flow. These simulation programs can be classified into two broad categories, microscopic and macroscopic. Microscopic simulation models focus on one individual vehicle as it follows another vehicle. Popular microscopic simulation programs in use today include, among others, SimTraffic, AIMSUN, and VISSIM. These programs record discrete traffic events at fixed-time intervals. Microscopic simulation programs provide great detail about various traffic scenarios such as the behaviors of drivers and pedestrians, and when data is aggregated, these software packages can provide macroscopic information about the entire facility.

For microscopic modeling applications, the Tennessee Department of Transportation has used VISSIM, among other tools, extensively. Developed at the University of Karlsruhe (Germany) during the early 1970s, VISSIM can model transit and traffic flow in urban areas and their connecting roadways on a microscopic level. This software tool is particularly useful because it enables users to assess the effects of new vehicle technologies, including autonomous vehicle technologies, on traffic flow. VISSIM has the capability of restricting various classes of vehicles from certain lanes. This research project will utilize VISSIM for simulation of the HOV corridors under consideration to study the impacts of individual drivers' decision making upon facility performance and to verify the vehicular delay functions assumed for modeling HOV facilities via user equilibrium techniques. However, we will seek to view the results of traffic microsimulation through the lens of results of macroscopic models because analysis of interstate corridors has been performed for many years with reasonable results using macroscopic modeling techniques. The most valuable operational insights are likely to come when results that deviate from the macroscopic results are found and understood. Should certain driver behaviors or decisions lead to the breakdown of a facility when the breakdown is unexpected, potential problems may be revealed and understanding the results of the simulation model may provide useful insights for improving operations. In this project, VISSIM will be used for microscopic simulation, and the microscopic modeling effort will be detailed in Chapters 9-11.

While microscopic models are powerful and capable of generating tremendous insight into problems in traffic operations, they are sometimes difficult to calibrate and validate. In contrast, macroscopic simulation models can provide a global view of various traffic scenarios by representing traffic flow in aggregate measures but do not model trajectories of each vehicle or decisions of each driver. These models are typically much easier to assess and validate and have for a long time been capable of providing reasonable approximations for the behavior of traffic on freeways. For this reason, Chapter 8 is devoted to the macroscopic simulation of traffic flow on the southbound I-65 corridor south of Nashville.

As the work in Chapters 6 and 7 required an assumption of homogeneity along the highway, which is likely valid for light traffic, the macroscopic models that will be constructed in this chapter will require no such assumptions of homogeneity. Rather, the macroscopic simulation will allow for both the testing of homogeneity as well as the understanding of the impacts of inhomogeneities of the boundary value problem with respect to the fundamental diagram. As traffic data is available from sources like Google Maps for the evaluation of the evolution of speed and density of traffic streams over time, the use of macrosimulation can allow for confirmation of the existence of various types of operational phenomena on the freeway. Hence, macroscopic simulation is a valuable and necessary modeling activity

Often, but not always, macroscopic simulation models evolve speed, flow, and density over space and time. Popular macroscopic simulation programs in use today include TRANSYT-7F and PASSER. While TRANSYT-7F is capable of handling oversaturated flow conditions, PASSER is unsuited to handling these conditions. These tools are often useful in modeling traffic flows in signalized networks and for optimizing signal timing plans. While various programs of this type utilize different strategies for modeling traffic flows on networks, traffic dynamics on interstate corridors are often modeled using the LWR PDE. The LWR PDE can be stated as

$$\frac{\partial k}{\partial t} + \frac{\partial q(k)}{\partial x} = 0 \tag{8-1}$$

inside the problem domain, where:

$k$ = density

$q(\rho)$ = flux or flow of vehicles as a function of density (such a relationship is referred to as the fundamental diagram)

$x$ = location on highway facility

$t$ = time

Boundary conditions require special attention if control of facilities governed by the LWR PDE is to be accomplished, and often involve prescribing the flux entering (or perhaps leaving) the domain. In managed lane facilities pricing controls are also available to control demand for the managed lane and the mixed-flow lanes.

Most macroscopic models that effectively model traffic dynamics solve the LWR PDE. The LWR PDE can be solved using the Method of Characteristics, but there are difficulties in solving the LWR PDE for all boundary conditions. There may be infinitely many solutions to the

LWR PDE, but not all are physically relevant. The proper notion of weak solution for the LWR PDE, called the entropy solution, was first defined by Oleinik (1957). Even though this work was known to the traffic community, it does not (as far as we know) appear explicitly in the transportation literature before the 1990s with the work of Ansorge (1990). The entropy solution has been since acknowledged as the proper weak solution to the LWR PDE for traffic models.

Unfortunately, the work of Oleinik in its initial form does not hold for bounded domains, i.e., it would only work for infinitely long highways with no on-ramps or off-ramps. Bounded domains, i.e., highways of finite length (required to model on and off-ramps) imply the use of boundary conditions, for which the existence and uniqueness of a weak solution are not straightforward. In general, one cannot expect the boundary conditions to be fulfilled point-wise almost everywhere (a.e.). For instance, one cannot impose arbitrary fluxes on an entrance ramp for a segment when the flow in the segment of the highway immediately downstream of the entrance ramp is congested. Such a flux boundary condition to the LWR PDE can only be satisfied when the traffic downstream of the entrance ramp is sufficiently free-flowing to allow for the prescribed flux of vehicles to join the traffic stream on the main line. Further, it is impossible to prescribe a flux at an exit ramp, as this flow is governed in part by the flow immediately upstream of the exit.

In short, boundary conditions for the LWR PDE (and all conservation laws) can only be prescribed on a boundary when the characteristic curves of the solution enter the domain through the boundary. When boundary conditions are prescribed such that they are satisfied almost everywhere only when the characteristics of the PDE enter the domain through the boundary, such a formulation of the boundary conditions is said to be a weak formulation. This is in no way a weakness of continuum models like the LWR PDE as a modeling approach, but whatever numerical scheme is implemented to solve the LWR PDE and its boundary conditions must be able to handle the requirement of weak boundary conditions.

For a numerical solution algorithm to be useful for the LWR PDE, the algorithm should result in a solution that satisfies the entropy condition and should allow for the specification of weak boundary conditions. The Cell Transmission Model (CTM) as developed by Daganzo (1994) satisfies the entropy criterion and also assures that the weak boundary conditions are implemented in its solution approach. The CTM requires a temporal and spatial discretization of the problem domain such that traffic traveling at free-flow speed can travel the length of the spatially discrete cell in exactly one clock tick. (A clock tick is the length of time required for a vehicle traveling at free-flow speed to traverse a cell.) Traffic evolves in such a way that the accumulation of vehicles in the cell is equal to inflow minus outflow for each clock tick. However, the number of cars that can move from cell to cell is taken as the minimum of the number of cars that can be sent from the upstream cell (which is the minimum of the number of cars in the upstream cell and the capacity flux) and the number of cars that can be received by the downstream cell (which is the minimum of the capacity flux and the maximum number of vehicles that can be received into the cell in the next time step).

## 8.2 Theory of the Cell Transmission Model

### 8.2.1 Basic Premise

The CTM simulates traffic conditions by proposing to simulate the system with a *time-scan* strategy where current conditions are updated with every tick of a clock. The road section under consideration is divided into homogeneous sections called *cells*, numbered from $i$ = 1 to I. The lengths of the sections are set equal to the distances traveled in light traffic by a typical vehicle in one clock tick. Under light traffic conditions, all the vehicles in a cell can be assumed to advance to the next with each clock tick. i.e.,

$$n_{i+1}(t+1) = n_i(t) \tag{8-2}$$

where $n_i(t)$ is the number of vehicles in cell $i$ at time $t$. However, equation (8-2) is not reasonable when the flow exceeds capacity. Hence a more robust set of flow advancement equations is needed.

### 8.2.2 Flow Advancement Equations

We seek a more reasonable set of flow advancement equations. First, two constants associated with each cell are defined as: (i) $N_i(t)$, the maximum number of vehicles that can be present in cell $i$ at time $t$, and (ii) $Q_i(t)$, the maximum number of vehicles that can flow into cell $i$ when the clock advances from $t$ to $t+1$ (time interval $t$), is the minimum of the capacity of cells from $i-1$ and $i$. This is called the capacity of cell $i$. $Q_i(t)$ represents the maximum flow that can be transferred from $i-1$ to $i$. We allow these constants to vary with time to be able to model transient traffic incidents. Now the flow advancement equation can be written as, the cell occupancy at time $t+1$ equals its occupancy at time t, plus the inflow and minus the outflow, i.e.,

$$n_i(t+1) = n_i(t) + y_i(t) - y_{i+1}(t) \tag{8-3}$$

where, $n_i(t+1)$ is the cell occupancy at time $t+1$, $n_i(t)$ the cell occupancy at time $t$, $y_i(t)$ is the inflow at time $t$, $y_{i+1}(t)$ is the outflow at time $t$. The flows are related to the current conditions at time $t$ as indicated below:

$$y_i(t) = min\,[n_{i-1}(t), Q_i(t), N_i(t) - n_i(t)] \tag{8-4}$$

where, $n_{i-1}(t)$: is the number of vehicles in cell $i-1$ at time $t$, $Q_i(t)$: is the capacity flow into $i$ for time interval $t$, $N_i(t)$ - $n_i(t)$: is the amount of empty space in cell $i$ at time $t$ (see Fig. 8-1).

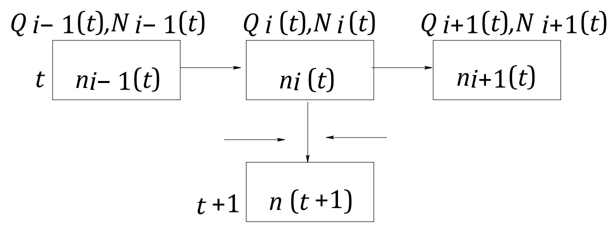



Figure 8-1 Flow advancement in CTM

### 8.3.3 Boundary conditions

Boundary conditions are specified utilizing input and output cells. The output cell, a sink for all exiting traffic, should have infinite size ($N_{I+1} = \infty$) and a suitable, possibly time-varying, capacity. Input flows can be modeled by a cell pair. A *source* cell numbered *00* with an infinite number of vehicles ($n_{00}(O) = \infty$) that discharges into an empty *gate* cell *00* of infinite size, $N_0(t) = \infty$. The inflow capacity $Q_0(t)$ of the gate cell is set equal to the desired link input flow for time interval $t + 1$.

### 8.3.4 Generalized CTM

As formulated in Equation (8-4) the flow advancement equations do not permit the use of fundamental diagrams with backward waves with speed $w \leq v$ (see Figs. 8-2 and 8-3), nor does it permit a nontriangular shape to the fundamental diagram. Hence the flow advancement equation (8-4) does not represent a realistic model since on many occasions the speed of backward waves will not be the same as the free-flow speed. Lo (2001) proposed the formulations of the flow advancement equations for the generalized CTM.

$$y_i(t) = min\ [n_{i-1}(t), Q_i(t), w/v\{N_i(t) - n_i(t)\}] \tag{8-5}$$

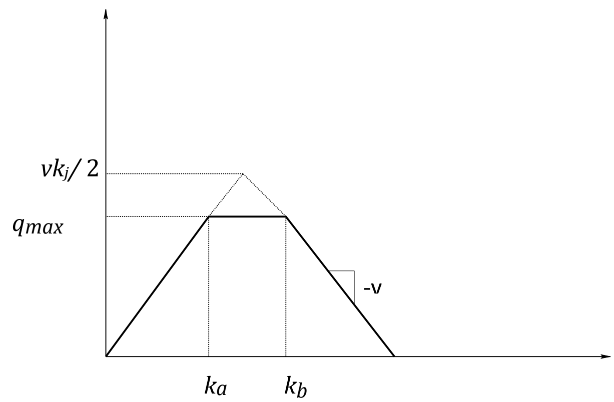



Figure 8-2 Flow-density relationship for the basic CTM

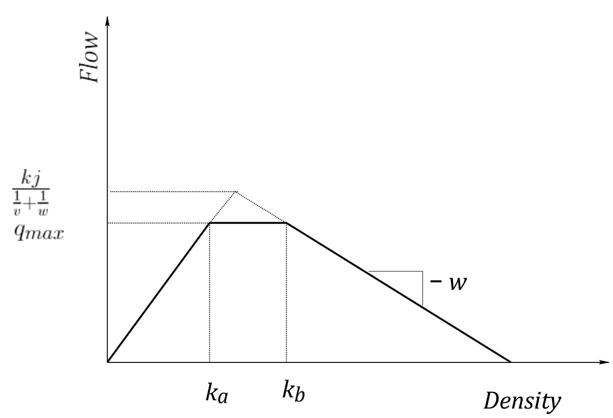



Figure 8-3 Flow-density relationship for the generalized CTM

At a merge cell, all traffic on an on-ramp is given priority for entry to the prior cell before traffic on the main line is allowed to enter the cell. This effectively causes a capacity drop at the main line equal to the influx of vehicles from the on-ramp. At a diverge cell, it is assumed all vehicles wishing to leave the diverge can. Hence if the exit probability after a diverge cell is $p$, then the maximum number of vehicles that can be sent into the downstream cell is 1-$p$ times the number of vehicles in the cell.

## 8.3 Implementation for Southbound I-65 South of Nashville

To provide a baseline comparison for the results of VISSIM microsimulation, the CTM was implemented using Microsoft Excel to simulate three hours of traffic flow over which the ramp fluxes are held constant at a fixed percentage of the AADT. The roadway was assumed to be initially empty, and after a brief warmup period flows on the network reached a steady state. This steady-state is similar regardless of ramp influxes at peak demand, as the first bottleneck is located between the off-ramp for Exit 78, at which Southbound I-65 has a lane drop, and the on-ramp for Exit 79, at which the analysis of Google traffic indicates that there is a merge bottleneck.

The simulation assumes that the performance of the mixed-flow lanes is homogeneous with a triangular fundamental diagram defined by a free flow speed of 75 miles per hour, a capacity of 1650 vehicles per lane per hour, and a jam density of 200 vehicles per mile per lane. The HOV lane is assumed to be homogeneous in its performance with a free flow speed of 75 miles per hour, a capacity of 1800 vehicles per hour, and a jam density of 200 vehicles per mile per lane. The overall fundamental diagram of the combined section is hence assumed to be triangular and defined by a free flow speed of 75 miles per hour, a jam density of 800 vehicles per mile (for the case of three mixed-flow lanes and the HOV lane) or 1000 vehicles per mile (for the case of four mixed-flow lanes and an HOV lane), and a capacity of 6600 vehicles per hour (for the case of three mixed-flow lanes and the HOV lane) or 8400 vehicles per hour (for the case of four mixed-flow lanes and an HOV lane). The simulation uses cells of length 0.1 mi and a time step of 4.8 seconds.

The CTM evolution equations track how density evolves over time. This is related to space mean speed by the relation $q = kv_s$. The fundamental diagram relates flow q to the density k. Hence the CTM is capable of determining both the space mean speed of the vehicles in each cell and the density at any point. As the road is modeled with single cells at each point on the freeway, it is desired to recover conditions in the mixed-flow lanes and the HOV lane. This is done using regression equations developed in Chapter 3. The space mean speed in the mixed-flow lanes is related to the space mean speed of all vehicles on the highway by the relation.

$$v_s^{MF} = 1.006 v_s^{ALL} - 1.442 \tag{8-6}$$

The space mean speed of vehicles in the HOV lane is estimated by the following equations:

$$v_s^{HOV} = 0.999 v_s^{ALL} + 7.02 \quad (v_s^{ALL} \geq 70\ mph) \tag{8-7}$$

$$v_s^{HOV} = 0.804 v_s^{ALL} + 20.29 \quad (v_s^{ALL} \leq 70\ mph) \tag{8-8}$$

With these relationships, it becomes possible to estimate the speeds of traffic in the mixed-flow lanes and the HOV lane from a CTM with one cell including traffic in all lanes on the highway.

The boundary conditions shown in Table 1 are implemented in the CTM as fluxes into the main line. These fluxes are derived by applying a percentage of the on-ramp annual average daily traffic (AADT) to the on-ramp or to the source node using the equation

$$Ramp\ Flux = K * Ramp\ AADT \tag{8-9}$$

$$Source\ Flux = K * 0.5 * Interstate\ Two\ Way\ AADT \tag{8-10}$$

The study contained in this part of the report covers cases where K = 0.08, K = 0.09, K = 0.10, K = 0.11, and K = 0.12. In the network, the source node also has a capacity of 8400 vehicles per hour as the beginning of the HOV corridor has four mixed-flow lanes.

Table 8-1 On-Ramp Fluxes for Southbound I-65 South of Nashville

| | K = 0.08 | K = 0.09 | K = 0.10 | K = 0.11 | K = 0.12 |
|---|---|---|---|---|---|
| MM 80 | 8409 | 8600 | 9556 | 10511 | 11467 |
| Entrance 79 | 538 | 550 | 612 | 673 | 734 |
| Entrance 78 | 924 | 945 | 1051 | 1156 | 1261 |
| Entrance 74 | 1363 | 1394 | 1549 | 1703 | 1858 |
| Entrance 71 | 666 | 681 | 757 | 832 | 908 |
| Entrance 69 | 718 | 735 | 817 | 898 | 980 |
| Entrance 68 | 580 | 594 | 660 | 726 | 792 |
| Entrance 67 | 423 | 432 | 481 | 529 | 577 |
| Entrance 65 | 623 | 638 | 709 | 779 | 850 |
| Entrance 61 | 194 | 198 | 221 | 243 | 265 |

The following exit probabilities shown below in Table 8-2 are then derived based on the fluxes provided in Table 8-1:

Table 8-2 Exit Probabilities for Southbound I-65

| Exit | Exit Probability |
|---|---|
| Exit 79 | 0.08 |
| Exit 78 A and B | 0.16 |
| Exit 74 A and B | 0.25 |
| Exit 71 | 0.09 |
| Exit 69 A and B | 0.13 |
| Exit 68 | 0.22 |
| Exit 67 | 0.12 |
| Exit 65 | 0.25 |
| Exit 61 | 0.15 |

## 8.4 Results for Southbound I-65 Corridor

Within the first fifteen minutes of the simulation the queue formed by this bottleneck reaches the beginning of the HOV corridor. This is in agreement with the observations available from mobile sensing from Google traffic. The bottleneck near the beginning of the HOV corridor leads to capacity discharge over a significant part of the corridor, with enough vehicles exiting the freeway to allow for significantly less than capacity operations only after the Cool Springs

Boulevard exit, at which point enough vehicles have exited the freeway to have less than capacity demand.

The figures in Appendix B show the results for the space mean speed of all vehicles, for the mixed-flow lanes, and for the HOV lane. A typical plot of the occupancy for the I-65 corridor is shown in Figure 8-4. Figure 8-5 shows typical space mean speeds for all vehicles along the length of the corridor. Figure 8-6 shows a typical plot of the estimated time mean speed for the HOV lane along the length of the corridor.

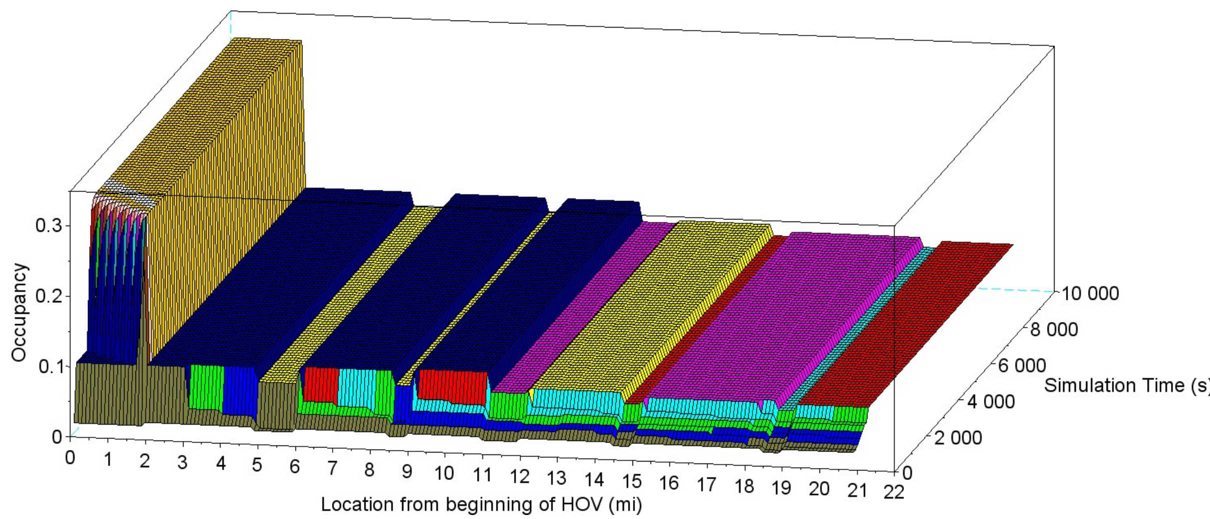



Figure 8-4 Occupancy as a function of simulation time and location for southbound I-65 south of downtown Nashville and constant demand equal to 8% of AADT

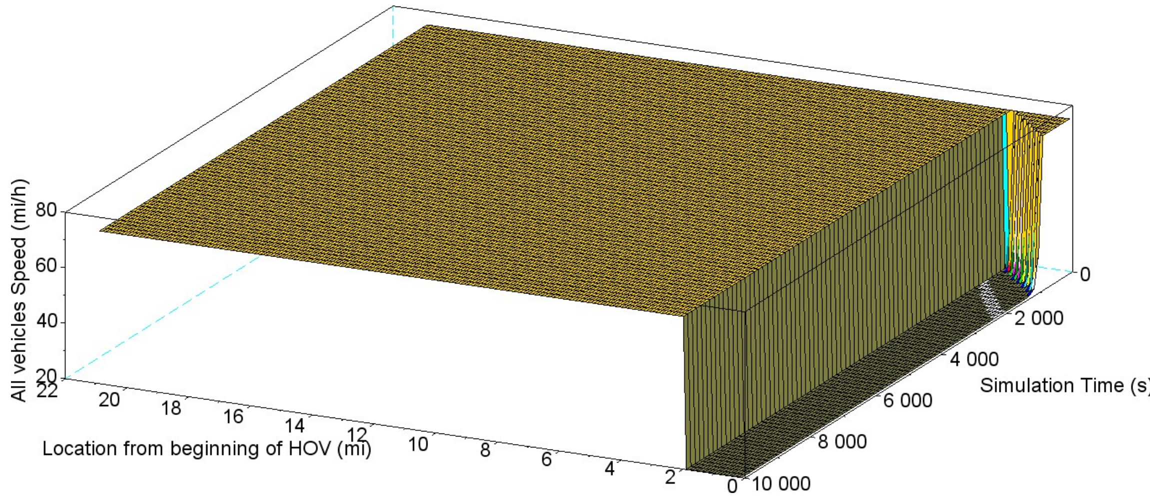



Figure 8-5 Space mean speed of all vehicles as a function of simulation time and location for southbound I-65 south of downtown Nashville and demand equal to 8% of AADT~~Figure 8-5~~

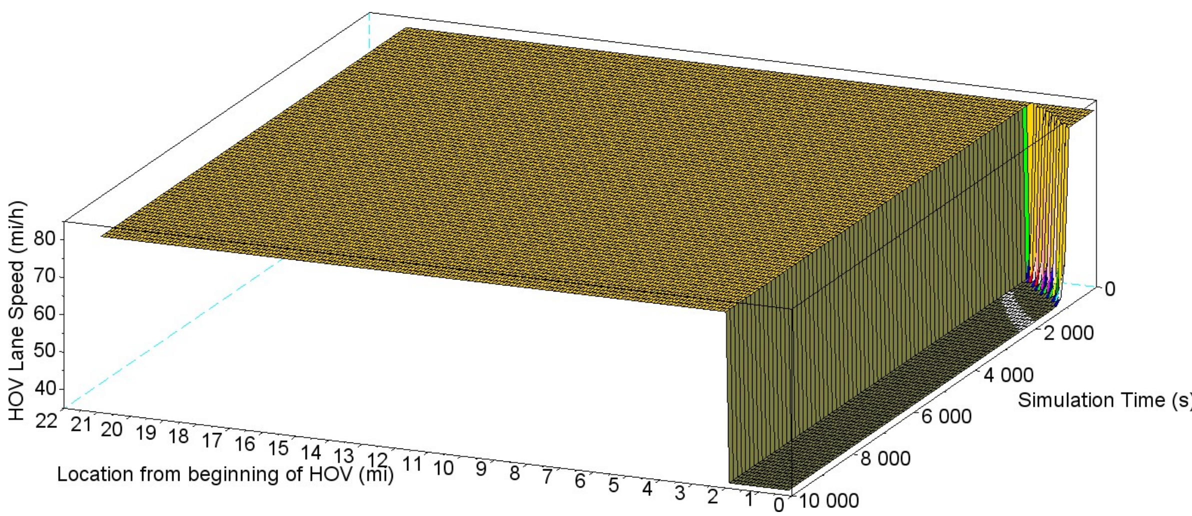



Figure 8-6 Time mean speed of vehicles in HOV lane as a function of simulation time and location for southbound I-65 south of downtown Nashville and demand equal to 8% of AADT

Traffic conditions in the CTM simulation reach steady state after approximately 30 minutes from the beginning of the simulation. A typical steady-state solution depicting the values for occupancy on the freeway, mixed-flow lane speed, and HOV lane speed is shown in Figure 8-7,

Figure 8-8, and Figure 8-9, respectively. It should be noted that this steady-state solution for southbound I-65 between the beginning of the corridor and Cool Springs Boulevard is invariant with respect to the demand as the K-factor increases. The performance of this part of the facility is currently at capacity with the first major bottleneck acting as a flow control, much like a sluice gate in a hydraulic flume. Only when a sufficient number of vehicles exit the freeway do the facility traffic conditions improve to below capacity flow.

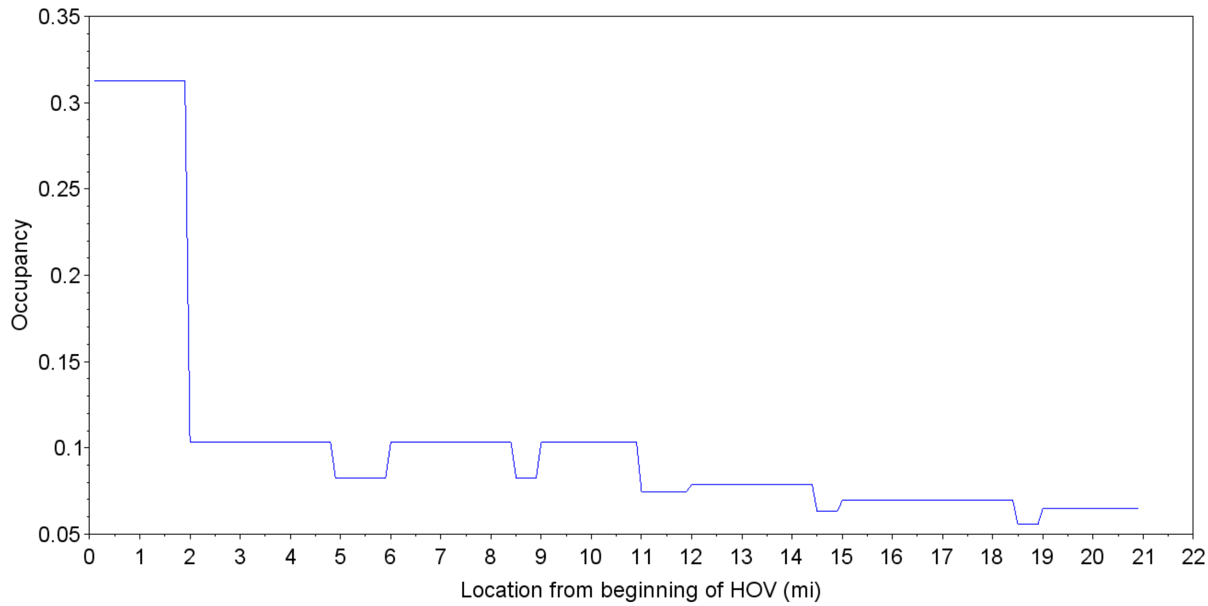



Figure 8-7 Steady-state occupancy as a function of simulation time and location for southbound I-65 south of downtown Nashville and constant demand equal to 8% of AADT

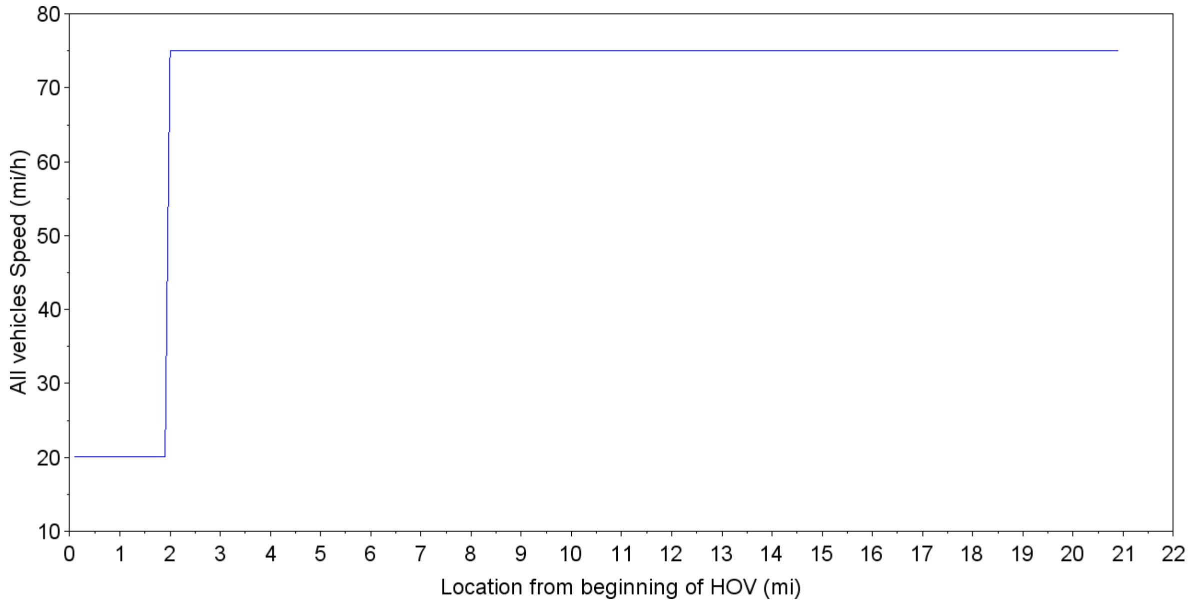



Figure 8-8 Steady-state space mean speed of all vehicles as a function of simulation time and location for southbound I-65 south of downtown Nashville and constant demand equal to 8% of AADT

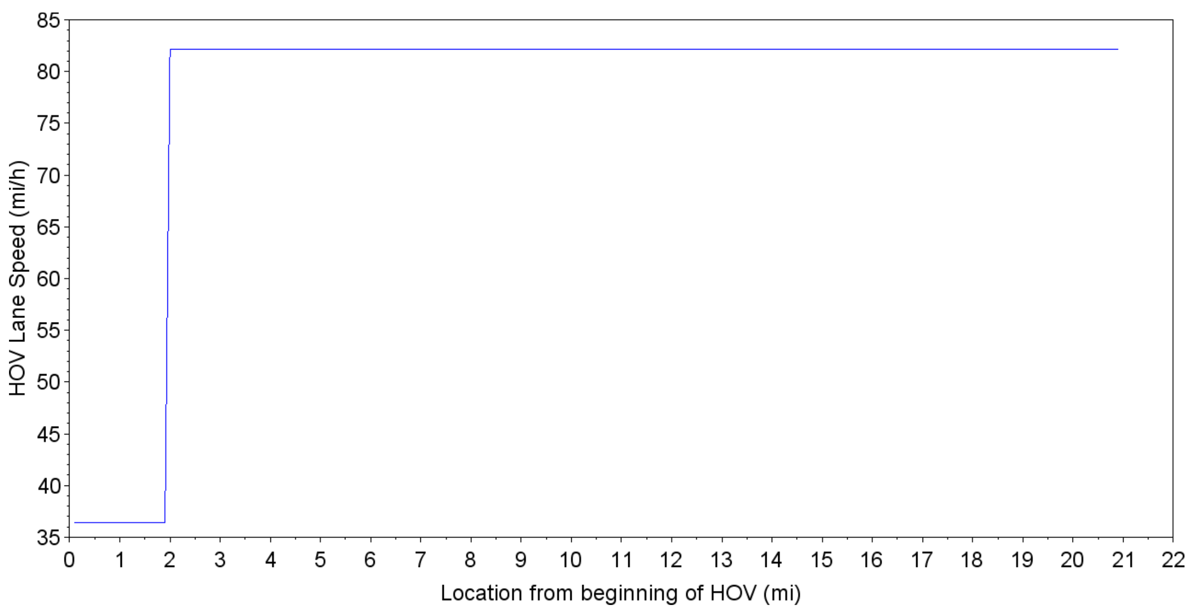



Figure 8-9 Steady-state time mean speed of vehicles in HOV lane as a function of simulation time and location for southbound I-65 south of downtown Nashville and demand equal to 8% of AADT

## 8.5 Comparison of CTM Results with Google Traffic Data

A major congestion wave propagates backward from the main bottleneck at the lane drop following Exit 78. This is seen by the spike in occupancy in the plot in Figure 8-4 and Figure 8-7, as well as the low speeds in the first two miles of the facility as shown in Figure 8-5, Figure 8-6, Figure 8-8 and Figure 8-9. The CTM would assume that the lane drop creates a bottleneck when flows exceeding the capacity of the bottleneck are occurring at peak time causing the congestion wave to propagate backward rapidly. This often happens shortly after 4 PM on a typical day as observed in mobile sensing data collected in Google Traffic. Figure 8-10 shows the bottleneck at 4:00 PM on a typical Monday. Note that the bottleneck has not yet activated, but the flow on the I-440 interchange entering southbound I-65 is clearly at capacity. Figure 8-11 shows the same bottleneck as it is beginning to activate at 4:10 PM. Note that there are clear diverging problems that occur at both Exit 79 and Exit 78 at almost the same time. By 4:15 the entire segment between the I-440 entrance to I-65 and Exit 78 has reached capacity flow and is starting to break down, as shown in Figure 8-12. Later in the day, there exists the possibility of further breakdown at Exit 74. On some days (but not typically all) this bottleneck can become activated, as shown in Figures 8-13 and 8-14. This is a somewhat unexpected result, showing that weaving behavior can be a significant problem near this exit, though this does indicate that capacity flow at peak time is a reasonable prediction of the CTM model. However, the failure of the CTM model to predict the full extent of the breakdown at Exit 79 shows that the fundamental diagram is not homogeneous for the highway section near the bottleneck. The behaviors of the vehicles near the exit cause a significant deviation in the performance of the facility.


Figure 8-10 Bottleneck before activation north of Exit 78 at 4:00 PM on a typical Monday

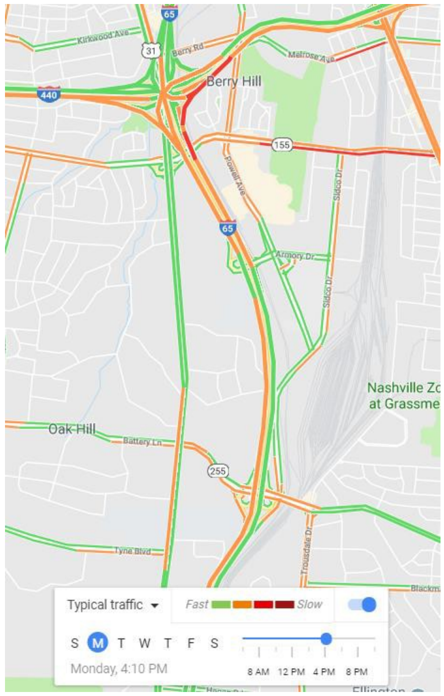



Figure 8-11 Bottleneck activation at Exits 78 and 79 4:10 PM on a typical Monday

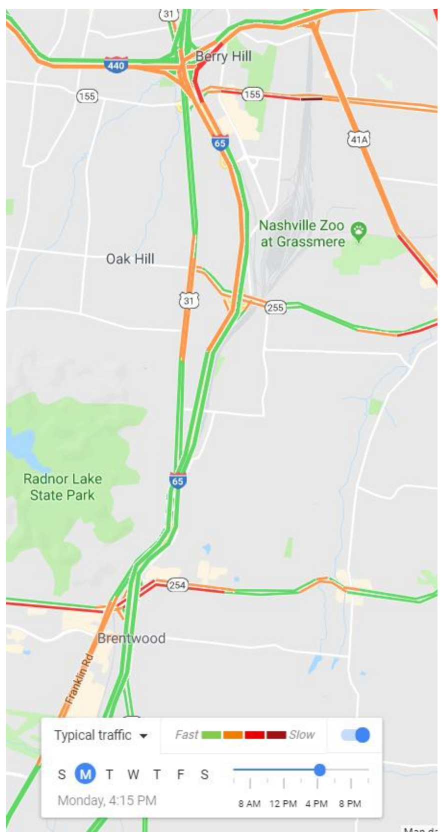



Figure 8-12 Bottleneck activation at Exits 78 and 79 at 4:15 PM on a typical Monday

Notice that in Figure 8-13, capacity discharge is moving toward Exit 74 (Old Hickory Boulevard). However, there seems to be some thinning of this traffic stream as it moves toward Exit 74, as some drivers have higher desired speeds than other drivers. The conditions of the bottleneck at 5:35 PM show that even though the bottleneck at Exit 78 has been providing near capacity discharge, it is not always the case that the diverge at Exit 74 causes significant problems. It appears that on most days this thinning mechanism is sufficient to prevent major bottlenecks from occurring at Exit 74, but this is not always true. On occasion, weaving problems can cause a significant enough capacity drop to create the formation of a secondary bottleneck at this location, particularly on a day for which demand is heavy, such as a typical Thursday as shown in Figure 8-14.

On the most heavily trafficked days, weaving impacts can also cause problems near Exit 71 (Concord Road) and an active bottleneck exists for at least the merge, and possibly the diverge, at Exit 71. The merge and diverge can both present problems at interchange 71 from approximately 4:45 to 6:00 on a day with a heavy PM peak demand, as shown in Figure 15. It should be noted that the impacts of weaving on the performance of I-65 might be able to be mitigated by changes to access management strategies at the Concord Road interchange, though care must be taken to avoid causing exiting traffic to spill back into the interstate if influx to the interstate is to be controlled at the interchange's signalized intersection. However, even under the heaviest traffic conditions typically faced, traffic usually has thinned enough so that there is no significant problem at exits south of Exit 69, Moore's Lane.

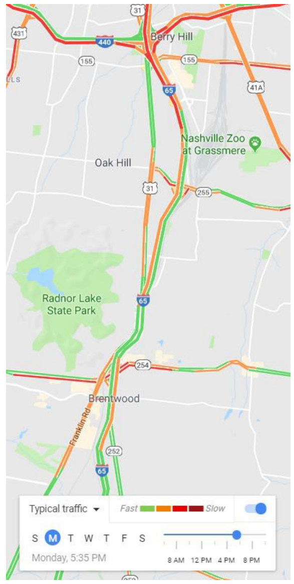



Figure 8-13 Traffic Conditions at Exit 74 at 5:35 PM on a typical Monday

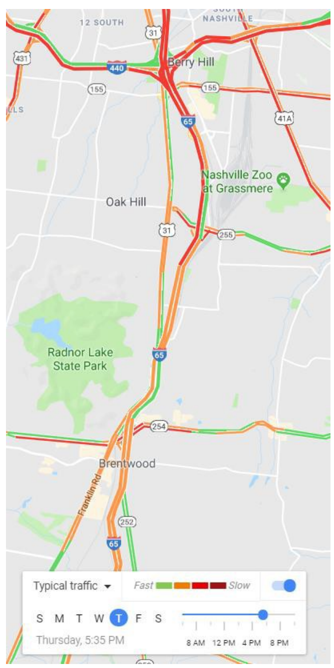



Figure 8-14 Traffic conditions at 5:35 PM on a typical Thursday

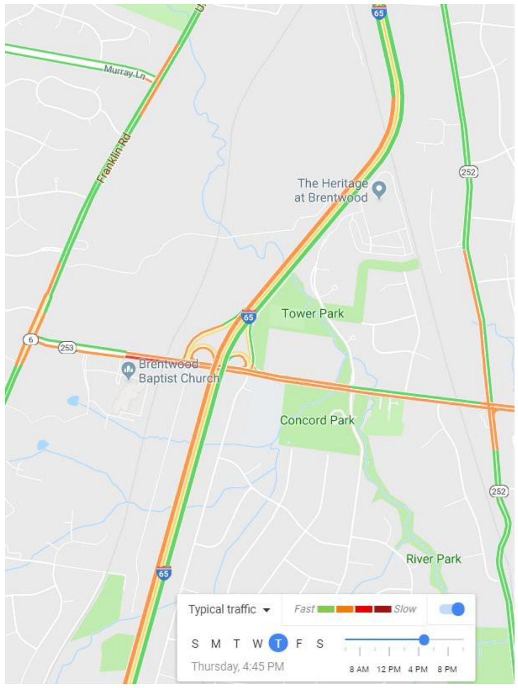



Figure 8-15 Traffic conditions at Exit 71 (Concord Road) at 4:45 PM on a typical Thursday

## 8.6 Conclusions

In this chapter, a cell transmission model was built to simulate the flow of traffic on the southbound I-65 HOV corridor. The basic CTM approach has been combined with regression analysis to predict likely conditions in both the mixed-flow lanes and the HOV lane using the results of a one-dimensional model where the freeway is represented by single cells. The results of the LWR PDE are similar to typical traffic conditions observed on the highway via mobile sensing.

On this corridor, it was found that the major bottleneck would be the lane drop at Exit 78 of the corridor, and that flow downstream of the bottleneck would generally be at capacity for a significant distance beyond the bottleneck. In this region, congestion should be expected in both the mixed-flow and HOV lanes, with the HOV lanes operating at fairly low speeds. If the models are reasonably accurate, these facilities may operate at speeds near 40 mph during peak times. Although the performance of this particular section is significantly degraded, it is unlikely that further degradation will occur under heavier traffic loadings, as the bottleneck at Exit 78 governs the flow of the system, and the performance of this part of the system cannot be further degraded by higher fluxes upstream. This is because the LWR PDE has characteristics that are moving backward, and the weak boundary conditions required to have a well-posed boundary value problem make the flow uncontrollable from upstream, as flow at this point is controlled by downstream conditions. The flow in this segment is only controllable by modifying conditions downstream by increasing throughput at bottlenecks.

The CTM indicates that flow should be at or near capacity for a long section of highway from Exit 78 to well into Franklin (Exits 69, 68, and 67). Traffic does, however, have the space to thin after the bottleneck at Exit 78 due to the natural variation in desired speeds, and this thinning effect suggests that in general I-65 operates in an uncongested state on most days during the PM peak.

However, this natural thinning of traffic does not always suffice to avoid the complications caused by (primarily) diverge and (occasionally) merging bottlenecks on the corridor. Given that operations at or near capacity are very unstable near the peak of the fundamental diagram and that a capacity loss of ten percent or more is not uncommon as traffic flow moves from an uncongested regime to a congested regime, careful attention should be paid to traffic at or near merge bottlenecks.

Finally, this chapter has made a contribution to the study of HOV lanes using traffic macrosimulation models. As the CTM is a one-dimensional model that does not account for differences in lane speeds, this chapter has leveraged the regression equations in Chapter 3 that relate the speeds in the HOV lane and the mixed-flow lane to the average speed of all vehicles on the highway. By implementing these equations, the basic CTM has been extended to handle simulations on the HOV corridor. As a result, the CTM can be used as a useful benchmarking tool for the study of HOV corridors by more sophisticated microsimulation techniques.

# Chapter 9 Process of Development, Calibration, and Validation of VISSIM Models and Implementation on Southbound I-65 Corridor

The I-65 Southbound corridor from MM 80 to MM 59 has been studied in PTV VISSIM to gain additional insights into the performance of the corridor. While the cell transmission model provides a reasonable approximation to the evolution of the macroscopic flow variables for I-65 across space, it cannot identify problems caused by weaving issues at or near bottlenecks. Microsimulation provides a useful tool that can often aid in the diagnosis of operational problems faced by traffic facilities by providing more realistic modeling of individual driver behaviors and allowing the interaction of drivers to produce the macroscopic properties of traffic flow.

As a result of the modeling process, one is expected to have a more thorough understanding of how drivers on the facility behave. This will give a better insight into the performance of the Cell Transmission Model and its shortcomings. It will also give better insight into the operational problems facing the corridor.

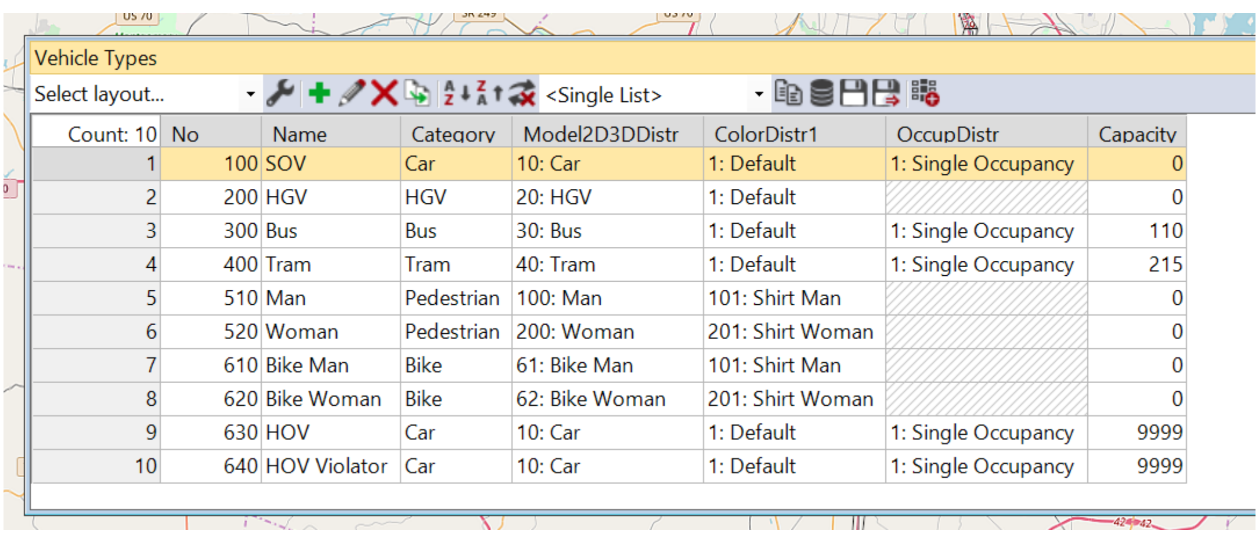
## 9.1 Model Inputs

### 9.1.1 Network Construction

The network has been modeled in VISSIM 9.0 by constructing links to represent the main line and the entrance and exit ramps. These links have no signalized controls, and it is assumed that all vehicles that wish to enter or exit can do so freely without disturbing operations on the main line. Upon review of Google Traffic data, there seems to be no queue spillback into the interstate at any exit, and drivers typically can merge at will into the traffic stream, making the lack of traffic control in the VISSIM model unproblematic. The links are set up such that trucks cannot access the leftmost two lanes (including the HOV lane) and SOV vehicles cannot access the HOV lane. HOV’s and HOV violators are permitted to use the HOV lane. All link behaviors are considered to be Urban (motorized) and use the Wiedemann 74 driver behavior model using the slow lane rule (preventing overtaking in the slow lane) and cooperative lane change behaviors. This choice has been made because of the difficulty in modeling the weaving behaviors near the merge and diverge bottlenecks on this facility.

### 9.1.2 Vehicle Types

The standard VISSIM vehicle types and associated base data have been used, but two new vehicle types have been added to study the performance of the HOV corridor and the behaviors of drivers as shown in Figure 9-1. The HOV vehicle type has been added (No. 630) and is assigned the 10: Car vehicle class. The HOV Violator vehicle type has been added No. 640) and is also assigned the 10: Car vehicle class. Only the HOV and HOV Violator Vehicle classes will be given access to the HOV lane. However, only the SOV, HGV, HOV, and HOV Violator vehicle types will be used.


Vehicle Types

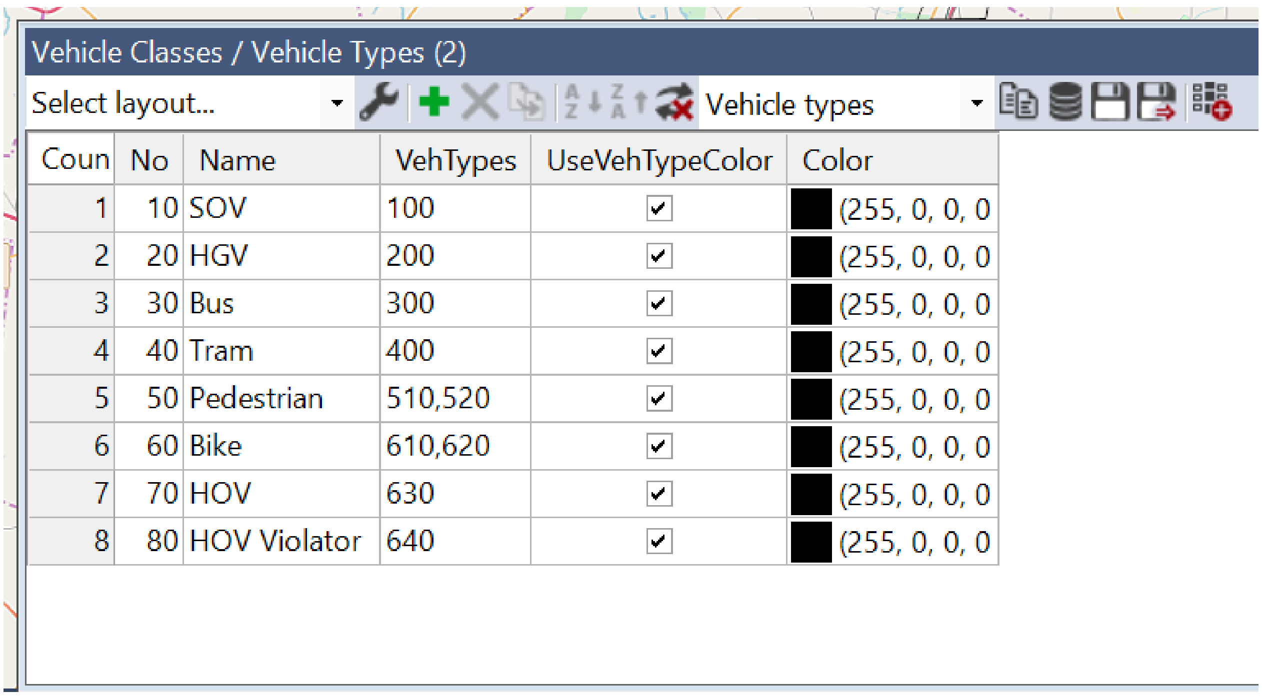
Select layout... <Single List>

| Count: 10 | No | Name | Category | Model2D3DDistr | ColorDistr1 | OccupDistr | Capacity |
|---|---|---|---|---|---|---|---|
| 1 | 100 | SOV | Car | 10: Car | 1: Default | 1: Single Occupancy | 0 |
| 2 | 200 | HGV | HGV | 20: HGV | 1: Default | | 0 |
| 3 | 300 | Bus | Bus | 30: Bus | 1: Default | 1: Single Occupancy | 110 |
| 4 | 400 | Tram | Tram | 40: Tram | 1: Default | 1: Single Occupancy | 215 |
| 5 | 510 | Man | Pedestrian | 100: Man | 101: Shirt Man | | 0 |
| 6 | 520 | Woman | Pedestrian | 200: Woman | 201: Shirt Woman | | 0 |
| 7 | 610 | Bike Man | Bike | 61: Bike Man | 101: Shirt Man | | 0 |
| 8 | 620 | Bike Woman | Bike | 62: Bike Woman | 201: Shirt Woman | | 0 |
| 9 | 630 | HOV | Car | 10: Car | 1: Default | 1: Single Occupancy | 9999 |
| 10 | 640 | HOV Violator | Car | 10: Car | 1: Default | 1: Single Occupancy | 9999 |

Figure 9-1 VISSIM vehicle type inputs for simulation of the I-65 southbound corridor

### 9.1.3 Vehicle Classes

Figure 9-2 shows the vehicle types used in the VISSIM simulation. The model uses the standard VISSIM vehicle classes and default base data associated with those classes, with two new vehicle classes added. The HOV vehicle class (No. 70) is added and uses the vehicle type 630: HOV. The HOV Violator vehicle class (No. 80) is added and uses the vehicle type 640: HOV Violator.




| Coun | No | Name | VehTypes | UseVehTypeColor | Color |
|---|---|---|---|---|---|
| 1 | 10 | SOV | 100 | ✓ | (255, 0, 0, 0 |
| 2 | 20 | HGV | 200 | ✓ | (255, 0, 0, 0 |
| 3 | 30 | Bus | 300 | ✓ | (255, 0, 0, 0 |
| 4 | 40 | Tram | 400 | ✓ | (255, 0, 0, 0 |
| 5 | 50 | Pedestrian | 510,520 | ✓ | (255, 0, 0, 0 |
| 6 | 60 | Bike | 610,620 | ✓ | (255, 0, 0, 0 |
| 7 | 70 | HOV | 630 | ✓ | (255, 0, 0, 0 |
| 8 | 80 | HOV Violator | 640 | ✓ | (255, 0, 0, 0 |

Figure 9-2 VISSIM vehicle class inputs for simulation of I-65 southbound corridor

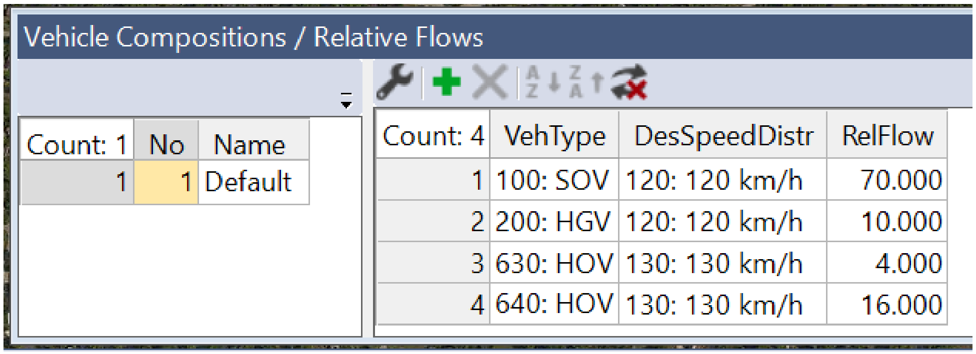
### 9.1.4 Vehicle Compositions

Figure 9-3 shows a typical vehicle composition input. Vehicle compositions will be varied through the course of the simulation, but as the speed limit is constant through the entire freeway, it will generally suffice to use one desired speed distribution per vehicle class. These are assigned under vehicle compositions. Unless otherwise indicated in this section, it will be assumed that the default traffic composition includes ten percent trucks and twenty percent HOVs in the vehicle composition. The HOV and SOV vehicle classes are all assumed to follow the default 120 km/h desired speed distribution. The HOV and HOV Violator classes are expected to have a higher desired speed and are assigned the default 130 km/h desired speed distribution.

As a major objective of this study is to understand the behaviors of users on the highway, varying the vehicle composition can be accomplished to determine the proportion of SOV's willing to violate HOV lane use restrictions. As it is relatively well established through other studies that approximately 20% of vehicles are HOV's, the relative size of the HOV violator class can be varied to match VISSIM's violation rates to those observed in the field. (This rate is very close to 80 percent at Old Hickory Boulevard according to TDOT project number RES2016-05). Further, the utilization rate for the HOV lane is currently only approximately 15% to 20%, so calibration will be performed to set the HOV lane flows in the 15 to 20 percent range.

To develop a reasonable default vehicle composition, we will interpret the vehicle classes in the following ways. We will interpret the HOV class as the HOV's who are willing to use the HOV lane. This will likely be significantly smaller than the actual proportion of HOVs in the actual traffic stream. The SOV vehicle class will be interpreted as the vehicles that are unwilling to access the HOV lane regardless of occupancy. The HOV Violator class will be interpreted as the single-occupant vehicles willing to use the HOV lane.

Calibration was performed by keeping the ratio of the HOV to HOV Violator relative flows fixed at 1:4, assuring a violation rate near 80 percent. The HOV relative flow was varied until HOV lane utilization was approximately 15 to 20 percent of the total flow on the corridor. The resulting vehicle class inputs are shown in Figure 3 and were derived after joint calibration of driver behavior and vehicle composition parameters.


Vehicle Compositions / Relative Flows

| Count: 1 | No | Name |
|---|---|---|
| 1 | 1 | Default |

| Count: 4 | VehType | DesSpeedDistr | RelFlow |
|---|---|---|---|
| 1 | 100: SOV | 120: 120 km/h | 70.000 |
| 2 | 200: HGV | 120: 120 km/h | 10.000 |
| 3 | 630: HOV | 130: 130 km/h | 4.000 |
| 4 | 640: HOV | 130: 130 km/h | 16.000 |

Figure 9-3 Final calibration results for VISSIM simulation model inputs for southbound I-65 corridor.

If it is assumed on the basis of the Parsons (2012) study that 22 percent of the traffic can be assumed to be high occupancy vehicles, then by the interpretation of the SOV class as both single and high occupancy vehicles unwilling to use the HOV lane, it can be seen that the 70% of the relative traffic assigned to the SOV Vehicle Class can be broken down into approximately the remaining 18 percent of the high occupancy vehicles who are unwilling to use the HOV lane and 52 percent of compliant single-occupant vehicles. This means that 23.5% of the traffic stream comprises of willing violators. Of the 393 individuals who answered question number 25 of the survey, 26.7 percent admitted to violating HOV lane restrictions more than ten percent of the time spent driving on the corridors. Because of the similarity in these figures and the fact that VISSIM allows drivers to make discretionary lane changes to minimize delay, ***it is reasonable to assume that approximately one in four drivers will be willing to violate the HOV lane restrictions to save travel time.***

### 9.1.5 Vehicle Inputs

For the development of a base model of operations of the I-65 southbound corridor, the vehicular inputs shown in Table 9-1 were used. These correspond to a level of demand given to K = 0.08 for the studies undertaken in Chapter 3 of this report.

Table 9-1 Source and In-Ramp Fluxes for Southbound I-65 South of Nashville

| Source/Ramp | Flux |
|---|---|
| MM 80 | 8409 |
| Entrance 79 | 539 |
| Entrance 78 | 925 |
| Entrance 74 | 1363 |
| Entrance 71 | 666 |
| Entrance 69 | 719 |
| Entrance 68 | 581 |
| Entrance 67 | 423 |
| Entrance 65 | 624 |
| Entrance 61 | 194 |

### 9.1.6 Static Vehicle Routing

Two primary types of vehicle routing decisions have been placed on the network. The first type of vehicular routing decision is used to prevent vehicles entering the highway from being lost from the simulation whenever their auxiliary lane terminates. The other type of static vehicle routing decision is placed in advance of an exit and requires a relative flow split. Vehicular exit probabilities are generally chosen to be consistent with the cell transmission model simulations in Chapter 3 of this report and are determined in the same manner as in Chapter 3 of this report. Some interchanges with A-B exits require further detailed description in the specification of static vehicle routing decisions in VISSIM. Table 9-2 gives the relative flows at each static vehicle routing decision.

Table 9-2 Vehicle Static Routing Decisions

| Decision Name | Route Number | Route Name | Relative Flow |
|---|---|---|---|
| Exit 79 | 1 | Through | 93 |
| | 2 | Exit 79 | 7 |
| Exit 78 | 1 | Through | 87 |
| | 2 | Exit 78 | 13 |
| Exit 74 | 1 | Through | 80 |
| | 2 | Exit 74 A | 12 |
| | 3 | Exit 74 B | 8 |
| Exit 71 | 1 | Through | 92 |
| | 2 | Exit 71 | 8 |
| Exit 69 | 1 | Through | 79 |
| | 2 | Exit 69 | 21 |
| Exit 68 | 1 | Through | 84 |
| | 2 | Exit 68A | 6 |
| | 3 | Exit 68 B | 10 |
| Exit 67 | 1 | Through | 91 |
| | 2 | Exit 67 | 9 |
| Exit 65 | 1 | Through | 75 |
| | 2 | Exit 65 | 25 |
| Exit 61 | 1 | Through | 89 |
| | 2 | Exit 61 | 11 |

### 9.1.7 Driver Behaviors

The development of the models for this corridor encountered significant difficulty in accurately capturing weaving behaviors, especially near diverge bottlenecks. Specifically, with the parameters of the Wiedemann 74 model left at their default values, drivers in the leftmost lanes would continue in the leftmost lanes until it was practically too late for the driver to take the exit without a serious disturbance to traffic. In some instances, the driver would stop for several seconds of the simulation until a sufficient gap existed to get off the interstate at the diverge exit.

While this behavior is not uncommon in practice, and while this behavior is a major contributor to the breakdown of diverge bottlenecks, the extent to which drivers engage in this behavior is largely unrealistic. An example of such problems with the use of the default Wiedemann 74 is shown in Figure 9-4. Note that the two vehicles with red dots are moving at an unrealistic angle for exiting vehicles, and these two vehicles have been stopped for a few seconds with other traffic moving at near free-flow speeds. The red dots indicate blinking turn signals, showing the intent of drivers to change lanes. Under default parameters of the Wiedemann 74 model, the drivers are unable to merge before getting to their exits. This behavior suggests that the default Wiedemann 74 parameters are unacceptable to realistically model the merging behavior near the diverge bottlenecks.

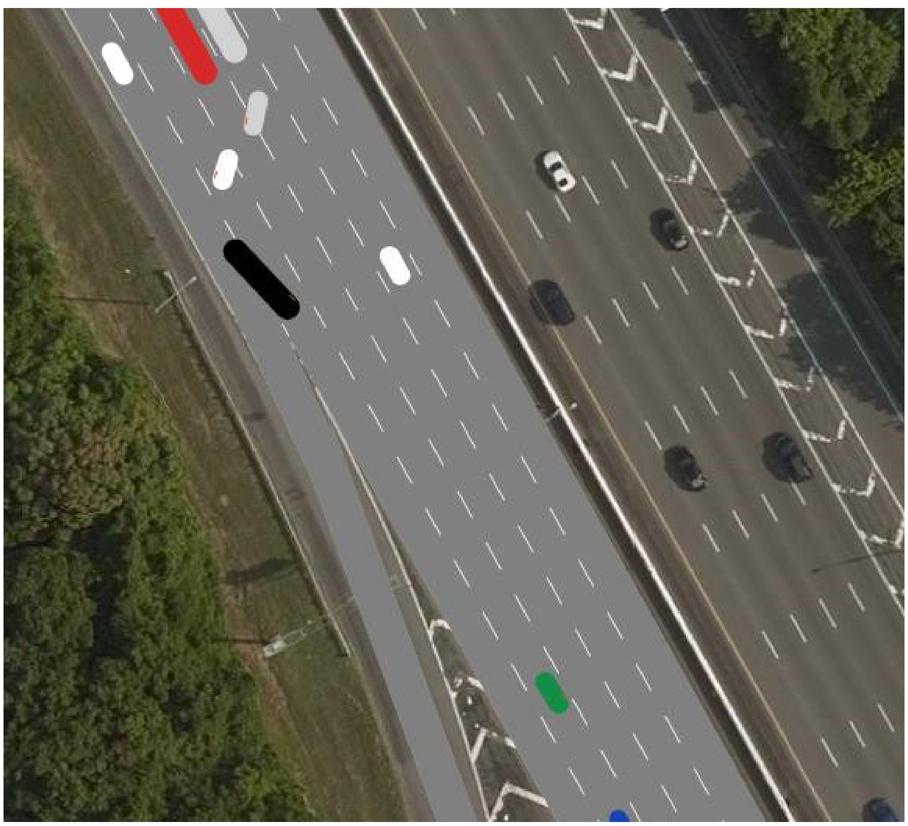


Figure 9-4 Unrealistic merging behaviors in VISSIM

The performance of the model was improved by changing the default standstill spacing in the Wiedemann 74 model of driver behavior to an assumed average vehicle length of 20 feet, thereby providing more reasonable spaces for drivers to change lanes. This standstill distance led to more conservative and cooperative behavior in the model. The increase in spacing leads to a greater separation in the traffic at or near jam density as shown in Figure 9-5:

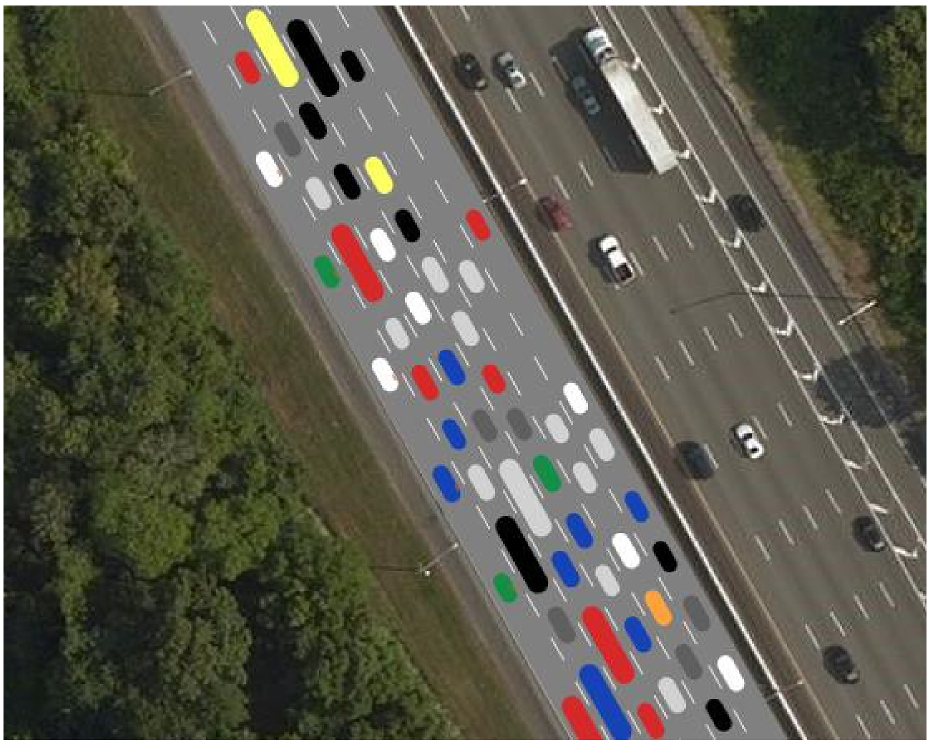


Figure 9-5 Longer spacing between vehicles at jam density

### 9.1.8 Evaluation Objects

The VISSIM model has been equipped with several evaluation objects to facilitate data collection. As shown in Figure 9-6, each on and off-ramp and interchange has been equipped with data collection points and travel time measurements. Typically, data collection points (light pink lines across freeway) are placed at overpasses along with travel time measurements (light green lines across freeway). Figure 9-6 shows a typical layout of evaluation objects.

Figure 9-6 Layout of data collection points and travel time measurements

To compute total emissions and total delays at each interchange, nodes were drawn around each interchange to include the entrance and exit ramps. These nodes extend to approximately halfway between interchanges in either direction. The nodes are drawn as shown in Figure 9-7.

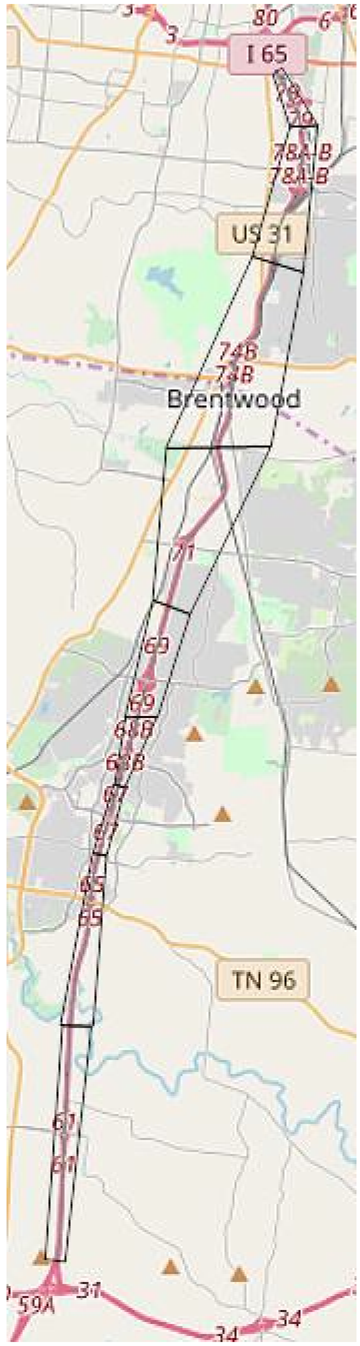



Figure 9-7 Layout of nodes for evaluation of interchanges (indicated by lines across the interstate)

## 9.2 Comparison of VISSIM Model with Mobile Sensing Data

The VISSIM model as calibrated does a reasonable job of approximating key features of the traffic stream at the times of heaviest demand. The screenshots in this section show typical features of the traffic flow pattern in VISSIM along with the corresponding features of traffic observed in Google Traffic.

### 9.2.1 Interchange 78 and 79 Bottlenecks

The section between the beginning of the HOV corridor and Exit 78 is of primary importance to the traffic patterns downstream. This section, located at the beginning of the corridor, contains the corridor’s primary bottleneck and is responsible for controlling the majority of flow downstream of the bottleneck. Figure 9-8 and Figure 9-9 show the formation of diverge bottlenecks starting at Exit 79 and Exit 78 respectively. As can be seen from Figure 9-10 and Figure 9-11, Entrance 79 tends to operate freely until queue spillback from Exit 78 reaches Entrance 79. However, once queue spillback reaches Entrance 79, major merge problems begin to occur, and often the merge bottleneck at Entrance 79 controls the flow on this segment as shown in Figure 9-12 and Figure 9-13.

Figure 9-8 Diverge bottleneck forming at Exit 79

Figure 9-9 Diverge Bottleneck forming at Exit 78

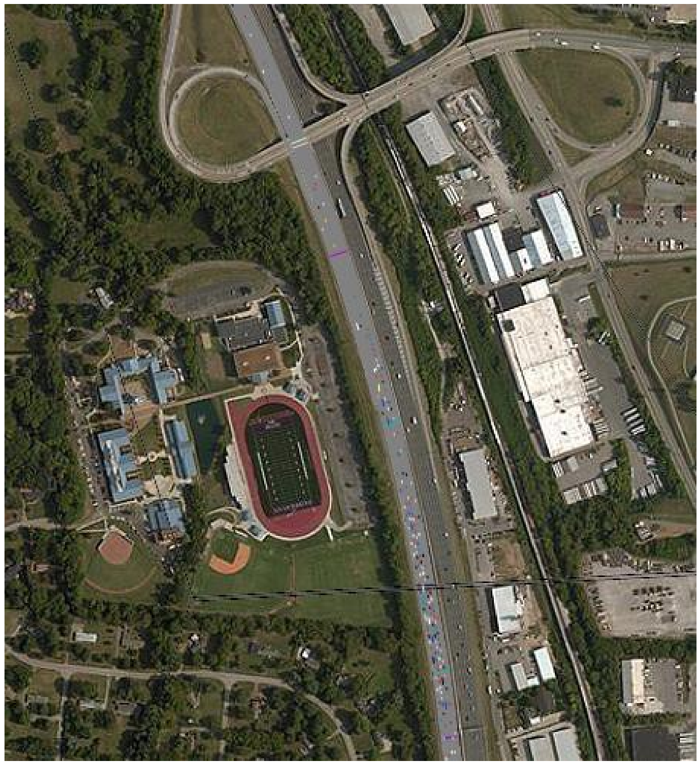


Figure 9-10 Queue spillback from Exit 78 approaching a freely flowing Entrance 79


Figure 9-11 Google Traffic data showing queue spillback from Exit 78

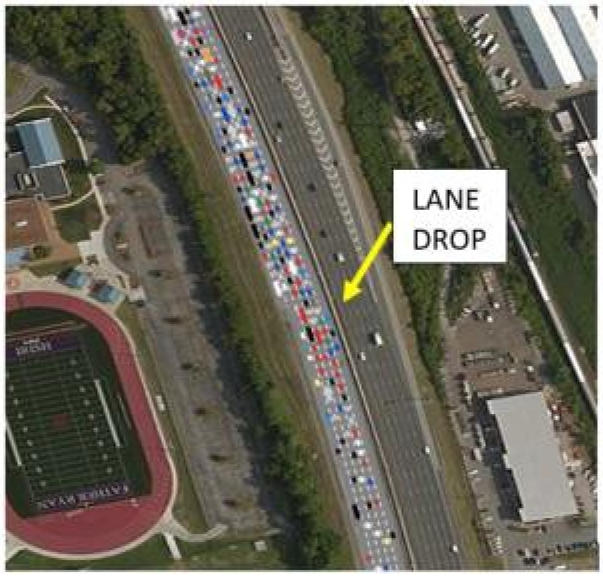



Figure 9-12 Merge bottleneck at Entrance 79 controlling flow between MM 80 and MM 78. Note the change in density of traffic immediately before and after the lane drop located near the north end zone (labeled “IRISH”)

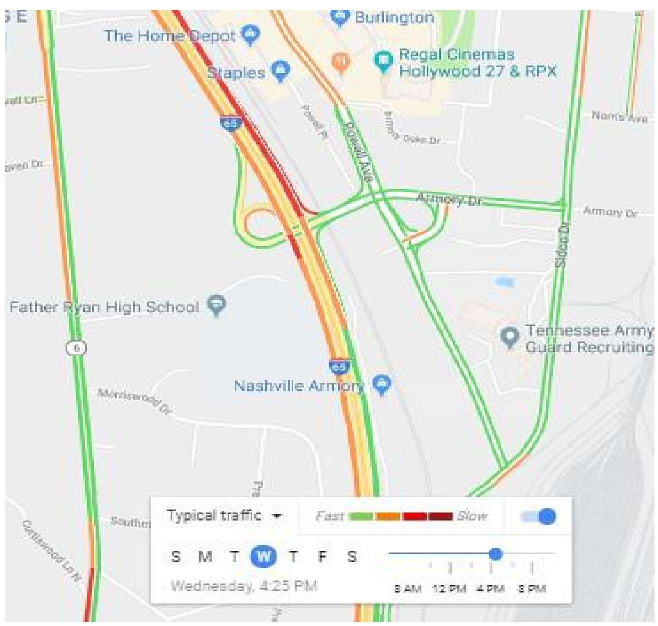



Figure 9-13 Confirmation of merge bottleneck at Entrance 79 controlling flow between MM 80 and MM 78

### 9.2.2 Interchange 74

As expected, traffic typically thins between Exit 78 and Exit 74, but there is often a diverge bottleneck that activates at Exit 74B. Figure 9-14 shows this bottleneck formation in the VISSIM simulation. Figure 9-15 shows the bottleneck formation in Google Traffic’s mobile sensing data. As can be seen in both the VISSIM and Google Traffic data shown in Figure 9-14 and Figure 9-15, a diverge bottleneck activates at Exit 74B first, but Exit 74A can become problematic on its own, even without problems arising from spillback from Exit 74B, as shown in Figure 9-16. This independent activation of a diverge bottleneck at Exit 74A is shown in Figure 9-17 where two orange stretches of highway exist immediately before Exit 74A and Exit 74B.

Figure 9-14 Bottleneck formation at Exit 74B

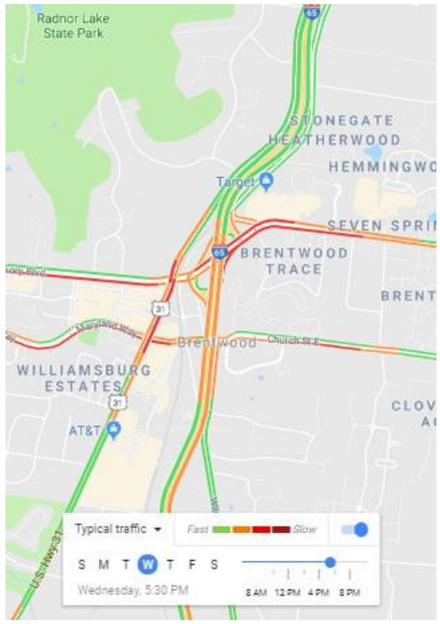



Figure 9-15 Confirmation of Bottleneck formation at Exit 74B in Google Traffic

Figure 9-16 Independent bottleneck activation at Exit 74A

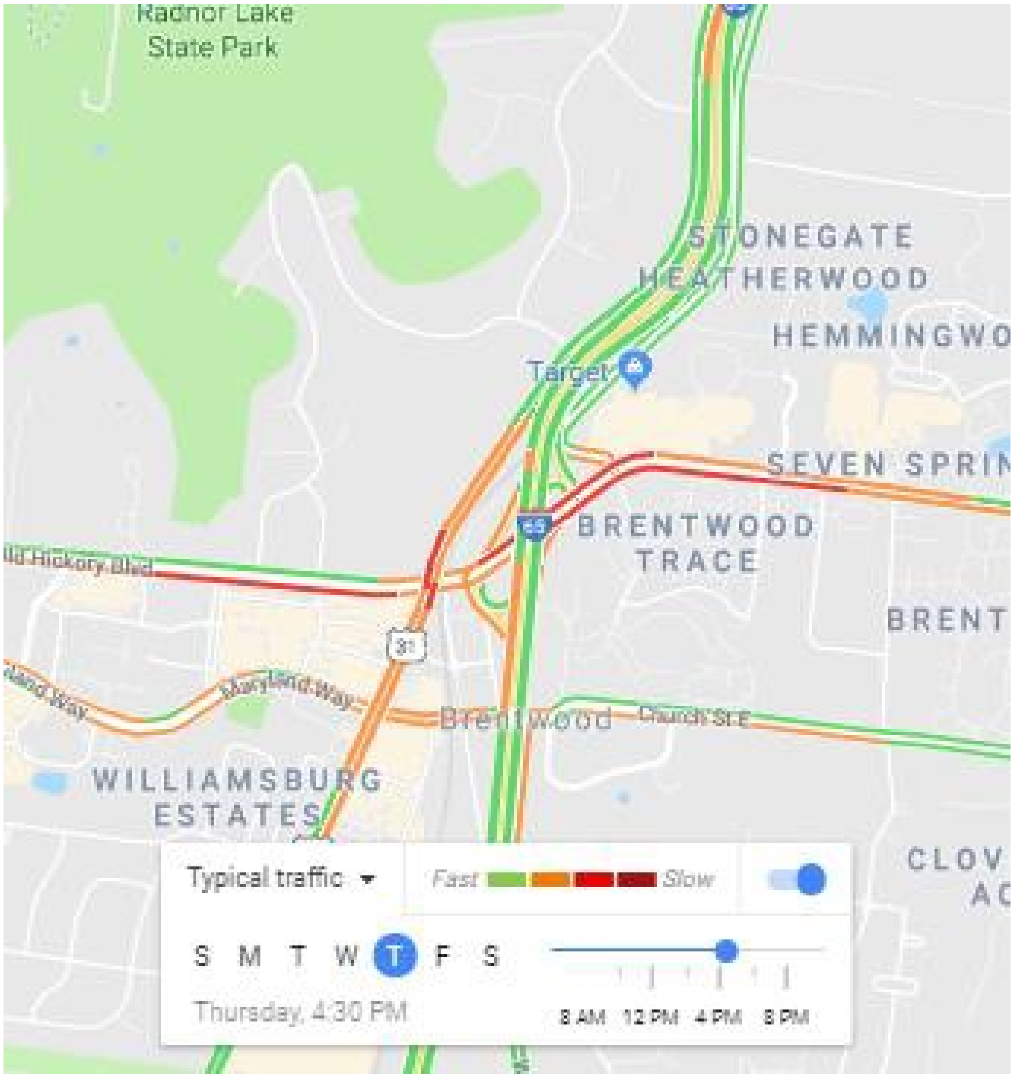



Figure 9-17 Confirmation of independent bottleneck activation at Exit 74A

### 9.2.3 Interchange 71

On heavily trafficked days, the basic freeway section between Exit 74 and Exit 71 can operate at capacity or a heavier density on occasion. The VISSIM simulation model screenshot in Figure 9-18 shows that this type of flow can happen and that mild to moderate congestion can take place. This is confirmed in Figure 9-19. Furthermore, Exit 71 can become a diverge bottleneck. This can happen at relatively lower volumes because of the high violation rate for the HOV lane. As more users enter the HOV lane, they must eventually exit the HOV lane, and many will choose to do so in ways that are disruptive to the progression of the overall traffic stream.

Diverge bottlenecks can activate whenever heavy traffic volumes exist near exits with high enough exit probabilities. This is likely the case at Exit 71, as shown in Figure 9-20 and Figure 9-21. However, this problem can become exacerbated as the merge bottleneck at Entrance 71 can spill back to Exit 71 on days with heavier volumes. When this happens, the entire section from Exit 74 to Exit 71 can experience delays.

Two problems could be improved with better queue discipline at this bottleneck. First, forcing exiting vehicles out of the HOV lane in a sufficiently early location will prevent the necessity of exiting vehicles to cross three lanes of traffic at the last minute. This will help prevent the breakdown of the diverge bottleneck. Secondly, making it easier for through-bound vehicles in the mixed-flow lanes to move right will likely improve the performance of the corridor by enabling cooperative lane changing. Preventing disruptive weaving maneuvers before the exit by barrier separation, a pair of double solid white lines with reflectors or some other means could improve the conditions near the interchange.

Figure 9-18 Heavy traffic between Exit 74 and Exit 71

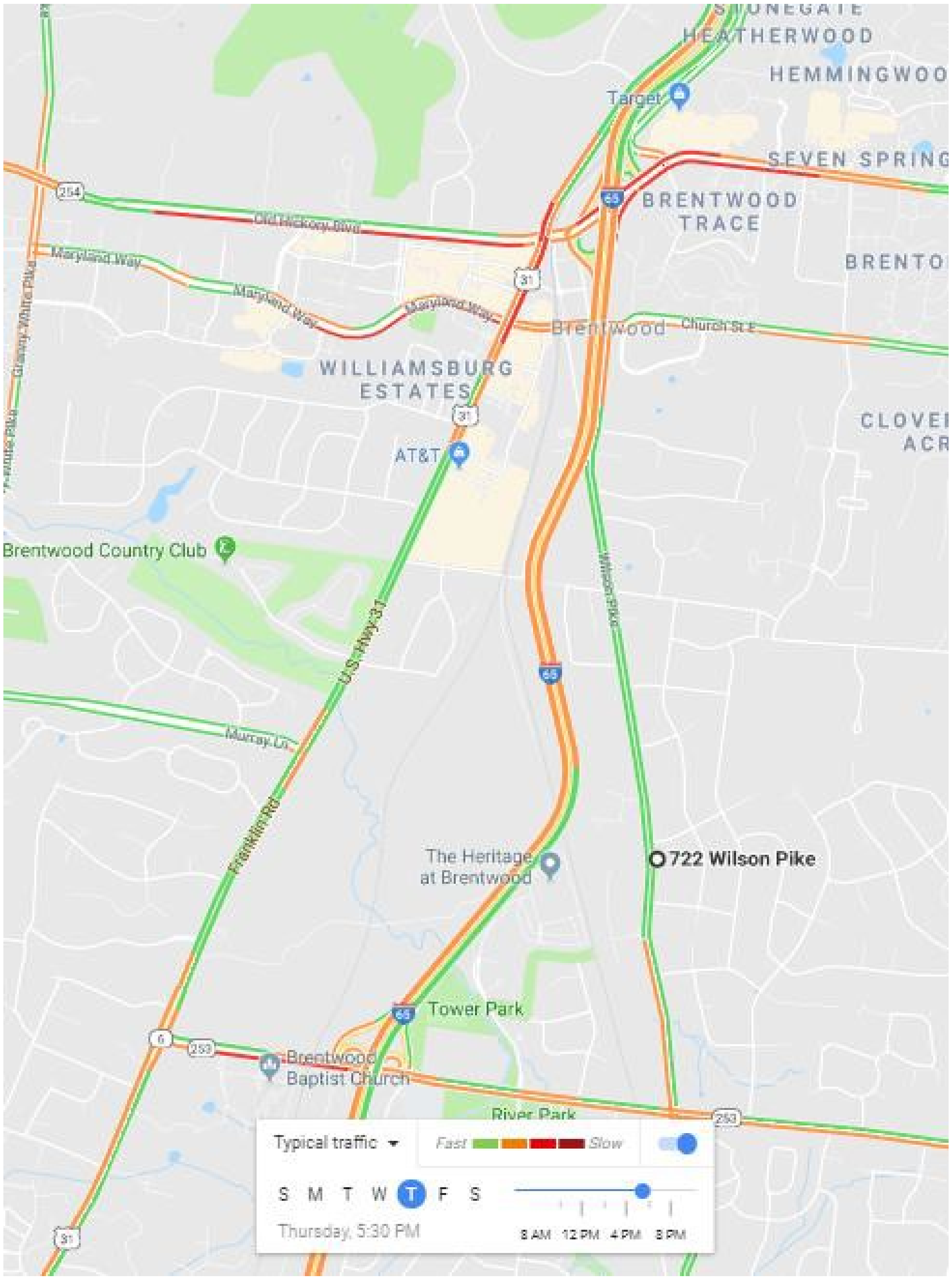



Figure 9-19 Confirmation of heavy traffic on I-65 between Exit 74 and Exit 71 during PM peak

Figure 9-20 Diverge formation at Exit 71

Figure 9-21 Merge bottleneck formation at Exit 71

### 9.2.4 Interchange 69

The segment of I-65 between Exit 71 and Exit 69 has significant weaving. It can be rather congested, though a relatively long auxiliary lane alleviates congestion closer to Exit 69. The VISSIM model captures this weaving behavior reasonably well. Traffic in the VISSIM simulation is typically stop-and-go near the diverge; bottlenecks may form and dissipate. As Exit 69 is located near a major commercial area, it would not be unrealistic for traffic to become congested here at times. It occasionally happens throughout the simulation that one final diverge bottleneck appears at Exit 69. Most of the time these queues dissipate rapidly in the VISSIM model. However, it is more typical for congestion to dissipate near the addition of the auxiliary lane. Google Traffic, however, does not typically show that the traffic near the diverge has significant delays although there is the possibility of queue spillback near the traffic signal for Exit 69. Figure 9-22 and Figure 9-23 show the typical dissipation of congestion upstream of Exit 69. Figure 9-24 shows the occasional bottlenecking that can occur at Exit 69.

Figure 9-22 Dissipation of congestion in advance of Exit 69

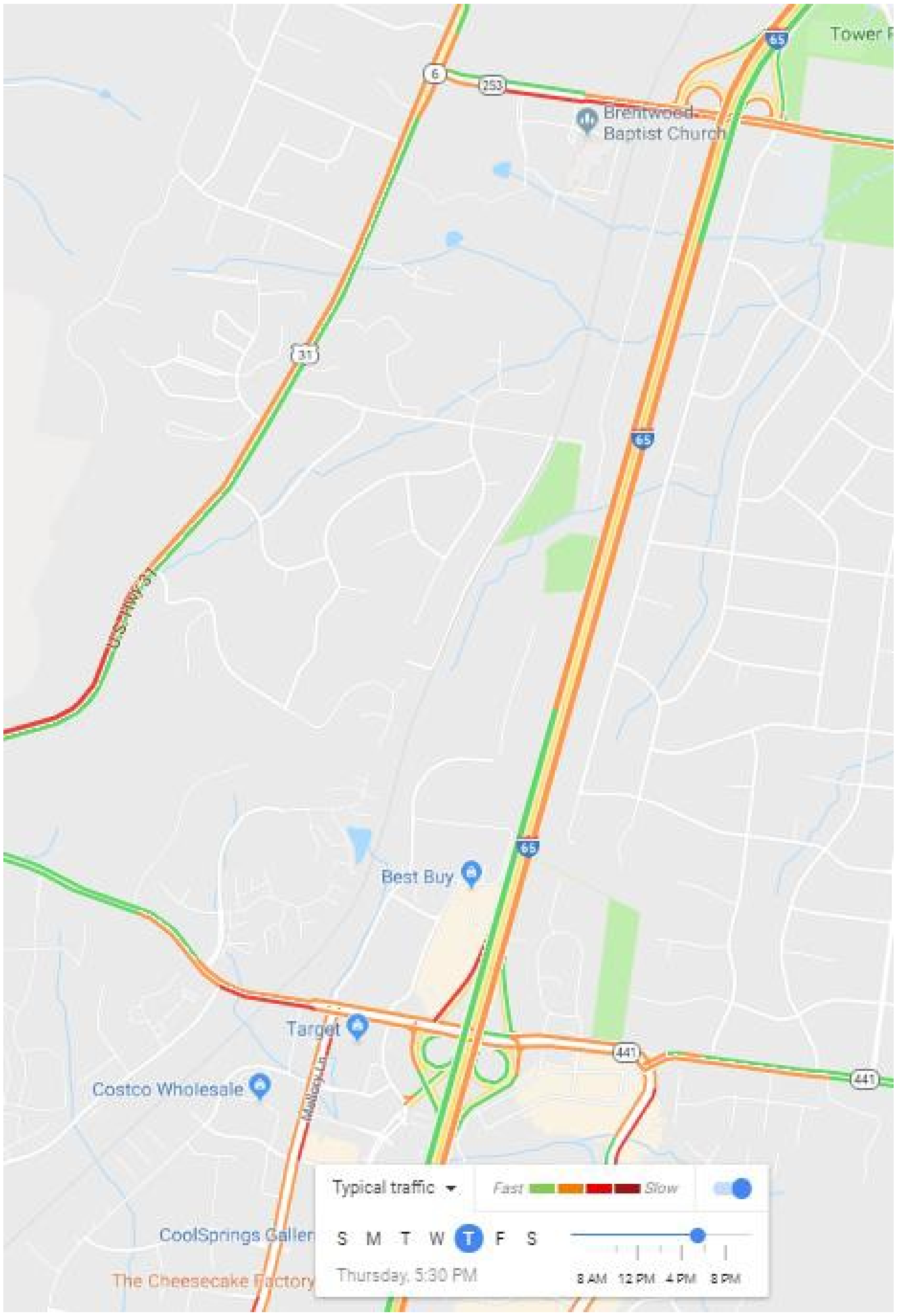



Figure 9-23 Confirmation of typical dissipation of congestion in advance of Exit 69

Figure 9-24 Diverge Bottleneck Formation near Exit 69

### 9.2.5 Conclusions

After calibration of the driver behavior model by adjusting the standstill distance in the Wiedemann 74 model, the VISSIM simulation can simulate traffic dynamics on the I-65 Southbound corridor from MM 80 to MM 59. By adjusting the vehicle composition and reinterpreting the vehicle classes, it is reasonable to assume that approximately one in four drivers of a single-occupant vehicle are willing to repeatedly violate the HOV lane use restrictions if it would reduce their delay.

The calibrated model reproduced many features of traffic flow modeling that agree with mobile sensing data collected and displayed in Google Traffic. Notable among these are:

- Initial activation of merge bottlenecks at Exit 79 and Exit 78 before activation of the merge bottleneck at Entrance 79.
- Control of the flow of the segment extending from MM 80 to MM 78 by the lane drop immediately following Entrance 79.
- Thinning of traffic at or near capacity discharge following Exit 78.
- The primary bottleneck forming at interchange 74 forming at Exit 74B, with independent formation of a bottleneck at Exit 74A, exacerbated by queue spillback from Exit 74B.
- Mild to moderate congestion between MM 74 and MM 71.
- The merge activating at Entrance 71 and spilling back to Exit 71.
- Moderate congestion between MM 71 and MM 69.
- The regular dissipation of the queue occurring near the auxiliary lane before Exit 69.
- Occasional bottlenecking at Exit 69

As the VISSIM model is capable of faithfully representing the traffic conditions appearing in Google Traffic, there is good reason to have a high degree of confidence in its calibration and results.

## 9.3 Comparison of Results of VISSIM Models and Field Data

Plots of the fundamental diagrams derived from the results of the VISSIM model and observed in the field are shown, respectively, in Figure 9-25 and Figure 9-26 for the mixed-flow lanes and Figure 9-27 and Figure 9-28 for the HOV lane. The field data used has been collected by TDOT at multiple locations along I-65 and I-24 corridors and was analyzed in Chapter 3 of this report to develop fundamental diagrams for the corridors.

There is a great deal of agreement between these figures, but there are some obvious discrepancies. Some of the differences in the figures can be attributed to the method of collection of the field data. Field data were collected over 24 hours, and each data point represents an observation taken over one hour. The field data consists of an aggregation of operational data from both the I-65 and I-24 corridors over 24-hour periods. The simulation period, however, is focused on peak demand with measurements taken at five-minute intervals. Therefore, the data from the simulation is focused on the peak of the fundamental diagram at near-capacity operations.

Some of the data collected in the field were collected at locations where the facility has different features from the Old Hickory interchange (i.e., Exit 78). As such the field data may indicate a higher capacity because other locations at which field measurements were taken could have had a higher capacity. However, the general shape of the diagrams tends to be similar, and a triangular shape for the fundamental diagram may be more reasonable.

One notable point is that in the figures below, the capacity of the facility appears to be lower than that assumed in the cell transmission models developed in Chapter 8. This is true at least in the vicinity of the bottlenecks. While locations between a downstream and upstream bottleneck may both be active at different points in time, and both congested and uncongested operations may be observed, the facility may never operate at its capacity at the measurement location if the flow is controlled at the point by upstream and downstream bottlenecks.

Hence it is unsurprising that the maximal flows observed in VISSIM simulations are lower than that observed in the amalgamation of field data. What may appear to be a capacity flow at Old Hickory Boulevard may not be indicative of the capacity of the highway at Old Hickory Boulevard, but rather of the capacity of some point upstream of Old Hickory Boulevard that discharges toward Old Hickory Boulevard. Analysis of the highway corridor using cumulative plots can be carried out by plotting traffic counts vs. time. A time shift based on the travel time from location to location on the freeway can be used to identify the location of the controlling bottleneck. This technique was developed in Bertini (2003).

It should be noted that the observed capacity of the HOV lane appears to be lower than the capacity of the mixed-flow lane. This is also sensible if one considers the impacts that late lane changes can have at diverge bottlenecks. If drivers who are seeking to merge right slow down to make the merge, then the capacity of the HOV lane will be reflective of this driver behavior. This is indicative of typical problems that can be encountered at diverge bottlenecks at times of peak demand. However, operations near capacity are often unstable, so it is difficult to conclude significance from the visual observation of differences in the areas near the peak of the fundamental diagram. It should also be noted that the data in Figure 9-28 includes data obtained on basic freeway sections upstream or downstream of bottlenecks. It is entirely possible, if not likely, that the capacity of the HOV lane is lower overall near bottlenecks than would be depicted in Figure 9-28 as some drivers are trying to exit the HOV lane and join slower moving traffic. Hence, the VISSIM models show good agreement with data obtained on Interstates 65 and 24 for the mixed-flow and HOV lanes.

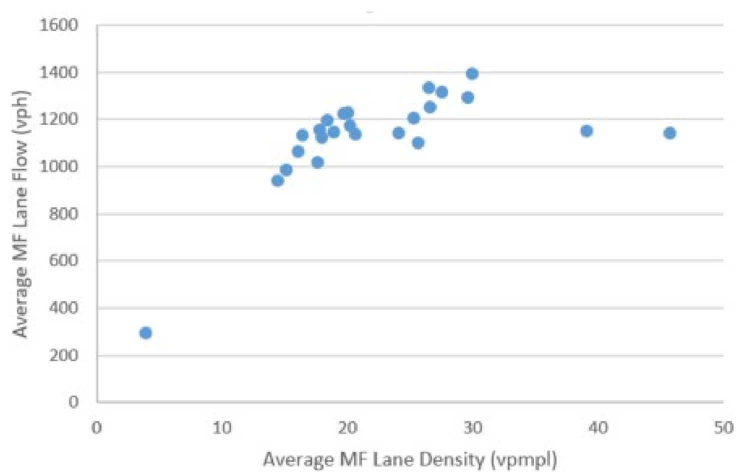



Figure 9-25 Mixed-flow lanes fundamental diagram at Old Hickory Boulevard constructed from VISSIM simulation results

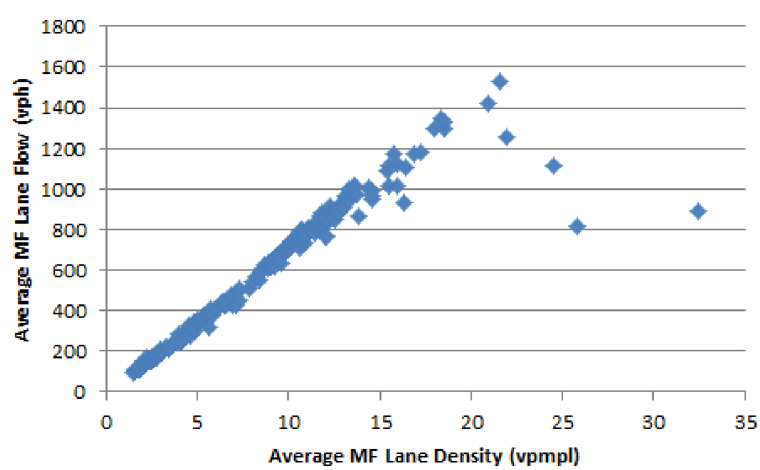



Figure 9-26 Fundamental diagram constructed based on hourly average flow and density values for all mixed-flow lanes at various locations on I-65 and I-24

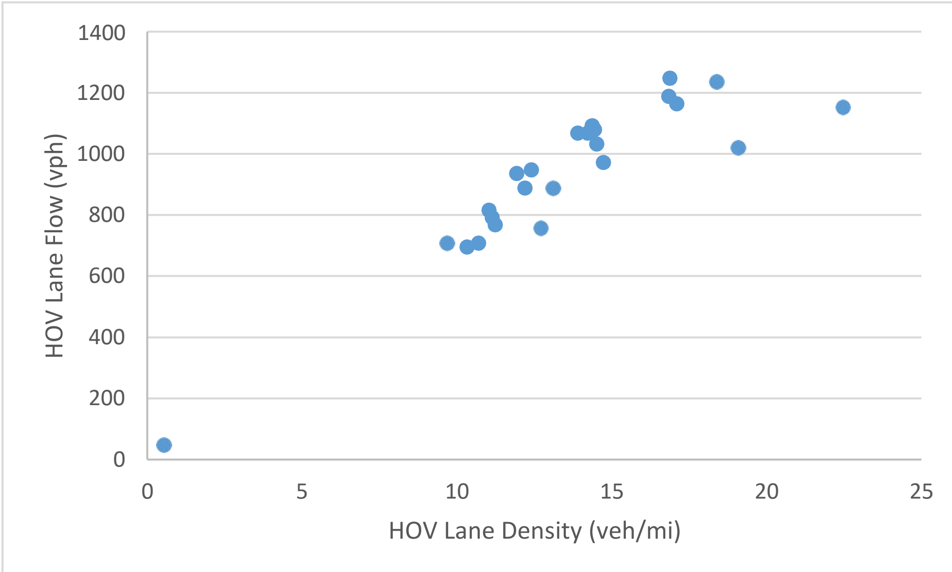



Figure 9-27 HOV lane fundamental diagram at Old Hickory Boulevard constructed from VISSIM simulation data

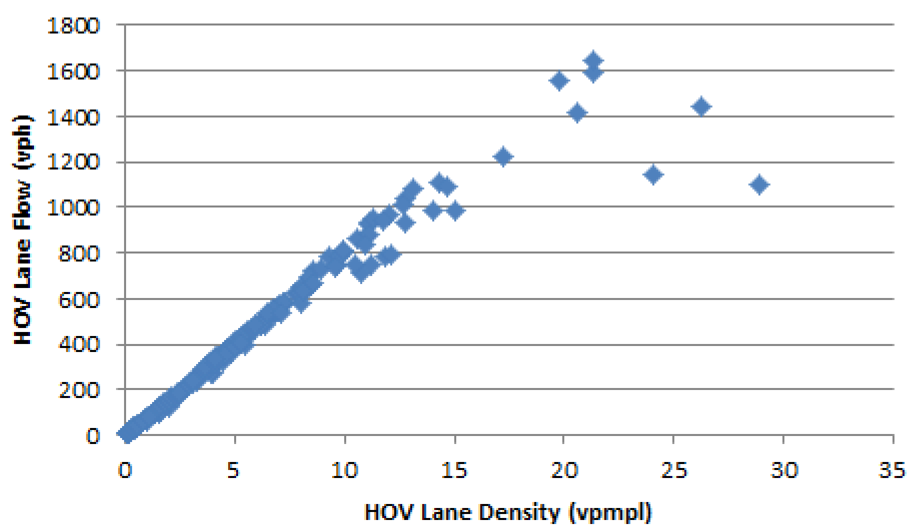



Figure 9-28 Fundamental diagram constructed based on hourly average flow and density values for HOV lanes at various locations on I-65 and I-24

In conclusion, there is a great deal of agreement in the speed, flow, and density data obtained through field studies and the speed, flow, and density data obtained through VISSIM. The field data and the VISSIM data tend to indicate that bottlenecks on the I-65 southbound corridor have lower capacities than those assumed in the cell transmission model developed in Chapter 3. As such, the cell transmission model's assumptions should be updated in light of the agreement among VISSIM results, mobile sensing data, and field data. This recalibration has been performed and is discussed in the next section.

## 9.4 Cell Transmission Model Revisions

In light of the poor ability of the cell transmission models as specified in Chapter 8 to predict the behavior of traffic near the bottlenecks, the capacity of the freeway at only the bottlenecks was modified. The capacity of the primary bottleneck at Exit 78 was reduced to a total of 5000 veh/h across all lanes. Additionally, the bottlenecks at Exit 74 and Exit 71 were reduced to a value of 99 percent of the capacity of the sections approaching them. The resulting cell transmission model much more faithfully represents conditions on the highway as congestion at these diverge bottlenecks is more realistically represented. Occupancy and speed in the segment between MM 80 and MM 78 are more closely matched to field observed values. Areas of high congestion are observed immediately upstream of the bottlenecks as shown in the occupancy plots of Figure 9-29 and Figure 9-30. The speed data for all vehicles and the HOV lane are shown in Figure 9-31-Figure 9-34. The speeds in the congested areas much more closely match those in the VISSIM simulation. For ease of visualizing the contours on the surface plot, the standard RGB scheme for graphics in Scilab's plotting functions has been used with colors automatically selected based on the values of the respective vertical axes in Figure 9-29, Figure 9-31, and Figure 9-33.

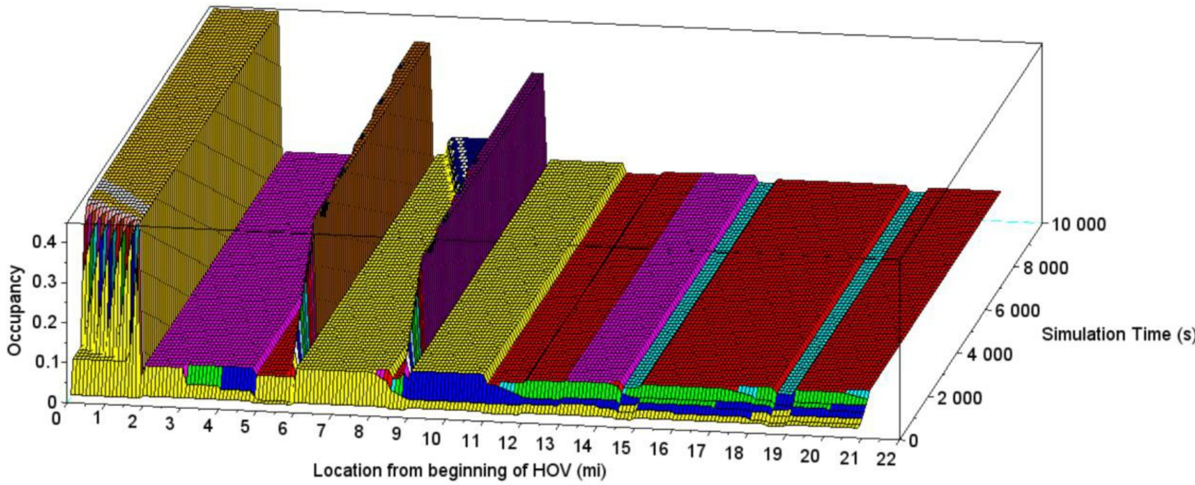



Figure 9-29 HOV lane occupancy data obtained from the cell transmission model simulation of I-65 southbound corridor with reduced capacity at bottlenecks taken at a simulation time of 9000 seconds

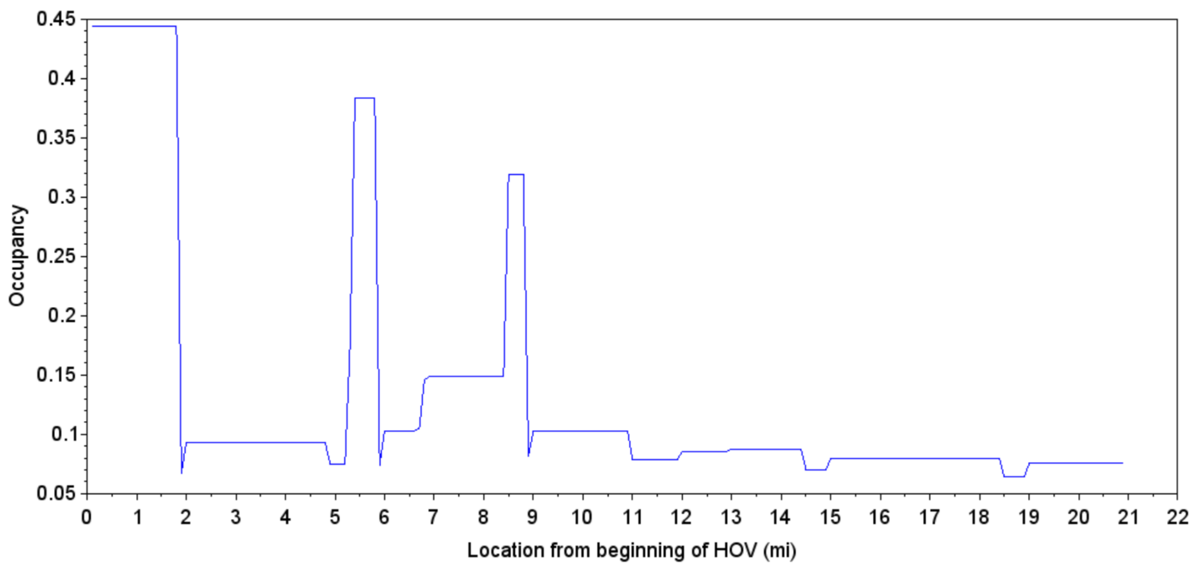



Figure 9-30 Occupancy data obtained from the cell transmission model simulation of I-65 southbound corridor with reduced capacity at bottlenecks at simulation time = 9000 seconds

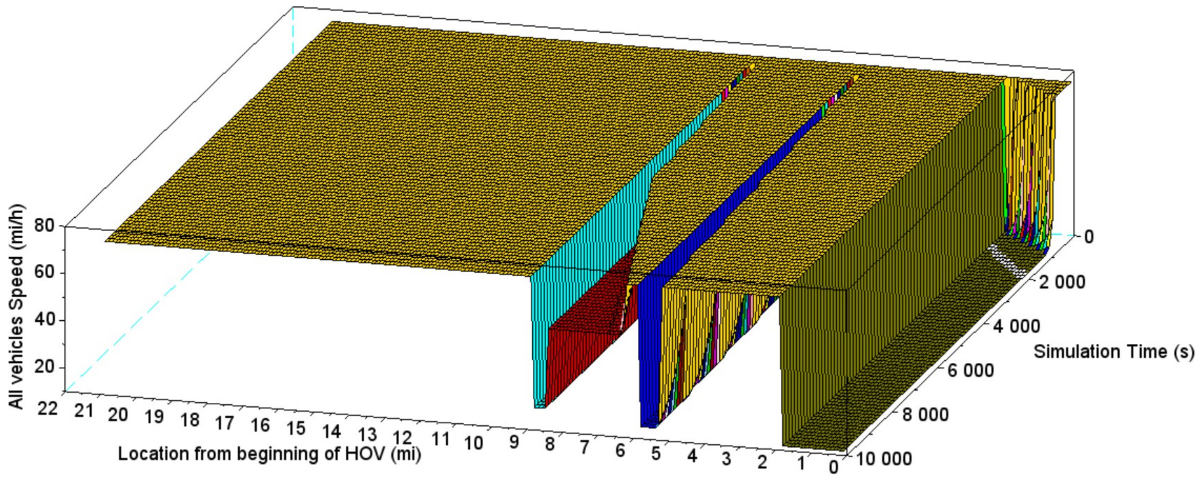



Figure 9-31 Space mean speed data obtained from the cell transmission model simulation of I-65 southbound corridor with reduced capacity at bottlenecks

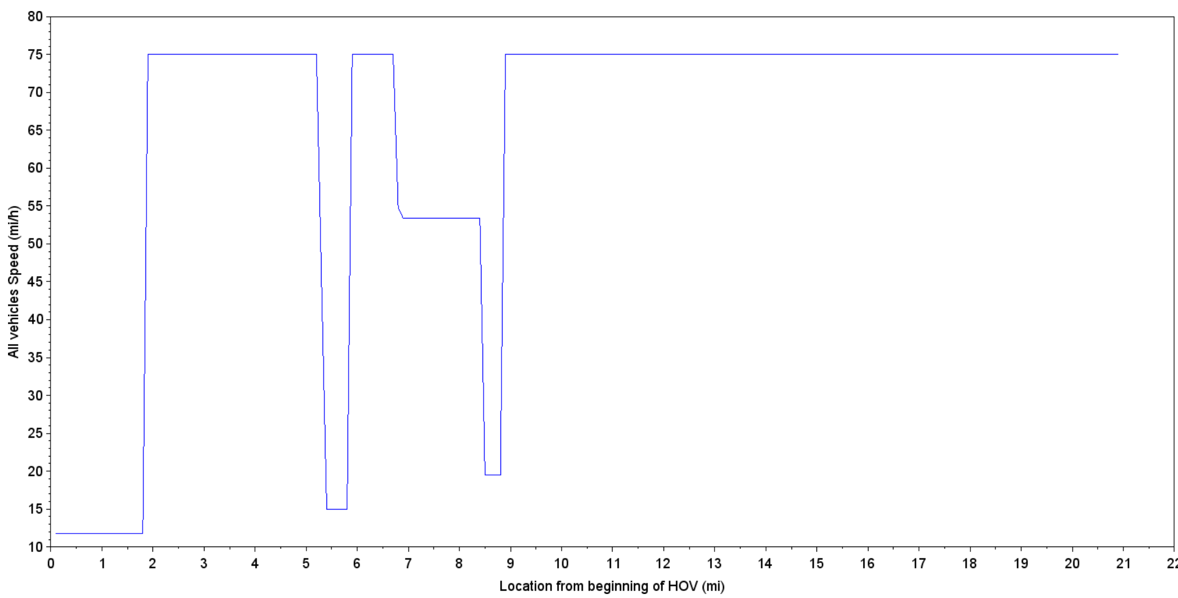



Figure 9-32 Space mean speed data obtained from the cell transmission model simulation of I-65 southbound corridor with reduced capacity at bottlenecks obtained at a simulation time of 9000 seconds

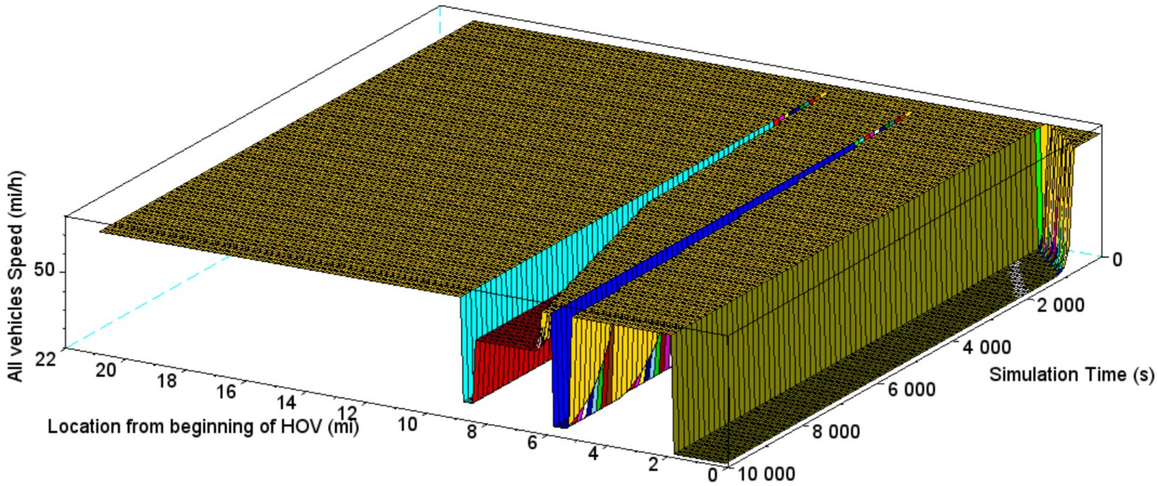



Figure 9-33 HOV lane speed data obtained from the cell transmission model simulation of I-65 southbound corridor with reduced capacity at bottlenecks

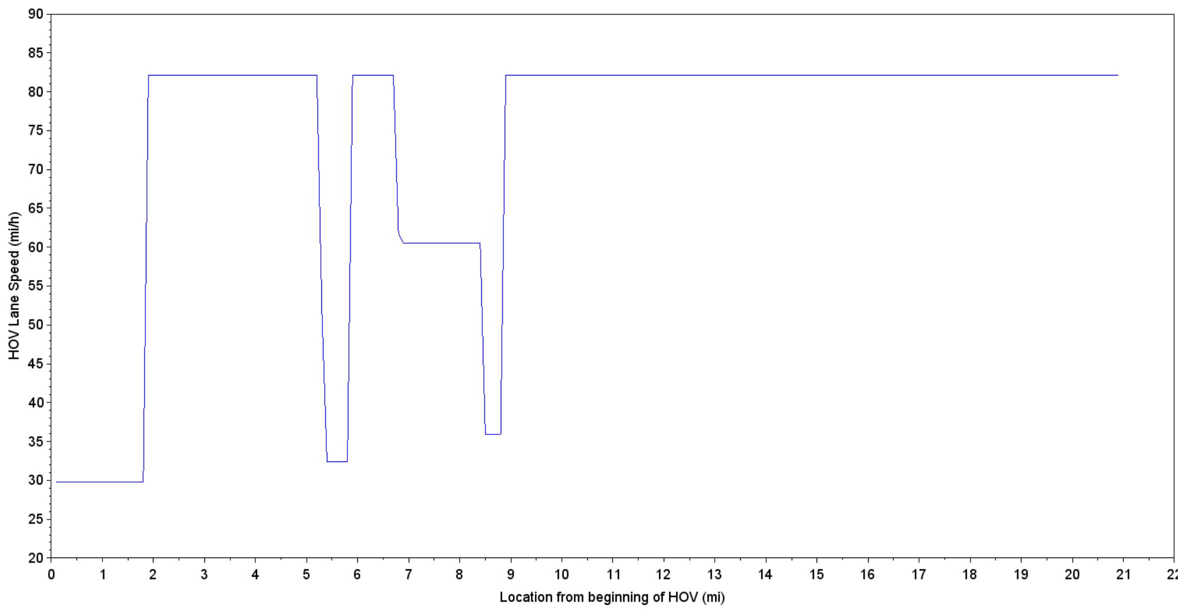



Figure 9-34 HOV lane speed data obtained from the cell transmission model simulation of I-65 southbound corridor with reduced capacity at bottlenecks taken at a simulation time of 9000 seconds

# Chapter 10 Scenario Construction and Evaluation for Southbound I-65 South of Nashville

In the previous chapters focused on user equilibrium modeling, models for a do-nothing scenario, a heavy enforcement scenario, and a lane reversion scenario were built. It should be noted that in the equilibrium models, it was impossible to accurately capture the impacts of high volumes in the HOV lane upon the performance of the mixed-flow lanes, as well as the impact of the congestion of the mixed-flow lanes upon the performance of the HOV lane. This is particularly troublesome at the bottlenecks which are most responsible for the degradation of the corridor under consideration. In this section of the progress report, we will consider the implications of making these changes to the operations of the facility.

In the base year cases of the model, a K factor of 0.08 will be used with the calibrated inputs as developed earlier. For future demand scenarios, a K factor of 0.10 will be used. This growth of twenty-five percent is predicated upon the future growth of Nashville and may be a modest assumption, given that the final report from the Nashville nMotion transit plan predicts that the population in Middle Tennessee will grow by one million people between 2016 and 2035 (Nashville MTA/RTA, 2016). This represents a 76 percent increase in population. While the forecast of future ramp demands and origin-destination (O-D) matrices is beyond the scope of this project, it would require land use forecasting, and should be considered in future research. The contribution of this study was to provide some insights about changes to operations that may result from a significant and general increase in demand on the HOV corridor.

In the case of heavy enforcement, whether by toll or by automated enforcement, it will be assumed that the share of willing HOV users increases from four percent to five percent. In the heavy enforcement scenario that the violation rate is 10 percent, consistent with the violation rates on well-performing HOV facilities, with the violators removed from the HOV Violator class reclassified in the SOV vehicle class. The heavy enforcement scenario intends to investigate the operational impacts of removal of a large proportion of users from the HOV lane; it is not designed to incorporate predictive analytics regarding how legal HOVs might shift their lane choice preferences. Prediction of actual driver response to changes in operational conditions would require the development of O-D matrices, and an understanding of how various classes of drivers would respond to conditions in the network. Such understanding of the system would require an understanding of land use forecasting and a much more comprehensive and targeted revealed preference survey and is beyond the scope of the current project. However, by considering the removal of a significant number of vehicles from the HOV lane, or by considering full reversion of the HOV lane, the impact of broad changes to the usage policy for the HOV lanes can be identified and operations can be better understood under a range of scenarios.

Through the definition of nodes as polygons drawn around the interchanges, measures of effectiveness (MoE) can be evaluated for each interchange. The following MoEs are used for the interchanges:

- Delay
- Fuel Consumption
- Nitrogen Oxide Emissions
- Carbon Monoxide Emissions
- Volatile Organic Compound Emissions

A microsimulation-based level of service is computed for each data collection measurement based upon the density at the data collection point. The density in vehicles per mile is calculated by dividing the flow at the location by the harmonic (space) mean speed. To convert the density from vehicles per mile to passenger car equivalents per mile, it is assumed that each vehicle is equivalent to 1.1 passenger car equivalents. The level of service is then classified as determined by the criteria in the Highway Capacity Manual (Transportation Research Board, 2016).

## 10.1 Base Year Do-Nothing Scenario

For the base year do-nothing scenario, the VISSIM simulation was run at the calibrated parameter values determined in the model inputs section with demands chosen such that K = 0.08. The assumed vehicle composition consists of 16% HOV Violators, 4% HOV, 10% Trucks, and 70% SOV. The SOV class includes the compliant SOV drivers as well as the HOV drivers unwilling to use the HOV lane. The model results are reported, using these vehicle class interpretations, in Table 10-1 through Table 10-4.

Table 10-1 Peak Hour Flow, Space Mean Speed, Density, and LOS at Data Collection Points for the Base Year Do-Nothing Scenario

| Data Collection Point | Flow (vph) | Space Mean Speed (mph) | Density (vpmpl) | Microsimulation Based LOS* |
|---|---|---|---|---|
| 1: MM 80 Ln 1 | 1085 | 10.6 | 102.4 | F |
| 2: MM 80 Ln 2 | 522 | 5.6 | 93.2 | F |
| 3: MM 80 Ln 3 | 791 | 9.6 | 82.8 | F |
| 4: MM 80 Ln 4 | 1185 | 15.1 | 78.7 | F |
| 5: MM 80 HOV | 838 | 64.1 | 13.1 | B |
| 6: 79 OFF | 266 | 34.8 | 7.6 | A |
| 7: 79 ON | 570 | 48.1 | 11.9 | B |
| 8: 78 OFF Ln 1 | 388 | 41.7 | 9.3 | A |
| 9: 78 OFF Ln 2 | 237 | 42.2 | 5.6 | A |
| 10: Harding Ln 1 | 802 | 63.5 | 12.6 | B |
| 11: Harding Ln 2 | 1092 | 67.0 | 16.3 | B |
| 12: Harding Ln 3 | 1562 | 69.7 | 22.4 | C |
| 13: Harding HOV | 449 | 72.4 | 6.2 | A |
| 14: 78 ON | 915 | 72.4 | 12.6 | B |
| 15: 74 A Ln 1 | 394 | 54.7 | 7.2 | A |
| 16: 74 A Ln 2 | 153 | 48.9 | 3.1 | A |
| 17: 74 B | 400 | 37.3 | 10.7 | B |
| 18: OHB Ln 1 | 929 | 45.2 | 20.5 | C |
| 19: OHB Ln 2 | 1199 | 46.9 | 25.6 | D |

| | | | | |
|---|---|---|---|---|
| 20: OHB Ln 3 | 1232 | 53.2 | 23.2 | C |
| 21: OHB HOV | 958 | 67.8 | 14.1 | B |
| 22: 74 ON | 1038 | 15.1 | 68.6 | F |
| 23: 71 OFF | 370 | 35.2 | 10.5 | B |
| 24: Concord Rd Ln 1 | 946 | 15.9 | 59.6 | F |
| 25: Concord Rd Ln 2 | 1014 | 19.8 | 51.2 | F |
| 26: Concord Rd Ln 3 | 1483 | 26.6 | 55.7 | F |
| 27: Concord Rd HOV | 727 | 39.4 | 18.4 | C |
| 28: 69 Ln 1 | 570 | 40.7 | 14.0 | B |
| 29: 69 Ln 2 | 436 | 40.0 | 10.9 | B |
| 30: Moore's Ln 1 | 833 | 64.0 | 13.0 | B |
| 31: Moore's Ln 2 | 1081 | 67.2 | 16.1 | B |
| 32: Moore's Ln 3 | 1474 | 69.4 | 21.2 | C |
| 33: Moore's Ln HOV | 411 | 73.2 | 5.6 | A |
| 34: 69 ON | 693 | 73.1 | 9.5 | A |
| 35: 68 A | 460 | 59.6 | 7.7 | A |
| 36: 68 B | 248 | 38.5 | 6.4 | A |
| 37: 68 ON | 557 | 73.1 | 7.6 | A |
| 38: CSB Ln 1 | 255 | 39.7 | 6.4 | A |
| 39: CSB Ln 2 | 1048 | 36.9 | 28.4 | D |
| 40: CSB Ln 3 | 971 | 39.6 | 24.5 | D |
| 41: CSB Ln 4 | 1324 | 46.3 | 28.6 | D |
| 42: CSB HOV | 465 | 60.7 | 7.7 | A |
| 43: 67 OFF Ln 1 | 307 | 49.1 | 6.3 | A |
| 44: 67 OFF Ln 2 | 118 | 46.1 | 2.6 | A |
| 45: McEwen Ln 1 | 862 | 62.6 | 13.8 | B |
| 46: McEwen Ln 2 | 1155 | 65.4 | 17.7 | C |
| 47: McEwen Ln 3 | 1517 | 68.4 | 22.2 | C |
| 48: McEwen HOV | 409 | 75.2 | 5.4 | A |
| 49: 67 ON | 432 | 75.0 | 5.8 | A |
| 50: 65 Ln 1 | 603 | 61.1 | 9.9 | A |
| 51: 65 Ln 2 | 500 | 60.8 | 8.2 | A |
| 52: Murfreesboro Ln 1 | 898 | 66.7 | 13.5 | B |
| 53: Murfreesboro Ln 2 | 829 | 71.3 | 11.6 | B |
| 54: Murfreesboro Ln 3 | 725 | 74.2 | 9.8 | A |
| 55: Murfreesboro Ln 4 | 677 | 76.7 | 8.8 | A |
| 56: Murfreesboro HOV | 149 | 80.8 | 1.8 | A |
| 57: 65 ON | 643 | 73.7 | 8.7 | A |
| 58: 61 OFF Ln 1 | 290 | 74.6 | 3.9 | A |
| 59: 61 OFF Ln 2 | 49 | 78.3 | 0.6 | A |
| 60: Peytonsville Ln 1 | 938 | 71.1 | 13.2 | B |
| 61: Peytonsville Ln 2 | 810 | 75.1 | 10.8 | B |
| 62: Peytonsville Ln 3 | 698 | 79.0 | 8.8 | A |

| | | | | |
|---|---|---|---|---|
| 63: Peytonsville HOV | 119 | 84.0 | 1.4 | A |
| 64: 61 ON | 208 | 75.2 | 2.8 | A |
| 65: END Ln 1 | 997 | 71.8 | 13.9 | B |
| 66: END Ln 2 | 848 | 76.0 | 11.2 | B |
| 67: END Ln 3 | 788 | 79.7 | 9.9 | A |
| 68: END HOV | 131 | 84.3 | 1.6 | A |

### Table 10-2 HOV Lane Usage Statistics at Selected Locations for Base Year Do-Nothing Scenario

| Location | Violation Rate | Utilization Rate | Average Speed (mph) | Legal Utilization (vph) | Violators (vph) | Total Users (vph) |
|---|---|---|---|---|---|---|
| Harding Place | 82% | 11% | 72.42 | 79 | 370 | 449 |
| Old Hickory Boulevard | 81% | 22% | 67.83 | 87 | 374 | 461 |
| Concord Road | 82% | 17% | 39.42 | 125 | 553 | 678 |
| Moore's Lane | 81% | 11% | 73.23 | 76 | 332 | 408 |
| Cool Springs Boulevard | 81% | 11% | 60.68 | 72 | 302 | 374 |
| McEwen Drive | 82% | 10% | 75.23 | 71 | 321 | 392 |
| Murfreesboro Road | 79% | 5% | 80.75 | 30 | 115 | 145 |
| Peytonsville Road | 76% | 5% | 84.02 | 27 | 87 | 114 |

### Table 10-3 Vehicle Travel Time Statistics for Base Year-Do Nothing Scenario

| Segment | Segment Length (mi) | Free Flow Trip Time (s)* | Average Trip Time for All Vehicles (s) | Average Trip Time for SOV (s) | Average Trip Time for Trucks (s) | Average Trip Time for All HOV (s) | Average Trip Time for HOV Violators (s) |
|---|---|---|---|---|---|---|---|
| 1: Start to Armory | 0.65 | 31 | 315 | 362 | 469 | 102 | 91 |
| 2: Armory to Harding | 1.32 | 63 | 368 | 416 | 517 | 143 | 130 |
| 3: Harding to OHB | 3.28 | 157 | 180 | 181 | 197 | 168 | 166 |
| 4: OHB to Concord | 3.12 | 150 | 622 | 716 | 677 | 280 | 287 |
| 5: Concord to Moore's | 2.23 | 107 | 434 | 485 | 520 | 210 | 230 |
| 6: Moore's to CSB | 1.32 | 63 | 73 | 73 | 81 | 67 | 67 |
| 7: CSB to McEwen | 0.96 | 46 | 78 | 80 | 102 | 65 | 61 |
| 8: McEwen to Murfreesboro | 1.41 | 67 | 73 | 72 | 82 | 69 | 69 |
| 9: Murfreesboro to Peytonsville | 3.80 | 183 | 183 | 184 | 200 | 176 | 176 |
| 10: Peytonsville to END | 2.02 | 97 | 96 | 96 | 103 | 93 | 93 |
| Corridor Totals | 20.10 | 965 | 2423 | 2665 | 2949 | 1374 | 1369 |

*Free flow trip time calculation is based on an assumed free-flow speed of 75 mph

Table 10-4 Vehicle Emissions and Fuel Consumption Data for Base Year Do-Nothing Scenario

| Segment | Total CO Emissions (g) | Total NOx Emissions (g) | Total VOC Emissions (g) | Total Fuel Consumption (gal) |
|---|---|---|---|---|
| 1: Interchange 79 | 202658 | 39430 | 46968 | 2899 |
| 2: Interchange 78 | 103973 | 20229 | 24097 | 1487 |
| 3: Interchange 74 | 108075 | 21027 | 25047 | 1546 |
| 4: Interchange 71 | 201463 | 39197 | 46691 | 2882 |
| 5: Interchange 69 | 77365 | 15052 | 17930 | 1107 |
| 6: Interchange 68 | 16077 | 3128 | 3726 | 230 |
| 7: Interchange 67 | 23721 | 4615 | 5498 | 339 |
| 8: Interchange 65 | 19770 | 3847 | 4582 | 283 |
| 9: Interchange 61 | 29890 | 5816 | 6927 | 428 |
| Corridor Totals | 782992 | 152342 | 181466 | 11202 |

## 10.2 Base Year Lane Reversion Scenario

For the base year lane reversion scenario, the VISSIM simulation was run at the calibrated parameter values determined in the model inputs section with demands chosen such that K = 0.08. However, the assumed vehicle composition was changed to consist of 20% HOV Violators, 70% HOV, and 10% Trucks. The SOV class was fully eliminated from the vehicle composition because there are now no passenger cars restricted from the HOV lane. As in all simulations, trucks are restricted from using the leftmost two lanes. The model results are reported, using these vehicle class interpretations, in Table 10-5 through Table 10-8.

Table 10-5 Peak Hour Flow, Space Mean Speed, Density, and LOS at Data Collection Points for Base Year Lane Reversion Scenario

| Data Collection Point | Flow (vph) | Space Mean Speed (mph) | Density (vpmpl) | Microsimulation Based LOS* |
|---|---|---|---|---|
| 1: MM 80 Ln 1 | 1054 | 10.1 | 103.9 | F |
| 2: MM 80 Ln 2 | 512 | 5.4 | 95.7 | F |
| 3: MM 80 Ln 3 | 790 | 9.2 | 86.0 | F |
| 4: MM 80 Ln 4 | 1245 | 14.1 | 88.1 | F |
| 5: MM 80 HOV | 1261 | 15.1 | 83.8 | F |
| 6: 79 OFF | 302 | 35.1 | 8.6 | A |
| 7: 79 ON | 570 | 57.2 | 10.0 | A |

| | | | | |
|---|---|---|---|---|
| 8: 78 OFF Ln 1 | 426 | 41.3 | 10.3 | B |
| 9: 78 OFF Ln 2 | 271 | 41.8 | 6.5 | A |
| 10: Harding Ln 1 | 828 | 63.6 | 13.0 | B |
| 11: Harding Ln 2 | 1051 | 67.3 | 15.6 | B |
| 12: Harding Ln 3 | 1137 | 70.1 | 16.2 | B |
| 13: Harding HOV | 1488 | 70.6 | 21.1 | C |
| 14: 78 ON | 915 | 72.6 | 12.6 | B |
| 15: 74 A Ln 1 | 399 | 52.5 | 7.6 | A |
| 16: 74 A Ln 2 | 197 | 45.7 | 4.3 | A |
| 17: 74 B | 434 | 37.7 | 11.5 | B |
| 18: OHB Ln 1 | 862 | 54.1 | 15.9 | B |
| 19: OHB Ln 2 | 1032 | 56.7 | 18.2 | C |
| 20: OHB Ln 3 | 1108 | 62.6 | 17.7 | C |
| 21: OHB HOV | 1701 | 67.8 | 25.1 | D |
| 22: 74 ON | 1385 | 71.6 | 19.3 | C |
| 23: 71 OFF | 458 | 35.9 | 12.8 | B |
| 24: Concord Rd Ln 1 | 940 | 29.4 | 32.0 | E |
| 25: Concord Rd Ln 2 | 1099 | 37.6 | 29.3 | D |
| 26: Concord Rd Ln 3 | 1312 | 37.8 | 34.7 | E |
| 27: Concord Rd HOV | 1608 | 42.4 | 37.9 | E |
| 28: 69 Ln 1 | 615 | 40.6 | 15.2 | B |
| 29: 69 Ln 2 | 494 | 40.6 | 12.2 | B |
| 30: Moore's Ln 1 | 809 | 63.6 | 12.7 | B |
| 31: Moore's Ln 2 | 998 | 68.4 | 14.6 | B |
| 32: Moore's Ln 3 | 1063 | 72.0 | 14.8 | B |
| 33: Moore's Ln 4 | 1376 | 73.1 | 18.8 | C |
| 34: 69 ON | 693 | 73.2 | 9.5 | A |
| 35: 68 A | 508 | 58.9 | 8.6 | A |
| 36: 68 B | 271 | 36.4 | 7.4 | A |
| 37: 68 ON | 557 | 73.0 | 7.6 | A |
| 38: CSB Ln 1 | 226 | 37.1 | 6.1 | A |
| 39: CSB Ln 2 | 1020 | 34.8 | 29.3 | D |
| 40: CSB Ln 3 | 818 | 13.8 | 59.1 | F |
| 41: CSB Ln 4 | 974 | 42.2 | 23.1 | C |
| 42: CSB HOV | 1385 | 50.8 | 27.3 | D |
| 43: 67 OFF Ln 1 | 327 | 47.9 | 6.8 | A |
| 44: 67 OFF Ln 2 | 128 | 45.8 | 2.8 | A |
| 45: McEwen Ln 1 | 842 | 62.3 | 13.5 | B |
| 46: McEwen Ln 2 | 1005 | 65.5 | 15.3 | B |
| 47: McEwen Ln 3 | 1044 | 69.4 | 15.0 | B |
| 48: McEwen HOV | 1379 | 69.9 | 19.7 | C |
| 49: 67 ON | 432 | 75.0 | 5.8 | A |
| 50: 65 Ln 1 | 632 | 62.0 | 10.2 | B |
| 51: 65 Ln 2 | 541 | 60.5 | 8.9 | A |

| | | | | |
|---|---|---|---|---|
| 52: Murfreesboro Ln 1 | 922 | 66.9 | 13.8 | B |
| 53: Murfreesboro Ln 2 | 886 | 72.0 | 12.3 | B |
| 54: Murfreesboro Ln 3 | 746 | 75.2 | 9.9 | A |
| 55: Murfreesboro Ln 4 | 509 | 78.8 | 6.5 | A |
| 56: Murfreesboro HOV | 466 | 80.2 | 5.8 | A |
| 57: 65 ON | 643 | 73.6 | 8.7 | A |
| 58: 61 OFF Ln 1 | 284 | 75.3 | 3.8 | A |
| 59: 61 OFF Ln 2 | 59 | 78.4 | 0.8 | A |
| 60: Peytonsville Ln 1 | 946 | 71.3 | 13.3 | B |
| 61: Peytonsville Ln 2 | 810 | 75.1 | 10.8 | B |
| 62: Peytonsville Ln 3 | 553 | 79.4 | 7.0 | A |
| 63: Peytonsville HOV | 434 | 81.5 | 5.3 | A |
| 64: 61 ON | 208 | 75.2 | 2.8 | A |
| 65: END Ln 1 | 1025 | 71.6 | 14.3 | B |
| 66: END Ln 2 | 896 | 76.1 | 11.8 | B |
| 67: END Ln 3 | 590 | 80.9 | 7.3 | A |
| 68: END HOV | 426 | 84.3 | 5.1 | A |

Table 10-6 HOV Lane Usage Statistics at Selected Locations for Base Year Lane Reversion Scenario

| Location | Violation Rate | Utilization Rate | Average Speed (mph) | Legal Utilization (vph) | Violators (vph) | Total Users (vph) |
|---|---|---|---|---|---|---|
| Harding Place | N/A | 33% | 70.588095 | N/A | N/A | 1488 |
| Old Hickory Boulevard | N/A | 36% | 67.825555 | N/A | N/A | 1701 |
| Concord Road | N/A | 32% | 42.379004 | N/A | N/A | 1608 |
| Moore's Lane | N/A | 32% | 73.123766 | N/A | N/A | 1376 |
| Cool Springs Boulevard | N/A | 31% | 50.755303 | N/A | N/A | 1385 |
| McEwen Drive | N/A | 32% | 69.882752 | N/A | N/A | 1379 |
| Murfreesboro Road | N/A | 13% | 80.213563 | N/A | N/A | 466 |
| Peytonsville Road | N/A | 16% | 81.532042 | N/A | N/A | 434 |

Table 10-7 Vehicle Travel Time Statistics for Base Year Lane Reversion Scenario

| Segment | Segment Length (mi) | Free Flow Trip Time (s)* | Average Trip Time for All Vehicles (s) | Average Trip Time for SOV (s) | Average Trip Time for Trucks (s) | Average Trip Time for All HOV (s) | Average Trip Time for HOV Violators (s) |
|---|---|---|---|---|---|---|---|
| 1: Start to Armory | 0.65 | 31 | 316 | N/A | 472 | 309 | 298 |
| 2: Armory to Harding | 1.32 | 63 | 364 | N/A | 548 | 348 | 343 |
| 3: Harding to OHB | 3.28 | 157 | 172 | N/A | 193 | 169 | 170 |
| 4: OHB to Concord | 3.12 | 150 | 239 | N/A | 258 | 235 | 238 |
| 5: Concord to Moore's | 2.23 | 107 | 385 | N/A | 469 | 374 | 377 |
| 6: Moore's to CSB | 1.32 | 63 | 72 | N/A | 84 | 71 | 71 |
| 7: CSB to McEwen | 0.96 | 46 | 71 | N/A | 91 | 69 | 69 |
| 8: McEwen to Murfreesboro | 1.41 | 67 | 71 | N/A | 81 | 69 | 70 |
| 9: Murfreesboro to Peytonsville | 3.80 | 183 | 184 | N/A | 203 | 179 | 184 |
| 10: Peytonsville to END | 2.02 | 97 | 95 | N/A | 103 | 93 | 95 |
| Corridor Totals | 20.10 | 965 | 1968 | N/A | 2501 | 1917 | 1914 |

*Free flow trip time calculation is based on an assumed free-flow speed of 75 mph

Table 10-8 Vehicle Emissions and Fuel Consumption Data for Base Year Lane Reversion Scenario

| Segment | Total CO Emissions (g) | Total NOx Emissions (g) | Total VOC Emissions (g) | Total Fuel Consumption (gal) |
|---|---|---|---|---|
| 1: Interchange 79 | 223284 | 43443 | 51748 | 3194 |
| 2: Interchange 78 | 122170 | 23770 | 28314 | 1748 |
| 3: Interchange 74 | 46271 | 9003 | 10724 | 662 |
| 4: Interchange 71 | 116515 | 22670 | 27004 | 1667 |
| 5: Interchange 69 | 93949 | 18279 | 21774 | 1344 |
| 6: Interchange 68 | 17438 | 3393 | 4041 | 249 |
| 7: Interchange 67 | 20463 | 3981 | 4743 | 293 |
| 8: Interchange 65 | 21045 | 4095 | 4877 | 301 |
| 9: Interchange 61 | 33064 | 6433 | 7663 | 473 |
| Corridor Totals | 694199 | 135066 | 160887 | 9931 |

## 10.3 Base Year Heavy Enforcement Scenario

For the base year heavy enforcement scenario, the VISSIM simulation was run at the calibrated parameter values determined in the model inputs section with demands chosen such that K = 0.08. However, the assumed vehicle composition was changed to consist of 0.5% HOV Violators, 5% HOV, 10% Trucks, and 84.5% SOV. The SOV class includes the compliant SOV drivers, as well as the HOV drivers unwilling to use the HOV lane. This simulates a slight increase in the legal use of the HOV lane along with the removal of a large number of violators from the HOV lane. The model results are reported, using these vehicle class interpretations, in Table 10-9 through Table 10-12.

Table 10-9 Peak Hour Flow, Space Mean Speed, Density, and LOS at Data Collection Points for the Base Year Heavy Enforcement Scenario

| Data Collection Point | Flow (vph) | Space Mean Speed (mph) | Density (vpmpl) | Microsimulation Based LOS* |
|---|---|---|---|---|
| 1: MM 80 Ln 1 | 1038 | 10.7 | 96.7 | F |
| 2: MM 80 Ln 2 | 569 | 6.7 | 85.3 | F |
| 3: MM 80 Ln 3 | 756 | 9.4 | 80.3 | F |
| 4: MM 80 Ln 4 | 1467 | 16.6 | 88.6 | F |
| 5: MM 80 HOV | 243 | 73.3 | 3.3 | A |

| | | | | |
|---|---|---|---|---|
| 6: 79 OFF | 262 | 35.2 | 7.4 | A |
| 7: 79 ON | 570 | 55.6 | 10.3 | B |
| 8: 78 OFF Ln 1 | 400 | 42.3 | 9.4 | A |
| 9: 78 OFF Ln 2 | 208 | 42.1 | 4.9 | A |
| 10: Harding Ln 1 | 854 | 63.2 | 13.5 | B |
| 11: Harding Ln 2 | 1131 | 66.5 | 17.0 | C |
| 12: Harding Ln 3 | 1709 | 69.3 | 24.7 | D |
| 13: Harding HOV | 128 | 76.6 | 1.7 | A |
| 14: 78 ON | 915 | 72.4 | 12.6 | B |
| 15: 74 A Ln 1 | 339 | 46.9 | 7.2 | A |
| 16: 74 A Ln 2 | 191 | 44.0 | 4.3 | A |
| 17: 74 B | 386 | 38.0 | 10.2 | B |
| 18: OHB Ln 1 | 1037 | 38.3 | 27.1 | D |
| 19: OHB Ln 2 | 1168 | 35.2 | 33.1 | E |
| 20: OHB Ln 3 | 1317 | 39.0 | 33.8 | E |
| 21: OHB HOV | 663 | 51.3 | 12.9 | B |
| 22: 74 ON | 1104 | 11.1 | 99.7 | F |
| 23: 71 OFF | 388 | 36.4 | 10.7 | B |
| 24: Concord Rd Ln 1 | 1049 | 18.1 | 58.1 | F |
| 25: Concord Rd Ln 2 | 1209 | 21.8 | 55.6 | F |
| 26: Concord Rd Ln 3 | 1814 | 19.5 | 92.9 | F |
| 27: Concord Rd HOV | 320 | 35.8 | 8.9 | A |
| 28: 69 Ln 1 | 601 | 41.5 | 14.5 | B |
| 29: 69 Ln 2 | 443 | 41.9 | 10.6 | B |
| 30: Moore's Ln 1 | 833 | 62.8 | 13.3 | B |
| 31: Moore's Ln 2 | 1143 | 64.5 | 17.7 | C |
| 32: Moore's Ln 3 | 1809 | 66.2 | 27.3 | D |
| 33: Moore's Ln HOV | 127 | 74.0 | 1.7 | A |
| 34: 69 ON | 693 | 73.0 | 9.5 | A |
| 35: 68 A | 468 | 58.9 | 8.0 | A |
| 36: 68 B | 249 | 40.4 | 6.2 | A |
| 37: 68 ON | 557 | 73.1 | 7.6 | A |
| 38: CSB Ln 1 | 204 | 41.8 | 4.9 | A |
| 39: CSB Ln 2 | 1105 | 40.6 | 27.3 | D |
| 40: CSB Ln 3 | 1045 | 44.0 | 23.8 | D |
| 41: CSB Ln 4 | 1470 | 53.7 | 27.4 | D |
| 42: CSB HOV | 258 | 62.3 | 4.1 | A |
| 43: 67 OFF Ln 1 | 308 | 49.8 | 6.2 | A |
| 44: 67 OFF Ln 2 | 122 | 46.6 | 2.6 | A |
| 45: McEwen Ln 1 | 874 | 61.2 | 14.3 | B |
| 46: McEwen Ln 2 | 1258 | 63.9 | 19.7 | C |
| 47: McEwen Ln 3 | 1742 | 66.4 | 26.2 | D |
| 48: McEwen HOV | 115 | 75.3 | 1.5 | A |

| | | | | |
|---|---|---|---|---|
| 49: 67 ON | 432 | 74.9 | 5.8 | A |
| 50: 65 Ln 1 | 603 | 62.4 | 9.7 | A |
| 51: 65 Ln 2 | 516 | 62.2 | 8.3 | A |
| 52: Murfreesboro Ln 1 | 854 | 66.3 | 12.9 | B |
| 53: Murfreesboro Ln 2 | 855 | 70.9 | 12.1 | B |
| 54: Murfreesboro Ln 3 | 766 | 73.3 | 10.5 | B |
| 55: Murfreesboro Ln 4 | 820 | 76.4 | 10.7 | B |
| 56: Murfreesboro HOV | 42 | 80.5 | 0.5 | A |
| 57: 65 ON | 643 | 73.6 | 8.7 | A |
| 58: 61 OFF Ln 1 | 283 | 74.5 | 3.8 | A |
| 59: 61 OFF Ln 2 | 57 | 77.8 | 0.7 | A |
| 60: Peytonsville Ln 1 | 954 | 71.3 | 13.4 | B |
| 61: Peytonsville Ln 2 | 820 | 75.0 | 10.9 | B |
| 62: Peytonsville Ln 3 | 755 | 77.9 | 9.7 | A |
| 63: Peytonsville HOV | 34 | 84.7 | 0.4 | A |
| 64: 61 ON | 208 | 75.0 | 2.8 | A |
| 65: END Ln 1 | 987 | 71.4 | 13.8 | B |
| 66: END Ln 2 | 887 | 75.4 | 11.8 | B |
| 67: END Ln 3 | 854 | 79.1 | 10.8 | B |
| 68: END HOV | 28 | 85.6 | 0.3 | A |

Table 10-10 HOV Lane Usage Statistics at Selected Locations for Base Year Heavy Enforcement Scenario

| Location | Violation Rate | Utilization Rate | Average Speed (mph) | Legal Utilization (vph) | Violators (vph) | Total Users (vph) |
|---|---|---|---|---|---|---|
| Harding Place | 12% | 3% | 76.55 | 113 | 15 | 128 |
| Old Hickory Boulevard | 8% | 16% | 51.33 | 111 | 10 | 121 |
| Concord Road | 10% | 7% | 35.76 | 171 | 20 | 191 |
| Moore's Lane | 10% | 3% | 74.04 | 113 | 12 | 125 |
| Cool Springs Boulevard | 12% | 6% | 62.34 | 96 | 13 | 109 |
| McEwen Drive | 12% | 3% | 75.31 | 81 | 11 | 92 |
| Murfreesboro Road | 17% | 1% | 80.47 | 24 | 5 | 29 |
| Peytonsville Road | 13% | 1% | 84.73 | 14 | 2 | 16 |

Table 10-11 Vehicle Travel Time Statistics for Base Year Heavy Enforcement Scenario

| Segment | Segment Length (mi) | Free Flow Trip Time (s)* | Average Trip Time for All Vehicles (s) | Average Trip Time for SOV (s) | Average Trip Time for Trucks (s) | Average Trip Time for All HOV (s) | Average Trip Time for HOV Violators (s) |
|---|---|---|---|---|---|---|---|
| 1: Start to Armory | 0.65 | 31 | 330 | 332 | 467 | 64 | 55 |
| 2: Armory to Harding | 1.32 | 63 | 366 | 370 | 479 | 103 | 112 |
| 3: Harding to OHB | 3.28 | 157 | 189 | 188 | 206 | 167 | 164 |
| 4: OHB to Concord | 3.12 | 150 | 546 | 562 | 564 | 259 | 221 |
| 5: Concord to Moore's | 2.23 | 107 | 336 | 342 | 367 | 183 | 180 |
| 6: Moore's to CSB | 1.32 | 63 | 73 | 72 | 83 | 67 | 64 |
| 7: CSB to McEwen | 0.96 | 46 | 69 | 68 | 83 | 57 | 58 |
| 8: McEwen to Murfreesboro | 1.41 | 67 | 73 | 72 | 83 | 69 | 69 |
| 9: Murfreesboro to Peytonsville | 3.80 | 183 | 184 | 184 | 195 | 177 | 175 |
| 10: Peytonsville to END | 2.02 | 97 | 97 | 96 | 103 | 94 | 94 |
| Corridor Totals | 20.10 | 965 | 2262 | 2287 | 2629 | 1241 | 1192 |

*Free flow trip time calculation is based on an assumed free flow speed of 75 mph

Table 10-12 Vehicle Emissions and Fuel Consumption Data for Base Year Heavy Enforcement Scenario

| Segment | Total CO Emissions (g) | Total NOx Emissions (g) | Total VOC Emissions (g) | Total Fuel Consumption (gal) |
|---|---|---|---|---|
| 1: Interchange 79 | 194190 | 37782 | 45005 | 2778 |
| 2: Interchange 78 | 94870 | 18458 | 21987 | 1357 |
| 3: Interchange 74 | 108652 | 21140 | 25181 | 1554 |
| 4: Interchange 71 | 143429 | 27906 | 33241 | 2052 |
| 5: Interchange 69 | 57428 | 11173 | 13310 | 822 |
| 6: Interchange 68 | 15108 | 2939 | 3501 | 216 |
| 7: Interchange 67 | 18267 | 3554 | 4234 | 261 |
| 8: Interchange 65 | 19923 | 3876 | 4617 | 285 |
| 9: Interchange 61 | 29411 | 5722 | 6816 | 421 |
| Corridor Totals | 681278 | 132552 | 157893 | 9746 |

## 10.4 Future Year Do Nothing Scenario

For the future year do-nothing scenario, the VISSIM simulation was run at the calibrated parameter values determined in the model inputs section with demands chosen such that K = 0.10. The assumed vehicle composition consists of 16% HOV Violators, 4% HOV, 10% Trucks, and 70% SOV. The SOV class includes the compliant SOV drivers, as well as the HOV drivers unwilling to use the HOV lane. The model results are reported, using these vehicle class interpretations, in Table 10-13 through Table 10-16.

Table 10-13 Peak Hour Flow, Space Mean Speed, Density, and LOS at Data Collection Points for Future Year Do-Nothing Scenario

| Data Collection Point | Flow (vph) | Space Mean Speed (mph) | Density (vpmpl) | Microsimulation Based LOS* |
|---|---|---|---|---|
| 1: MM 80 Ln 1 | 1015 | 9.6 | 106.2 | F |
| 2: MM 80 Ln 2 | 494 | 5.6 | 88.0 | F |
| 3: MM 80 Ln 3 | 770 | 7.2 | 107.4 | F |
| 4: MM 80 Ln 4 | 1229 | 15.4 | 79.8 | F |
| 5: MM 80 HOV | 792 | 65.0 | 12.2 | B |
| 6: 79 OFF | 270 | 34.3 | 7.9 | A |
| 7: 79 ON | 702 | 34.6 | 20.3 | C |
| 8: 78 OFF Ln 1 | 427 | 42.1 | 10.1 | B |
| 9: 78 OFF Ln 2 | 228 | 42.0 | 5.4 | A |
| 10: Harding Ln 1 | 844 | 63.0 | 13.4 | B |
| 11: Harding Ln 2 | 1129 | 66.3 | 17.0 | C |
| 12: Harding Ln 3 | 1650 | 69.6 | 23.7 | D |
| 13: Harding HOV | 498 | 73.3 | 6.8 | A |
| 14: 78 ON | 1134 | 71.9 | 15.8 | B |
| 15: 74 A Ln 1 | 326 | 40.2 | 8.1 | A |
| 16: 74 A Ln 2 | 185 | 36.3 | 5.1 | A |
| 17: 74 B | 356 | 36.4 | 9.8 | A |
| 18: OHB Ln 1 | 1104 | 18.1 | 61.1 | F |
| 19: OHB Ln 2 | 821 | 11.7 | 69.9 | F |
| 20: OHB Ln 3 | 1032 | 17.0 | 60.7 | F |
| 21: OHB HOV | 1058 | 25.1 | 42.2 | F |
| 22: 74 ON | 781 | 9.7 | 80.4 | F |
| 23: 71 OFF | 346 | 34.5 | 10.0 | B |
| 24: Concord Rd Ln 1 | 977 | 10.5 | 92.8 | F |
| 25: Concord Rd Ln 2 | 950 | 13.0 | 73.2 | F |
| 26: Concord Rd Ln 3 | 1366 | 23.3 | 58.6 | F |
| 27: Concord Rd HOV | 764 | 37.2 | 20.5 | C |
| 28: 69 Ln 1 | 579 | 41.7 | 13.9 | B |
| 29: 69 Ln 2 | 449 | 41.6 | 10.8 | B |
| 30: Moore's Ln 1 | 838 | 63.7 | 13.1 | B |
| 31: Moore's Ln 2 | 1100 | 67.0 | 16.4 | C |
| 32: Moore's Ln 3 | 1495 | 69.4 | 21.5 | C |
| 33: Moore's Ln 4 | 438 | 74.3 | 5.9 | A |
| 34: 69 ON | 891 | 72.8 | 12.2 | B |
| 35: 68 A | 489 | 55.4 | 8.8 | A |
| 36: 68 B | 263 | 37.0 | 7.1 | A |
| 37: 68 ON | 721 | 71.0 | 10.1 | B |
| 38: CSB Ln 1 | 290 | 27.4 | 10.6 | B |
| 39: CSB Ln 2 | 1017 | 24.3 | 41.8 | F |
| 40: CSB Ln 3 | 1009 | 25.6 | 39.4 | E |

| | | | | |
|---|---|---|---|---|
| 41: CSB Ln 4 | 1305 | 35.0 | 37.3 | E |
| 42: CSB HOV | 645 | 56.7 | 11.4 | B |
| 43: 67 OFF Ln 1 | 323 | 44.8 | 7.2 | A |
| 44: 67 OFF Ln 2 | 138 | 43.2 | 3.2 | A |
| 45: McEwen Ln 1 | 865 | 61.0 | 14.2 | B |
| 46: McEwen Ln 2 | 1203 | 63.9 | 18.8 | C |
| 47: McEwen Ln 3 | 1774 | 66.9 | 26.5 | D |
| 48: McEwen HOV | 484 | 75.1 | 6.4 | A |
| 49: 67 ON | 537 | 74.7 | 7.2 | A |
| 50: 65 Ln 1 | 620 | 60.9 | 10.2 | B |
| 51: 65 Ln 2 | 598 | 60.8 | 9.8 | A |
| 52: Murfreesboro Ln 1 | 913 | 66.3 | 13.8 | B |
| 53: Murfreesboro Ln 2 | 942 | 71.3 | 13.2 | B |
| 54: Murfreesboro Ln 3 | 822 | 74.0 | 11.1 | B |
| 55: Murfreesboro Ln 4 | 784 | 76.3 | 10.3 | B |
| 56: Murfreesboro HOV | 180 | 80.3 | 2.2 | A |
| 57: 65 ON | 803 | 73.1 | 11.0 | B |
| 58: 61 OFF Ln 1 | 311 | 74.2 | 4.2 | A |
| 59: 61 OFF Ln 2 | 68 | 78.3 | 0.9 | A |
| 60: Peytonsville Ln 1 | 948 | 70.5 | 13.5 | B |
| 61: Peytonsville Ln 2 | 951 | 74.3 | 12.8 | B |
| 62: Peytonsville Ln 3 | 890 | 77.1 | 11.5 | B |
| 63: Peytonsville HOV | 191 | 81.2 | 2.4 | A |
| 64: 61 ON | 256 | 74.6 | 3.4 | A |
| 65: END Ln 1 | 1023 | 70.9 | 14.4 | B |
| 66: END Ln 2 | 1022 | 75.1 | 13.6 | B |
| 67: END Ln 3 | 994 | 78.4 | 12.7 | B |
| 68: END HOV | 180 | 85.0 | 2.1 | A |

Table 10-14 HOV Lane Usage Statistics at Selected Locations for Future Year Do-Nothing Scenario

| Location | Violation Rate | Utilization Rate | Average Speed | Legal Utilization | Violators | Total Users |
|---|---|---|---|---|---|---|
| Harding Place | 82% | 12% | 73.349821 | 91 | 407 | 498 |
| Old Hickory Boulevard | 80% | 26% | 25.092718 | 123 | 501 | 624 |
| Concord Road | 80% | 19% | 37.242195 | 136 | 549 | 685 |
| Moore's Lane | 81% | 11% | 74.336203 | 84 | 351 | 435 |
| Cool Springs Boulevard | 80% | 15% | 56.657598 | 97 | 381 | 478 |
| McEwen Drive | 80% | 11% | 75.12262 | 94 | 378 | 472 |
| Murfreesboro Road | 83% | 5% | 80.327806 | 29 | 137 | 166 |
| Peytonsville Road | 79% | 6% | 81.22848 | 38 | 142 | 180 |

## Table 10-15 HOV Lane Usage Statistics at Selected Locations for Future Year Do-Nothing Scenario

| Segment | Segment Length (mi) | Free Flow Trip Time (s)* | Average Trip Time for All Vehicles (s) | Average Trip Time for SOV (s) | Average Trip Time for Trucks (s) | Average Trip Time for All HOV (s) | Average Trip Time for HOV Violators (s) |
|---|---|---|---|---|---|---|---|
| 1: Start to Armory | 0.65 | 31 | 327 | 369 | 498 | 85 | 102 |
| 2: Armory to Harding | 1.32 | 63 | 355 | 396 | 514 | 127 | 133 |
| 3: Harding to OHB | 3.28 | 157 | 341 | 365 | 424 | 230 | 236 |
| 4: OHB to Concord | 3.12 | 150 | 865 | 997 | 1005 | 381 | 365 |
| 5: Concord to Moore's | 2.23 | 107 | 438 | 485 | 538 | 245 | 249 |
| 6: Moore's to CSB | 1.32 | 63 | 77 | 78 | 92 | 68 | 69 |
| 7: CSB to McEwen | 0.96 | 46 | 96 | 96 | 132 | 70 | 78 |
| 8: McEwen to Murfreesboro | 1.41 | 67 | 73 | 72 | 83 | 69 | 69 |
| 9: Murfreesboro to Peytonsville | 3.80 | 183 | 190 | 191 | 208 | 181 | 180 |
| 10: Peytonsville to END | 2.02 | 97 | 97 | 97 | 104 | 94 | 93 |
| Corridor Totals | 20.10 | 965 | 2858 | 3146 | 3596 | 1549 | 1575 |

*Free flow trip time calculation is based on an assumed free flow speed of 75 mph

## Table 10-16 Vehicle Emissions and Fuel Consumption Data for Future Year Do-Nothing Scenario

| Segment | Total CO Emissions (g) | Total NOx Emissions (g) | Total VOC Emissions (g) | Total Fuel Consumption (gal) |
|---|---|---|---|---|
| 1: Interchange 79 | 212077 | 41263 | 49151 | 3034 |
| 2: Interchange 78 | 104111 | 20256 | 24129 | 1489 |
| 3: Interchange 74 | 203670 | 39627 | 47202 | 2914 |
| 4: Interchange 71 | 257961 | 50190 | 59785 | 3690 |
| 5: Interchange 69 | 73498 | 14300 | 17034 | 1051 |
| 6: Interchange 68 | 22021 | 4285 | 5104 | 315 |
| 7: Interchange 67 | 26917 | 5237 | 6238 | 385 |
| 8: Interchange 65 | 22218 | 4323 | 5149 | 318 |
| 9: Interchange 61 | 36339 | 7070 | 8422 | 520 |
| Corridor Totals | 958814 | 186550 | 222214 | 13717 |

## 10.5 Future Year Lane Reversion Scenario

For the future year lane reversion scenario, the VISSIM simulation was run at the calibrated parameter values determined in the model inputs section with demands chosen such that K = 0.10. However, the assumed vehicle composition was changed to consist of 20% HOV Violators, 70% HOV, and 10% Trucks. The SOV class was fully eliminated from the vehicle composition because there are now no passenger cars restricted from the HOV lane. As in all simulations, trucks are restricted from using the leftmost two lanes. The model results are reported using these vehicle class interpretations in Table 10-17 through Table 10-20.

Table 10-17 Peak Hour Flow, Space Mean Speed, Density, and LOS at Data Collection Points for Future Year Lane Reversion Scenario

| Data Collection Point | Flow (vph) | Space Mean Speed (mph) | Density (vpmpl) | Microsimulation Based LOS* |
|---|---|---|---|---|
| 1: MM 80 Ln 1 | 1068 | 10.5 | 101.4 | F |
| 2: MM 80 Ln 2 | 537 | 5.7 | 94.7 | F |
| 3: MM 80 Ln 3 | 812 | 9.7 | 83.6 | F |
| 4: MM 80 Ln 4 | 1558 | 18.6 | 83.7 | F |
| 5: MM 80 HOV | 228 | 73.5 | 3.1 | A |
| 6: 79 OFF | 267 | 35.3 | 7.6 | A |
| 7: 79 ON | 702 | 38.2 | 18.4 | C |
| 8: 78 OFF Ln 1 | 403 | 42.9 | 9.4 | A |
| 9: 78 OFF Ln 2 | 219 | 42.3 | 5.2 | A |
| 10: Harding Ln 1 | 797 | 62.0 | 12.9 | B |
| 11: Harding Ln 2 | 1213 | 65.3 | 18.6 | C |
| 12: Harding Ln 3 | 1759 | 68.0 | 25.9 | D |
| 13: Harding HOV | 141 | 74.7 | 1.9 | A |
| 14: 78 ON | 1116 | 33.1 | 33.7 | E |
| 15: 74 A Ln 1 | 330 | 37.1 | 8.9 | A |
| 16: 74 A Ln 2 | 185 | 36.6 | 5.1 | A |
| 17: 74 B | 375 | 34.8 | 10.8 | B |
| 18: OHB Ln 1 | 1218 | 18.7 | 65.2 | F |
| 19: OHB Ln 2 | 846 | 11.0 | 77.3 | F |
| 20: OHB Ln 3 | 1088 | 15.7 | 69.4 | F |
| 21: OHB HOV | 921 | 25.4 | 36.3 | E |
| 22: 74 ON | 996 | 7.6 | 131.3 | F |
| 23: 71 OFF | 362 | 35.6 | 10.2 | B |
| 24: Concord Rd Ln 1 | 1068 | 11.2 | 95.2 | F |

| | | | | |
|---|---|---|---|---|
| 25: Concord Rd Ln 2 | 1071 | 12.5 | 85.4 | F |
| 26: Concord Rd Ln 3 | 1677 | 25.0 | 67.2 | F |
| 27: Concord Rd HOV | 352 | 32.3 | 10.9 | B |
| 28: 69 Ln 1 | 611 | 42.4 | 14.4 | B |
| 29: 69 Ln 2 | 472 | 42.7 | 11.0 | B |
| 30: Moore's Ln 1 | 873 | 62.6 | 14.0 | B |
| 31: Moore's Ln 2 | 1218 | 64.8 | 18.8 | C |
| 32: Moore's Ln 3 | 1846 | 67.7 | 27.3 | D |
| 33: Moore's Ln HOV | 148 | 74.5 | 2.0 | A |
| 34: 69 ON | 891 | 72.7 | 12.2 | B |
| 35: 68 A | 511 | 52.8 | 9.7 | A |
| 36: 68 B | 263 | 41.4 | 6.3 | A |
| 37: 68 ON | 721 | 70.5 | 10.2 | B |
| 38: CSB Ln 1 | 245 | 32.4 | 7.6 | A |
| 39: CSB Ln 2 | 1075 | 34.6 | 31.1 | D |
| 40: CSB Ln 3 | 1154 | 37.4 | 30.9 | D |
| 41: CSB Ln 4 | 1629 | 48.5 | 33.6 | E |
| 42: CSB HOV | 303 | 55.9 | 5.4 | A |
| 43: 67 OFF Ln 1 | 330 | 43.4 | 7.6 | A |
| 44: 67 OFF Ln 2 | 137 | 43.1 | 3.2 | A |
| 45: McEwen Ln 1 | 825 | 58.9 | 14.0 | B |
| 46: McEwen Ln 2 | 1305 | 60.8 | 21.5 | C |
| 47: McEwen Ln 3 | 2098 | 62.9 | 33.4 | E |
| 48: McEwen HOV | 159 | 74.3 | 2.1 | A |
| 49: 67 ON | 537 | 74.5 | 7.2 | A |
| 50: 65 Ln 1 | 644 | 62.1 | 10.4 | B |
| 51: 65 Ln 2 | 575 | 61.4 | 9.4 | A |
| 52: Murfreesboro Ln 1 | 919 | 66.7 | 13.8 | B |
| 53: Murfreesboro Ln 2 | 950 | 70.9 | 13.4 | B |
| 54: Murfreesboro Ln 3 | 807 | 73.3 | 11.0 | B |
| 55: Murfreesboro Ln 4 | 927 | 75.8 | 12.2 | B |
| 56: Murfreesboro HOV | 78 | 80.7 | 1.0 | A |
| 57: 65 ON | 803 | 73.0 | 11.0 | B |
| 58: 61 OFF Ln 1 | 329 | 75.4 | 4.4 | A |
| 59: 61 OFF Ln 2 | 49 | 78.7 | 0.6 | A |
| 60: Peytonsville Ln 1 | 961 | 70.3 | 13.7 | B |
| 61: Peytonsville Ln 2 | 961 | 73.7 | 13.0 | B |
| 62: Peytonsville Ln 3 | 1001 | 76.6 | 13.1 | B |
| 63: Peytonsville HOV | 54 | 80.8 | 0.7 | A |
| 64: 61 ON | 256 | 74.5 | 3.4 | A |
| 65: END Ln 1 | 1076 | 70.9 | 15.2 | B |
| 66: END Ln 2 | 1039 | 74.7 | 13.9 | B |
| 67: END Ln 3 | 1086 | 78.1 | 13.9 | B |
| 68: END HOV | 61 | 84.1 | 0.7 | A |

Table 10-18 HOV Lane Usage Statistics at Selected Locations for Future Year Lane Reversion Scenario

| Table 24: | | | | | | |
|---|---|---|---|---|---|---|
| Location | Violation Rate | Utilization Rate | Average Speed | Legal Utilization | Violators | Total Users |
| Harding Place | N/A | 35% | 69.557329 | N/A | N/A | 1588 |
| Old Hickory Boulevard | N/A | 32% | 32.140853 | N/A | N/A | 1548 |
| Concord Road | N/A | 25% | 17.975592 | N/A | N/A | 1142 |
| Moore's Lane | N/A | 34% | 72.258495 | N/A | N/A | 1414 |
| Cool Springs Boulevard | N/A | 32% | 53.23468 | N/A | N/A | 1459 |
| McEwen Drive | N/A | 36% | 67.831049 | N/A | N/A | 1626 |
| Murfreesboro Road | N/A | 18% | 79.382535 | N/A | N/A | 690 |
| Peytonsville Road | N/A | 23% | 78.230856 | N/A | N/A | 718 |

Table 10-19 Vehicle Travel Time Statistics for Future Year Lane Reversion Scenario

| Segment | Segment Length (ft) | Free Flow Trip Time (s)* | Average Trip Time for All Vehicles (s) | Average Trip Time for SOV (s) | Average Trip Time for Trucks (s) | Average Trip Time for All HOV (s) | Average Trip Time for HOV Violators (s) |
|---|---|---|---|---|---|---|---|
| 1: Start to Armory | 0.65 | 31 | 326 | N/A | 507 | 307 | 307 |
| 2: Armory to Harding | 1.32 | 63 | 359 | N/A | 566 | 340 | 335 |
| 3: Harding to OHB | 3.28 | 157 | 207 | N/A | 222 | 205 | 207 |
| 4: OHB to Concord | 3.12 | 150 | 772 | N/A | 727 | 779 | 766 |
| 5: Concord to Moore's | 2.23 | 107 | 481 | N/A | 613 | 467 | 465 |
| 6: Moore's to CSB | 1.32 | 63 | 72 | N/A | 84 | 70 | 71 |
| 7: CSB to McEwen | 0.96 | 46 | 79 | N/A | 102 | 76 | 77 |
| 8: McEwen to Murfreesboro | 1.41 | 67 | 72 | N/A | 84 | 71 | 72 |
| 9: Murfreesboro to Peytonsville | 3.80 | 183 | 188 | N/A | 216 | 185 | 186 |
| 10: Peytonsville to END | 2.02 | 97 | 95 | N/A | 105 | 94 | 94 |
| Corridor Totals | 20.10 | 965 | 2650 | N/A | 3227 | 2595 | 2580 |

*Free flow trip time calculation is based on an assumed free flow speed of 75 mph

Table 10-20 Vehicle Emissions and Fuel Consumption Data for Future Year Lane Reversion Study

| Segment | Total CO Emissions (g) | Total NOx Emissions (g) | Total VOC Emissions (g) | Total Fuel Consumption (gal) |
|---|---|---|---|---|
| 1: Interchange 79 | 236319 | 45979 | 54769 | 3381 |
| 2: Interchange 78 | 124577 | 24238 | 28872 | 1782 |
| 3: Interchange 74 | 145599 | 28328 | 33744 | 2083 |
| 4: Interchange 71 | 291836 | 56781 | 67636 | 4175 |
| 5: Interchange 69 | 95597 | 18600 | 22156 | 1368 |
| 6: Interchange 68 | 17993 | 3501 | 4170 | 257 |
| 7: Interchange 67 | 25473 | 4956 | 5904 | 364 |
| 8: Interchange 65 | 24518 | 4770 | 5682 | 351 |
| 9: Interchange 61 | 39306 | 7648 | 9110 | 562 |
| Corridor Totals | 1001220 | 194801 | 232042 | 14324 |

## 10.6 Future Year Heavy Enforcement Scenario

For the future year heavy enforcement scenario, the VISSIM simulation was run at the calibrated parameter values determined in the model inputs section with demands chosen such that K = 0.10. However, the assumed vehicle composition was changed to consist of 0.5% HOV Violators, 5% HOV, 10% Trucks, and 84.5% SOV. The SOV class includes the compliant SOV drivers, as well as the HOV drivers unwilling to use the HOV lane. This simulates a slight increase in the legal use of the HOV lane along with the removal of a large number of violators from the HOV lane. The model results are reported using these vehicle class interpretations in Table 10-21 through Table 10-24.

Table 10-21 Peak Hour Flow, Space Mean Speed, Density, and LOS at Data Collection Points for Future Year Heavy Enforcement Scenario

| Data Collection Point | Flow (vph) | Space Mean Speed (mph) | Density (vpmpl) | Microsimulation Based LOS* |
|---|---|---|---|---|
| 1: MM 80 Ln 1 | 1068 | 10.5 | 101.4 | F |
| 2: MM 80 Ln 2 | 537 | 5.7 | 94.7 | F |
| 3: MM 80 Ln 3 | 812 | 9.7 | 83.6 | F |
| 4: MM 80 Ln 4 | 1558 | 18.6 | 83.7 | F |
| 5: MM 80 HOV | 228 | 73.5 | 3.1 | A |
| 6: 79 OFF | 267 | 35.3 | 7.6 | A |
| 7: 79 ON | 702 | 38.2 | 18.4 | C |
| 8: 78 OFF Ln 1 | 403 | 42.9 | 9.4 | A |
| 9: 78 OFF Ln 2 | 219 | 42.3 | 5.2 | A |
| 10: Harding Ln 1 | 797 | 62.0 | 12.9 | B |
| 11: Harding Ln 2 | 1213 | 65.3 | 18.6 | C |
| 12: Harding Ln 3 | 1759 | 68.0 | 25.9 | D |
| 13: Harding HOV | 141 | 74.7 | 1.9 | A |
| 14: 78 ON | 1116 | 33.1 | 33.7 | E |
| 15: 74 A Ln 1 | 330 | 37.1 | 8.9 | A |
| 16: 74 A Ln 2 | 185 | 36.6 | 5.1 | A |
| 17: 74 B | 375 | 34.8 | 10.8 | B |
| 18: OHB Ln 1 | 1218 | 18.7 | 65.2 | F |
| 19: OHB Ln 2 | 846 | 11.0 | 77.3 | F |
| 20: OHB Ln 3 | 1088 | 15.7 | 69.4 | F |
| 21: OHB HOV | 921 | 25.4 | 36.3 | E |
| 22: 74 ON | 996 | 7.6 | 131.3 | F |
| 23: 71 OFF | 362 | 35.6 | 10.2 | B |
| 24: Concord Rd Ln 1 | 1068 | 11.2 | 95.2 | F |
| 25: Concord Rd Ln 2 | 1071 | 12.5 | 85.4 | F |
| 26: Concord Rd Ln 3 | 1677 | 25.0 | 67.2 | F |
| 27: Concord Rd HOV | 352 | 32.3 | 10.9 | B |
| 28: 69 Ln 1 | 611 | 42.4 | 14.4 | B |
| 29: 69 Ln 2 | 472 | 42.7 | 11.0 | B |
| 30: Moore's Ln 1 | 873 | 62.6 | 14.0 | B |
| 31: Moore's Ln 2 | 1218 | 64.8 | 18.8 | C |
| 32: Moore's Ln 3 | 1846 | 67.7 | 27.3 | D |
| 33: Moore's Ln 4 | 148 | 74.5 | 2.0 | A |
| 34: 69 ON | 891 | 72.7 | 12.2 | B |
| 35: 68 A | 511 | 52.8 | 9.7 | A |
| 36: 68 B | 263 | 41.4 | 6.3 | A |
| 37: 68 ON | 721 | 70.5 | 10.2 | B |
| 38: CSB Ln 1 | 245 | 32.4 | 7.6 | A |
| 39: CSB Ln 2 | 1075 | 34.6 | 31.1 | D |
| 40: CSB Ln 3 | 1154 | 37.4 | 30.9 | D |

| | | | | |
|---|---|---|---|---|
| 41: CSB Ln 4 | 1629 | 48.5 | 33.6 | E |
| 42: CSB HOV | 303 | 55.9 | 5.4 | A |
| 43: 67 OFF Ln 1 | 330 | 43.4 | 7.6 | A |
| 44: 67 OFF Ln 2 | 137 | 43.1 | 3.2 | A |
| 45: McEwen Ln 1 | 825 | 58.9 | 14.0 | B |
| 46: McEwen Ln 2 | 1305 | 60.8 | 21.5 | C |
| 47: McEwen Ln 3 | 2098 | 62.9 | 33.4 | E |
| 48: McEwen HOV | 159 | 74.3 | 2.1 | A |
| 49: 67 ON | 537 | 74.5 | 7.2 | A |
| 50: 65 Ln 1 | 644 | 62.1 | 10.4 | B |
| 51: 65 Ln 2 | 575 | 61.4 | 9.4 | A |
| 52: Murfreesboro Ln 1 | 919 | 66.7 | 13.8 | B |
| 53: Murfreesboro Ln 2 | 950 | 70.9 | 13.4 | B |
| 54: Murfreesboro Ln 3 | 807 | 73.3 | 11.0 | B |
| 55: Murfreesboro Ln 4 | 927 | 75.8 | 12.2 | B |
| 56: Murfreesboro HOV | 78 | 80.7 | 1.0 | A |
| 57: 65 ON | 803 | 73.0 | 11.0 | B |
| 58: 61 OFF Ln 1 | 329 | 75.4 | 4.4 | A |
| 59: 61 OFF Ln 2 | 49 | 78.7 | 0.6 | A |
| 60: Peytonsville Ln 1 | 961 | 70.3 | 13.7 | B |
| 61: Peytonsville Ln 2 | 961 | 73.7 | 13.0 | B |
| 62: Peytonsville Ln 3 | 1001 | 76.6 | 13.1 | B |
| 63: Peytonsville HOV | 54 | 80.8 | 0.7 | A |
| 64: 61 ON | 256 | 74.5 | 3.4 | A |
| 65: END Ln 1 | 1076 | 70.9 | 15.2 | B |
| 66: END Ln 2 | 1039 | 74.7 | 13.9 | B |
| 67: END Ln 3 | 1086 | 78.1 | 13.9 | B |
| 68: END HOV | 61 | 84.1 | 0.7 | A |

Table 10-22 HOV Lane Usage Statistics at Selected Locations for Future Year Heavy Enforcement Scenario

| Location | Violation Rate | Utilization Rate | Average Speed | Legal Utilization | Violators | Total Users |
|---|---|---|---|---|---|---|
| Harding Place | 11% | 4% | 74.653 | 125 | 16 | 141 |
| Old Hickory Boulevard | 14% | 23% | 25.352752 | 173 | 28 | 201 |
| Concord Road | 11% | 8% | 32.312846 | 188 | 24 | 212 |
| Moore's Lane | 13% | 4% | 74.520781 | 124 | 19 | 143 |
| Cool Springs Boulevard | 14% | 7% | 55.937465 | 112 | 18 | 130 |
| McEwen Drive | 15% | 4% | 74.301318 | 126 | 22 | 148 |
| Murfreesboro Road | 12% | 2% | 80.717227 | 44 | 6 | 50 |
| Peytonsville Road | 10% | 2% | 80.797406 | 35 | 4 | 39 |

Table 10-23 Vehicle Travel Time Statistics for Future Year Heavy Enforcement Scenario

| Segment | Segment Length (mi) | Free Flow Trip Time (s)* | Average Trip Time for All Vehicles (s) | Average Trip Time for SOV (s) | Average Trip Time for Trucks (s) | Average Trip Time for All HOV (s) | Average Trip Time for HOV Violators (s) |
|---|---|---|---|---|---|---|---|
| 1: Start to Armory | 0.65 | 31 | 309 | 307 | 443 | 63 | 61 |
| 2: Armory to Harding | 1.32 | 63 | 341 | 343 | 441 | 104 | 120 |
| 3: Harding to OHB | 3.28 | 157 | 523 | 536 | 572 | 261 | 277 |
| 4: OHB to Concord | 3.12 | 150 | 686 | 714 | 689 | 273 | 281 |
| 5: Concord to Moore's | 2.23 | 107 | 343 | 348 | 379 | 193 | 188 |
| 6: Moore's to CSB | 1.32 | 63 | 81 | 80 | 94 | 70 | 67 |
| 7: CSB to McEwen | 0.96 | 46 | 127 | 125 | 165 | 92 | 89 |
| 8: McEwen to Murfreesboro | 1.41 | 67 | 74 | 73 | 83 | 69 | 67 |
| 9: Murfreesboro to Peytonsville | 3.80 | 183 | 191 | 191 | 205 | 181 | 178 |
| 10: Peytonsville to END | 2.02 | 97 | 97 | 97 | 103 | 95 | 90 |
| Corridor Totals | 20.10 | 965 | 2770 | 2813 | 3176 | 1401 | 1418 |

Table 10-24 Vehicle Emissions and Fuel Consumption Data for Future Year Heavy Enforcement Scenario

| Segment | Total CO Emissions (g) | Total NOx Emissions (g) | Total VOC Emissions (g) | Total Fuel Consumption (gal) |
|---|---|---|---|---|
| 1: Interchange 79 | 183994 | 35798 | 42642 | 2632 |
| 2: Interchange 78 | 112434 | 21876 | 26058 | 1609 |
| 3: Interchange 74 | 229104 | 44575 | 53097 | 3278 |
| 4: Interchange 71 | 184826 | 35960 | 42835 | 2644 |
| 5: Interchange 69 | 55688 | 10835 | 12906 | 797 |
| 6: Interchange 68 | 28248 | 5496 | 6547 | 404 |
| 7: Interchange 67 | 37453 | 7287 | 8680 | 536 |
| 8: Interchange 65 | 22093 | 4298 | 5120 | 316 |
| 9: Interchange 61 | 36509 | 7103 | 8461 | 522 |
| Corridor Totals | 890348 | 173229 | 206347 | 12737 |

# Chapter 11 Corridor-Level Results of Microsimulation of I-65 and I-24 HOV Corridors

VISSIM simulation has been performed for both the northbound and southbound directions Interstate 65 north and south of Nashville, and the eastbound and westbound corridors of I-24. A similar approach to that of Chapters 9 and 10, the development of the models has been followed for the development of VISSIM models for the other corridors. As these models went through the similar developmental processes to that described for the southbound I-65 corridor south of Nashville, only summary information will be presented in this chapter, along with a discussion of a few significant features of the models most responsible for the results obtained.

Scenarios have been constructed using available ramp traffic counts, with a few assumptions required when ramp traffic counts were not found on the TDOT ramp count maps, found at: https://www.tn.gov/tdot/driver-how-do-i/look-at-or-order-state-maps/maps/county-ramp-aadt-counts.html. Additional traffic data to generate vehicle inputs was obtained from AADT values available online from TDOT at: https://www.arcgis.com/apps/webappviewer/index.html?id=075987cdae37474b88fa400d65681354. Base year traffic is assumed to be generated by a K-value of 0.08 for the base year and 0.10 for the future year. Important system-level metrics of performance are HOV lane utilization rates and operating speeds at various locations along the corridor, travel time for the entire corridor by vehicle class, $CO_2$ emissions, nitrogen oxide emissions, volatile organic compound emissions, and fuel consumption.

## 11.1 Southbound I-65 South of Nashville

Chapters 9 and 10 have presented the modeling assumptions and results from each of the six case studies under consideration for the I-65 southbound corridor from MM 80 to MM 59. A summarization of the most important network-level metrics is provided in Table 11-1, and a discussion of the differences across the previous six scenarios; base year do nothing (BYDN), base year heavy enforcement (BYHE), base year lane reversion (BYLR), future year do nothing (FYDN), future year heavy enforcement (FYHE), and future year lane reversion (FYLR); will be provided here.

HOV lane utilization follows a relatively expected trend. Under the heavy enforcement scenario, the utilization rate drops, while under the lane reversion scenario, the utilization of the HOV lane generally increases. Both of these trends are as expected. However, there are a few important features in this data that should be noted. Under the heavy enforcement scenario, only five percent of the traffic is, in fact, eligible to use the HOV lane, yet the utilization at Old Hickory Boulevard is 16 percent. This is not an artifact of the vehicle composition, but rather of the relative capacity of the HOV lane near the diverge bottleneck that can occasionally form at Exit 74A. The weaving problems at the diverge just upstream of the location of the data collection point disproportionately affect the capacities of the rightward lanes, whereas the HOV lane can operate at closer to its capacity in the absence of weaving problems. Comparison of the utilization under the base and future year do nothing scenarios reveals that the utilization at the downstream sections (Old Hickory and Cool Springs Boulevards) increases more than at Harding Place (Exit 78). This is because Harding Place is the primary bottleneck and is already operating at capacity. An increase of demand upstream of Harding Place does little to change operations at this bottleneck because the flow from MM 80 to MM 78 is controlled by the two diverge bottlenecks activating at Exits 78 and 79 and the spillback from Exit 78 interfering with the merge at

Entrance 79 to create a major merge bottleneck.

A comparison of the speeds observed in the HOV lane is also informative about the nature of traffic operations, especially near diverge bottlenecks. Under present conditions, the performance of the HOV lanes can be degraded under heavy traffic. This is observed as the speeds at Old Hickory Boulevard and Cool Springs Boulevard are predicted by VISSIM to be significantly lower than the free-flow speed. However, in most scenarios, it is common for speeds in the HOV lane to be 10-15 mph faster than in the fastest mixed-flow lane and more than 20 mph faster than in the right-hand lane at Old Hickory Boulevard and Cool Springs Boulevard. This is indicative of the clear difficulty in merging to exit the facility, as the slowing is certainly due to drivers seeking to exit the lane needing to slow down ~~to~~ make lane changes, or to be able to make them at all before missing their exit.

One counterintuitive phenomenon observed is that heavy enforcement failed to restore travel speeds in the HOV lane to free-flow speed. In some cases, it resulted in caused degradation of performance in the HOV lane. This is most likely frictive slowing, and the degradation is certainly due to the reduction in available gaps to allow for vehicles in the HOV lane to merge into the mixed-flow lane. Under the base year demand conditions, the degradation was quite severe at Old Hickory Boulevard- over ten miles per hour slower than under the do-nothing conditions. Under the future year scenario, the HOV lane generally moves at a speed close to that of the mixed-flow lanes, as is necessary to enable safe lane changes.

When strategies are compared with respect to operational and environmental metrics for the performance of the corridor as a whole, it becomes clear that for this corridor, a heavy enforcement strategy that allows the HOV lane to be used by a smaller number of users is the preferred strategy. It is the superior alternative with respect to every metric, both under the base year and future year scenarios. However, in the current regulatory climate, where manual enforcement is impractical and not effective in deterring violators, it is impossible to achieve this kind of operation. However, it may be possible to do so with either automated enforcement or through the use of pricing controls in a HOT lane framework, as SOVs would face a certain toll for use of the HOV lane.

Given that the models in Chapters 6 and 7 predict that better outcomes should occur from lane reversion and microsimulation indicates that heavy enforcement is the preferred alternative, these outcomes warrant further explanation. The results of Chapters 6 and 7 were developed based on the BPR formulas for link performance and choice models developed based on revealed preference. In the appropriate use of the BPR models, demand should not exceed capacity. Since there is a significant and sudden deterioration in travel speeds as capacity is approached or exceeded, the BPR model provides no ability to capture the intricate details of the traffic flows in weaving areas when bottlenecks are active.

To a point, violators in the HOV lane do not significantly degrade the performance of the HOV lane. However, the bulk of delay at diverge bottlenecks arises from the need of drivers exiting from the left-most lane to cross all mixed-flow lanes. At low to moderate levels of HOV lane usage, a few more drivers do not significantly impair operations in the HOV lane, though it can exacerbate the breakdown of the mixed-flow lanes near the diverge bottleneck.

However, as more and more vehicles occupy the interstate, and particularly the mixed-flow lanes, the weaving volume will create more and more conflicts with the traffic in the mixed-flow lanes, requiring more severe speed reductions near the bottleneck. The increases in HOV lane volumes, mixed-flow lane volumes, and weaving volumes together will result in speed adjustments in both the mixed-flow lanes (as drivers let the weaving vehicle enter the lane) and in the HOV lane (as drivers following the weaving vehicle must adjust their speed).

If the HOV lane carries sufficient traffic and a significant proportion of drivers choose to exit the HOV lane too close to the diverge, progression in the HOV lane will begin to mirror progression in the mixed-flow lanes near the bottleneck. The progression in the mixed-flow lanes is also impaired with higher weaving volumes. As weaving volumes increase, the need for, and magnitude of, speed adjustments also increase, and traffic will become denser near bottlenecks. The queued state of operations is the most significant reason for the results of microsimulation standing in conflict with the results of Chapters 6 and 7, where the BPR performance functions were not equipped to handle bottlenecks and queued traffic conditions.

Since weaving volumes are most responsible for drops in bottleneck throughputs, the results of microsimulation support the conclusion that the control of weaving is more important to improving the throughput of the diverge bottlenecks than the addition of capacity that could result from opening the HOV lane to more vehicles on the southbound I-65 corridor south of Nashville. It should be noted however that the throughput of MM80 to MM78 seemed to suggest that the capacity of the lanes cannot simply be fixed by addressing/correcting weaving behaviors. The best management strategy for the corridor's diverge bottlenecks would be to prevent as many late lane changes as possible from the HOV lane in order to prevent the breakdown of both the HOV lane and the mixed-flow lanes by striping, barrier separation, or some other traffic control strategy while incentivizing those drivers exiting beyond the bottleneck to take advantage of the HOV lane.

As traffic volume grows on the corridor to the levels simulated in the future year scenarios, the differences generally become less between the heavy enforcement and lane reversion cases, while the do-nothing case is inferior to either approach. Lane reversion and heavy enforcement are equally effective operationally, with the heavy enforcement option preferable environmentally. The do-nothing scenario results in too few drivers taking advantage of the HOV lane to leverage its capacity while too many drivers are using the HOV lane to avoid, and subsequently improve, their respective travel time. Such HOV use also has the effect of providing more efficient operation of the mixed-flow lanes near the bottleneck.

While the results of future year simulations may be indicative that the benefits afforded by removal of a significant proportion of users from the HOV lane may not ultimately be sustainable under heavier demand situations, it is important to note that in these simulations there were no operational improvements modeled that would prevent late weaving behaviors from breaking down the facility. Providing some degree of separation of operations between the mixed-flow lane and the HOV lane would force drivers in the HOV lane through the bottleneck at free-flow speed and reduce weaving through the mixed-flow lanes, thereby improving bottleneck throughput. The present study, however, has been focused on operations of the lane as it currently operates. It is important to note that the environmental impacts of the heavy enforcement scenario are considerably less, making it the preferred solution if operational results are not significantly different across scenarios.

These results are likely counterintuitive in the mind of the public. The public largely perceives a monotonically increasing travel time to be associated with more traffic in each lane. The public is largely unaware of how and why bottlenecks form on highways or why the HOV lane is currently impacted to the extent it is by other lanes of traffic. While the HOV lane may not be operating at a volume that would normally require slower than free-flow operations, vehicular conflicts can occur with vehicles in other lanes, necessitating drivers in the HOV lane to modify their speeds to make a lane change out of the HOV lane. The public is also largely unaware that

HOV lane violators do not always result in significant slowing of the HOV lane, while they may cause very large delays for the mixed-flow lanes at bottlenecks.

Table 11-1 Corridor Performance Metrics for VISSIM Simulation of the Southbound I-65 South of Nashville (Preferred Outcomes Highlighted in Green)

| Metric | BYDN | BYLR | BYHE | FYDN | FYLR | FYHE |
|---|---|---|---|---|---|---|
| HOV Lane Speed at Harding | 72.4 | 70.6 | 76.6 | 73.3 | 69.6 | 74.6 |
| HOV Lane Speed at OHB | 67.8 | 67.8 | 57.3 | 25.1 | 32.1 | 25.4 |
| HOV Lane Speed at CSB | 60.7 | 50.8 | 62.3 | 56.7 | 53.2 | 55.9 |
| HOV Lane Flow at Harding | 449 | 1488 | 128 | 498 | 1588 | 141 |
| HOV Lane Flow at OHB | 958 | 1701 | 663 | 1058 | 1548 | 921 |
| HOV Lane Flow at CSB | 465 | 1385 | 258 | 645 | 1459 | 303 |
| Utilization at Harding | 11% | 33% | 3% | 12% | 35% | 4% |
| Utilization at OHB | 22% | 36% | 16% | 26% | 32% | 23% |
| Utilization at CSB | 11% | 31% | 6% | 15% | 32% | 7% |
| Corridor All Vehicles Travel Time (min) | 40.4 | 46.2 | 37.7 | 47.6 | 46.2 | 46.2 |
| Corridor Trip Time for SOV (min) | 44.4 | 46.9 | 38.1 | 52.4 | 46.9 | 46.9 |
| Corridor Trip Time for HGV (min) | 49.2 | 52.9 | 43.8 | 59.9 | 52.9 | 52.9 |
| Corridor Trip Time for HOV (min) | 22.9 | N/A | 20.7 | 25.8 | N/A | 23.4 |
| Total CO2 Emissions (g/hr) | 782992 | 694199 | 681278 | 958814 | 1001220 | 890348 |
| Total NOX Emissions (g/hr) | 152342 | 135066 | 132552 | 186550 | 194801 | 173229 |
| Total VOC Emissions (g/hr) | 181468 | 160877 | 157893 | 222214 | 232042 | 206347 |
| Total Fuel Consumption (gal/hr) | 11202 | 9931 | 9746 | 13717 | 14324 | 12737 |

Note: The N/A denotation in the BYLR and FYLR scenarios means that there are no vehicles with an HOV designation.

## 11.2 Northbound I-65 South of Nashville

The northbound I-65 HOV corridor south of Nashville has some important operational differences from the southbound corridor south of Nashville due to the distribution of the influx along the corridor. Downtown Nashville serves as a major trip attractor in the AM direction and a major trip producer in the PM direction. The distribution of the influx in the AM direction results in a system that is governed by a combination of merge and diverge bottlenecks distributed over approximately ten to fifteen miles from Franklin to downtown Nashville.

As can be seen in Figure 11-1, congestion generally becomes more severe closer to the end of the corridor, where the daily traffic counts are the highest along the corridor. The feature along the corridor responsible for the greatest generation of delay is the merge bottleneck that occurs immediately after the entrance ramp of Interchange 74. At this point, there is a heavy volume being carried in the main lanes, and there are initially two auxiliary lanes of traffic that merge into the freeway. As can be inferred from Figure 11-2, this bottleneck can often result in very slow conditions on days with the heaviest demand. Figure 11-3 and Figure 11-4 show the diverge and merge bottleneck formation at Interchange 74. VISSIM captures both bottlenecks at Interchange 74 and shows bottleneck formation at most interchanges from Franklin to downtown Nashville.

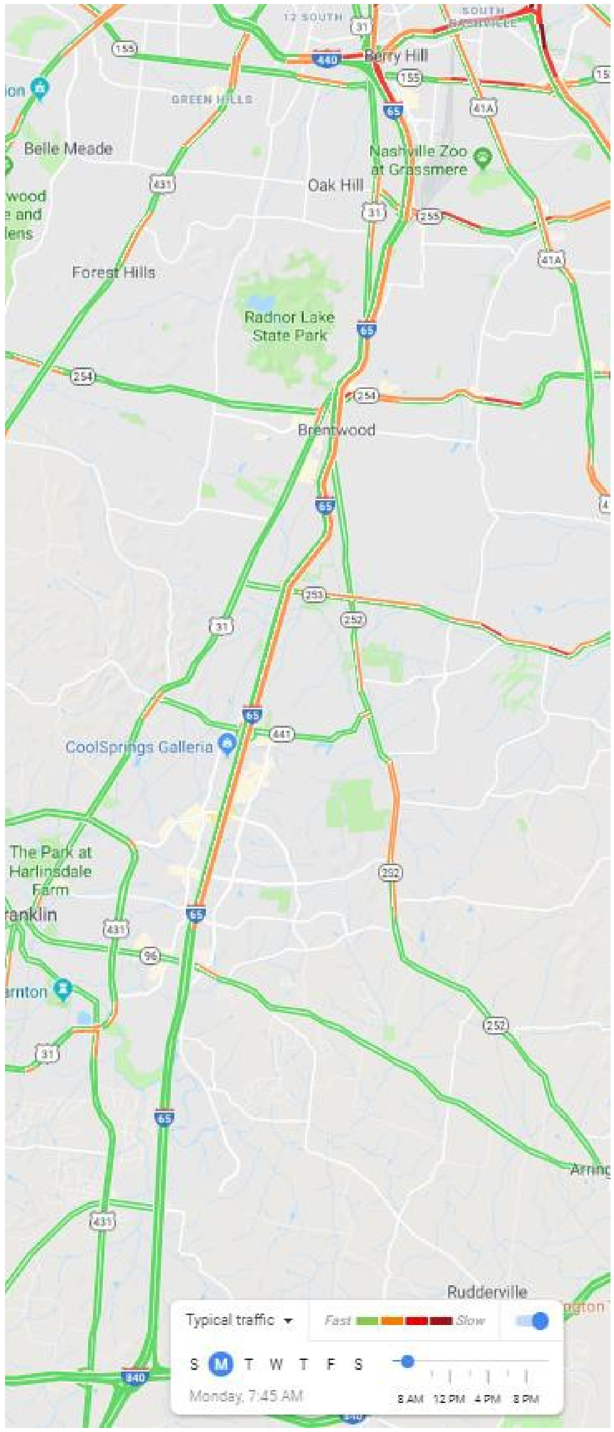



Figure 11-1 Typical AM peak conditions for northbound I-65 south of Nashville (image from Google Maps)

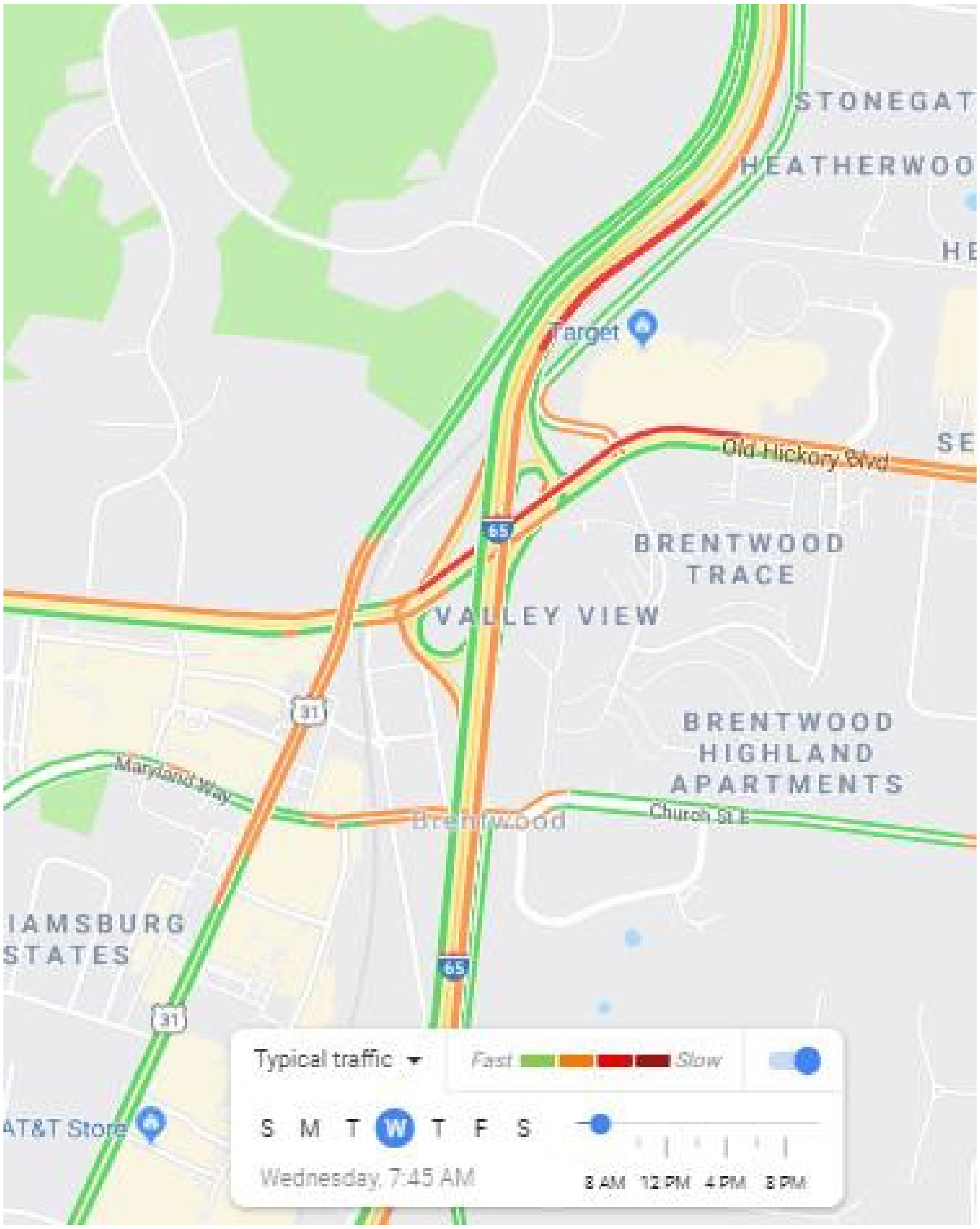



Figure 11-2 Merge bottleneck following interchange 74 (image from Google Maps)


Figure 11-3 Development of diverge bottlenecks at interchange 74 (image from Google Maps)

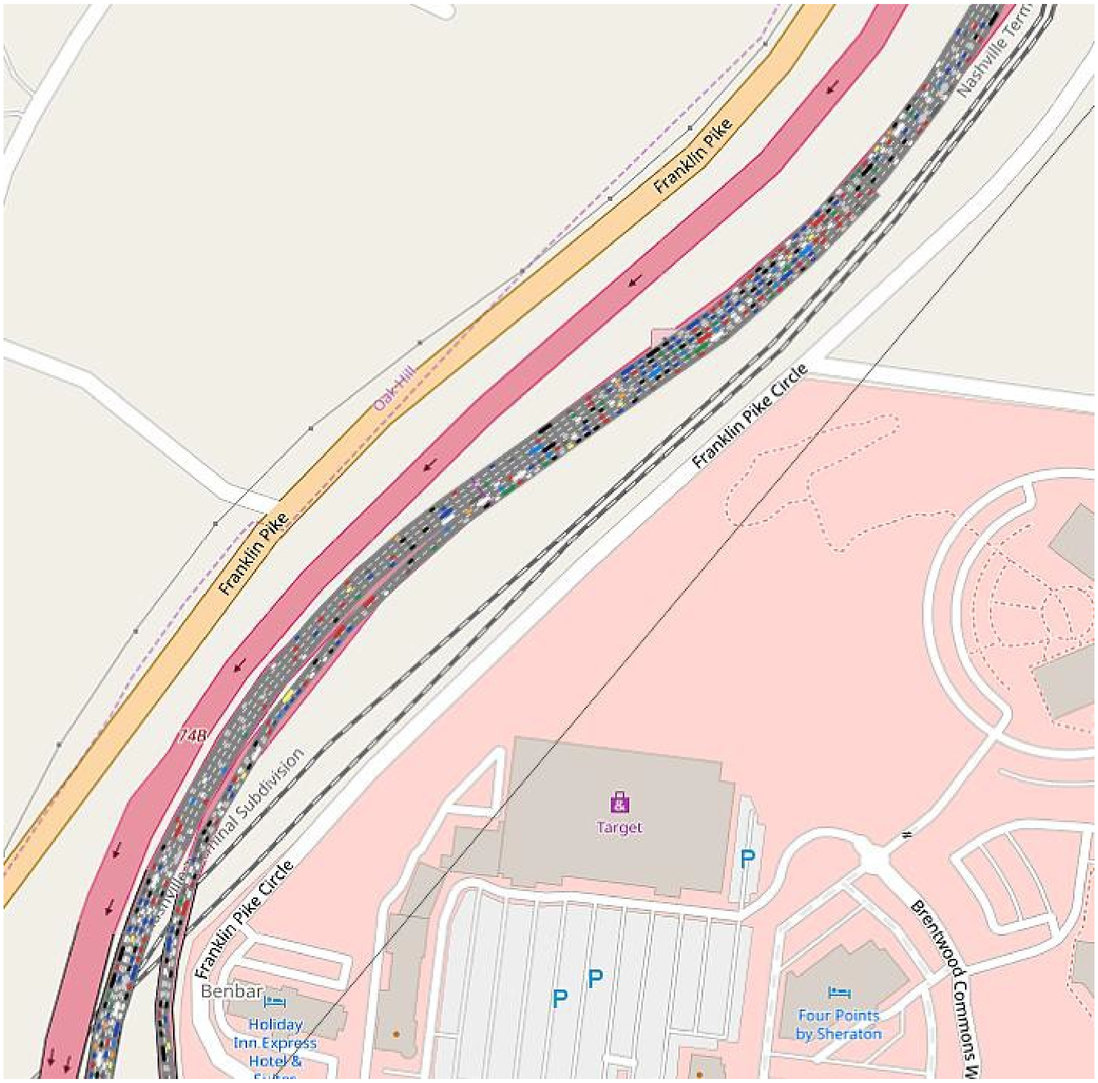



Figure 11-4 Merge bottleneck formation following interchange 74

Important corridor-level results are shown in Table 11-2. When strategies are compared with respect to operational and environmental metrics for the performance of the corridor as a whole, it becomes clear that for this corridor, as it was for the southbound corridor, a heavy enforcement strategy which allows the HOV lane to be used by a smaller number of users is the dominant strategy under the base year conditions. It is the superior alternative with respect to every metric, both under the base year and future year scenarios. From the consideration of other scenarios, it is clear that, as was the case for the southbound corridor, a significant increase in violations does not degrade the performance of the HOV lane significantly at the current level of HOV lane usage.

While under the base year demand levels it appears that the heavy enforcement strategy is preferable, it is questionable whether it will be the best strategy if traffic volumes increase significantly. There appears to be a future demand level at which the increase in traffic volume leads to underutilization of the HOV lane under the heavy enforcement scenario, as the do-nothing case becomes preferable. The northbound direction has some significant differences from the southbound due to the prevalence of a very significant merge bottleneck unlike any found on the southbound corridor. As a result, in future years it may be the case that the HOV lane would be underutilized in the heavy enforcement scenario.

While allowing a greater number of drivers to access the HOV lane in the vicinity of a merge bottleneck would be helpful for operations, another alternative for reducing delays at bottleneck locations is ramp metering, particularly near Interchanges 71 and 74. Ramp metering can be effective in increasing the throughput of merge bottlenecks by lessening the need for vehicles in the mixed-flow lanes to adjust their speeds to allow merging vehicles to enter. However, it should be noted that ramp metering is not a panacea for all problems with merge bottlenecks. Careful attention should be paid to impacts on surface streets near where the metering solution is applied to determine the impacts to surface streets. Applied improperly, ramp metering can worsen problems on surface streets that do not have the same vehicle storage capacity as the interstate.

Table 11-2 Corridor Metrics of Performance for VISSIM Simulation of Northbound I-65 South of Nashville (Preferred Outcomes Highlighted in Green)

| Metric | BYDN | BYLR | BYHE | FYDN | FYLR | FYHE |
|---|---|---|---|---|---|---|
| HOV Lane Speed at Harding | 65.3 | 66.5 | 65.7 | 65.7 | 66.4 | 67.1 |
| HOV Lane Speed at OHB | 44.7 | 33.4 | 45.3 | 19.0 | 20.9 | 25.0 |
| HOV Lane Speed at CSB | 63.0 | 48.6 | 63.8 | 60.3 | 44.9 | 62.9 |
| HOV Lane Flow at Harding | 1505 | 1523 | 1478 | 1546 | 1546 | 1530 |
| HOV Lane Flow at OHB | 1466 | 1497 | 1399 | 1321 | 1315 | 1448 |
| HOV Lane Flow at CSB | 632 | 1611 | 232 | 702 | 1765 | 256 |
| Utilization at Harding | 26% | 26% | 26% | 26% | 27% | 27% |
| Utilization at OHB | 29% | 28% | 30% | 25% | 25% | 27% |
| Utilization at CSB | 11% | 28% | 4% | 12% | 28% | 5% |
| Corridor All Vehicles Travel Time (min) | 25.9 | 26.4 | 25.6 | 37.9 | 40.9 | 40.5 |
| Corridor Trip Time for SOV (min) | 26.4 | 26.2 | 25.6 | 39.8 | 40.7 | 41.1 |
| Corridor Trip Time for HGV (min) | 29.8 | 29.0 | 28.7 | 43.1 | 45.5 | 43.7 |
| Corridor Trip Time for HOV (min) | 23.3 | N/A | 21.9 | 31.8 | N/A | 30.3 |
| Total CO2 Emissions (g/hr) | 394422 | 391643 | 375751 | 595911 | 620733 | 582562 |
| Total NOX Emissions (g/hr) | 76740 | 76200 | 73108 | 115943 | 120772 | 113345 |
| Total VOC Emissions (g/hr) | 91411 | 90767 | 87084 | 138108 | 143861 | 135014 |
| Total Fuel Consumption (gal/hr) | 5643 | 5603 | 5376 | 8525 | 8880 | 8334 |

Note: The N/A denotation in the BYLR and FYLR scenarios means that there are no vehicles with an HOV designation.

## 11.3 Northbound I-65 North of Nashville

From the observation of Google Maps data for a typical Monday at 3:40 PM, a merge bottleneck activates on I-65 North after the Long Hollow Pike, as shown in Figure 11-5. A diverge bottleneck also activates at or near 4:00 at the TN 368/ Vietnam Veterans Boulevard exit as shown in Figure 6. These two bottlenecks cause I-65 to flow at or near the bottleneck capacity, as queuing waves form and slow the progression of traffic elsewhere on I-65 North, as shown in Figure 11-6. Traffic densifies rapidly thereafter, as shown in Figure 11-7.

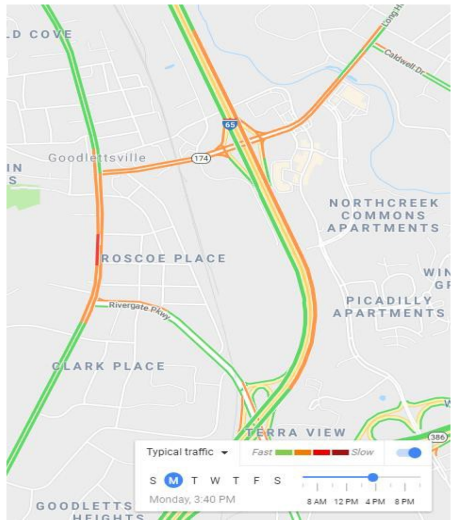



Figure 11-5 Typical merge bottleneck activation on I-65 North at Long Hollow Park Exit (image from Google Maps)

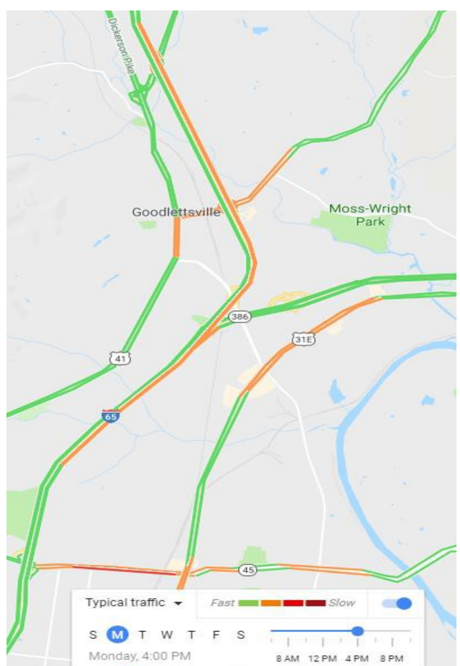



Figure 11-6 Diverge bottleneck activation at Vietnam Veterans Boulevard Exit on North I-65 (image from Google Maps)

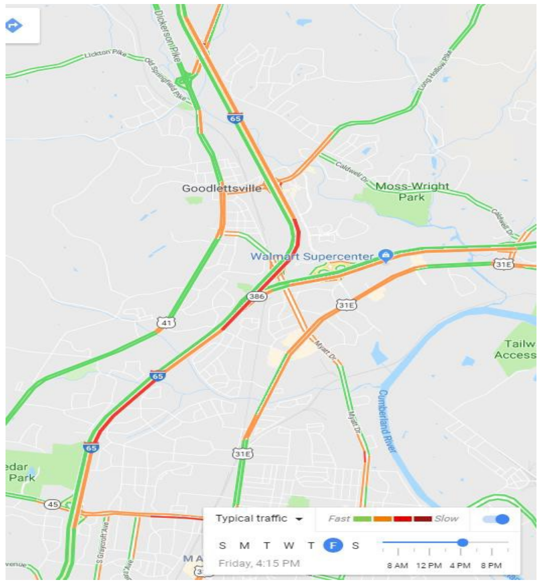



Figure 11-7 PM Queue propagation and traffic stream densification on North I-65 (image from Google Maps)

The VISSIM model was constructed such that the network stopped before consideration of the Long Hollow Park exit for the following reasons. First, the HOV corridor stops before reaching Long Hollow Park exit. Second, the bottleneck at Vietnam Veterans Boulevard activates before the bottleneck at Long Hollow activates and capacity discharge occurs on Interstate 65 while the segment between the Vietnam Veterans Boulevard exit and the Long Hollow Park exit operates at a freely flowing speed. Third, even when downstream queues spill back to the Vietnam Veterans Boulevard exit, they move at a faster speed than traffic at the Vietnam Veterans Boulevard exit.

Typically, the activation of the bottleneck at the Vietnam Veterans Boulevard exit creates a backward wave of traffic operating at near-standstill speeds. This ultimately extends back up the Interstate 65 corridor to the beginning of the HOV corridor at MM 90. The HOV lane has slowed in sympathy with the mixed-flow lanes to the point that TDOT is now no longer able to certify to FHWA that the HOV lane meets minimum performance standards of a better than 45 mi/h operating speed with better than 90 percent reliability.

When simulated in VISSIM, the reason for the slowdown in the HOV lane becomes obvious. As seen in Figure 11-8, a bottleneck forms at the divergence of Vietnam Veterans Boulevard and Interstate 65. The HOV lane is not utilized by most drivers, as the lane change maneuvers required to make the Vietnam Veterans Boulevard exit require getting across multiple lanes of dense traffic. However, the HOV lane can serve as a "queue jump" in which vehicles can use the relatively free-flowing conditions in the HOV lane and merge back into the main traffic stream after passing the queue in the mixed-flow lanes that have formed upstream of the bottleneck. (In fact, this is the intended purpose of the HOV lane- to provide those who carpool with a queue jump.) If the exiting vehicle wishes to continue on I-65 past Vietnam Veterans Boulevard, the use of the HOV lane is essentially harmless to the performance of the facility. However, if the vehicle using the HOV lane is using the lane to jump ahead of congested conditions before the Vietnam Veterans'exit and seeks to change lanes to exit the facility at the Vietnam Veterans' exit, then the use of the HOV lane as a queue jump is harmful, as last-minute lane changes are highly disruptive at the diverge.

Unfortunately, the volume of traffic on I-65 has grown to the point where exiting to Vietnam Veterans Boulevard requires traffic in the HOV lane to match the speed of traffic in the mixed-flow lanes to make the lane change. Figure 11-8 shows a queue of vehicles in the HOV lane that is not presently creating a clearing wave (where the spacing of the lead vehicles would be increasing) because the lead vehicle is attempting to make a lane change after it is significantly later than desirable to make the lane change. The lead driver has saved a significant amount of time by leveraging the queue jump. However, a large number of other drivers pay a heavy price in delay for the lead driver to be able to take advantage of the queue jump.

Given that the corridor is so short, it may be reasonable to restrict lane changes to only certain locations along the corridor or to even barrier-separate the HOV lane such that it bypasses the Vietnam Veterans Boulevard starting a half-mile or more before the diverge. Similar strategies have been implemented successfully on the I-405 HOV lanes in Seattle, WA. Figure 11-9 shows this kind of pavement marking on the I-405 corridor. In this figure, a double-solid white line extends upstream from the exit for approximately one-half mile. It is illegal to cross the double solid white line, and citations are regularly issues by the Washington State Highway Patrol to double solid white line violators.

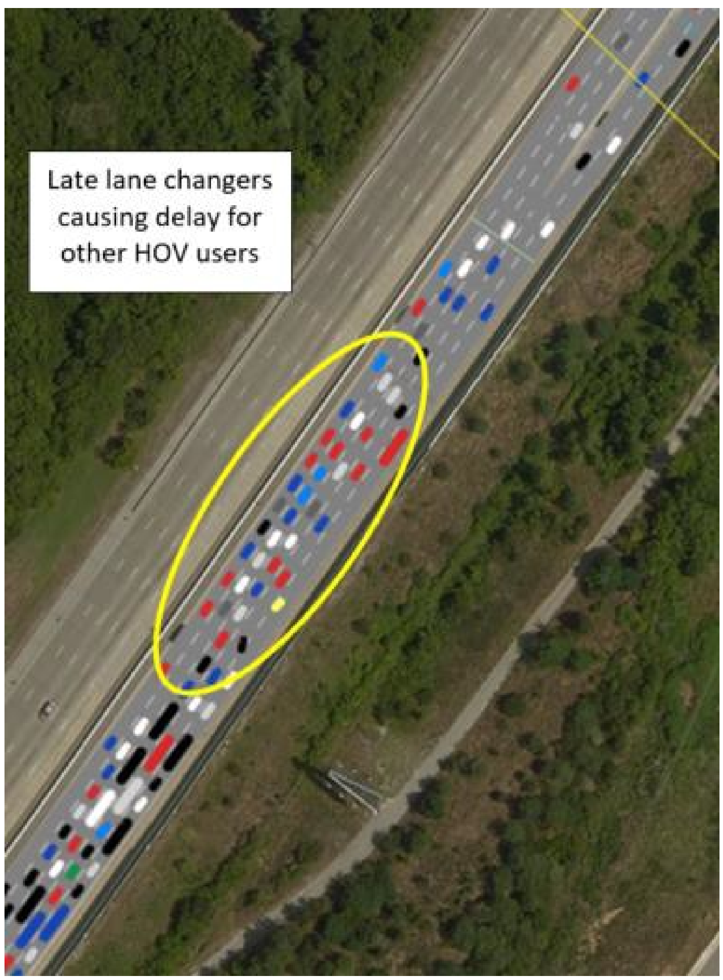



Figure 11-8 Queue formation in HOV lane due to vehicles exiting from the HOV lane

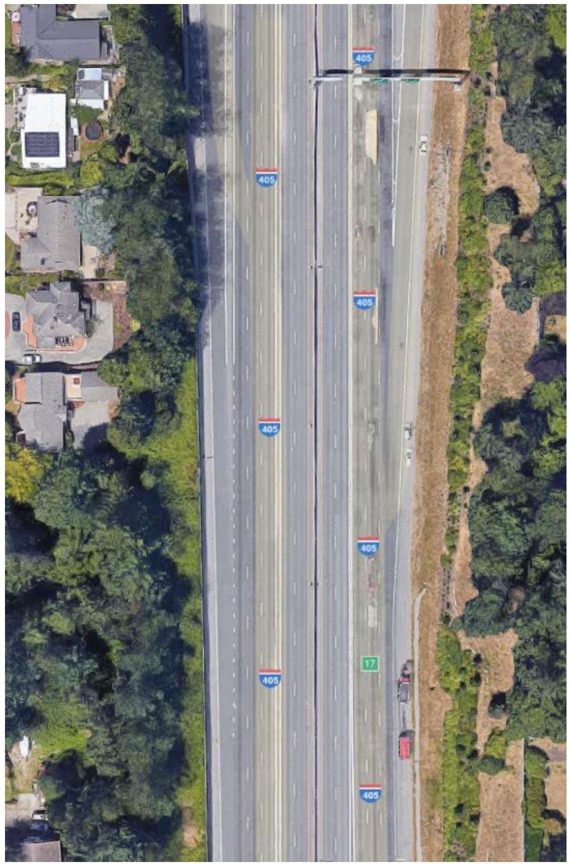


Figure 11-9 Double solid white lines preventing frictive slowing and diverge bottleneck breakdown at a diverge on I-405 in Seattle, WA (Image from Google Maps)

Table 11-3 shows important corridor-level metrics for the northbound I-65 HOV corridor north of Nashville. A view of conditions for the BYDN, BYHE, and FYHE cases shows that frictive slowing becomes progressively worse as vehicles travel from Exit 92 (TN-45, Old Hickory Blvd.) to the end of the corridor. In the BYLR, FYLR, and FYDN cases enough vehicles have used the HOV lane as a queue jump and are having enough difficulty with the lane changes for the entire HOV lane to operate at very slow speeds over three miles away from the bottleneck location. Future growth in traffic will further deteriorate the corridor.

If considering options from among those considered in this study, there is no single dominant alternative as there was for the I-65 corridor south of Nashville. However, if heavy enforcement is implemented, travel times for both the single-occupant vehicles and the high occupancy vehicles would decrease. This is despite an increase in the average travel time, which currently is the best under the do-nothing scenario because violators who are going through the bottleneck on the I-65 side can leverage the HOV lane to bypass the bottleneck.

However, the study of this corridor has identified a major operational design weakness with the corridor. If the HOV was separated from the mixed-flow lanes by either a barrier or double solid white line, and the HOV lane was focused on moving those desiring to go past the Vietnam Veterans Boulevard exit past the bottleneck, the capacity of the bottleneck would increase, significantly, reducing delay for the entire corridor. As this improvement requires a simple application of striping, it is cost-effective and, in the author's opinion, should be done before any consideration of implementing a HOT lane on the corridor.

Table 11-3 Corridor Performance Metrics for VISSIM Simulation of the Northbound I-65 Corridor North of Nashville (Preferred Outcomes Highlighted in Green)

| Metric | BYDN | BYLR | BYHE | FYDN | FYLR | FYHE |
|---|---|---|---|---|---|---|
| Exit 92 HOV Speed | 63.04 | 8.51 | 67.1 | 7.82 | 7.82 | 69.79 |
| Alta Loma Speed | 46 | 11.94 | 67.7 | 12.89 | 12.89 | 66.55 |
| END HOV Speed | 9.82 | 11.73 | 24.3 | 11.87 | 11.87 | 20.77 |
| Exit 92 HOV Lane Flow | 842 | 556 | 274 | 837 | 537 | 285 |
| Alta Loma HOV Lane Flow | 884 | 913 | 290 | 917 | 1051 | 281 |
| END HOV Lane Flow | 685 | 897 | 278 | 719 | 1107 | 271 |
| Exit 92 Utilization | 31% | 21% | 10% | 18% | 18% | 10% |
| Alta Loma HOV Utilization | 28% | 29% | 9% | 31% | 31% | 8% |
| END HOV Utilization | 22% | 28% | 8% | 32% | 32% | 8% |
| Corridor All Vehicles Travel Time (min) | 39.8 | 47.4 | 44.6 | 44.0 | 55.1 | 47.4 |
| Corridor Trip Time for SOV (min) | 55.2 | 47.4 | 49.3 | 61.6 | 55.0 | 52.0 |
| Corridor Trip Time for HGV (min) | 55.3 | 48.0 | 49.8 | 61.2 | 56.7 | 53.4 |
| Corridor Trip Time for HOV (min) | 10.9 | N/A | 5.2 | 12.3 | N/A | 5.4 |
| Total CO2 Emissions (g/hr) | 916329 | 1073588 | 1022544 | 1041827 | 1358958 | 1102764 |
| Total NOX Emissions (g/hr) | 178284 | 208881 | 198950 | 202702 | 264404 | 214558 |
| Total VOC Emissions (g/hr) | 212368 | 248814 | 236984 | 241453 | 314952 | 255576 |
| Total Fuel Consumption (gal/hr) | 13109 | 15359 | 14629 | 14905 | 19441 | 15776 |

Note: The N/A denotation in the BYLR and FYLR scenarios means that there are no vehicles with an HOV designation.

## 11.4 Southbound I-65 North of Nashville

This downtown Nashville- bound corridor has very different operational challenges from the northbound corridor, as well as any other corridor under consideration. As shown in Figure 11-10, the corridor has significant downstream flow control at the end as the bottleneck caused by the merge of I-24 and I-65 can result in extremely slow conditions that can spill back into the corridor. This effect of end control is modeled by placing the desired speed decision in all lanes for all vehicle classes near the place where the back of the queue for the I-24/I-65 merge bottleneck is located.

However, the most important features of the corridor are high flows at the beginning of the corridor, into which traffic must merge. As such, bottlenecks that form on the facility are primarily merge bottlenecks, like the one shown in Figure 11-11. As the capacity of merge bottlenecks is increased by allowing vehicles on the main line to merge left to allow entering vehicles to find a gap, it is unsurprising that in the results contained in Table 11-4, heavy enforcement is shown to be a completely dominated option, with inferior results in every operational and environmental metric. There needs to be more utilization of the HOV lane for the corridor to function more effectively.

Given the two non-dominated options, the pertinent question becomes one of determining the desirable level of HOV lane usage. The do-nothing option does provide an HOV lane with reasonable progression- almost as good as the heavy enforcement case- while offering significant improvements for the main line and the best environmental outcomes. The lane reversion option would provide both operational and environmental improvements over heavy enforcement, with the best operational outcomes for single-occupancy vehicles and trucks. Finding the best choice for operational strategy will require TDOT to determine which performance indicators it values most and to set targets for the usage of the HOV lane per those objectives.

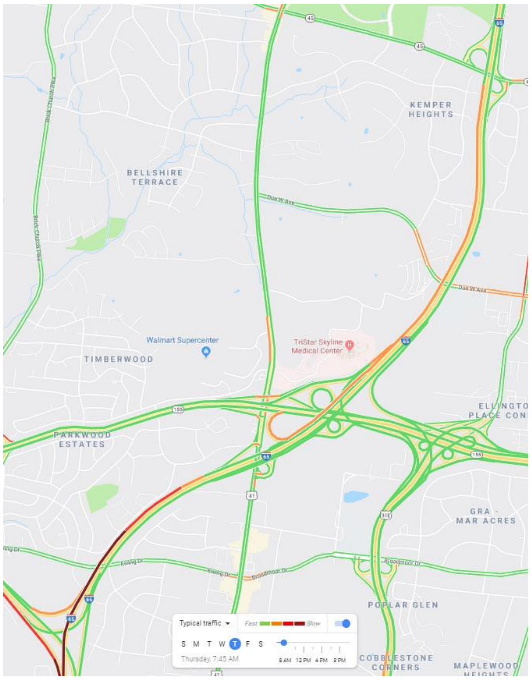



Figure 11-10 Downstream flow control at the merge of I-65 and I-24 (image from Google Maps)


Figure 11-11 Merge bottlenecks replicated by VISSIM

Table 11-4 Corridor Performance Metrics for VISSIM Simulation of the Southbound I-65 North of Nashville (Preferred Outcomes Highlighted in Green)

| Metric | BYDN | BYLR | BYHE | FYDN | FYLR | FYHE |
|---|---|---|---|---|---|---|
| HOV Lane Speed at Exit 92 (mph) | 70.9 | 65.0 | 71.0 | 62.7 | 61.7 | 71.3 |
| HOV Lane Speed at Exit 90 (mph) | 68.5 | 71.1 | 69.2 | 65.7 | 66.6 | 69.7 |
| HOV Lane Flow at Exit 92 (vph) | 425 | 950 | 151 | 468 | 966 | 109 |
| HOV Lane Flow at Exit 90 (vph) | 733 | 1383 | 204 | 677 | 1758 | 177 |
| HOV Lane Utilization at Exit 92 | 14% | 32% | 6% | 16% | 30% | 5% |
| HOV Lane Utilization at Exit 90 | 17% | 33% | 5% | 16% | 36% | 5% |
| Corridor All Vehicles Travel Time (min) | 17.1 | 15.6 | 24.5 | 24.0 | 23.6 | 36.0 |
| Corridor Trip Time for SOV (min) | 19.7 | 15.5 | 25.7 | 28.2 | 23.5 | 37.9 |
| Corridor Trip Time for HGV (min) | 20.4 | 16.6 | 27.9 | 30.1 | 24.7 | 41.2 |
| Corridor Trip Time for HOV (min) | 7.6 | N/A | 7.0 | 8.5 | N/A | 6.8 |
| Total CO2 Emissions (g/hr) | 196661 | 225914 | 244827 | 241805 | 302545 | 365943 |
| Total NOX Emissions (g/hr) | 38263 | 43955 | 47634 | 47046 | 58864 | 71199 |
| Total VOC Emissions (g/hr) | 45578 | 52358 | 56741 | 56041 | 70118 | 84811 |
| Total Fuel Consumption (gal/hr) | 2813 | 3232 | 3503 | 3459 | 4328 | 5235 |

Note: The N/A denotation in the BYLR and FYLR scenarios means that there are no vehicles with an HOV designation.

## 11.5 Eastbound I-24

The eastbound I-24 corridor shares many characteristics with the southbound I-65 corridor south of Nashville. Both routes are significant in length, with the I-65 corridor spanning roughly eighteen miles and the I-24 corridor spanning approximately 23 miles. Both connect downtown Nashville to smaller cities of significant population that creates a substantial volume of commuting traffic. Both have heavy congestion near downtown at the PM peak. Both facilities have several interchanges, with a typical spacing on the order of two to four miles, though some interchanges are more closely spaced on I-65 in Franklin. As can be seen in Figure 11-12 and Figure 11-13, the facility is primarily controlled by diverge bottlenecks at the off-ramps, features of traffic flow on the corridor successfully replicated in VISSIM.

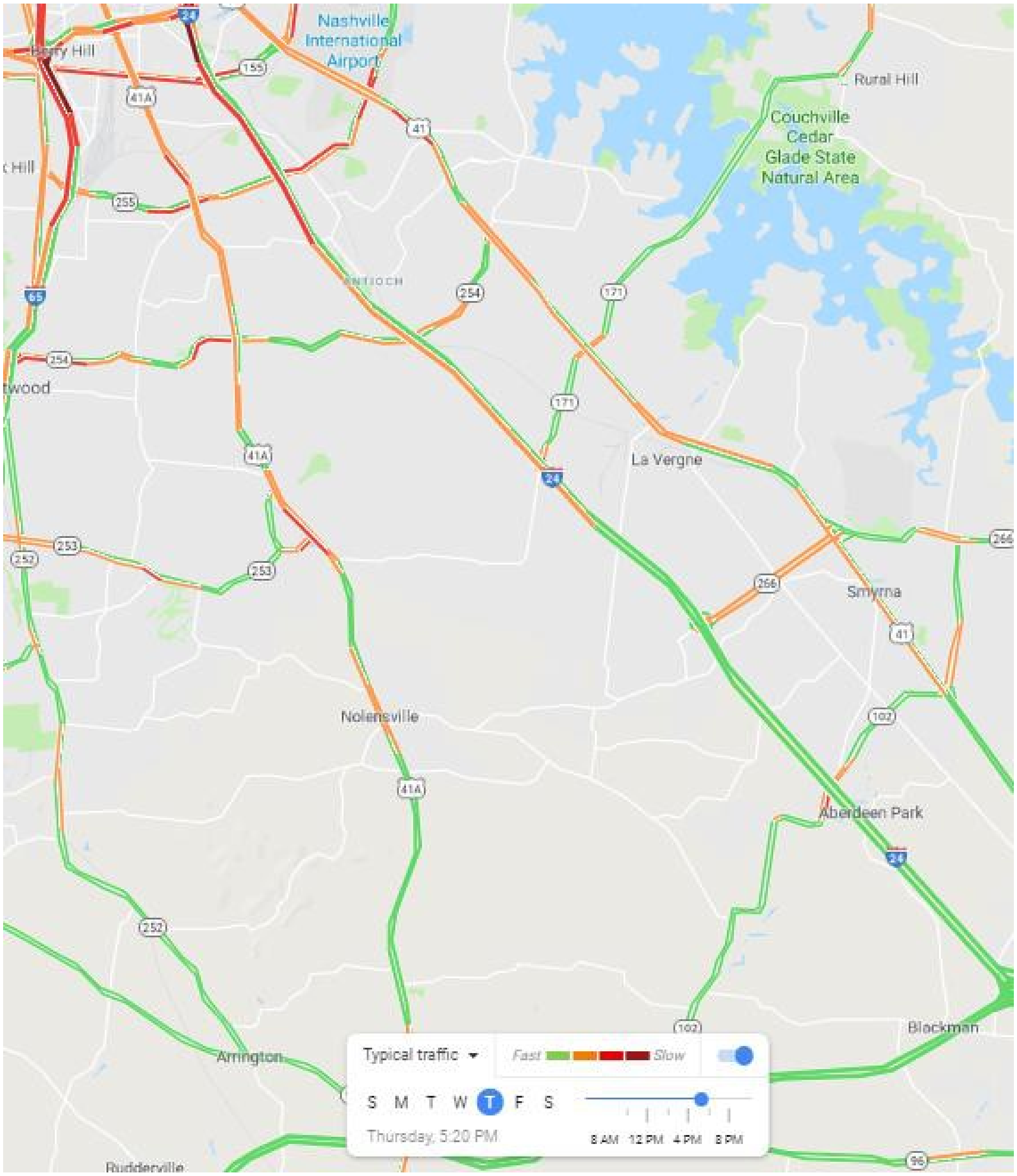



Figure 11-12 Typical PM peak conditions on I-24 eastbound (image from Google Maps)

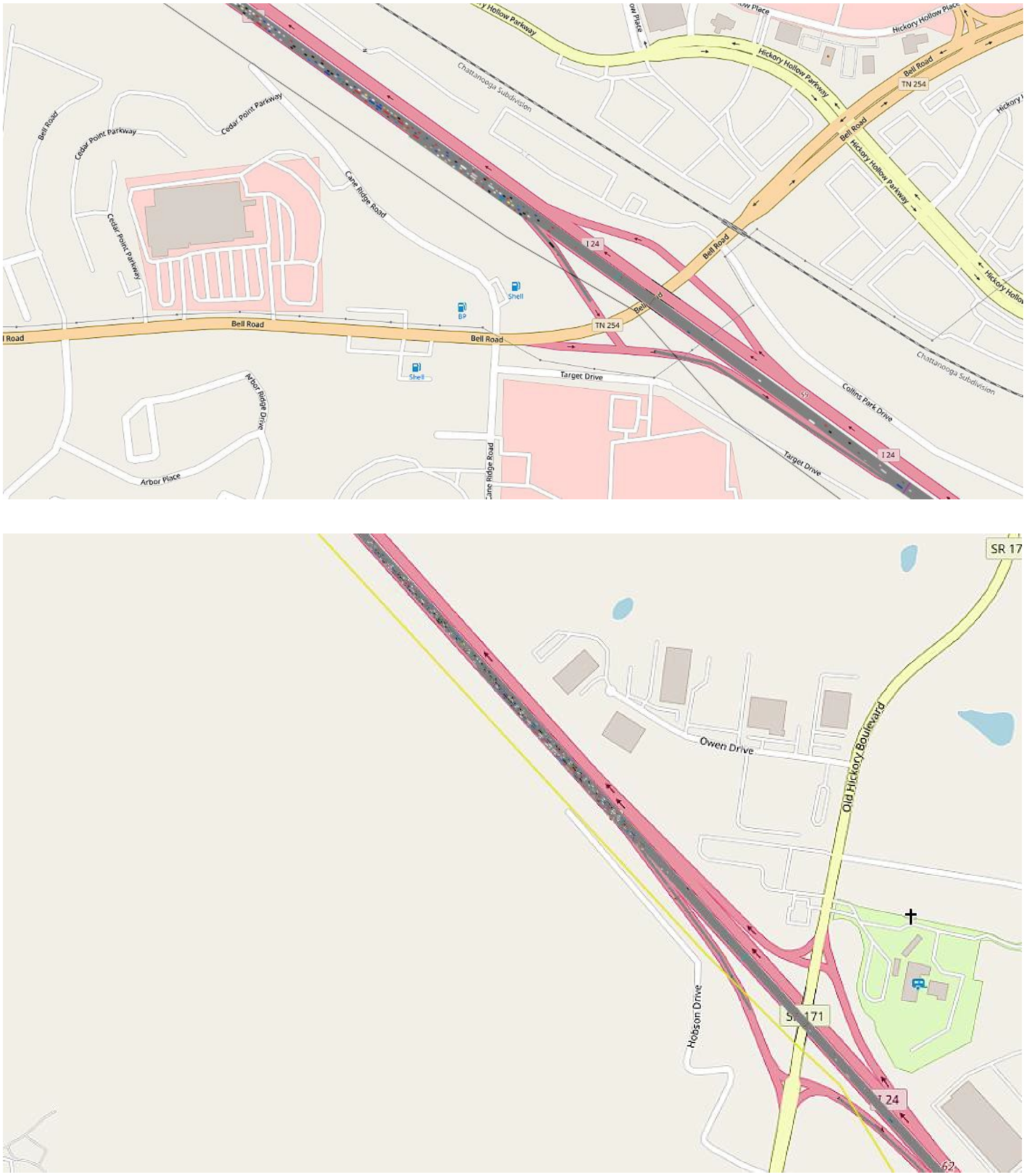



Figure 11-13 Diverge bottlenecks in series controlling flow on eastbound I-24

Results for the simulations performed on the eastbound I-24 corridor are summarized in Table 11-5. It was observed in the simulations of both I-65 and I-24 that the removal of traffic from the HOV lane during the heavy enforcement scenario failed to restore travel speeds in the HOV lane to free-flow speed. This observation is in agreement with observations of speed data in Chapter 3 of this report that shows that speeds in the HOV lane are highly correlated with speeds in the mixed-flow lane. However, in the heavy enforcement case, it was almost enough to restore operations in the HOV lane to near the speed limit, and the frictive slowing was not as dramatic as in the case of I-65.

When strategies are compared with respect to operational and environmental metrics for the performance of the corridor as a whole, it becomes clear that for this corridor, a heavy enforcement strategy which allows the HOV lane to be used by a smaller number of users is the dominant strategy under base year demand levels. It is the superior alternative with respect to every metric, both under the base year and future year scenarios. However, in the current regulatory climate, it is impossible to achieve this kind of operation, though it could be possible to do so with pricing controls in a HOT lane framework. From the consideration of other scenarios, it is clear that a significant increase in violations does not degrade the performance of the HOV lane significantly, but it does degrade the performance of the mixed-flow lanes significantly in the do-nothing and lane reversion cases in the base year.

As was the case for the southbound I-65 corridor south of Nashville, these results are counterintuitive in the mind of the public. The public largely perceives a monotonically increasing travel time to be associated with more traffic in each lane. The public is largely unaware of how and why bottlenecks form on highways or why the HOV lane is currently impacted to the extent it is by other lanes of traffic. While the HOV lane may not be operating at a volume that would normally require slower than free-flow operations, vehicular conflicts can occur with vehicles in other lanes, necessitating drivers in the HOV lane to modify their speeds to make a lane change out of the HOV lane. The public is also largely unaware that HOV lane violators do not always result in significant slowing of the HOV lane, while they may cause very large delays for the mixed-flow lanes at bottlenecks. Note that although the HOV lanes are generally unpopular with the public, according to the results of microsimulation, reverting the HOV lane to a mixed-flow lane would save the driver less than two minutes on a commute of roughly 45 minutes in the base year, and the savings would be even less in the future.

It is uncertain whether all of the operational benefits to the general public are sustainable by implementing a heavy enforcement strategy. As demand grows, the average time for all vehicles in the corridor becomes closer for the do-nothing and heavy enforcement scenarios. However, several important features would lead the heavy enforcement to become the preferable alternative. While the do-nothing scenario does provide equal travel times when averaged across all vehicles, it should also be noted that to reduce individual travel times, individuals must change lanes more frequently and accelerate to move with the pace of the new lane. This is wasteful of fuel and creates more emissions. Second, with more weaving maneuvers there is a greater potential for crashes. Although not numerically captured in the VISSIM simulation, the heavy enforcement scenario is more likely to provide stable and reliable trip times for drivers.

Table 11-5 Corridor Performance Metrics for VISSIM Simulation of the Eastbound I-24 Corridor (Preferred Outcomes Highlighted in Green)

| Metric | BYDN | BYLR | BYHE | FYDN | FYLR | FYHE |
|---|---|---|---|---|---|---|
| HOV Lane Speed at Bell Road (mph) | 62.5 | 59.1 | 67.4 | 63.5 | 59.0 | 68.1 |
| HOV Lane Speed at Sam Ridley Parkway (mph) | 66.6 | 53.7 | 68.6 | 62.9 | 53.1 | 69.9 |
| HOV Lane Speed at SR 96 (mph) | 74.9 | 71.4 | 73.3 | 72.5 | 69.8 | 73.9 |
| HOV Lane Flow at Bell Road (vph) | 376 | 934 | 150 | 413 | 952 | 134 |
| HOV Lane Flow at Sam Ridley Parkway (vph) | 373 | 807 | 118 | 416 | 858 | 164 |
| HOV Lane Flow at SR 96 (vph) | 309 | 690 | 120 | 344 | 840 | 136 |
| HOV Lane Utilization at Bell Road | 12% | 28% | 4% | 12% | 28% | 4% |
| HOV Lane Utilization at Sam Ridley Parkway | 13% | 29% | 4% | 14% | 29% | 5% |
| HOV Lane Utilization at SR 96 | 13% | 27% | 5% | 12% | 29% | 5% |
| Corridor All Vehicles Travel Time (min) | 41.1 | 45.1 | 37.7 | 43.4 | 50.6 | 43.3 |
| Corridor Trip Time for SOV (min) | 46.8 | 44.7 | 38.8 | 51.1 | 50.1 | 44.7 |
| Corridor Trip Time for HGV (min) | 50.0 | 48.3 | 42.1 | 52.5 | 55.3 | 47.8 |
| Corridor Trip Time for HOV (min) | 21.7 | N/A | 19.4 | 24.0 | N/A | 19.7 |
| Total CO2 Emissions (g/hr) | 871907 | 1066842 | 717935 | 1040549 | 1175423 | 820636 |
| Total NOX Emissions (g/hr) | 169641 | 207569 | 139684 | 202453 | 228695 | 159666 |
| Total VOC Emissions (g/hr) | 202073 | 247251 | 166388 | 241157 | 272416 | 190190 |
| Total Fuel Consumption (gal/hr) | 12474 | 15262 | 10271 | 14886 | 16816 | 11740 |

Note: The N/A denotation in the BYLR and FYLR scenarios means that there are no vehicles with an HOV designation.

## 11.6 Westbound I-24

The westbound I-24 HOV corridor has some important operational differences from the eastbound I-24 HOV corridor due to the distribution of the influx along the corridor. Downtown Nashville serves as a major trip attractor in the AM direction and a major trip producer in the PM direction and the distribution of the influx in the AM direction results in a system that is governed by a combination of merge and diverge bottlenecks distributed along the facility.

As can be seen in Figure 11-12, congestion generally becomes more severe closer to the downtown end of the corridor, where the daily traffic counts are the highest. As was the case in the northbound I-65 corridor south of Nashville, as well as the southbound I-65 corridor north of Nashville, merge bottlenecks are more prominent on the direction inbound to downtown. Figure

11-13 shows the formation of both a merge and diverge bottleneck at Sam Ridley Parkway. However, unlike the I-65 corridor south of Nashville, the number and prominence of these bottlenecks on the I-24 corridor are different enough to lead to significantly different trends in analysis from the I-65 corridor south of Nashville.

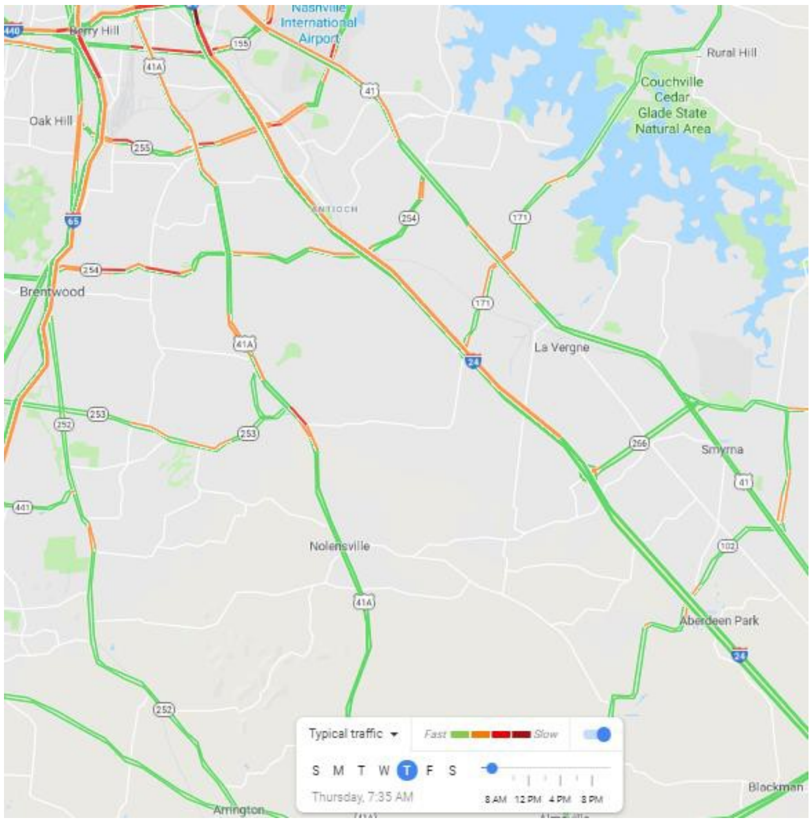



Figure 11-14 Typical AM peak conditions on westbound I-24.

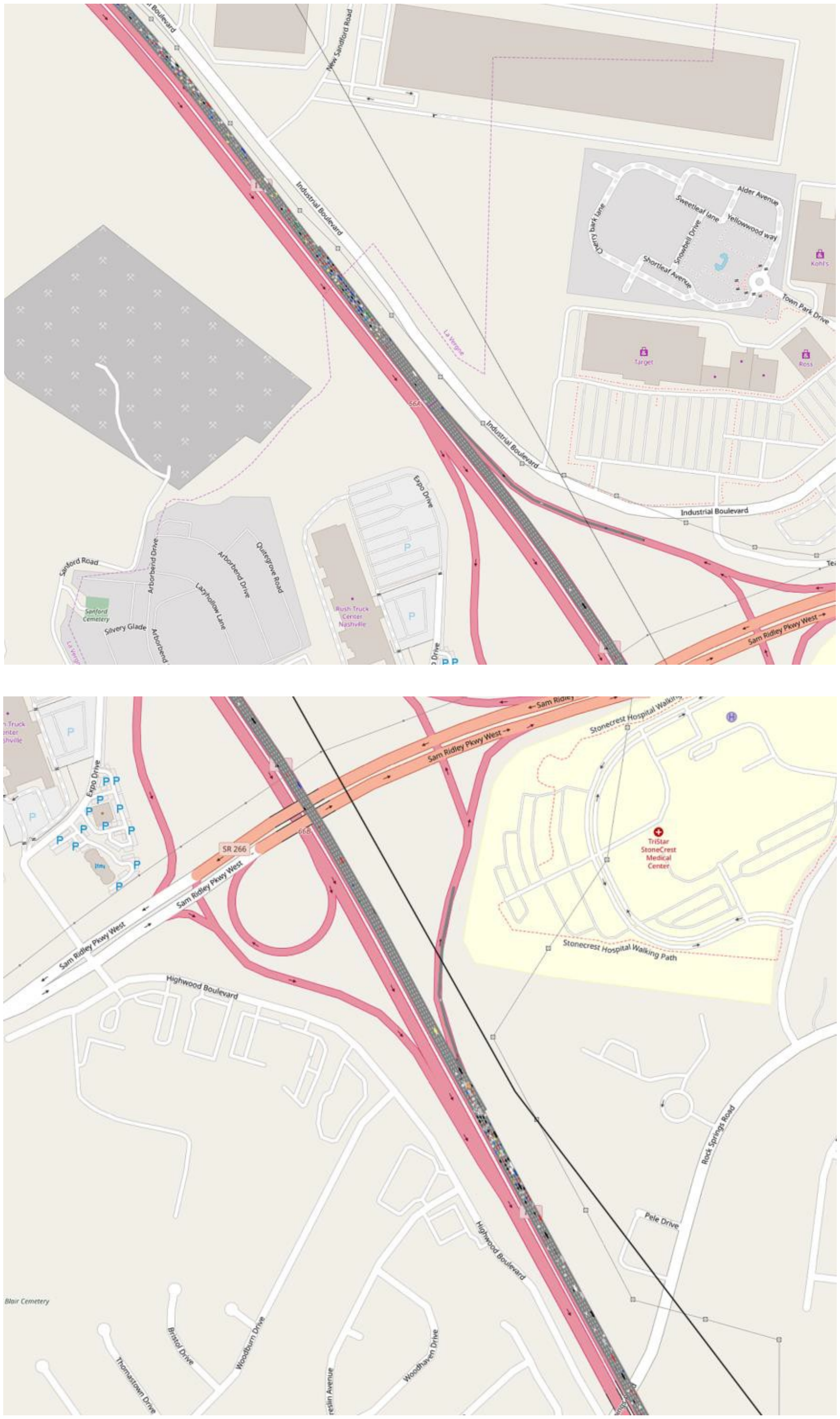



Figure 11-15 Merge and diverge bottlenecks at Sam Ridley Parkway and I-24 westbound

Table 11-6 shows the corridor-level results obtained from microsimulation analysis of the westbound I-24 HOV corridor. When considering operational metrics, the preferred scenario overall was the lane reversion scenario under base year conditions. Under future conditions, the do-nothing scenario becomes preferable in all metrics except single-occupant vehicle and truck travel times. Lane reversion saves approximately five minutes of delay on an approximately hour-long trip for these two vehicle classes in the future year, though all potential benefits of having an uncongested option are lost under this scenario. However, the lane reversion case also has the poorest environmental outcomes in both base and future year scenarios.

These results do support the conclusion that if operated as intended by current regulation, the HOV lane would be ineffective in reducing delays, although they would be effective in reducing air pollution and fuel consumption. However, as demand on the corridor grows, it is becoming clear that there will become a point at which the HOV lane, as designed, no longer can improve either air quality or traffic operations on the I-24 corridor by operating as it currently does. It is very reasonable to expect that this kind of growth may happen by 2035, as the final report from the Nashville nMotion transit plan predicts that the population in Middle Tennessee will grow by one million people between 2016 and 2035 (Nashville MTA/RTA, 2016). For the HOV lane to have its greatest benefit, it must carry a greater volume to alleviate merge bottlenecks.

These results also show that there are several undesirable outcomes with lane reversion. While lane reversion would likely reduce delay for all vehicle classes initially except for HOVs and the overall total travel time will reduce significantly, the advantage will erode with increased traffic demand. The microsimulation results suggest that eventually, a managed lane approach will save a significant amount of overall travel time while also providing the best environmental outcomes for the corridor.

Table 11-6 Corridor Performance Metrics for VISSIM Simulation of the Westbound I-24 Corridor (Preferred Outcomes in Green)

| Metric | BYDN | BYLR | BYHE | FYDN | FYLR | FYHE |
|---|---|---|---|---|---|---|
| HOV Lane Speed at SR 96 (mph) | 63.0 | 59.0 | 67.2 | 59.2 | 13.2 | 67.1 |
| HOV Lane Speed at Sam Ridley Parkway (mph) | 67.5 | 68.0 | 71.8 | 65.1 | 17.5 | 70.2 |
| HOV Lane Speed at Bell Road (mph) | 69.4 | 67.8 | 72.3 | 69.1 | 67.6 | 71.5 |
| HOV Lane Flow at SR 96 (vph) | 742 | 1585 | 243 | 699 | 1153 | 208 |
| HOV Lane Flow at Sam Ridley Parkway (vph) | 704 | 1364 | 233 | 820 | 1113 | 255 |
| HOV Lane Flow at Bell Road (vph) | 597 | 1351 | 233 | 671 | 1268 | 232 |
| HOV Lane Utilization at SR 96 | 16% | 31% | 5% | 17% | 25% | 5% |
| HOV Lane Utilization at Sam Ridley Parkway | 18% | 29% | 6% | 21% | 26% | 8% |
| HOV Lane Flow at Bell Road | 15% | 29% | 5% | 16% | 29% | 6% |
| Corridor All Vehicles Travel Time (min) | 41.54 | 39.77 | 46.26 | 49.87 | 58.69 | 58.26 |
| Corridor Trip Time for SOV (min) | 49.94 | 39.34 | 49.41 | 63.49 | 58.29 | 62.84 |
| Corridor Trip Time for HGV (min) | 51.73 | 46.18 | 52.92 | 65.39 | 63.96 | 65.83 |
| Corridor Trip Time for HOV (min) | 25.72 | N/A | 22.89 | 28.69 | N/A | 24.33 |
| Total CO2 Emissions (g/hr) | 676047 | 743376 | 620460 | 1041827 | 1358958 | 1102764 |
| Total NOX Emissions (g/hr) | 131534 | 144634 | 120719 | 202702 | 264404 | 214558 |
| Total VOC Emissions (g/hr) | 156680 | 172285 | 143798 | 241453 | 314952 | 255576 |
| Total Fuel Consumption (gal/hr) | 9672 | 10635 | 8876 | 14905 | 19441 | 15776 |

Note: The N/A denotation in the BYLR and FYLR scenarios means that there are no vehicles with an HOV designation.

While allowing a greater number of drivers to access the HOV lane in the vicinity of a merge bottleneck would be helpful for operations, Interstate 24 contains several merge bottlenecks at which a ramp metering solution could be sought, particularly near Sam Ridley Parkway. Ramp metering can be effective in increasing the throughput of merge bottlenecks by lessening the need for vehicles in the mixed-flow lanes to adjust their speeds to allow merging vehicles to enter. However, careful attention should be paid to impacts on surface streets near where the metering solution is applied to determine the impacts on their operation. Applied improperly, ramp metering can worsen problems on surface streets that do not have the same vehicle storage capacity as the interstate.

# Chapter 12 Conclusions, Recommendations, and Future Research Needs

This report has detailed a comprehensive and systematic program of research carried out to understand operations of the HOV corridors on Interstate 65 and Interstate 24. In this chapter, the major findings of the research will be synthesized. Based on the findings, recommendations will be made about potential improvements for the I-65 and I-24 corridors. Finally, future research needs will be identified.

Chapter 2 detailed the typical conditions found on the I-65 and I-24 corridors, leveraging data available on Google Maps. In that chapter, bottlenecks and their typical times of activation were identified. This information was vital in assessing the validity of microsimulation models as the features traffic simulation should replicate were made plain over space and time. It was found that at many locations congested times are beginning to extend outside the current HOV lane operational hours of 7 AM to 9 AM for the inbound direction and 4 PM to 6 PM for the outbound direction.

Chapter 3 provided an analysis of traffic data provided by TDOT, measuring speeds and volumes of traffic at various locations on the I-65 and I-24 corridors at different times of the day. Relationships between the speed in the HOV lane and the speed in the mixed-flow lanes were investigated. Correlation equations between the speed in the HOV lanes and the mixed-flow lanes were estimated. Fundamental diagrams of traffic flow are constructed.

In Chapter 3, it was found that the speeds in the HOV lane closely follow speeds in the mixed-flow lanes but are typically higher than in the mixed-flow lanes. This finding is ultimately unsurprising in retrospect. Given that the HOV lane often effectively functions as a passing lane for drivers frustrated with the slower conditions often associated with merge and diverge bottlenecks that impact the right-hand lanes. This pattern typically exists for traffic in the HOV lane regardless of time of day, and the pattern likely exists because (1) it is unsafe to exceed the speed in the lane to the right of the HOV lane by much more than 10 miles per hour given that the lane has continuous access and egress, and (2) drivers in the HOV lane must eventually reenter the mixed-flow lanes to exit the facility.

Chapter 4 contained insights provided from focus groups held with Tennessee state legislators and Tennessee Highway Patrol officers to qualitatively understand the perception of the public about HOV lanes, their effectiveness, and their enforcement. The following points offer an encapsulation of stakeholder attitudes arising from these focus groups:

- Violation rates are extremely high, on the order of eighty to ninety percent, for the HOV corridors on I-24 and I-65.
- HOV lanes are now effectively functioning as a passing lane, but they can become congested.
- It is likely the opinion of the majority of the public, and that of the members of the Tennessee state legislature focus group, that the requirement to operate the HOV lane as an HOV lane at peak demand time forces four lanes of traffic demand into three lanes, significantly worsening congestion.
- Current signage enhancements and striping markings enhancements are not likely to change many driver’s habits or lower violation rates.
- Speeding in HOV lanes happens on a very regular basis and is a public safety concern.
- Pulling over HOV lane violators for only a suspected HOV lane violation is not only dangerous for law enforcement and the driving public but also disruptive to traffic flow. The action of enforcement may well defeat the purpose of having an HOV lane.

- Along much of the HOV corridors on I-24 and I-65, there is no enforcement because there is no place for law enforcement to pull drivers over.
- The option of automated enforcement will not likely be well received by the public.
- The incentive of saving travel time is not presently sufficient to cause drivers to form new carpools to take advantage of the HOV lane.
- The consequences of an HOV violation must cause enough pain for people to change their behavior if enforcement activities are to be impactful. A fine of $50 is not viewed as much of a deterrent, especially when very little enforcement is done.
- From the analysis of revealed preference data, drivers are much less likely to choose to travel in the HOV lane when the mixed-flow lanes are highly congested. Drivers do not seem willing to make unnecessary lane changes to access and exit the HOV lane, especially if mixed-flow lanes provide adequate progression.
- Enforcing HOV lane restrictions will undoubtedly cause increasing dissatisfaction to the driving public, as most drivers will experience longer commutes in heavier traffic.
- While many constituents of areas surrounding Nashville view the HOV lane as an attempt to force four lanes of traffic into three lanes, many of the driving public are also irritated by HOV lane violators. Hence there will likely be a mixed reaction to any attempt to increase enforcement activities.

Chapter 5 presented the results of the survey of the public undertaken by the Lipscomb University psychology department. The survey instrument contained items covering basic demographics, qualifying questions, knowledge of HOV lane restrictions, compliance and noncompliance, respondents' value of time, responses to increases in fines, factors motivating or preventing carpooling, and aggressive driving behaviors. The following summarizes major findings of the survey:

- The commuter survey was administered to 476 individuals. The demographic data indicates a reasonably diverse population has been reached. This is especially true concerning household size, age, and income. However, approximately three-fourths of the respondents were female, and nine-tenths of the respondents were white.
- The vast majority of respondents are aware of what HOV lanes are and what the restrictions are. However, approximately three-quarters of the respondents self-reported having violated the HOV lane use restrictions, citing frustration with traffic conditions as the primary reason for violating.
- While a significant number of respondents self-reported violating HOV lane use restrictions, they reported violating infrequently and primarily to avoid slower moving traffic. This report should be of obvious concern for operations on the HOV corridors because this suggests an important mechanism for breakdown of the entire freeway's performance at diverge bottlenecks. If most drivers choose to change lanes leftward to use the HOV lane, those using the HOV lane to circumvent the queue may ultimately need to force their way back into the queue to make their exit. These lane changes can be disruptive, dropping the capacity of the bottleneck.
- Participants have varying opinions about carpooling. A large number of respondents felt that carpooling is not a possibility and nothing can be done to make it more appealing. However, others would consider convenience and facilities would make carpooling a more appealing choice. Some individuals could likely be swayed by monetary incentives to carpool. Some might be willing to consider carpooling with more flexibility in work

schedules. Finally, some feel discouraged by the lack of enforcement of HOV lane restrictions. Most individuals need a time savings benefit of 10 to 30 minutes to make either carpooling or use of a service like Uber or Lyft a desirable option.

- According to the response of users, the general public is very resistant to paying to travel in the HOV lane as a single-occupant vehicle, and a toll of as much as $1.00 would likely deter many from traveling in the HOV lane. The median valuation of time savings from the HOV lane appears to be on the order of $4.00 per hour. A modestly tolled express lane would likely be able to keep traffic in the HOV lane to low enough levels to prevent deterioration of the HOV lane, as well as the negative consequences to the mixed-flow lanes resulting from a heavily traveled HOV lane.
- Although most respondents would not participate in a peer reporting program similar to the HERO program implemented in Seattle WA, a significant number of individuals (approximately 15 percent saying they would be interested and another 15 percent who may be interested) would be willing to participate. This is a large enough number of respondents to far outnumber the number of available law enforcement agents available to patrol the HOV lanes. The primary reasons for wanting to participate in such a program include respect for the law, a desire to place a check on unsafe driving behaviors, a belief that people should not prosper from breaking the rules, frustration with a perceived lack of enforcement, and desire to be helpful and improve traffic conditions for society as a whole. Those averse to participating cited the desire not to be a “snitch”, the fear of distracted driving, the desire not to do the government’s job for the government, a general lack of concern or interest regarding HOV violations, a belief that the HOV lanes should not be used as such, an unwillingness to take the time to report, a belief that such actions violate

the spirit, if not the letter, of our nation's constitutional protections, the desire to not be reported when the respondent violates the HOV lane restrictions, a concern that people lie, a concern that people may be punished on flimsy evidence, and concern that people may abuse the system to maliciously and possibly falsely report drivers who have angered the one reporting.

Chapter 6 contained the fundamental analyses required to develop a stochastic user equilibrium model to explore comparative statics on a basic segment of an HOV corridor. In the analysis of revealed preferences of users, three important findings emerged.

- Congestion in the mixed-flow lane has little or no effect on an individual's decision to carpool.
- Heavy congestion on the freeway caused many legal HOV lane users to avoid using the HOV lane.
- The willingness of single-occupant vehicles to violate HOV lane restrictions increases with congestion in the mixed-flow lanes.

Chapter 7 extended the analytical work done in Chapter 6 to explore the implications of doing nothing, heavily enforcing the HOV lane restrictions (via toll measures or otherwise) and reverting the lane to a mixed-flow lane for the I-24 HOV corridor and the I-65 corridor south of Nashville. The analysis is performed under base year and future (design) year scenarios. These models are of significant value because these models are likely to help explain how many in the public may perceive changes to the corridor, whether or not the supply functions assumed in the analysis are realistic. The results of the equilibrium modeling effort yielded several insights, which can be best thought of as hypotheses to be tested using more detailed models of traffic microsimulation:

- Reversion of the HOV lane to a mixed-flow lane will likely reduce overall delay and may reduce some classifications of emissions, but it will do so at the expense of losing a rapid way for carpoolers, emergency vehicles, and transit/paratransit vehicles to traverse the HOV corridor.
- Heavy enforcement of HOV lanes will likely lead to a paradox in which more people seem to be willing to carpool, perhaps as a social response to having to drive daily in heavy traffic, but the heavy traffic will make the use of the HOV lane undesirable. Therefore, many travelers may form carpools but reject the HOV lanes intended to incentivize carpooling.
- Given the likely inelasticity of demand for driving SOV's with respect to overall congestion or conditions in the HOV lane, it is likely that heavy enforcement of the HOV lane as it currently functions will result in very large increases in both vehicular delay and emissions, although it would be difficult to quantify exactly how large the emissions and delay increases would be without resorting to traffic microsimulation.
- Analysis of speed data in HOV lanes shows that the HOV lane typically operates at significantly faster speeds than the mixed-flow lanes, even under peak hours when the HOV lane restrictions are in effect.
- A HOT lane project may have some success in raising revenue from drivers who do find it worthwhile to violate the HOV lane restrictions, as violation rates are very high. However, without strict enforcement, there is no incentive for users to pay a toll.
- The results of the user equilibrium models are found to be valid for uncongested flow when users can change lanes relatively easily, but may not be valid if conditions in adjacent lanes

affect the speeds of drivers. Hence further work is needed to model the impacts of heavier congestion that may occur near bottlenecks.

Chapters 8 through 11 provide the results of work undertaken with more detailed models of operations to test whether the hypotheses formed from user equilibrium studies are correct or represent even reasonable beliefs about how the HOV corridor performs. Chapter 8 develops a macroscopic model of traffic flow for the I-65 corridor south of Nashville. Using the fundamental diagram and the correlation equations relating the speed in the HOV and mixed-flow lanes to the speed of all vehicles, which were both developed in Chapter 3, the LWR PDE is solved by the Cell Transmission Model. Speeds in the mixed-flow lanes and the HOV lane are then inferred from the single 1-D solution to the LWR PDE.

Chapter 9 explained the process of development for VISSIM models. This chapter details the network construction process. Data sources used in the construction of the model inputs are documented, and the calibration process for various model parameters is explained. The model outputs are compared with mobile sensing data and field data. The Cell Transmission Model developed in Chapter 8 is refined considering the insights gained from the VISSIM modeling process. The process is implemented for the southbound I-65 HOV corridor south of Nashville. After updating the cell transmission model, a reasonable agreement was found among the field data, the cell transmission model, and the VISSIM model, giving confidence in the calibration process. One significant finding of the calibration process is that approximately one in four drivers of single-occupant vehicles is willing to violate HOV lane use restrictions, while fewer than one in five HOV drivers is willing to use the HOV lane. These findings were determined by matching HOV lane utilization and violation rates in VISSIM models to those reported in prior studies collecting field data on the I-65 and I-24 corridors.

Chapter 10 details the process of scenario construction and evaluation for VISSIM models. Six scenarios are constructed. For both base year and future year demands, the model is evaluated for three different vehicle compositions, reflecting a do-nothing scenario, lane reversion scenario, and a heavy enforcement scenario. Major results for the southbound I-65 HOV corridor south of Nashville are displayed and discussed.

Chapter 11 provided system-level analysis results from VISSIM models developed for all six HOV corridors in Middle Tennessee. Insights regarding system performance are inferred from the numerical results and major features of the remaining corridor simulations are shown. After performing six different analyses for each of the six HOV corridors on I-65 and I-24, based on do-nothing, lane reversion, and heavy enforcement actions for the base year and future demands, the following conclusions can be drawn:

For all six corridors the following conclusions apply:

- Significant frictive slowing of the HOV lane occurs not primarily because of traffic density in the HOV lane, but rather because of the need to make lane changes to exit the HOV lane.
- The allowance of continuous access and egress from the HOV lanes is a significant design flaw that will severely limit the ability of the HOV lane to perform well under heavy congestion.
- Delay on the corridor is caused by bottlenecks, which are typically caused by necessary weaving at the exits and entrances.
- Diverge bottlenecks are improved by reducing the number of vehicles who are weaving over short distances from the leftmost lanes and by drivers going through the bottleneck traveling in the leftmost lanes.

- Merge bottlenecks are improved by traffic on the main line moving leftward, thereby providing gaps for entering vehicles to join the traffic stream and increasing bottleneck throughput.
- Ramp metering may be helpful for managing throughput at merge bottlenecks but should be considered cautiously with a strategy specially tailored to the facility, traffic patterns, and surface street operations.

The following applies to the southbound I-65 HOV corridor south of Nashville and the eastbound I-24 HOV corridor:

- Under current operational regulations, the HOV lane on the southbound corridor of I-65 south of Nashville and the Eastbound corridor of I-24 is currently over-utilized. This might not be the case if double solid white lines were used to force access and egress from the HOV lane to occur in desirable locations, but without these modifications, the conflicts of vehicles exiting the HOV lane with vehicles in the leftmost mixed-flow lanes cause a significant slowing of traffic in the HOV lane.
- The southbound corridor of I-65 south of Nashville and the Eastbound corridor of I-24 are overwhelmingly controlled by diverge bottlenecks. The best way to improve operations at these diverge bottleneck is to (1) Encourage traffic exiting the freeway at exits beyond the bottleneck to use the leftward lanes, and (2) Prevent traffic from the leftmost lanes from moving rightward too late.
- The driving public does not likely perceive this to be the truth, but, likely, the improvements in queue discipline that would come from a heavily enforced HOV lane

would save the typical SOV driver more time than the reversion of the HOV lane to a mixed-flow lane.

- Enforcing the HOV lane restrictions in an automated manner through the use of tolling and a HOT lane regulatory framework would likely improve every aspect of the corridor’s performance for all users and reduce emissions and fuel consumption, while simultaneously opening access to the HOT lane to the entire driving public. Pricing controls give TDOT the ability to manage the number of individuals using the HOV lane by controlling the pricing, allowing for the operation to vary from nearly HOV-only to a full lane reversion.

The following applies to the northbound I-65 corridor north of Nashville:

- The slowing of the HOV lane to speeds below that required of HOV facilities is a result of the configuration of the egress from the HOV lane before the Vietnam Veterans Boulevard exit.
- The inability to prevent late lane changes out of the HOV lane by drivers using the HOV lane as a queue jump from the beginning of the corridor to Vietnam Veterans Boulevard causes additional stress to an otherwise major diverge, creating a significant bottleneck with a backward queueing wave that leaves most of I-65 operating at nearly standstill conditions through most of the period of peak demand.
- If considering options from among those considered in this study, there is no single dominant alternative as there was for the I-65 corridor south of Nashville. However, if heavy enforcement is implemented, travel times for both the single-occupant vehicles and the high occupancy vehicles would decrease. This is despite an increase in the average travel time, which currently is the best under the do-nothing scenario because violators

who are going through the bottleneck on the I-65 side can leverage the HOV lane to bypass the bottleneck to significant benefit.

- Under the heavy enforcement scenario, those who stand to gain the most are the honest people. Those who stand to lose the most are the HOV violators.
- With design improvements to control lane changes to more desirable locations, a HOT lane concept could provide the maximal benefit, as there are likely many drivers who are willing to pay to save half an hour of travel time if they knew that they could bypass the Vietnam Veterans Boulevard exit. Getting these drivers to take the HOV/HOT lane would create significant improvements to the operations of this corridor as they are taking the lane straight through the bottleneck and increasing bottleneck throughput.
- Lane reversion will decrease delays but will increase emissions on the corridor due to the stop-and-go nature of traffic on the corridor. A lane reversion would also lose all benefits of an uncongested route and would not provide as much benefit as a well-enforced HOT lane.
- In the author's opinion, the best solution for the northbound I-65 corridor north of Nashville is a combination of operational improvements to manage access and egress to the HOV lane and the conversion of the HOV lane to an HOT lane, as the HOT lane has enforcement mechanisms built into the design and concept of operations.

The following comments apply to the southbound I-65 HOV corridor north of Nashville:

- This facility is primarily controlled by merge bottlenecks.
- Enforcing HOV lane restrictions do not serve the interests of either operational efficiency or enhancement of environmental quality.

- The HOV lane reversion to a mixed-flow lane would provide the best operational outcomes for the facility.
- HOT lanes could be used to gain almost as favorable an operational scenario while preserving a minimally congested alternative and providing significant air quality enhancement over a simple lane reversion.

The following comments apply to the westbound I-24 HOV corridor:

- This corridor is a lengthy corridor, carrying a very large traffic volume- and is governed by both merge bottlenecks and diverge bottlenecks.
- The most important challenges facing this corridor are:
  - Getting exiting vehicles out of the leftmost lanes early enough to avoid causing operational problems at diverge bottlenecks.
  - Getting vehicles leftward at merge bottlenecks to allow for enough gaps for merging vehicles to join the traffic stream, and
  - Incentivizing through traffic to stay in the leftward lanes until time for an orderly exit.
- Solving the aforementioned operational challenges will likely require operational improvements preventing lane changes out of the HOV lanes at times that are too late to avoid degrading diverge bottlenecks.
- Lane reversion would likely provide significant operational benefit, but at significant environmental costs and the loss of an uncongested route through the corridor.
- The HOT lane concept could provide significant operational benefits to the corridor while reducing emissions over the lane reversion scenario.

- The most impactful thing that could be done to the HOV corridor to improve the performance of the corridor overall is to introduce significant segments of double solid white line demarcations (or some other more appropriate barrier) for the HOV lane to protect the HOV lane from frictive slowing at the bottlenecks.

This study has considered a broad set of perspectives on Tennessee's HOV lanes. It is appropriate to comment on how the different parts of the study relate to one another. Nashville's HOV lanes are not functioning as originally intended. These lane-miles were constructed in the early 1990s before Nashville experienced a sustained pattern of rapid growth. Nashville's highways are routinely operating at or near capacity, and often demand exceeds capacity. Naturally, this demand condition results in significant incentives for drivers of single-occupancy vehicles to drive in the HOV lane. Although the HOV lanes usually provide faster transport than the mixed-flow lanes, it is also clear that the HOV lanes are also congested during their hours of operation.

The commuting public in Middle Tennessee does not appear to support strong HOV enforcement. It is the public's perception that when more traffic shifts to the HOV lane it decongests the mixed-flow lanes, rewarding those who follow the law and those who illegally use the HOV lane. Those who are harmed are the legal users of the HOV lane, whose behavior the HOV lane was designed to encourage, who lose the benefits that were the reason why the HOV lanes were constructed.

The stochastic user equilibrium studies carried out based on demand models estimated from revealed preference combined with simplistic models of supply based on the BPR functional form for travel time estimation lead to intuitive results that echo the intuition of the public. These results are valid for the case of light traffic. Unfortunately, the assumptions made by many in the public, often implicitly and without careful examination, are not consistent with the reality of how freeways operate under heavier congestion as bottlenecks begin to form and control the flow of traffic.

Delays on freeways are primarily governed by bottleneck operations. If there are no active bottlenecks, point or moving, there is no delay on the freeway. Major delays happen because of diverge and merge bottlenecks on the highway. Weaving operations near bottlenecks are often responsible for the degradation of bottleneck capacity, and hence these operations are the primary culprit in the creation of delay. Further, the HOV lane slows in sympathy with the slowing of the mixed-flow lanes. The assumption that the travel speeds in the HOV and mixed-flow lanes are independent is simply wrong. They are tightly correlated. Field data from these facilities proves it. Microsimulation reveals why these variables are correlated by making reasonable assumptions about the behavior of individual drivers and observing system behaviors that result from the interaction of drivers.

This does not mean that the user equilibrium studies, though they came to wrong conclusions about the nature of operations of the system itself under heavier levels of congestion, are without value. These models provide reasonable predictions when demand does not exceed capacity. Further, these studies reflect equilibrium outcomes that consider what the public does in various circumstances in response to various operating conditions, coupled with a realistic model of what the public believes is likely to be true about the operations of the facility. Hence, it becomes immediately intuitive why the public may offer significant resistance to the implementation of HOT lanes and stricter enforcement, even if better models of operations under heavy traffic contradict what the public believes to be true.

In consideration of the HOT lane concept, the responses of the survey respondents concerning the questions eliciting the value of time saved by the use of the HOV lane merit particular consideration. First and foremost, it should be noted that at an appropriate level of pricing, the implementation of tolled access would serve as an effective deterrent to many violators. As most users tend to value the time savings at a rate of $4 to $6 per hour, it will not require large tolls to shift SOVs out of the HOT lane. This is a far more effective deterrent to entry to the HOV lane than an increase in fines for violation of HOV lane restrictions, as the perception of the public is that there is little to no chance of actually paying a fine for HOV lane violation. A certain loss is a much more effective behavior modification tool than a large fine the violator is likely to never have to pay.

Though tolls are an effective deterrent for SOVs to use the HOV lane, it should also be noted that in many jurisdictions, access to HOT lanes is priced differently at different times of day, with SOVs seeking to use the HOT lane at times of peak congestion paying the most for the privilege. In Washington state, the maximum toll is capped at $10.00, which based on the survey results would appear to give TDOT the ability to achieve a near-zero SOV use rate for the HOT lane. However, only a small percentage of drivers ever pay $10.00 to use the HOV lane, with an average toll of $4.00 and some tolls as low as $0.75. On I-66 in Virginia near Washington D.C., the maximal toll has been as high as $47.50, but only a small, small number of users ever pay a toll that high to use the express lane on I-66. When there are incidents on the interstate, the lanes can be made available for no toll to encourage the leftward movement of drivers. When tolls are not charged, the HOT lane would become effectively a reverted lane. When able to vary tolls, TDOT has an action lever that can allow for the balancing of lane flows as desired for the overall system benefit. When considering the nuanced approach that the HOT lane concept allows, the power of the HOT lane to deliver appropriate solutions makes it a far more useful tool for dealing with the operational intricacies that create the major problems faced by Nashville's HOV corridors.

***The results of microsimulation make it clear that there is no simple policy solution that can improve operations on the HOV corridors.*** The solutions must be nuanced. Myopic strategies that may improve conditions on one corridor may make conditions worse on other corridors. However, the insights gained from microsimulation also provide insights about how to solve some of the operational problems faced along these corridors. Solutions should be tailored based on how the flow is controlled, whether by upstream volume (uncongested flow), diverge bottleneck, or merge bottlenecks. In general, solutions should be pursued with respect to the operational case as follows:

**(1) Uncongested Flow:** HOV lane enforcement is counterproductive to achieving the best operational results for the facility. Removal of HOV lane restrictions should be considered in these times and at these locations, but barrier separation and/or striping to reduce the weaving volume near bottlenecks may be helpful for overall traffic operations.

**(2) Mixed-flow Controlled by Diverge Bottlenecks:** If possible, weaving from the HOV lane in the vicinity of exits should be prohibited to maximize throughput of the HOV lane and to prevent the breakdown of the mixed-flow lanes.

**(3) Mixed-flow Controlled by Merge Bottlenecks:** If possible, achieve maximal throughput in the HOV and leftmost lanes to increase bottleneck capacity. Ramp metering may be effective as well in preventing the breakdown of the bottleneck, but any ramp metering solution should be tailored carefully to the facility.

The research results lay out a path forward for improving the HOV corridors in Nashville. First, egress from the HOV lane should be controlled so that weaving occurs in locations more favorable to the operation of the mixed-flow and HOV lanes. Second, the HOV lane needs to always operate under uncongested conditions and reasonably full to maximize bottleneck throughput. Perhaps significant improvements to the HOV lane resulting from improved egress management will attract more carpoolers to the HOV lane, but since the HOV lanes are not the primary motivation behind carpooling decisions, it is uncertain that the HOV demand for the HOV lane is going to be sufficient for optimal operations. Third, target HOV lane volumes could be achieved by tolerating violations of the HOV lane, but the use of a HOT lane with variable tolls could provide a solution to the problem, bringing it closer to the SOV flow necessary to improve operating conditions. The HOT concept also provides some extent of automated enforcement via toll collection, a degree of basic fairness as those who seek to utilize the benefit of the HOV lane pay more of the social cost of using the HOV lane, and a practical price-based mechanism by which to control the flow of vehicles into the lane.

There are several future research needs in this problem space. It is evident that although the HOV lanes do not function as originally intended, reverting these lanes to mixed-flow lanes removes many valid and valuable strategies for managing operations on the corridor and will lead to significantly more atmospheric pollution and fuel consumption for gains that will be only modest for most drivers. Lane reversion in all cases removes the congestion-free option for all drivers. TDOT loses key operational controls over traffic if it were to revert the HOV lanes to mixed-flow lanes. However, there are many instances already in which the system could be improved by adding users to the HOV lanes. Through the use of pricing controls, along with other operational improvements, TDOT can help society avoid much of the social and environmental cost of anarchy by steering the system from operation at user equilibrium to a better system optimal flow pattern. Therefore, it is the author's opinion that future research should focus on the implementation of HOT lanes. HOT lanes have the advantage of flexibility, adaptability, and enforceability that the current HOV lanes do not.

In implementing the HOT lane concept, significant new research will be needed beyond what was accomplished in this project. Of all corridors where this program of research should begin, in the author's opinion, it should begin on Interstate 24, as this is the longest corridor and offers the public the greatest opportunities for time savings. The following goals will likely be important in achieving a successful implementation of the HOT lane concept on I-24:

- Identification of operational controls that will preserve the capacity of diverge bottlenecks and preserve the integrity of the HOV lanes, including improved striping and barrier controls.
- Developing a better understanding of land use patterns along the corridor and projections of future land usage for the corridor.
- Identifying an O-D matrix for the HOV corridor.
- Including a survey with some value-of-time questions to better elicit how the respondents value time and determining improved logit models to assist in modeling choice.
- Developing improved supply functions for the HOT lane corridor with the understanding that performance in the mixed-flow lanes and HOV lane may not be independent.
- Developing and solving equilibrium models for the corridor as a network.
- Validating the results of the equilibrium models using microsimulation.

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# APPENDIX A: RAW DATA USED IN AIR QUALITY MODEL DEVELOPMENT

Table A-1: Emissions Rate Raw Data at 55 Degrees Fahrenheit (c.f. May et al., 2007)

**FREQ Emission Rate Table Based on EMFAC2002**

**Statewide Totals - Avg 2020 Annual - 55 Degrees (F) - 40% Humidity**

| Vehicle Class | Grams per mile for average travel speeds (mph) of specific pollutant | | | | | | | | | | | | | | grams/ minute |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | "IDLE"* |
| **Total Hydrocarbons** | | | | | | | | | | | | | | | |
| Autos | 0.405 | 0.274 | 0.195 | 0.146 | 0.115 | 0.095 | 0.083 | 0.076 | 0.074 | 0.075 | 0.080 | 0.091 | 0.108 | 0.121 | 0.034 |
| Gas trucks | 0.871 | 0.579 | 0.404 | 0.296 | 0.227 | 0.182 | 0.153 | 0.134 | 0.124 | 0.121 | 0.122 | 0.129 | 0.145 | 0.147 | 0.073 |
| Diesel trucks | 0.961 | 0.754 | 0.605 | 0.497 | 0.416 | 0.357 | 0.313 | 0.280 | 0.257 | 0.240 | 0.230 | 0.225 | 0.225 | 0.230 | 0.080 |
| **Carbon Monoxide** | | | | | | | | | | | | | | | |
| Autos | 2.419 | 2.125 | 1.892 | 1.704 | 1.552 | 1.426 | 1.323 | 1.241 | 1.177 | 1.135 | 1.115 | 1.126 | 1.182 | 1.285 | 0.202 |
| Gas trucks | 5.262 | 4.139 | 3.401 | 2.894 | 2.532 | 2.268 | 2.071 | 1.930 | 1.833 | 1.780 | 1.774 | 1.825 | 1.954 | 2.131 | 0.438 |
| Diesel trucks | 4.589 | 3.164 | 2.283 | 1.725 | 1.363 | 1.128 | 0.976 | 0.884 | 0.838 | 0.832 | 0.864 | 0.939 | 1.068 | 1.271 | 0.382 |
| **Oxides of Nitrogen** | | | | | | | | | | | | | | | |
| Autos | 0.259 | 0.223 | 0.197 | 0.177 | 0.163 | 0.153 | 0.146 | 0.142 | 0.141 | 0.143 | 0.148 | 0.156 | 0.168 | 0.169 | 0.022 |
| Gas trucks | 0.579 | 0.519 | 0.475 | 0.446 | 0.426 | 0.414 | 0.408 | 0.407 | 0.412 | 0.421 | 0.437 | 0.458 | 0.488 | 0.494 | 0.048 |
| Diesel trucks | 4.589 | 3.164 | 2.283 | 1.725 | 1.363 | 1.128 | 0.976 | 0.884 | 0.838 | 0.832 | 0.864 | 0.939 | 1.068 | 1.271 | 0.382 |

* "IDLE" emission factors are calculated by converting the 5 mph emission factors (grams per mile) to grams per minute.

Table A-2: Emissions Rate Raw Data at 65 Degrees Fahrenheit (c.f. May et al., 2007)

**FREQ Emission Rate Table Based on EMFAC2002**

**Statewide Totals - Avg 2020 Annual - 65 Degrees (F) - 40% Humidity**

| Vehicle Class | Grams per mile for average travel speeds (mph) of specific pollutant | | | | | | | | | | | | | | grams/ minute |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | "IDLE"* |
| **Total Hydrocarbons** | | | | | | | | | | | | | | | |
| Autos | 0.408 | 0.275 | 0.195 | 0.146 | 0.115 | 0.095 | 0.083 | 0.076 | 0.074 | 0.074 | 0.080 | 0.090 | 0.107 | 0.119 | 0.034 |
| Gas trucks | 0.884 | 0.587 | 0.410 | 0.300 | 0.229 | 0.184 | 0.154 | 0.136 | 0.125 | 0.121 | 0.123 | 0.130 | 0.146 | 0.148 | 0.074 |
| Diesel trucks | 0.961 | 0.754 | 0.605 | 0.497 | 0.416 | 0.357 | 0.313 | 0.280 | 0.257 | 0.240 | 0.230 | 0.225 | 0.225 | 0.230 | 0.080 |
| **Carbon Monoxide** | | | | | | | | | | | | | | | |
| Autos | 2.385 | 2.098 | 1.869 | 1.685 | 1.534 | 1.409 | 1.307 | 1.224 | 1.160 | 1.115 | 1.092 | 1.098 | 1.144 | 1.234 | 0.199 |
| Gas trucks | 5.287 | 4.151 | 3.406 | 2.895 | 2.531 | 2.265 | 2.068 | 1.926 | 1.830 | 1.776 | 1.770 | 1.820 | 1.948 | 2.130 | 0.441 |
| Diesel trucks | 4.589 | 3.164 | 2.283 | 1.725 | 1.363 | 1.128 | 0.976 | 0.884 | 0.838 | 0.832 | 0.864 | 0.939 | 1.068 | 1.271 | 0.382 |
| **Oxides of Nitrogen** | | | | | | | | | | | | | | | |
| Autos | 0.227 | 0.196 | 0.173 | 0.155 | 0.143 | 0.134 | 0.128 | 0.125 | 0.124 | 0.126 | 0.130 | 0.137 | 0.147 | 0.148 | 0.019 |
| Gas trucks | 0.512 | 0.459 | 0.422 | 0.396 | 0.378 | 0.367 | 0.362 | 0.362 | 0.367 | 0.376 | 0.389 | 0.408 | 0.434 | 0.439 | 0.043 |
| Diesel trucks | 4.589 | 3.164 | 2.283 | 1.725 | 1.363 | 1.128 | 0.976 | 0.884 | 0.838 | 0.832 | 0.864 | 0.939 | 1.068 | 1.271 | 0.382 |

* "IDLE" emission factors are calculated by converting the 5 mph emission factors (grams per mile) to grams per minute.

Table A-3: Emissions Rate Raw Data at 75 Degrees Fahrenheit (c.f. May et al., 2007)

**FREQ Emission Rate Table Based on EMFAC2002**

**Statewide Totals - Avg 2020 Annual - 75 Degrees (F) - 40% Humidity**

| Vehicle Class | Grams per mile for average travel speeds (mph) of specific pollutant: 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | grams/ minute "IDLE"* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total Hydrocarbons** | | | | | | | | | | | | | | | |
| Autos | 0.429 | 0.288 | 0.205 | 0.153 | 0.121 | 0.100 | 0.086 | 0.079 | 0.076 | 0.077 | 0.082 | 0.092 | 0.109 | 0.121 | 0.036 |
| Gas trucks | 0.928 | 0.616 | 0.429 | 0.314 | 0.240 | 0.193 | 0.162 | 0.143 | 0.131 | 0.127 | 0.128 | 0.137 | 0.152 | 0.155 | 0.077 |
| Diesel trucks | 0.961 | 0.754 | 0.605 | 0.497 | 0.416 | 0.357 | 0.313 | 0.280 | 0.257 | 0.240 | 0.230 | 0.225 | 0.225 | 0.230 | 0.080 |
| **Carbon Monoxide** | | | | | | | | | | | | | | | |
| Autos | 2.607 | 2.296 | 2.048 | 1.847 | 1.681 | 1.545 | 1.431 | 1.338 | 1.266 | 1.213 | 1.182 | 1.179 | 1.215 | 1.295 | 0.217 |
| Gas trucks | 5.652 | 4.460 | 3.675 | 3.132 | 2.743 | 2.459 | 2.247 | 2.092 | 1.985 | 1.925 | 1.913 | 1.960 | 2.090 | 2.278 | 0.471 |
| Diesel trucks | 4.589 | 3.164 | 2.283 | 1.725 | 1.363 | 1.128 | 0.976 | 0.884 | 0.838 | 0.832 | 0.864 | 0.939 | 1.068 | 1.271 | 0.382 |
| **Oxides of Nitrogen** | | | | | | | | | | | | | | | |
| Autos | 0.206 | 0.178 | 0.156 | 0.141 | 0.129 | 0.121 | 0.116 | 0.113 | 0.113 | 0.114 | 0.117 | 0.124 | 0.134 | 0.135 | 0.017 |
| Gas trucks | 0.463 | 0.414 | 0.381 | 0.357 | 0.341 | 0.332 | 0.327 | 0.327 | 0.330 | 0.339 | 0.351 | 0.368 | 0.391 | 0.396 | 0.039 |
| Diesel trucks | 4.589 | 3.164 | 2.283 | 1.725 | 1.363 | 1.128 | 0.976 | 0.884 | 0.838 | 0.832 | 0.864 | 0.939 | 1.068 | 1.271 | 0.382 |

* "IDLE" emission factors are calculated by converting the 5 mph emission factors (grams per mile) to grams per minute.

Table A-4: Emissions Rate Raw Data at 85 Degrees Fahrenheit (c.f. May et al., 2007)

**FREQ Emission Rate Table Based on EMFAC2002**

**Statewide Totals - Avg 2020 Annual - 85 Degrees (F) - 40% Humidity**

| Vehicle Class | Grams per mile for average travel speeds (mph) of specific pollutant: 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | grams/ minute "IDLE"* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total Hydrocarbons** | | | | | | | | | | | | | | | |
| Autos | 0.467 | 0.315 | 0.223 | 0.167 | 0.131 | 0.108 | 0.094 | 0.086 | 0.083 | 0.084 | 0.089 | 0.100 | 0.118 | 0.130 | 0.039 |
| Gas trucks | 0.988 | 0.657 | 0.459 | 0.335 | 0.257 | 0.207 | 0.173 | 0.153 | 0.141 | 0.137 | 0.139 | 0.148 | 0.165 | 0.168 | 0.082 |
| Diesel trucks | 0.961 | 0.754 | 0.605 | 0.497 | 0.416 | 0.357 | 0.313 | 0.280 | 0.257 | 0.240 | 0.230 | 0.225 | 0.225 | 0.230 | 0.080 |
| **Carbon Monoxide** | | | | | | | | | | | | | | | |
| Autos | 3.022 | 2.663 | 2.376 | 2.143 | 1.951 | 1.792 | 1.660 | 1.553 | 1.468 | 1.406 | 1.371 | 1.366 | 1.408 | 1.499 | 0.252 |
| Gas trucks | 6.192 | 4.932 | 4.094 | 3.509 | 3.086 | 2.772 | 2.536 | 2.362 | 2.239 | 2.167 | 2.147 | 2.190 | 2.320 | 2.509 | 0.516 |
| Diesel trucks | 4.589 | 3.164 | 2.283 | 1.725 | 1.363 | 1.128 | 0.976 | 0.884 | 0.838 | 0.832 | 0.864 | 0.939 | 1.068 | 1.271 | 0.382 |
| **Oxides of Nitrogen** | | | | | | | | | | | | | | | |
| Autos | 0.194 | 0.167 | 0.147 | 0.132 | 0.121 | 0.114 | 0.109 | 0.106 | 0.105 | 0.107 | 0.110 | 0.116 | 0.126 | 0.127 | 0.016 |
| Gas trucks | 0.432 | 0.386 | 0.354 | 0.332 | 0.317 | 0.308 | 0.304 | 0.304 | 0.306 | 0.314 | 0.325 | 0.341 | 0.363 | 0.367 | 0.036 |
| Diesel trucks | 4.589 | 3.164 | 2.283 | 1.725 | 1.363 | 1.128 | 0.976 | 0.884 | 0.838 | 0.832 | 0.864 | 0.939 | 1.068 | 1.271 | 0.382 |

* "IDLE" emission factors are calculated by converting the 5 mph emission factors (grams per mile) to grams per minute.

# APPENDIX B: AIR QUALITY MODEL REGRESSION RESULTS

TABLE B-1: REGRESSION COEFFICIENTS FOR EMISSIONS MODELS AT 55 FAHRENHEIT

| | Total Hydrocarbons | | | Carbon Monoxide | | | Oxides of Nitrogen | | |
|---|---|---|---|---|---|---|---|---|---|
| | Autos | Gas Trucks | Diesel Trucks | Autos | Gas Trucks | Diesel Trucks | Autos | Gas Trucks | Diesel Trucks |
| Intercept | 6.09E-01 | 1.33E+00 | 1.25E+00 | 2.79E+00 | 6.94E+00 | 6.84E+00 | 3.00E-01 | 6.46E-01 | 6.84E+00 |
| $v$ | -5.03E-02 | -1.15E-01 | -6.76E-02 | -8.34E-02 | -4.08E-01 | -5.61E-01 | -8.68E-03 | -1.36E-02 | -5.61E-01 |
| $v^2$ | 2.14E-03 | 5.13E-03 | 2.24E-03 | 1.99E-03 | 1.63E-02 | 2.51E-02 | 3.11E-05 | -1.06E-04 | 2.51E-02 |
| $v^3$ | -5.06E-05 | -1.31E-04 | -4.84E-05 | -3.31E-05 | -4.03E-04 | -6.71E-04 | 1.01E-05 | 2.76E-05 | -6.71E-04 |
| $v^4$ | 6.58E-07 | 1.89E-06 | 6.72E-07 | 3.52E-07 | 5.87E-06 | 1.08E-05 | -3.65E-07 | -9.01E-07 | 1.08E-05 |
| $v^5$ | -4.12E-09 | -1.40E-08 | -5.32E-09 | -2.15E-09 | -4.53E-08 | -9.40E-08 | 5.24E-09 | 1.24E-08 | -9.40E-08 |
| $v^6$ | 8.82E-12 | 4.09E-11 | 1.82E-11 | 9.27E-12 | 1.47E-10 | 3.46E-10 | -2.71E-11 | -6.29E-11 | 3.46E-10 |
| R Square | 0.9999 | 0.9999 | 1 | 1 | 1 | 1 | 0.9997 | 0.9992 | 1 |

TABLE B-2: REGRESSION COEFFICIENTS FOR EMISSIONS MODELS AT 65 FAHRENHEIT

| | Total Hydrocarbons | | | Carbon Monoxide | | | Oxides of Nitrogen | | |
|---|---|---|---|---|---|---|---|---|---|
| | Autos | Gas Trucks | Diesel Trucks | Autos | Gas Trucks | Diesel Trucks | Autos | Gas Trucks | Diesel Trucks |
| Intercept | 6.16E-01 | 1.35E+00 | 1.25E+00 | 2.75E+00 | 6.99E+00 | 6.84E+00 | 2.61E-01 | 5.71E-01 | 6.84E+00 |
| $v$ | -5.14E-02 | -1.17E-01 | -6.76E-02 | -8.12E-02 | -4.15E-01 | -5.61E-01 | -6.98E-03 | -1.23E-02 | -5.61E-01 |
| $v^2$ | 2.20E-03 | 5.17E-03 | 2.24E-03 | 1.93E-03 | 1.68E-02 | 2.51E-02 | -2.83E-05 | -2.65E-05 | 2.51E-02 |
| $v^3$ | -5.21E-05 | -1.31E-04 | -4.84E-05 | -3.25E-05 | -4.21E-04 | -6.71E-04 | 1.10E-05 | 1.99E-05 | -6.71E-04 |
| $v^4$ | 6.73E-07 | 1.87E-06 | 6.72E-07 | 3.57E-07 | 6.25E-06 | 1.08E-05 | -3.57E-07 | -6.69E-07 | 1.08E-05 |
| $v^5$ | -4.13E-09 | -1.37E-08 | -5.32E-09 | -2.28E-09 | -4.97E-08 | -9.40E-08 | 4.89E-09 | 9.35E-09 | -9.40E-08 |
| $v^6$ | 8.39E-12 | 3.93E-11 | 1.82E-11 | 9.65E-12 | 1.67E-10 | 3.46E-10 | -2.47E-11 | -4.77E-11 | 3.46E-10 |
| R Square | 0.9999 | 0.9999 | 1 | 1 | 1 | 1 | 0.9997 | 0.9990 | 1 |

TABLE B-3: REGRESSION COEFFICIENTS FOR EMISSIONS MODELS AT 75 FAHRENHEIT

| | Total Hydrocarbons | | | Carbon Monoxide | | | Oxides of Nitrogen | | |
|---|---|---|---|---|---|---|---|---|---|
| | Autos | Gas Trucks | Diesel Trucks | Autos | Gas Trucks | Diesel Trucks | Autos | Gas Trucks | Diesel Trucks |
| Intercept | 6.53E-01 | 1.42E+00 | 1.25E+00 | 3.00E+00 | 7.43E+00 | 6.84E+00 | 2.35E-01 | 5.20E-01 | 6.84E+00 |
| v | -5.58E-02 | -1.23E-01 | -6.76E-02 | -8.86E-02 | -4.32E-01 | -5.61E-01 | -5.66E-03 | -1.21E-02 | -5.61E-01 |
| v2 | 2.49E-03 | 5.41E-03 | 2.24E-03 | 2.18E-03 | 1.73E-02 | 2.51E-02 | -1.06E-04 | 5.42E-05 | 2.51E-02 |
| v3 | -6.33E-05 | -1.36E-04 | -4.84E-05 | -4.11E-05 | -4.32E-04 | -6.71E-04 | 1.40E-05 | 1.52E-05 | -6.71E-04 |
| v4 | 9.02E-07 | 1.91E-06 | 6.72E-07 | 5.45E-07 | 6.40E-06 | 1.08E-05 | -4.20E-07 | -5.55E-07 | 1.08E-05 |
| v5 | -6.50E-09 | -1.38E-08 | -5.32E-09 | -4.41E-09 | -5.09E-08 | -9.40E-08 | 5.54E-09 | 8.02E-09 | -9.40E-08 |
| v6 | 1.81E-11 | 3.83E-11 | 1.82E-11 | 1.90E-11 | 1.71E-10 | 3.46E-10 | -2.72E-11 | -4.17E-11 | 3.46E-10 |
| R Square | 0.9999 | 1 | 1 | 1 | 1 | 1 | 0.9994 | 0.9992 | 1 |

TABLE B-4: REGRESSION COEFFICIENTS FOR EMISSIONS MODELS AT 85 FAHRENHEIT

| | Total Hydrocarbons | | | Carbon Monoxide | | | Oxides of Nitrogen | | |
|---|---|---|---|---|---|---|---|---|---|
| | Autos | Gas Trucks | Diesel Trucks | Autos | Gas Trucks | Diesel Trucks | Autos | Gas Trucks | Diesel Trucks |
| Intercept | 7.04E-01 | 1.51E+00 | 1.25E+00 | 3.47E+00 | 8.06E+00 | 6.84E+00 | 2.23E-01 | 4.84E-01 | 6.84E+00 |
| v | -5.87E-02 | -1.30E-01 | -6.76E-02 | -1.02E-01 | -4.53E-01 | -5.61E-01 | -5.75E-03 | -1.06E-02 | -5.61E-01 |
| v2 | 2.51E-03 | 5.72E-03 | 2.24E-03 | 2.44E-03 | 1.79E-02 | 2.51E-02 | -6.63E-05 | -4.86E-05 | 2.51E-02 |
| v3 | -6.00E-05 | -1.43E-04 | -4.84E-05 | -4.41E-05 | -4.44E-04 | -6.71E-04 | 1.19E-05 | 1.97E-05 | -6.71E-04 |
| v4 | 7.88E-07 | 2.03E-06 | 6.72E-07 | 5.54E-07 | 6.56E-06 | 1.08E-05 | -3.74E-07 | -6.59E-07 | 1.08E-05 |
| v5 | -5.01E-09 | -1.47E-08 | -5.32E-09 | -4.25E-09 | -5.18E-08 | -9.40E-08 | 5.04E-09 | 9.18E-09 | -9.40E-08 |
| v6 | 1.10E-11 | 4.13E-11 | 1.82E-11 | 1.81E-11 | 1.73E-10 | 3.46E-10 | -2.50E-11 | -4.67E-11 | 3.46E-10 |
| R Square | 0.9999 | 1 | 1 | 1 | 1 | 1 | 0.9994 | 0.9992 | 1 |

# APPENDIX C: AIR QUALITY MODEL CURVES

55 Degrees Fahrenheit (Used for December, January, and February)

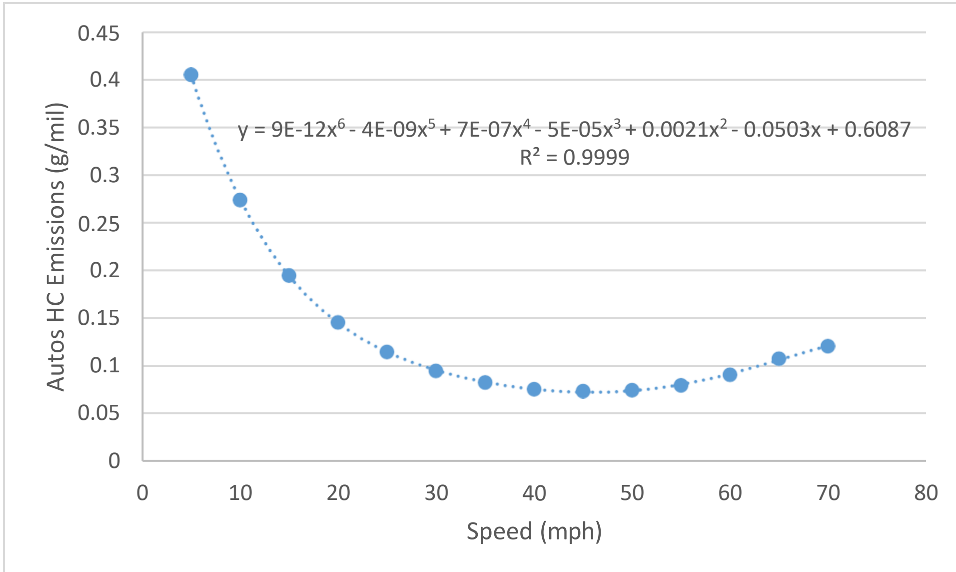


Figure C-1: Automobile Total Hydrocarbon Emissions vs. Speed at 55 Degrees Fahrenheit

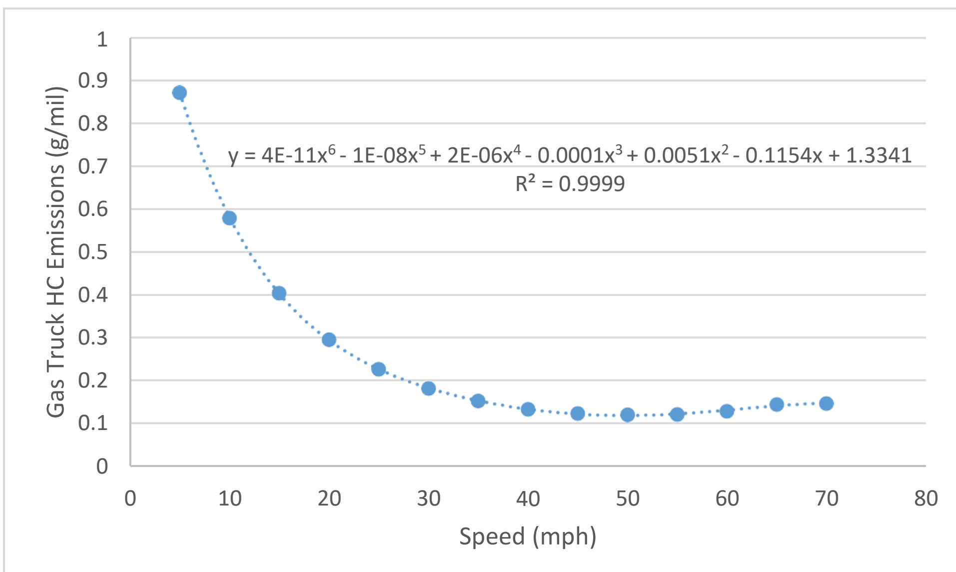


Figure C-2: Gas Truck Total Hydrocarbon Emissions vs. Speed for 55 Degrees Fahrenheit

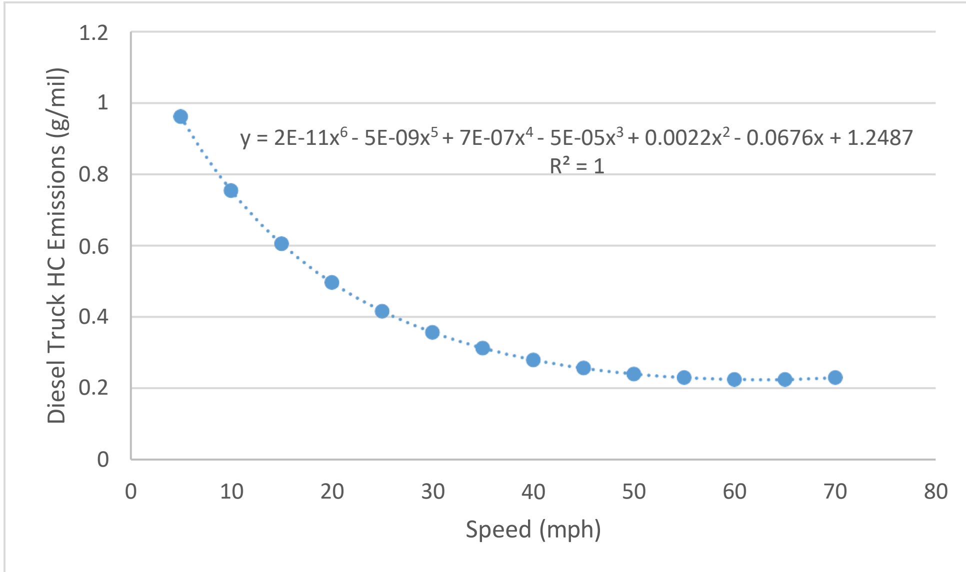


Figure C-3: Diesel Truck Total Hydrocarbon Emissions at 55 Degrees Fahrenheit

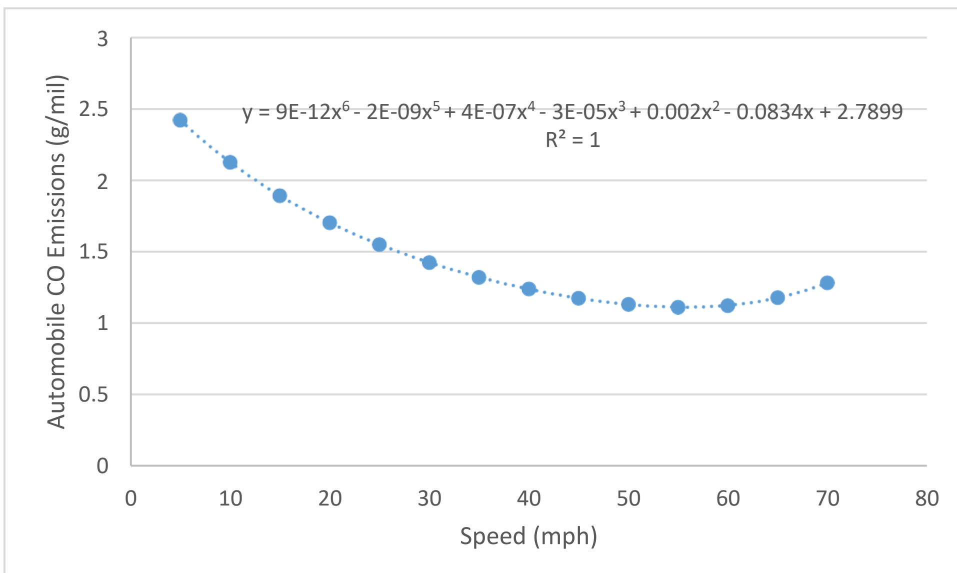


Figure C-4: Automobile Carbon Monoxide Emissions vs. Speed at 55 Degrees Fahrenheit

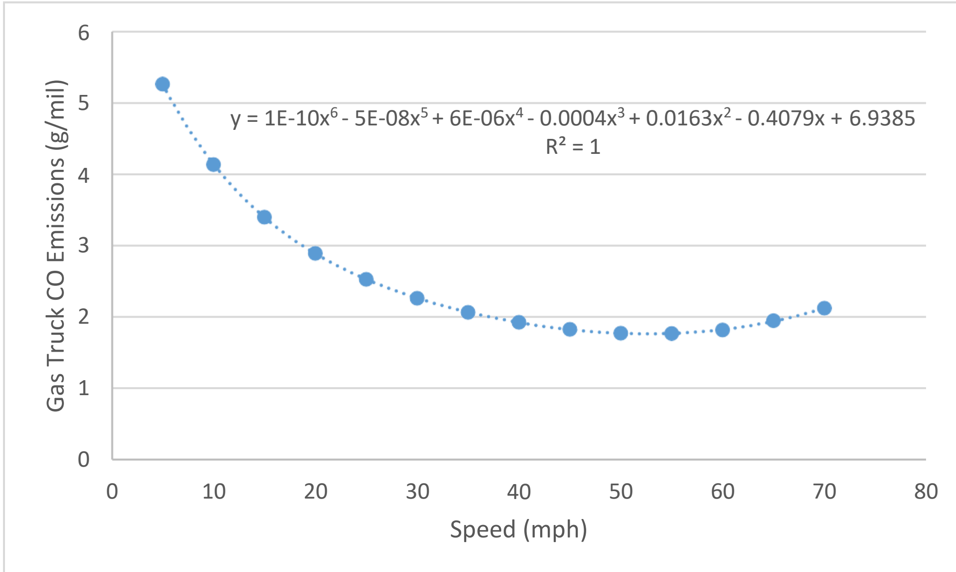


Figure C-5: Gas Truck Carbon Monoxide Emissions vs. Speed at 55 Degrees Fahrenheit

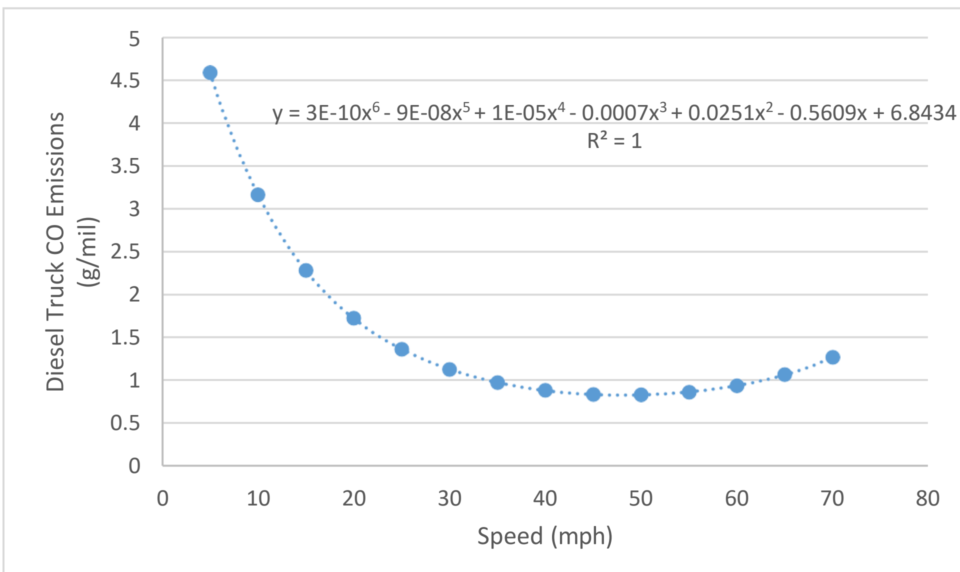


Figure C-6: Diesel Truck Carbon Monoxide Emissions vs. Speed at 55 Degrees Fahrenheit

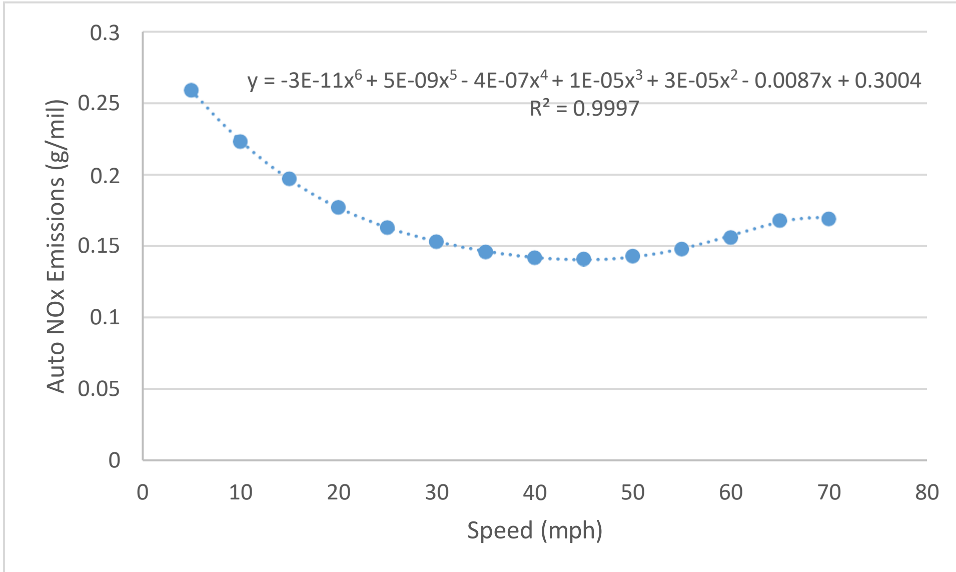


Figure C-7: Automobile Nitrogen Oxide Emissions vs. Speed at 55 Degrees Fahrenheit

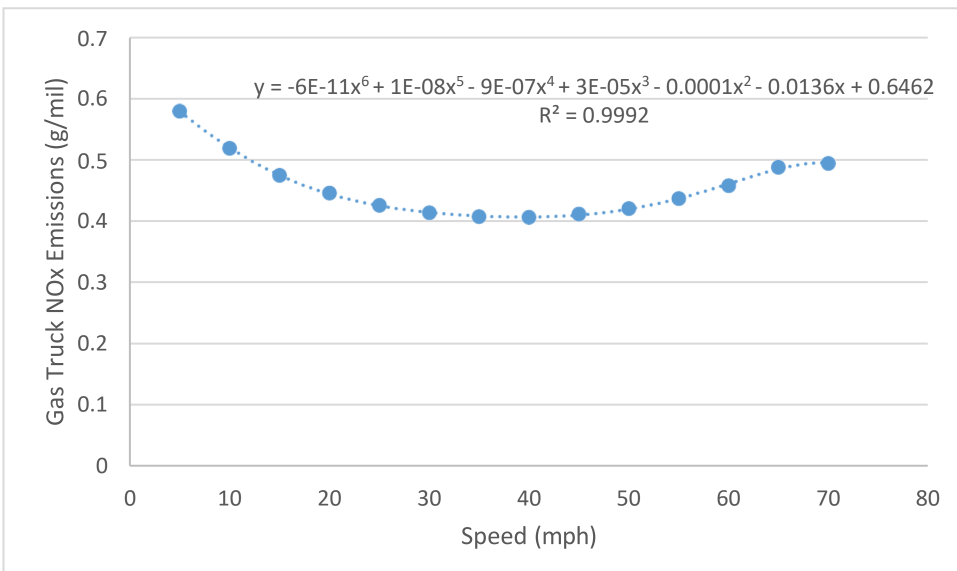


Figure C-8: Gas Truck Nitrogen Oxide Emissions vs. Speed at 55 Degrees Fahrenheit

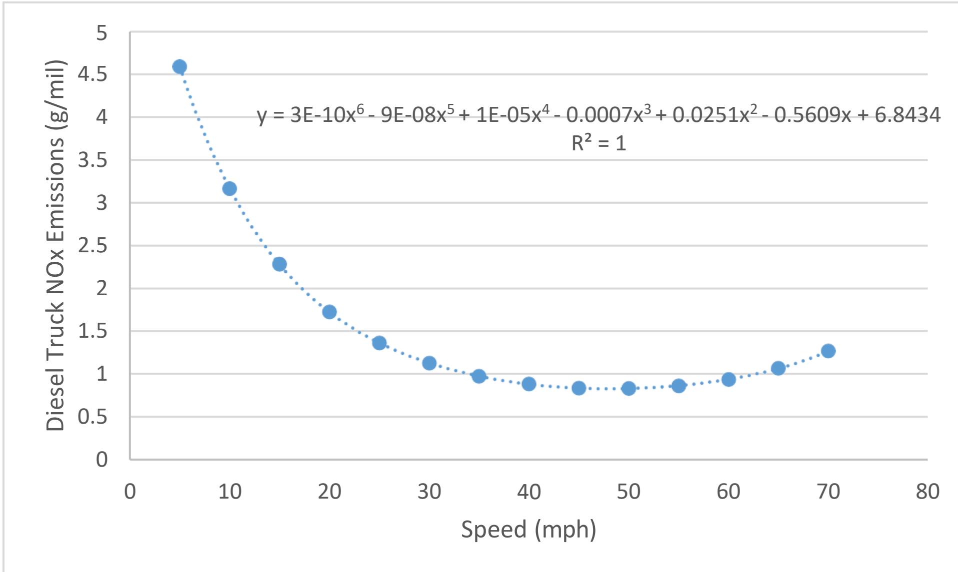


Figure C-9: Diesel Truck Nitrogen Oxide Emissions vs. Speed at 55 Degrees Fahrenheit

65 Degrees Fahrenheit (Used for March, October, and November)

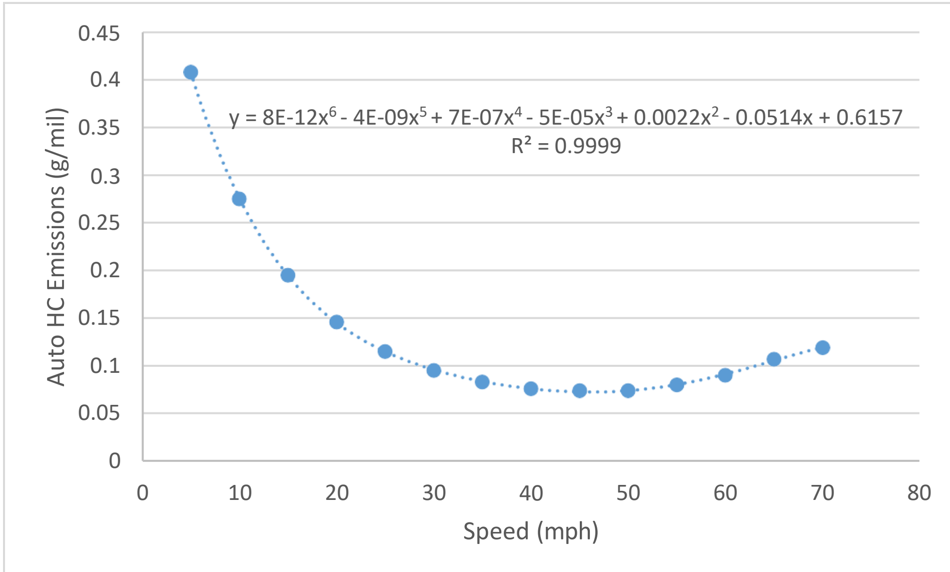


Figure C-10: Automobile Total Hydrocarbon Emissions vs. Speed at 65 Degrees Fahrenheit

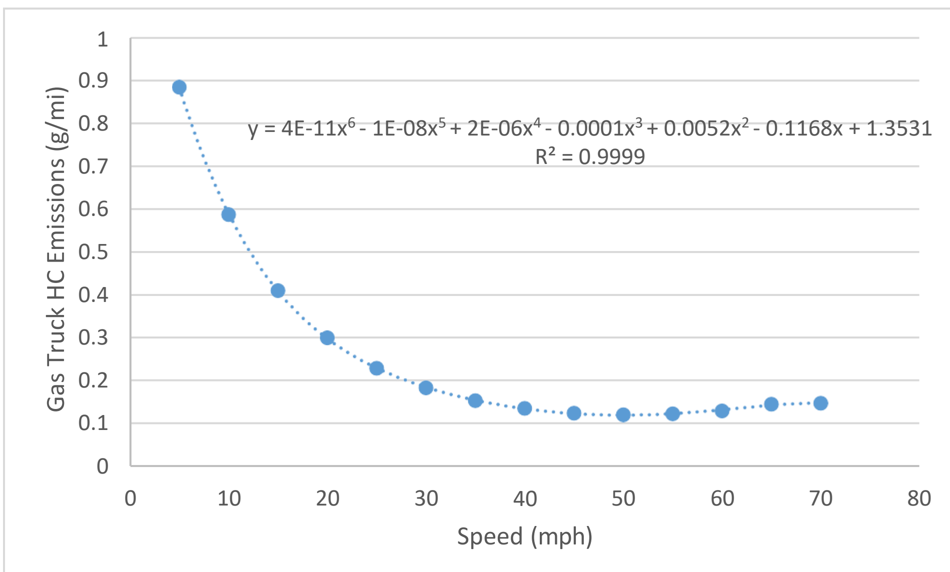


Figure C-11: Gas Truck Total Hydrocarbon Emissions vs. Speed for 65 Degrees Fahrenheit

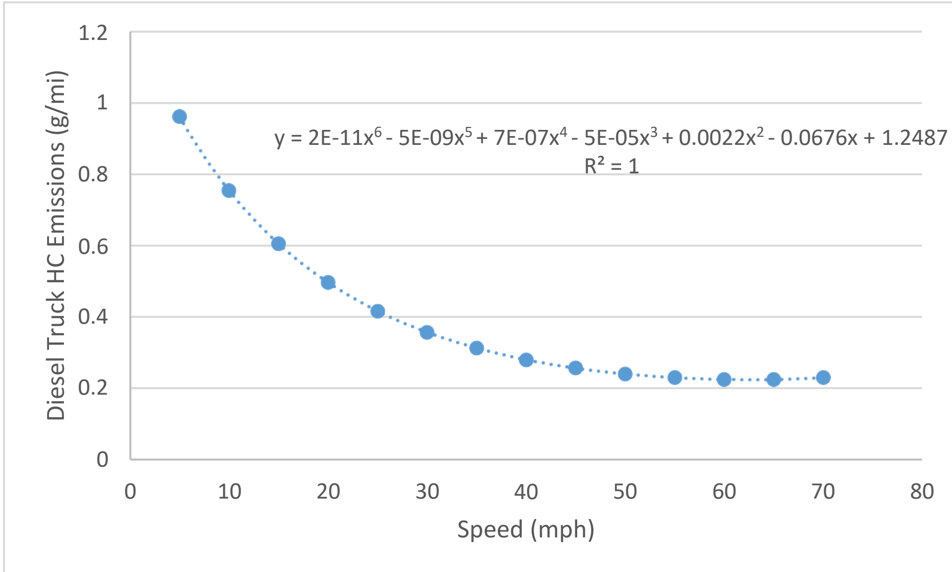


Figure C-12: Diesel Truck Total Hydrocarbon Emissions vs. Speed at 65 Degrees Fahrenheit

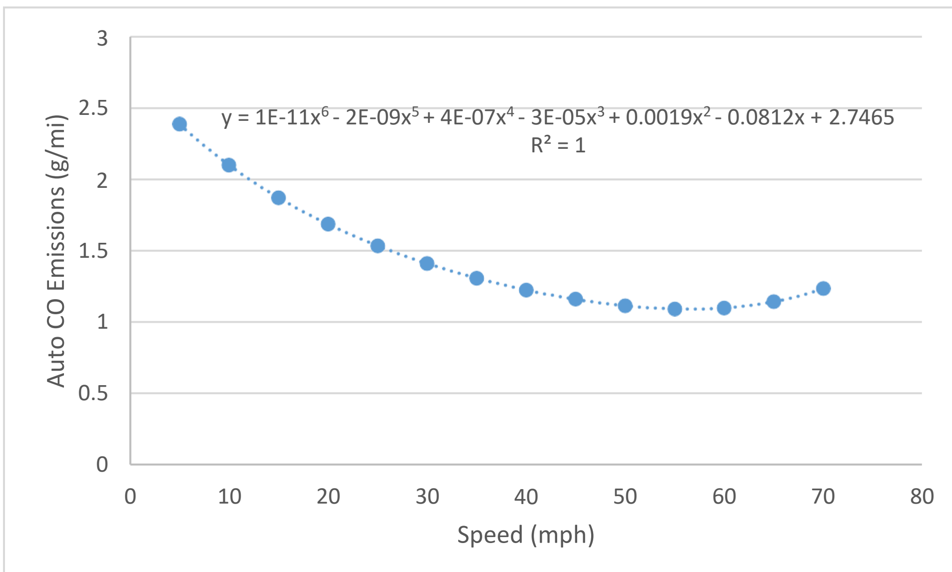


Figure C-13: Automobile Carbon Monoxide Emissions vs. speed at 65 Degrees Fahrenheit

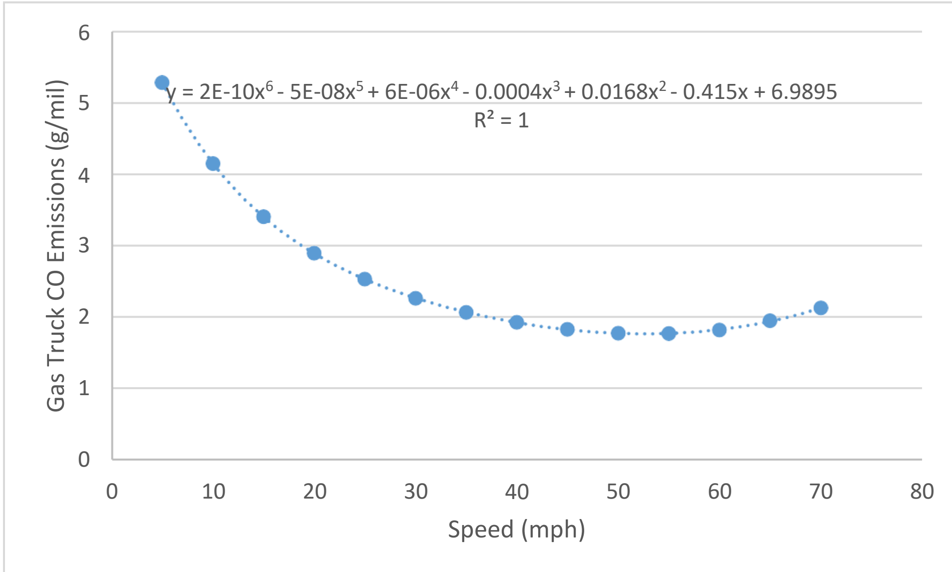


Figure C-14: Gas Truck Carbon Monoxide Emissions vs. Speed at 65 Degrees Fahrenheit

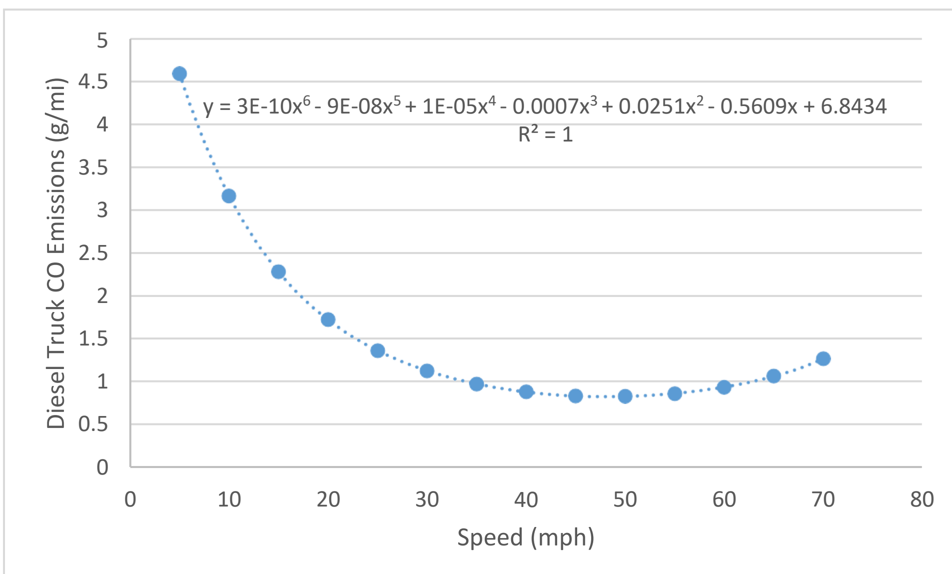


Figure C-15: Diesel Truck Carbon Monoxide Emissions vs. Speed at 65 Degrees Fahrenheit

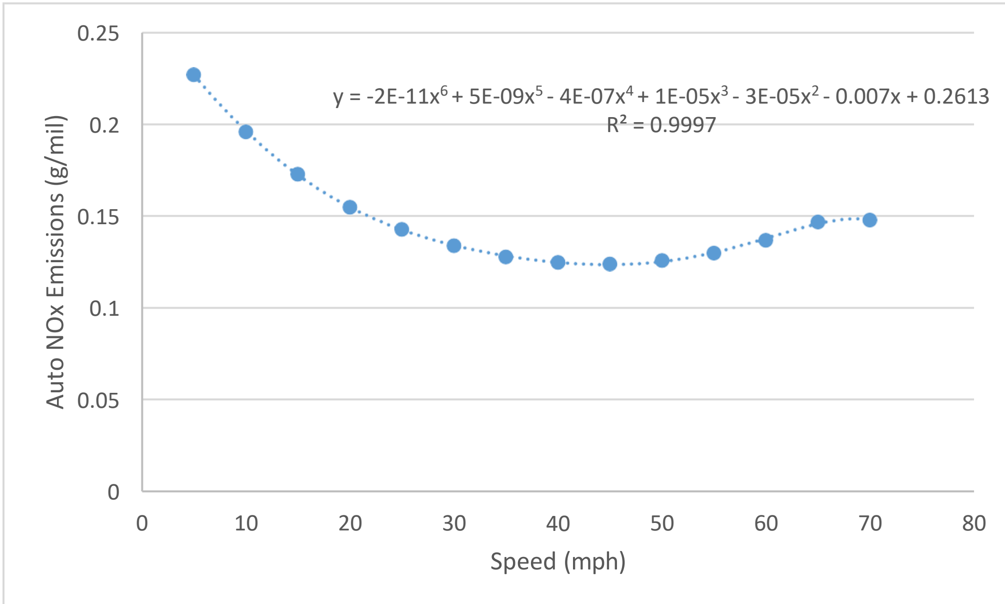


Figure C-16: Automobile Nitrogen Oxide Emissions vs. Speed at 65 Degrees Fahrenheit

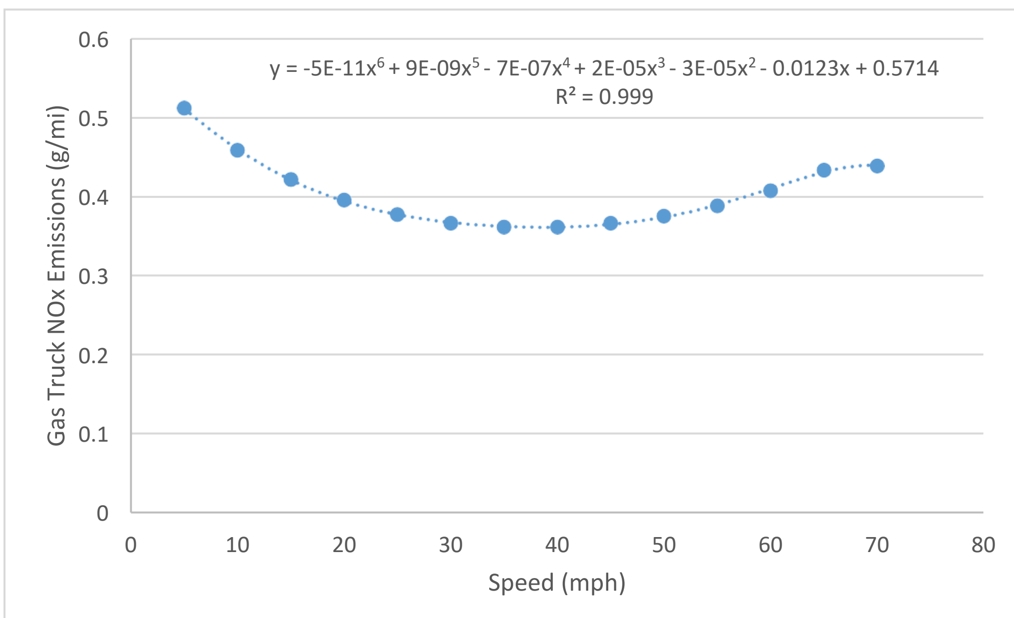


Figure C-17: Gas Truck Nitrogen Oxide Emissions vs. Speed at 65 Degrees Fahrenheit

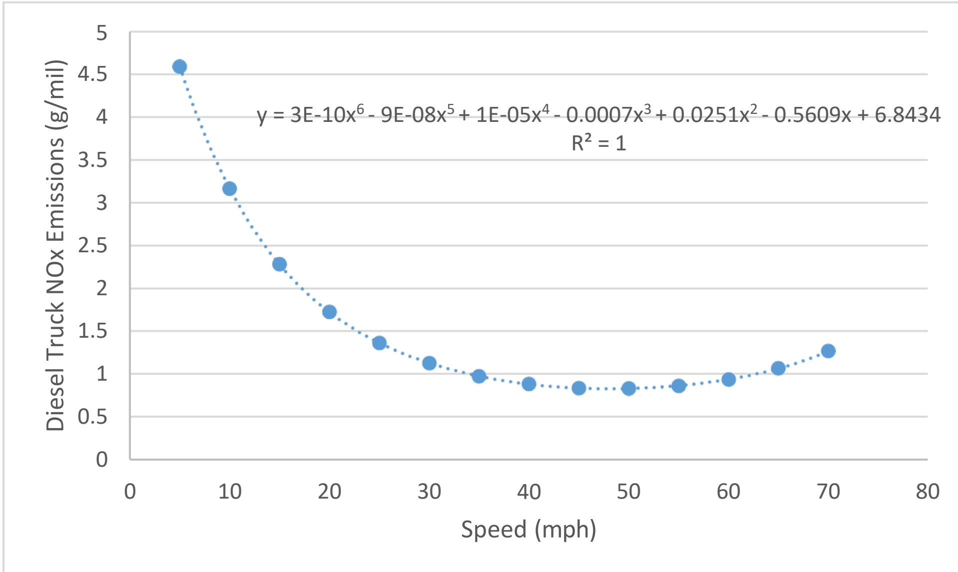


Figure C-18: Diesel Truck Nitrogen Oxide Emissions vs. Speed at 65 Degrees Fahrenheit

75 Degrees Fahrenheit (Used for April, May, and September)

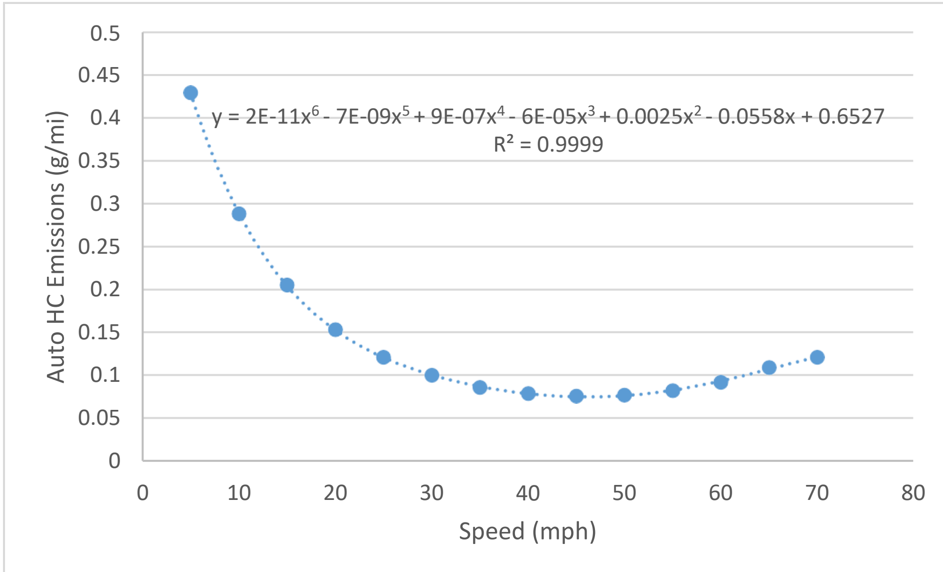


Figure C-19: Automobile Total Hydrocarbon Emissions vs. Speed at 75 Degrees Fahrenheit

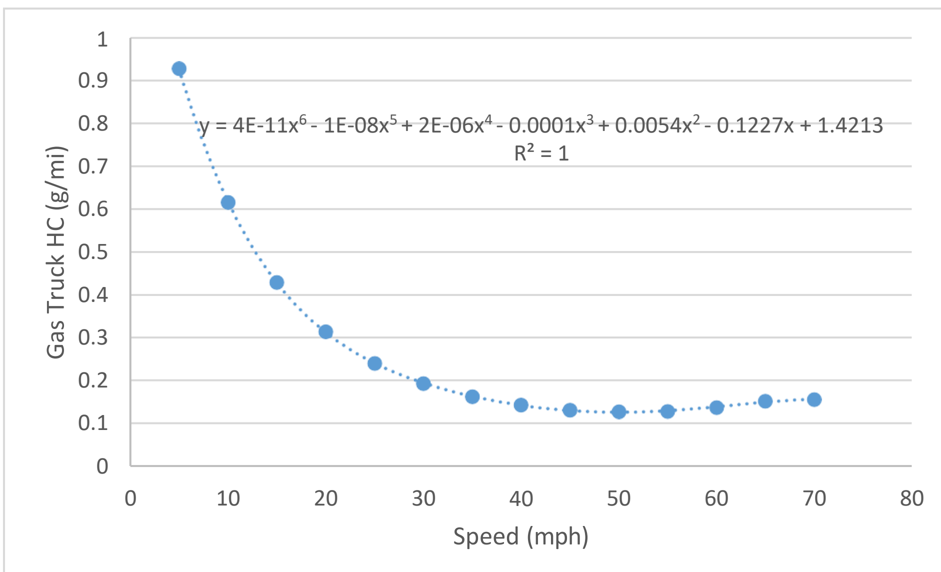


Figure C-20: Gas Truck Total Hydrocarbon Emissions vs. Speed for 75 Degrees Fahrenheit

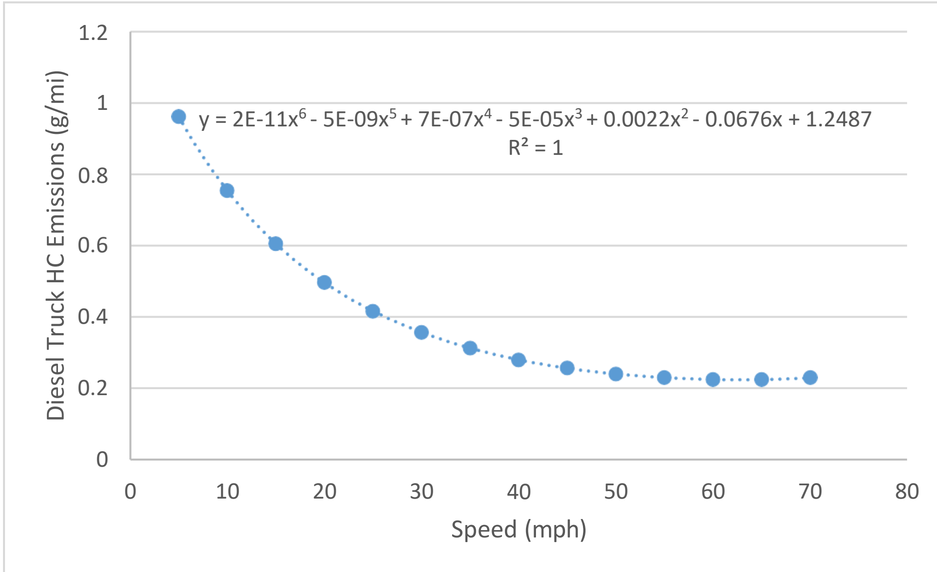


Figure C-21: Diesel Truck Total Hydrocarbon Emissions vs. Speed at 75 Degrees Fahrenheit

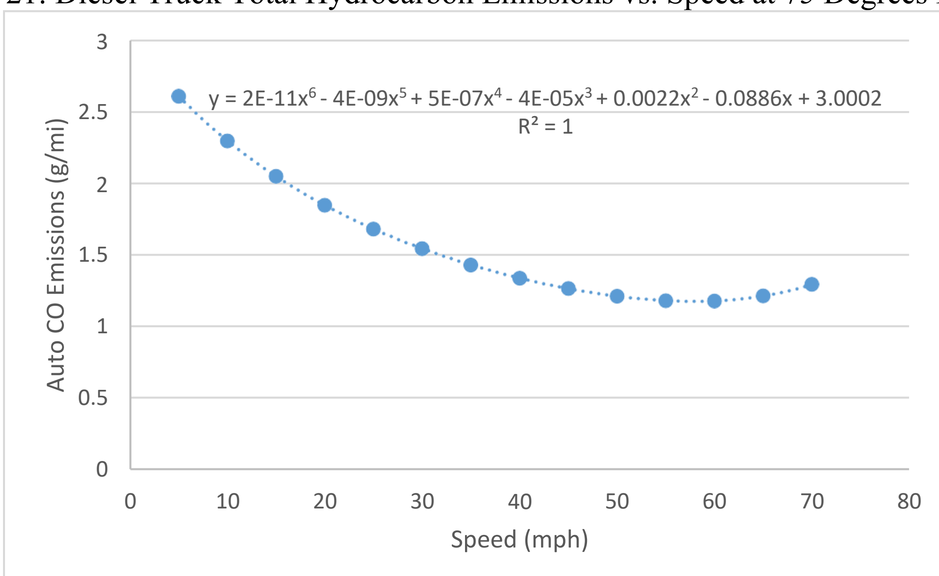


Figure. C-22: Automobile Carbon Monoxide Emissions vs. speed at 75 Degrees Fahrenheit

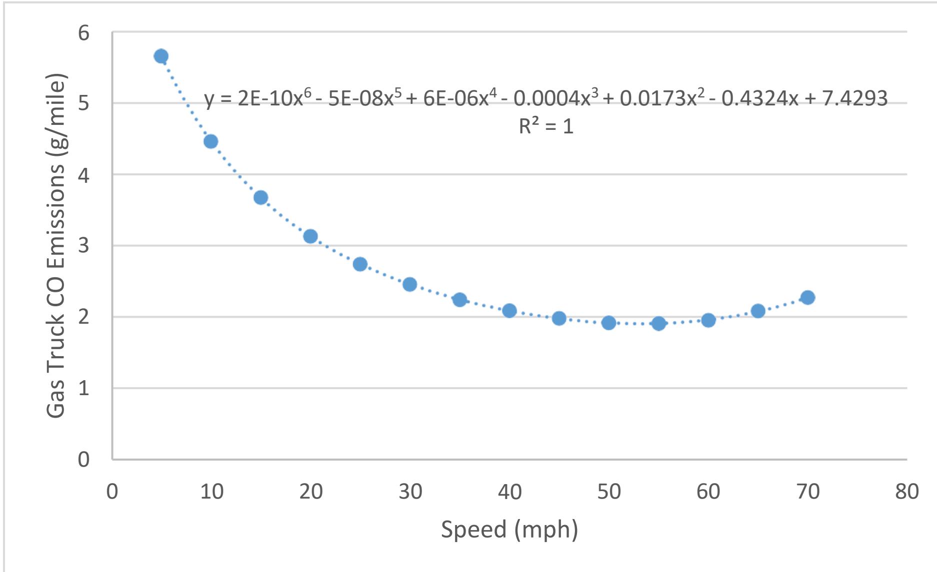


Figure C-23: Gas Truck Carbon Monoxide Emissions vs. Speed at 75 Degrees Fahrenheit

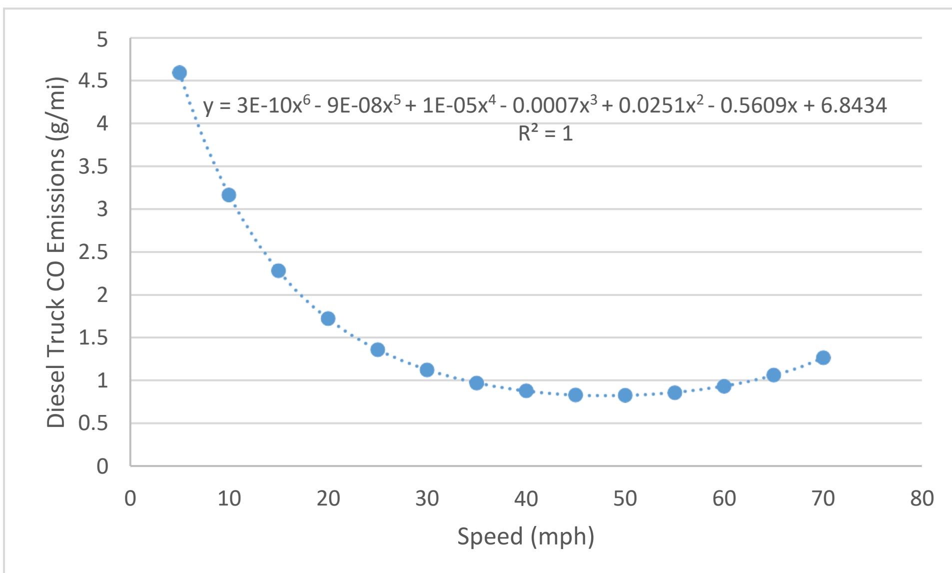


Figure C-24: Diesel Truck Carbon Monoxide Emissions vs. Speed at 75 Degrees Fahrenheit

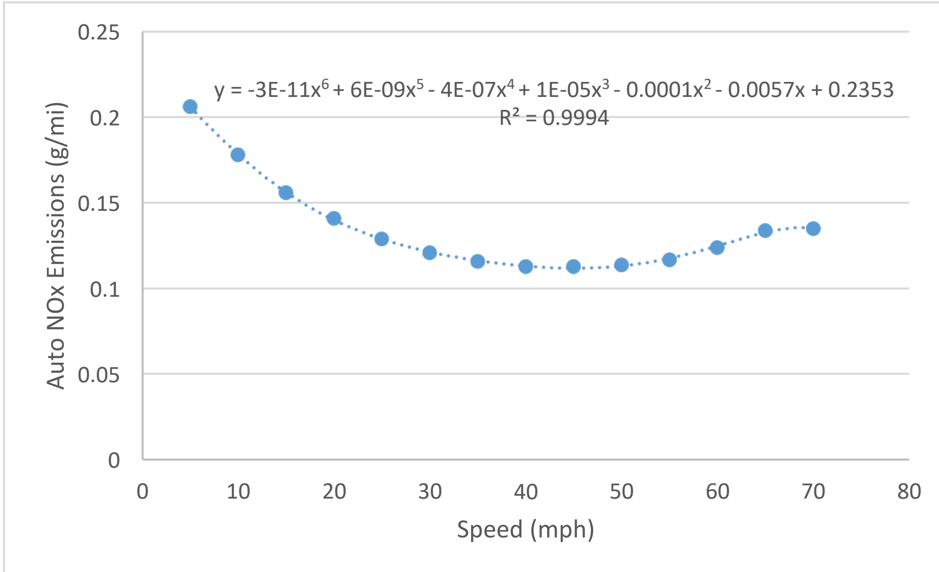


Figure C-25: Automobile Nitrogen Oxide Emissions vs. Speed at 75 Degrees Fahrenheit

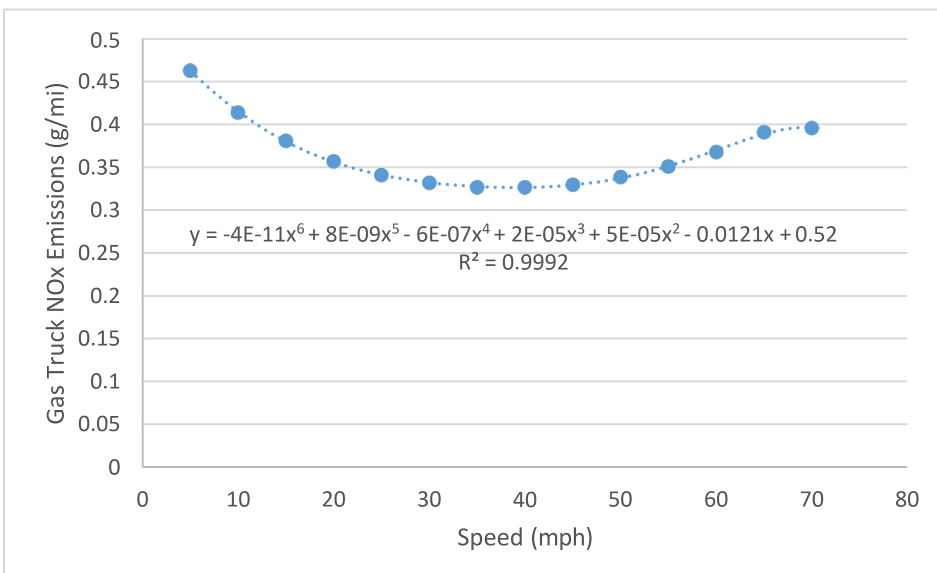


Figure C-26: Gas Truck Nitrogen Oxide Emissions vs. Speed at 75 Degrees Fahrenheit

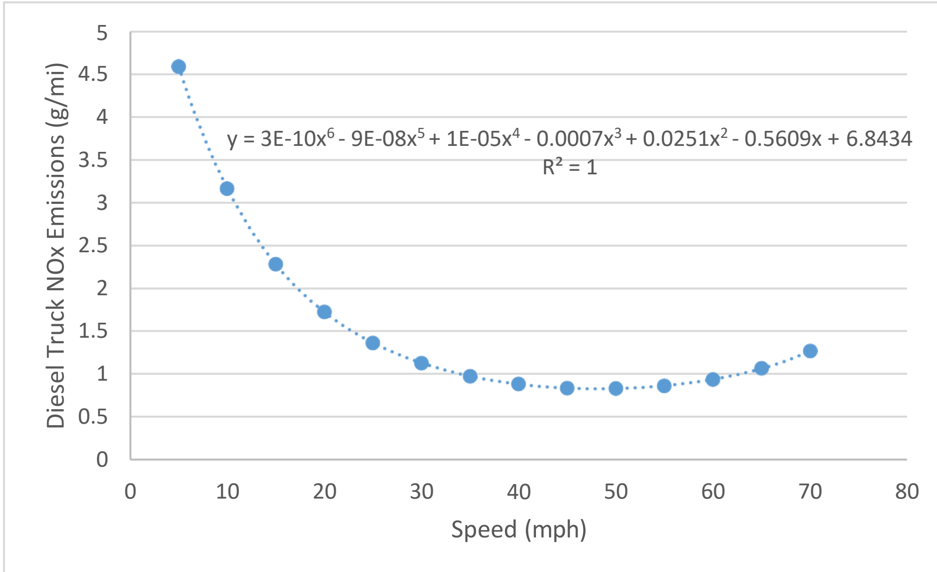


Figure C-27: Diesel Truck Nitrogen Oxide Emissions vs. Speed at 75 Degrees Fahrenheit

85 Degrees Fahrenheit (Used for June, July, and August)

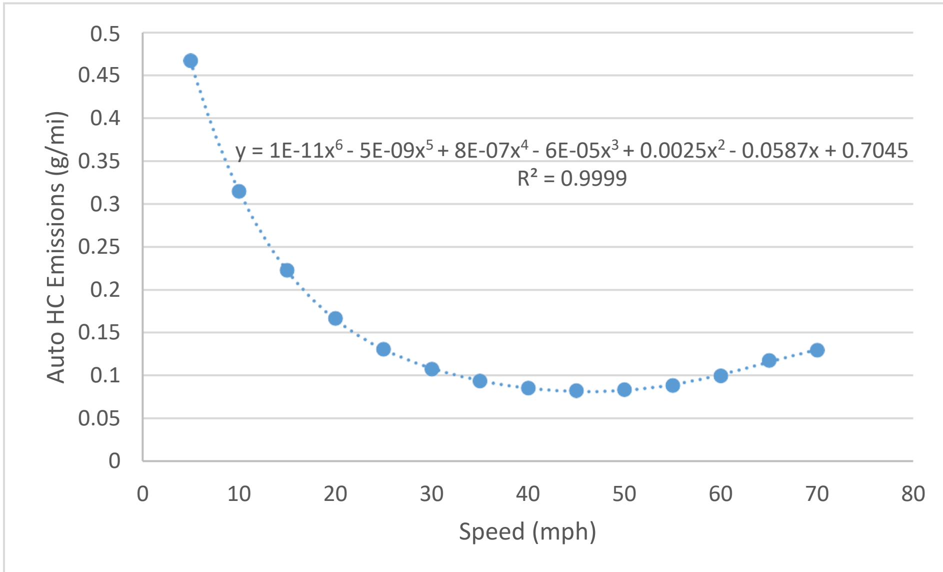


Figure C-28: Automobile Total Hydrocarbon Emissions vs. Speed at 85 Degrees Fahrenheit

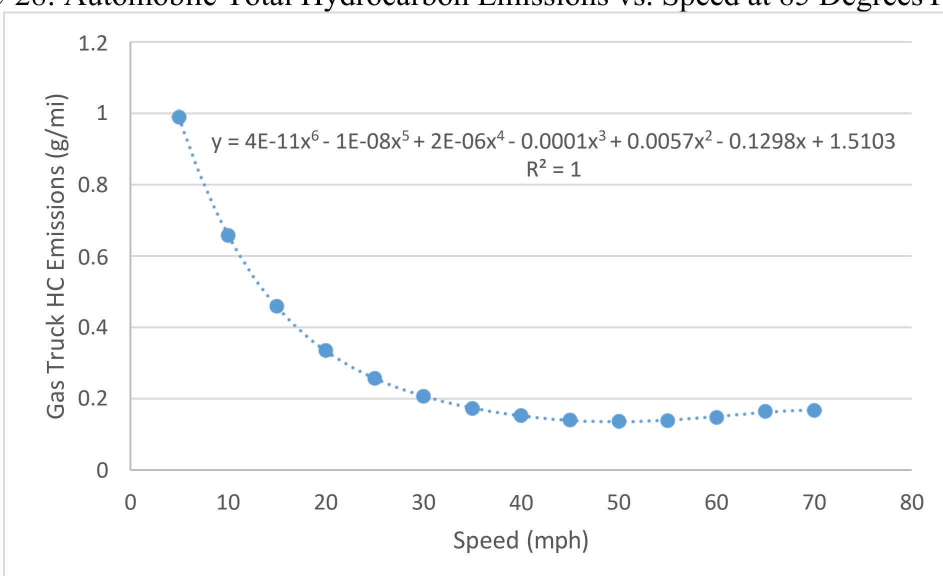


Figure C-29: Gas Truck Total Hydrocarbon Emissions vs. Speed for 85 Degrees Fahrenheit

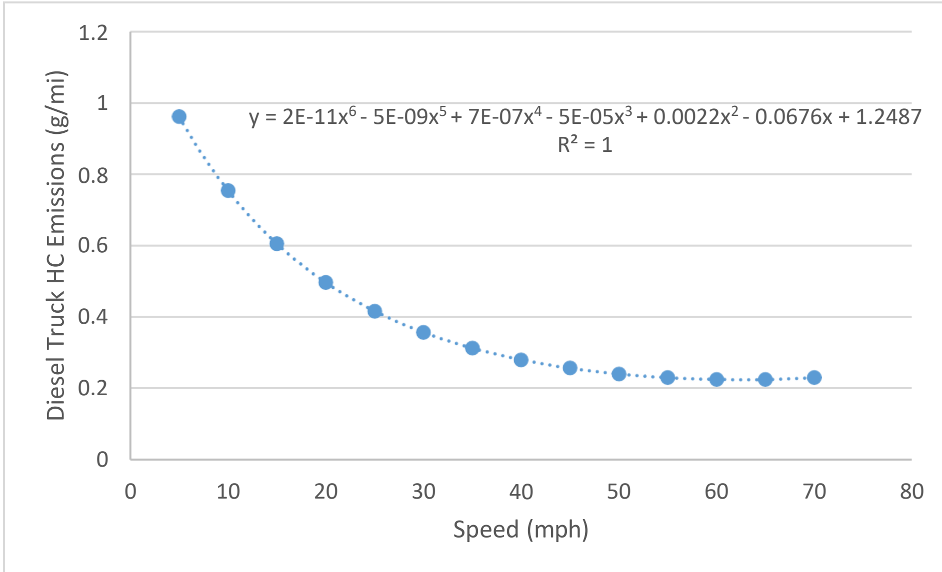


Figure C-30: Diesel Truck Total Hydrocarbon Emissions vs. Speed at 85 Degrees Fahrenheit

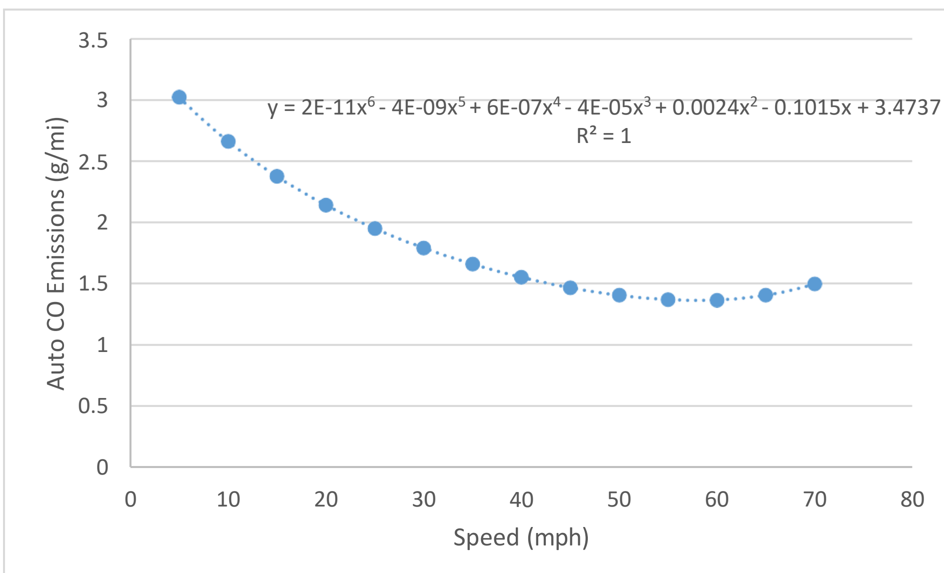


Figure C-31: Automobile Carbon Monoxide Emissions vs. speed at 85 Degrees Fahrenheit

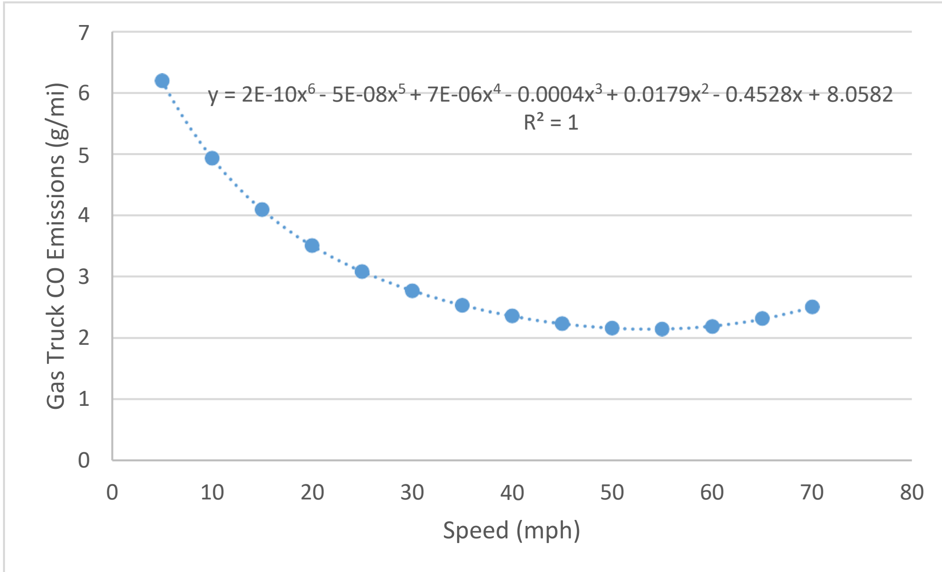


Figure. C-32: Gas Truck Carbon Monoxide Emissions vs. Speed at 85 Degrees Fahrenheit

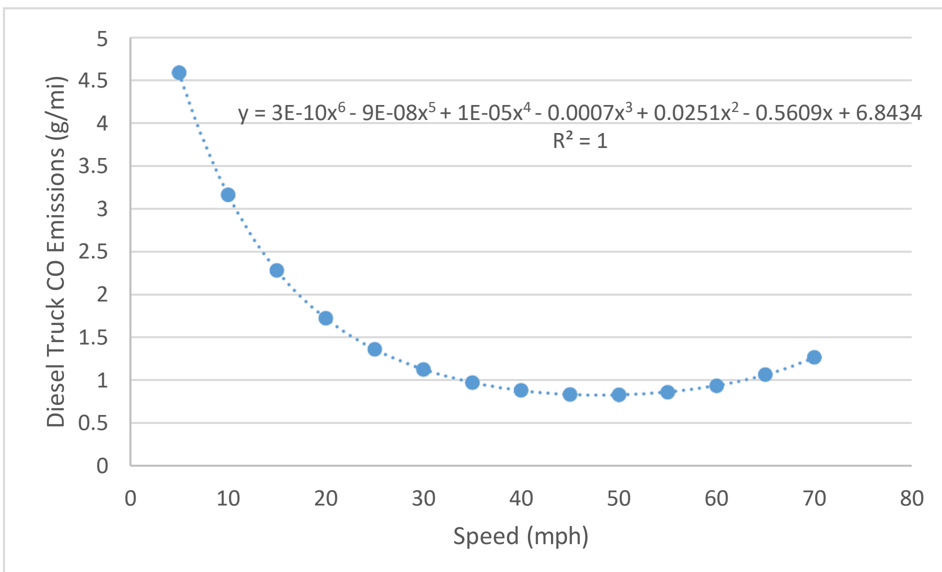


Figure C-33: Diesel Truck Carbon Monoxide Emissions vs. Speed at 85 Degrees Fahrenheit

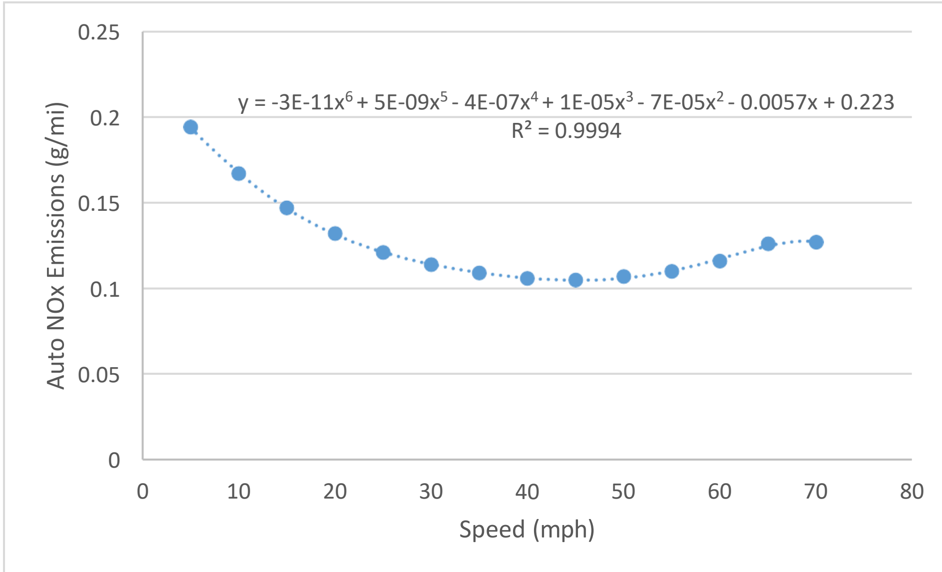


Figure C-34: Automobile Nitrogen Oxide Emissions vs. Speed at 85 Degrees Fahrenheit

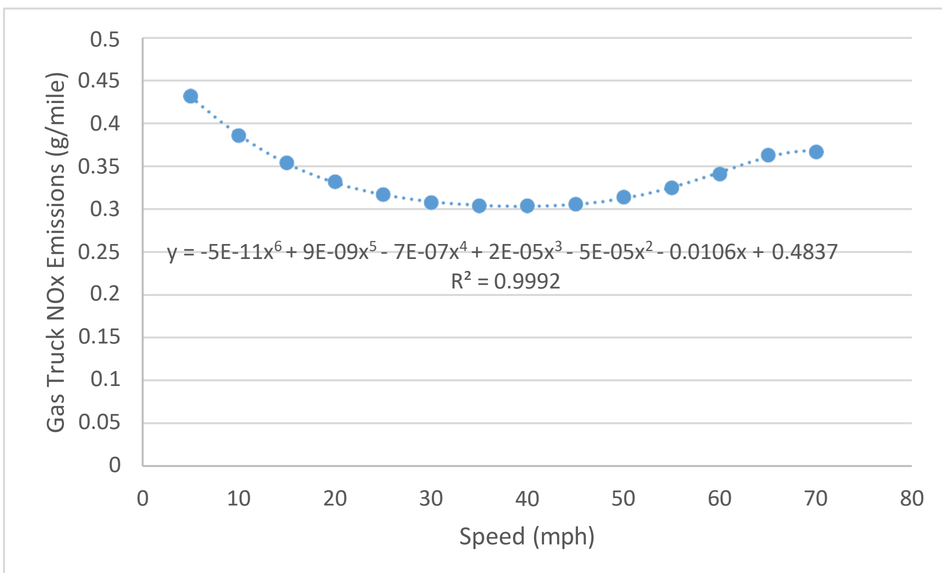


Figure C-35: Gas Truck Nitrogen Oxide Emissions vs. Speed at 85 Degrees Fahrenheit

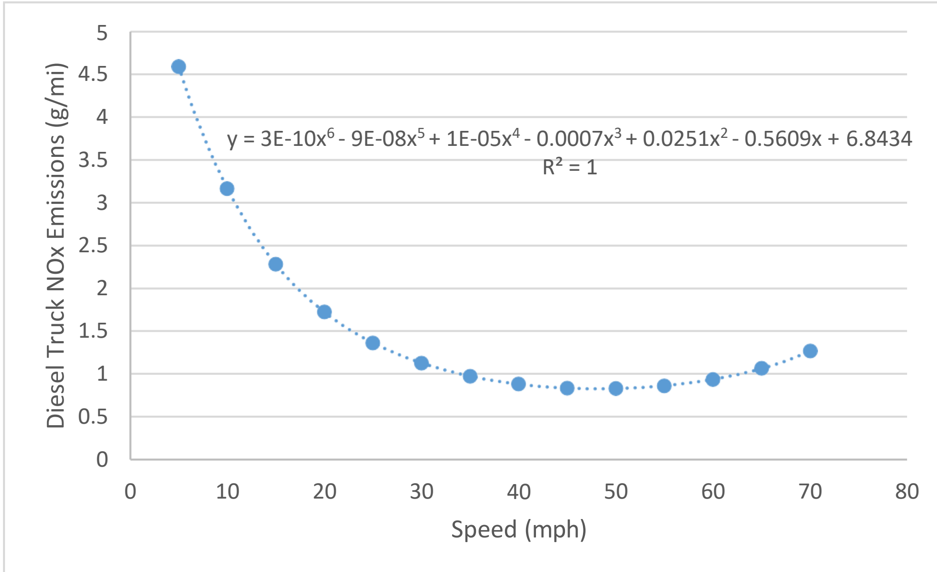


Figure C-36: Diesel Truck Nitrogen Oxide Emissions vs. Speed at 85 Degrees Fahrenheit

# APPENDIX D: CELL TRANSMISSION MODEL RESULTS FOR I-65 SOUTHBOUND FROM MM 80 to MM 59

***Results for K = 0.08***

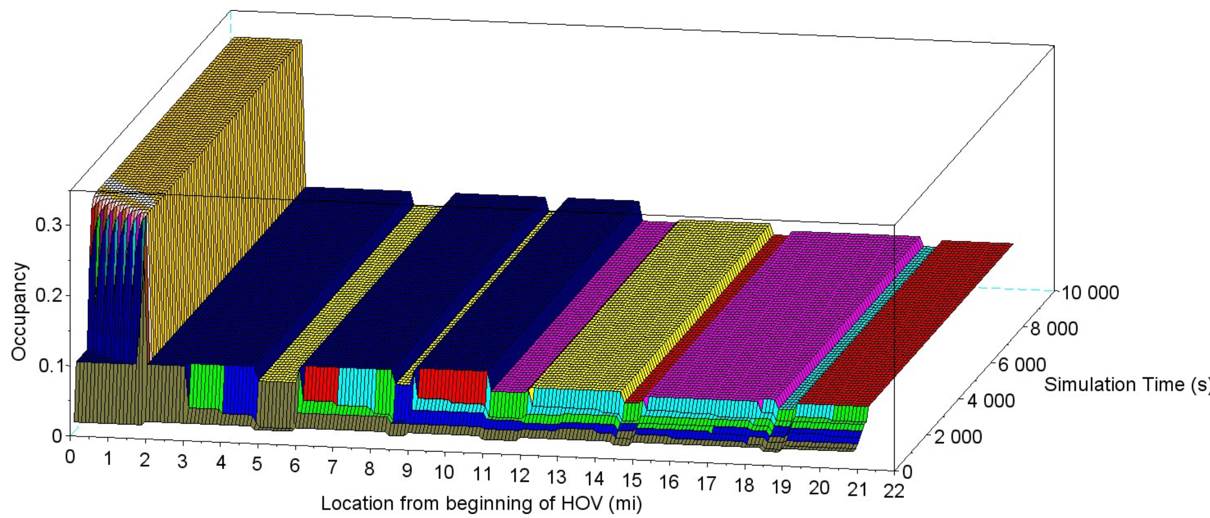


Figure D-1: Occupancy as function of simulation time and location for southbound I-65 south of downtown Nashville and constant demand equal to 8% of AADT.

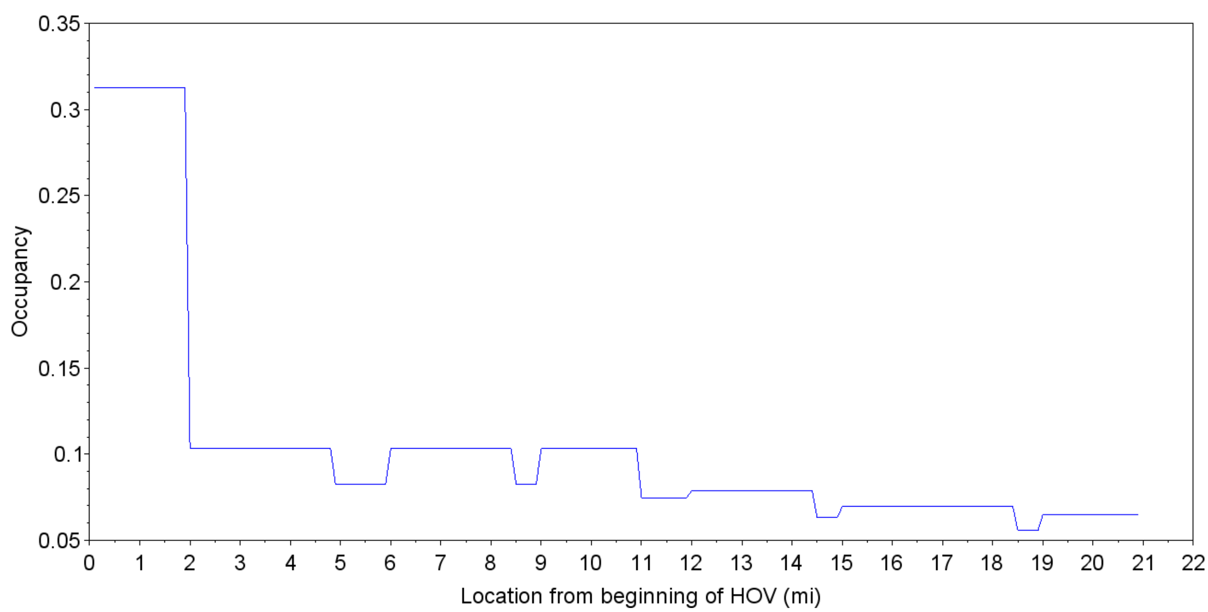


Figure D-2: Steady state occupancy as function of simulation time and location for southbound I-65 south of downtown Nashville and constant demand equal to 8% of AADT.

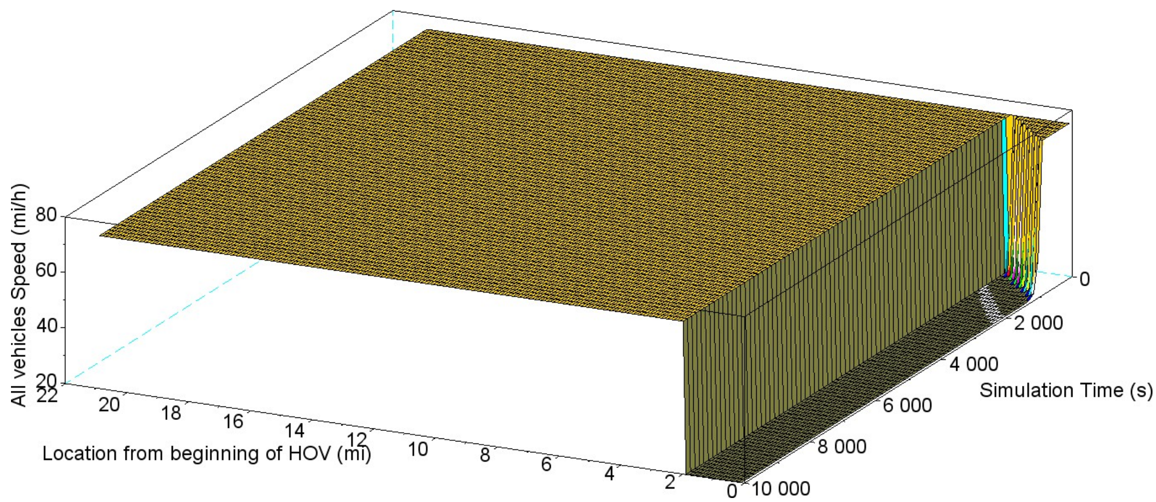


Figure D-3: Space mean speed of all vehicles as a function of simulation time and location for southbound I-65 south of downtown Nashville and demand equal to 8% of AADT.

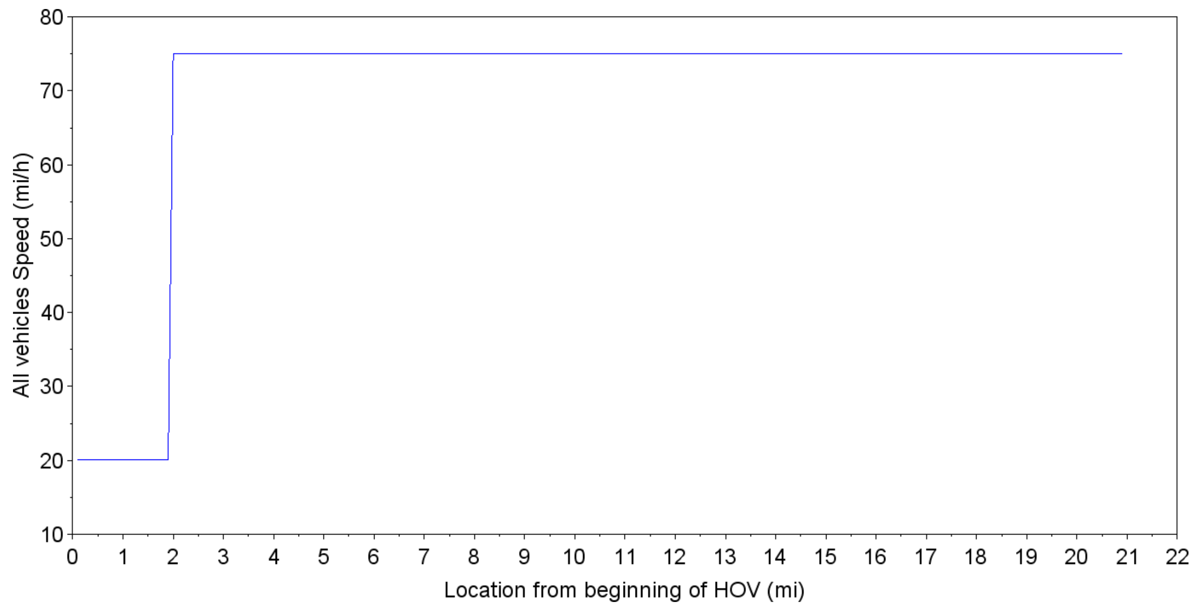


Figure D-4: Steady state space mean speed of all vehicles as function of simulation time and location for southbound I-65 south of downtown Nashville and constant demand equal to 8% of AADT.

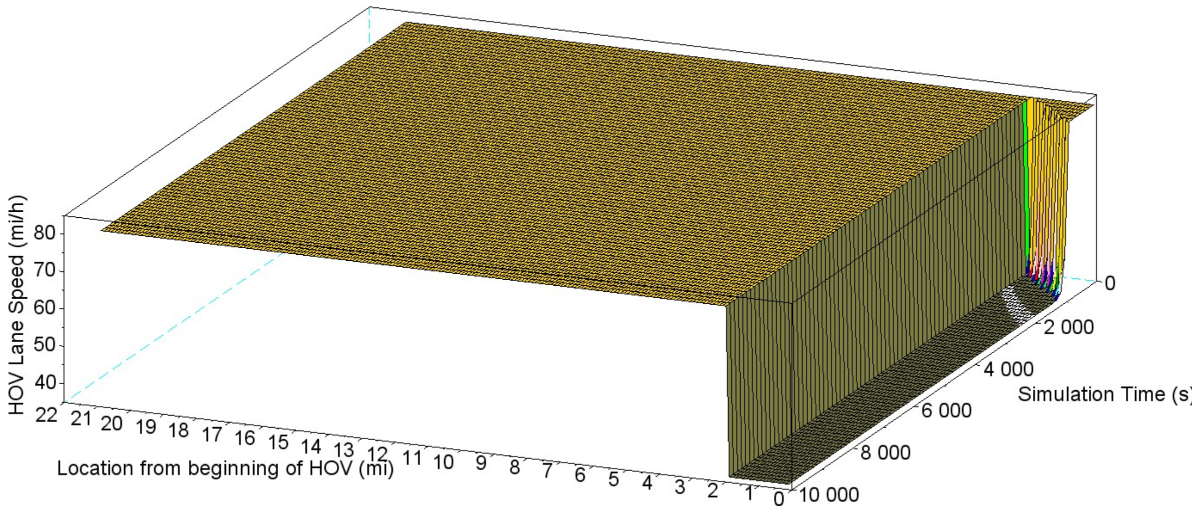


Figure D-5: Time mean speed of vehicles in HOV lane as a function of simulation time and location for southbound I-65 south of downtown Nashville and demand equal to 8% of AADT.

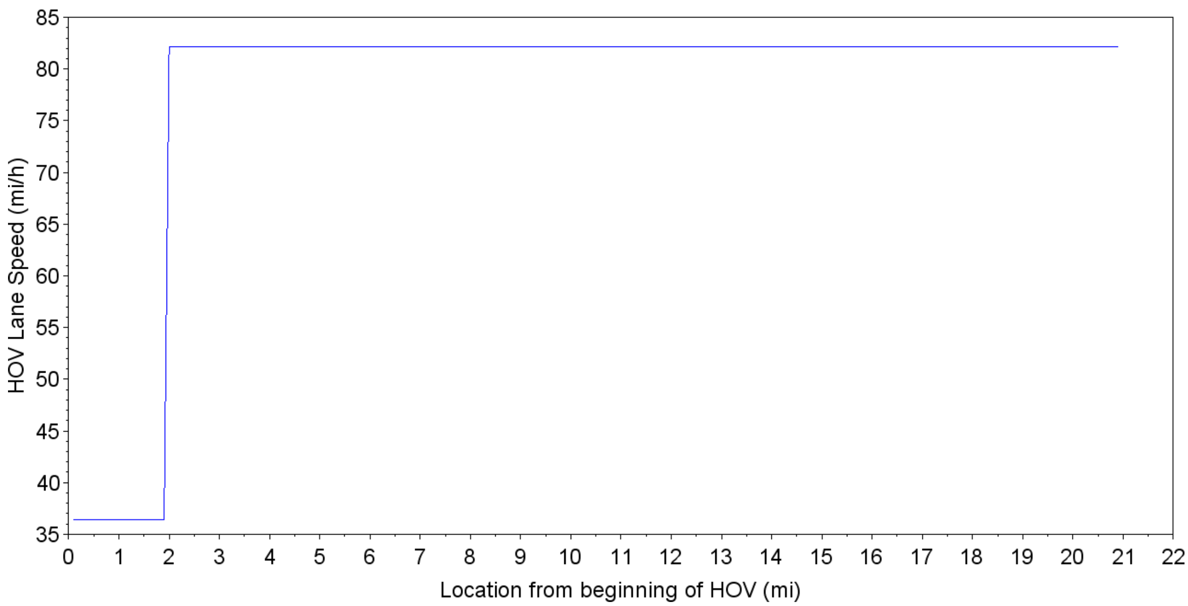


Figure D-6: Steady state time mean speed of vehicles in HOV lane as a function of simulation time and location for southbound I-65 south of downtown Nashville and demand equal to 8% of AADT.

***Results for K = 0.9***

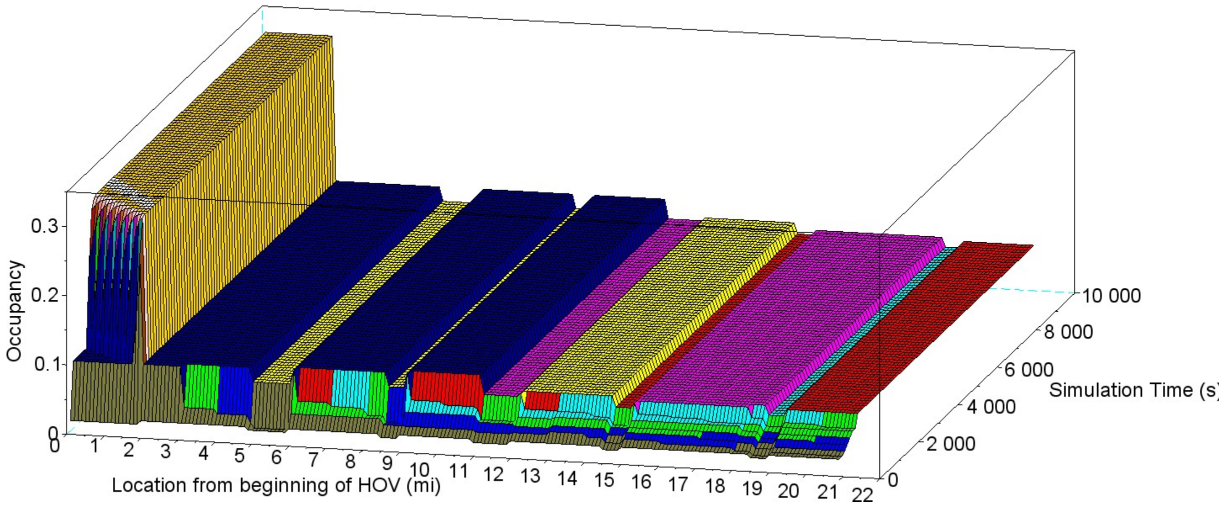


Figure D-7: Occupancy as function of simulation time and location for southbound I-65 south of downtown Nashville and constant demand equal to 9% of AADT.

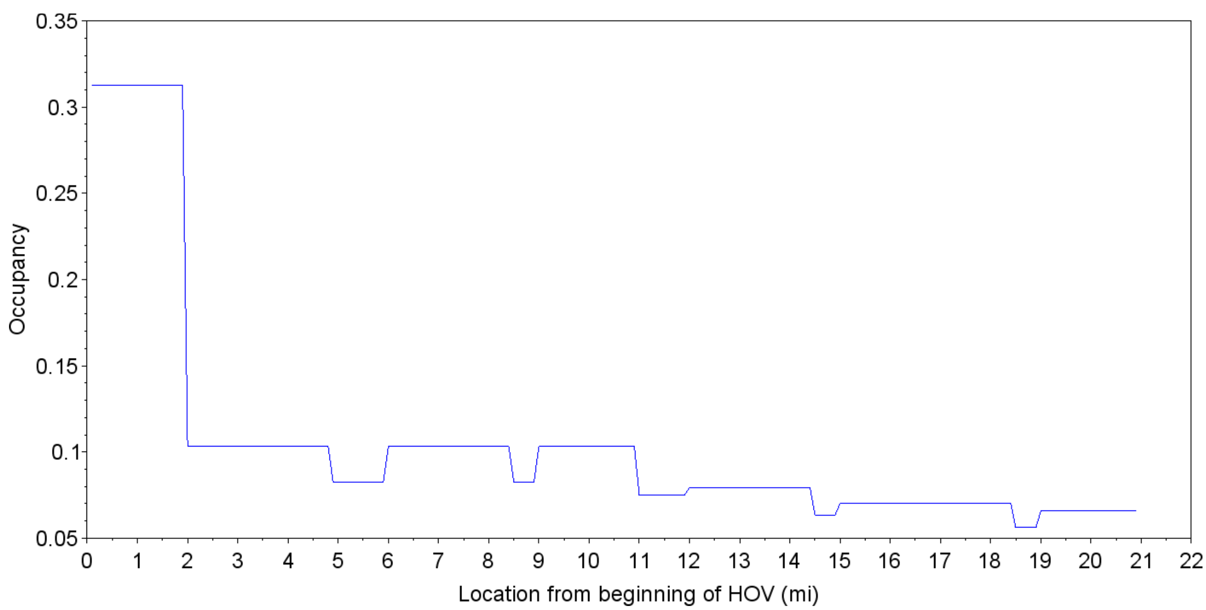


Figure D-8: Steady state occupancy as function of simulation time and location for southbound I-65 south of downtown Nashville and constant demand equal to 9% of AADT.

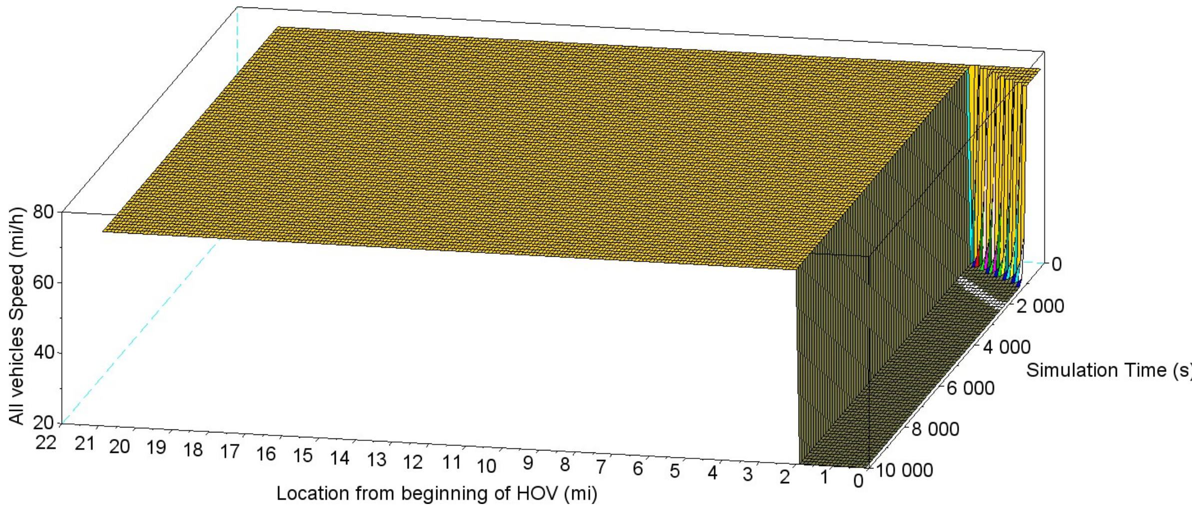


Figure D-9: Space mean speed of all vehicles as a function of simulation time and location for southbound I-65 south of downtown Nashville and demand equal to 9% of AADT.

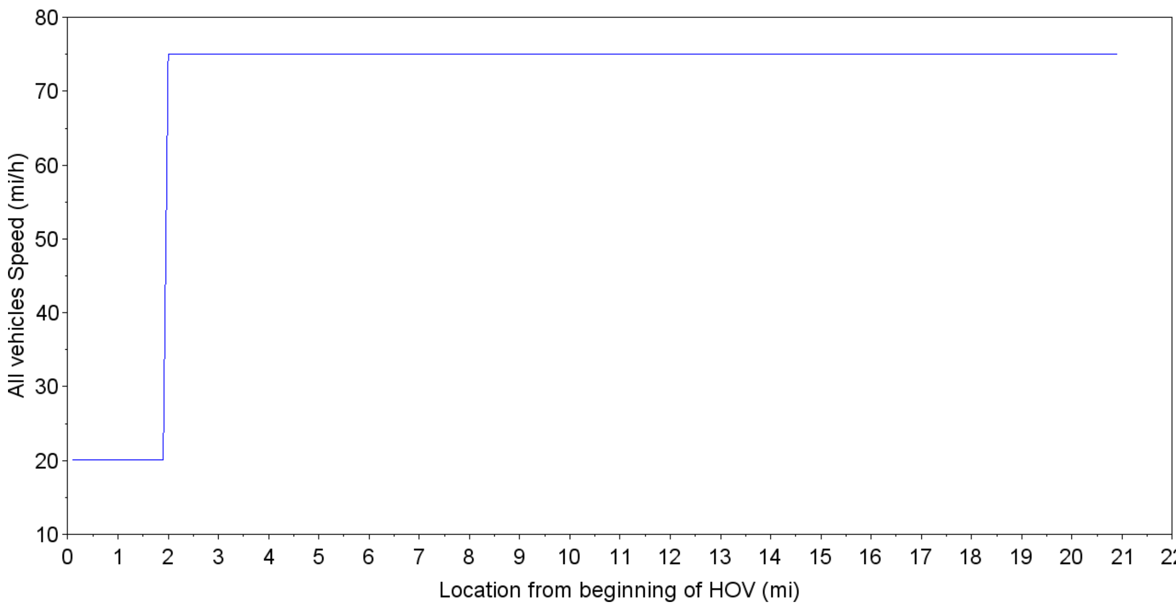


Figure D-10: Steady state space mean speed of all vehicles as function of simulation time and location for southbound I-65 south of downtown Nashville and constant demand equal to 9% of AADT.

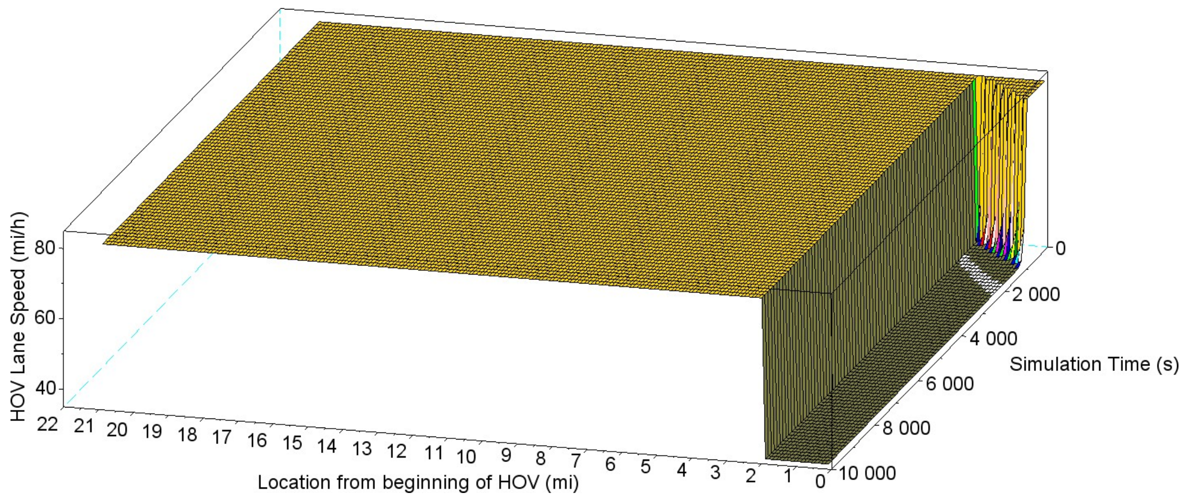


Figure D-11: Time mean speed of vehicles in HOV lane as a function of simulation time and location for southbound I-65 south of downtown Nashville and demand equal to 9% of AADT.

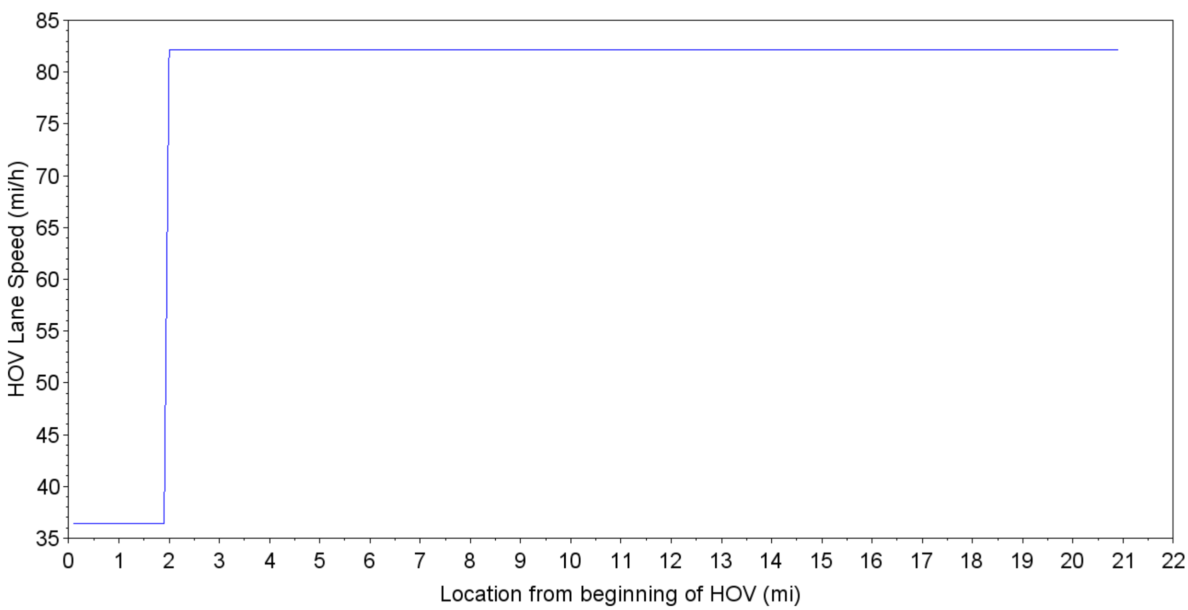


Figure D-12: Steady state time mean speed of vehicles in HOV lane as a function of simulation time and location for southbound I-65 south of downtown Nashville and demand equal to 9% of AADT.

***Results for K = 0.10***

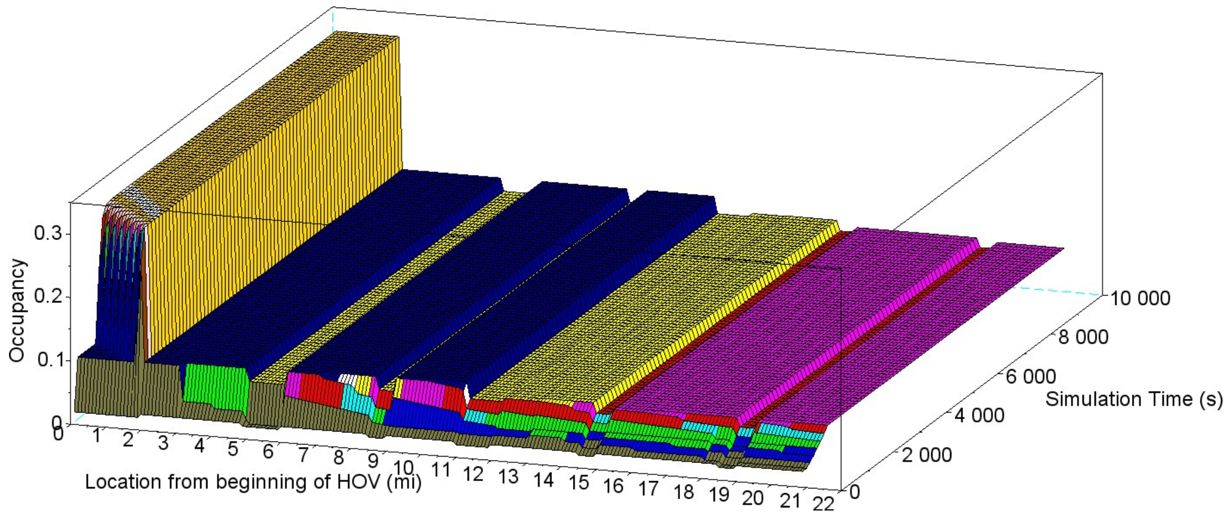


Figure D-13: Occupancy as function of simulation time and location for southbound I-65 south of downtown Nashville and constant demand equal to 10% of AADT.

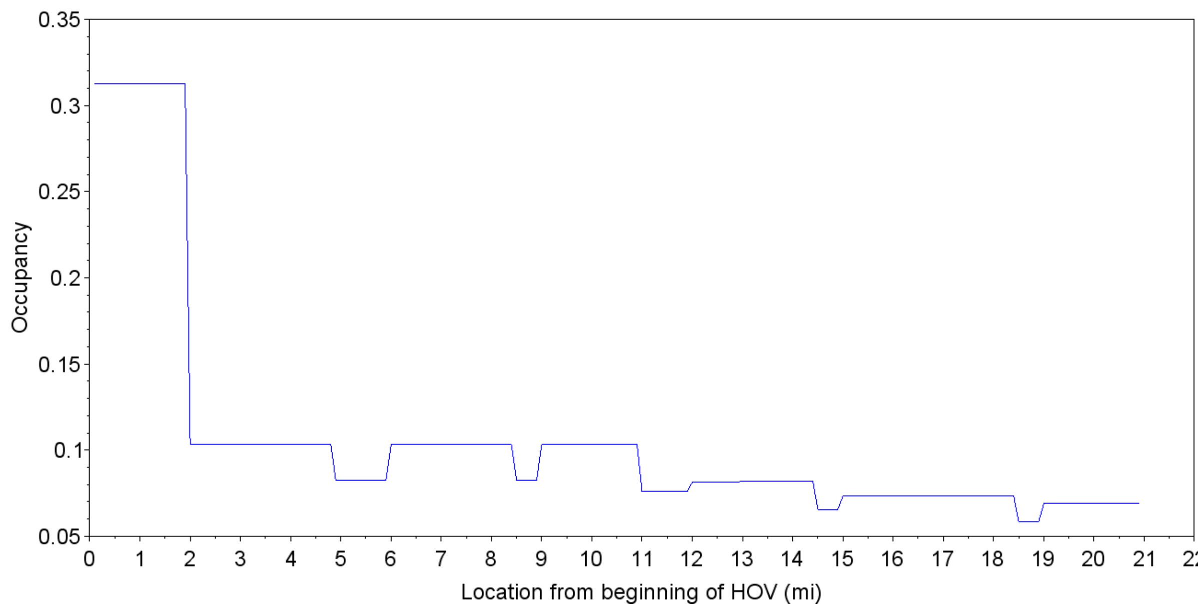


Figure D-14: Steady state occupancy as function of simulation time and location for southbound I-65 south of downtown Nashville and constant demand equal to 10% of AADT.

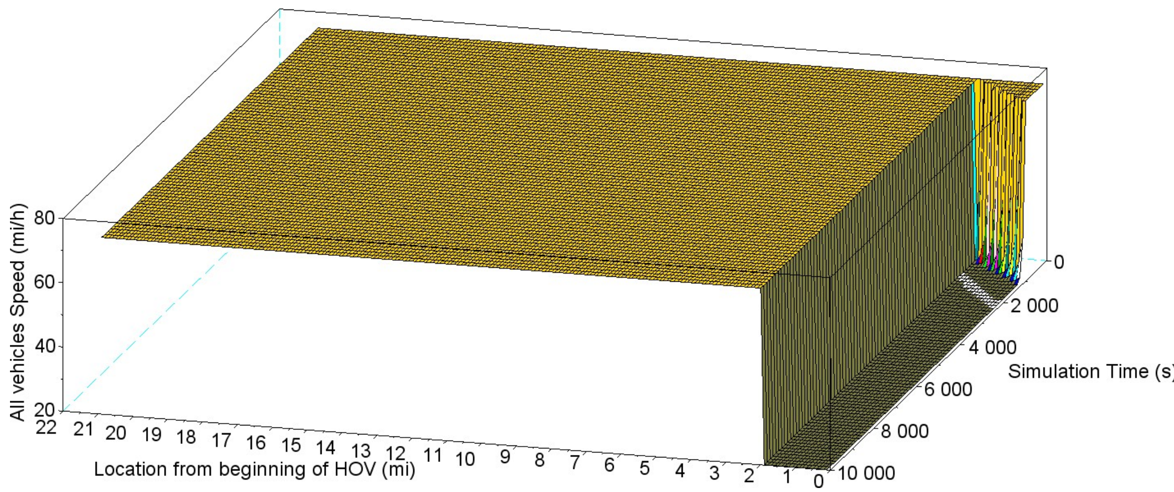


Figure D-15: Space mean speed of all vehicles as a function of simulation time and location for southbound I-65 south of downtown Nashville and demand equal to 10% of AADT.

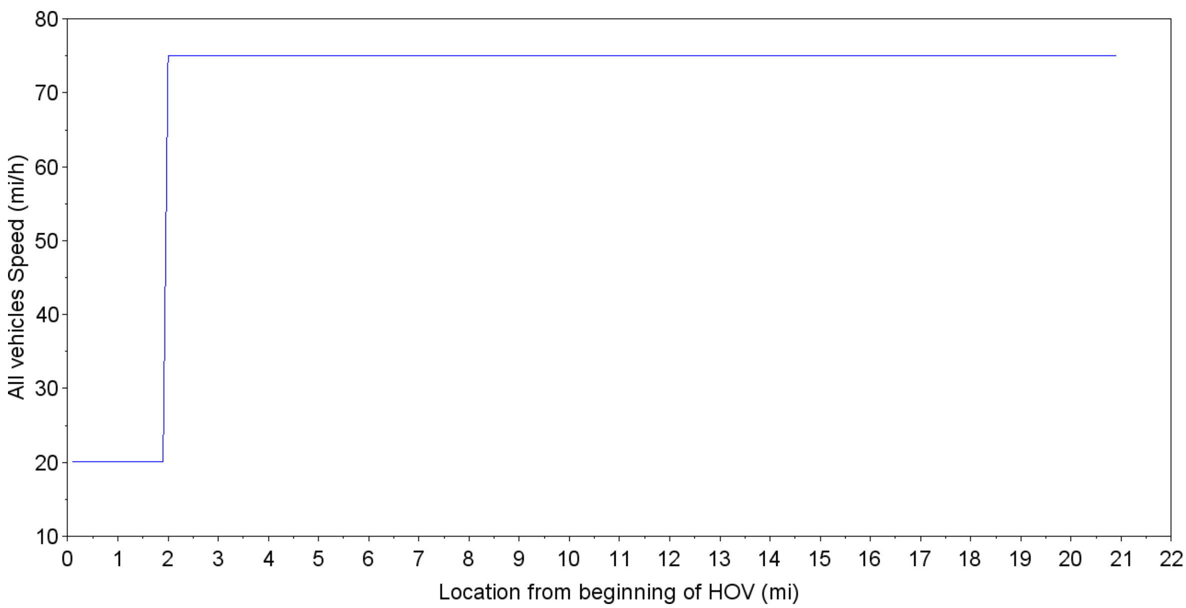


Figure D-16: Steady state space mean speed of all vehicles as function of simulation time and location for southbound I-65 south of downtown Nashville and constant demand equal to 10% of AADT.

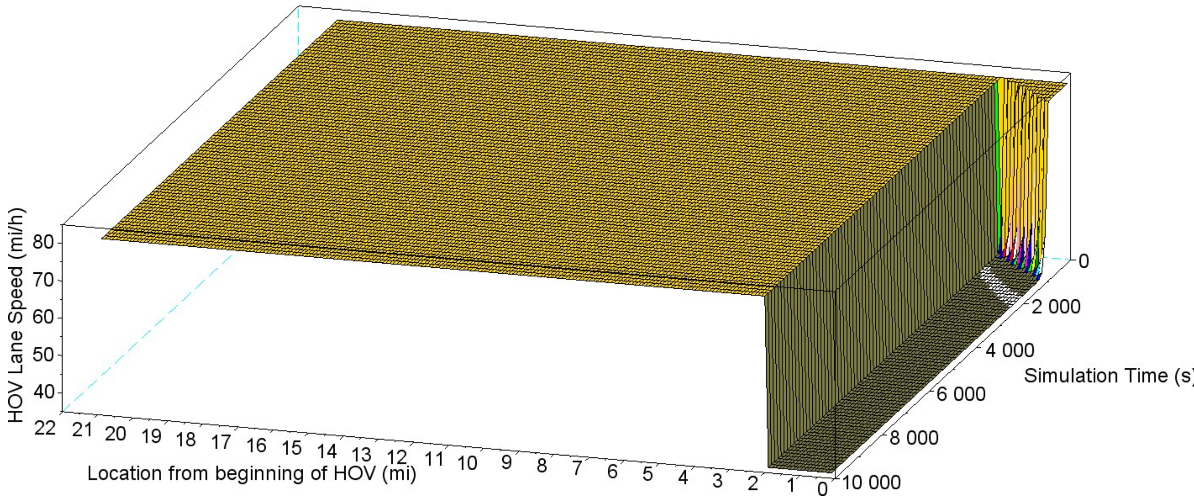


Figure D-17: Time mean speed of vehicles in HOV lane as a function of simulation time and location for southbound I-65 south of downtown Nashville and demand equal to 10% of AADT.

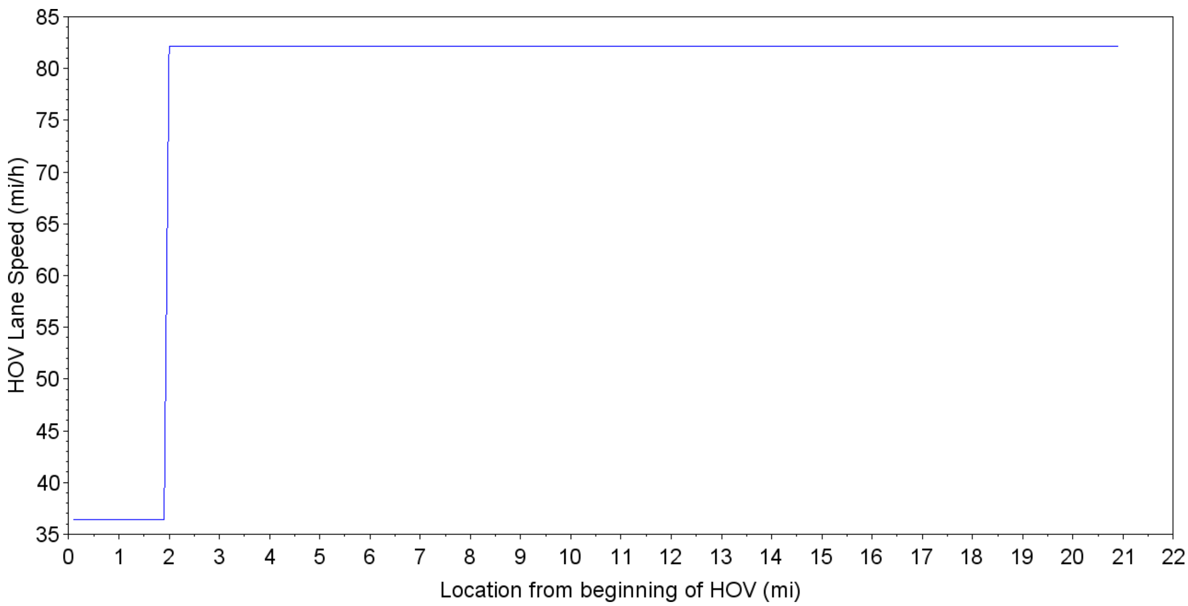


Figure D-18: Steady state time mean speed of vehicles in HOV lane as a function of simulation time and location for southbound I-65 south of downtown Nashville and demand equal to 10% of AADT.

***Results for K = 0.11***

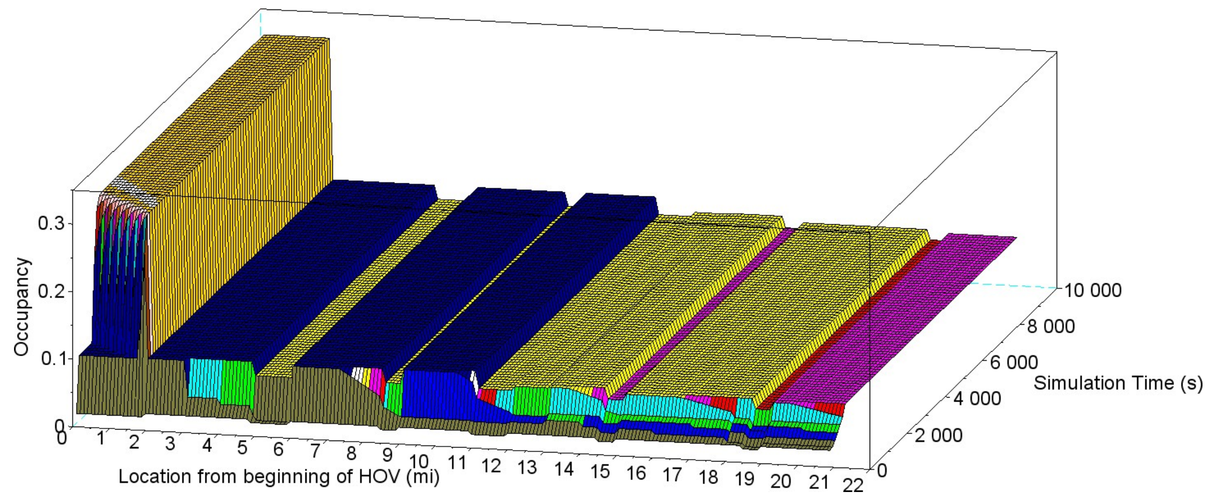


Figure D-19: Occupancy as function of simulation time and location for southbound I-65 south of downtown Nashville and constant demand equal to 11% of AADT.

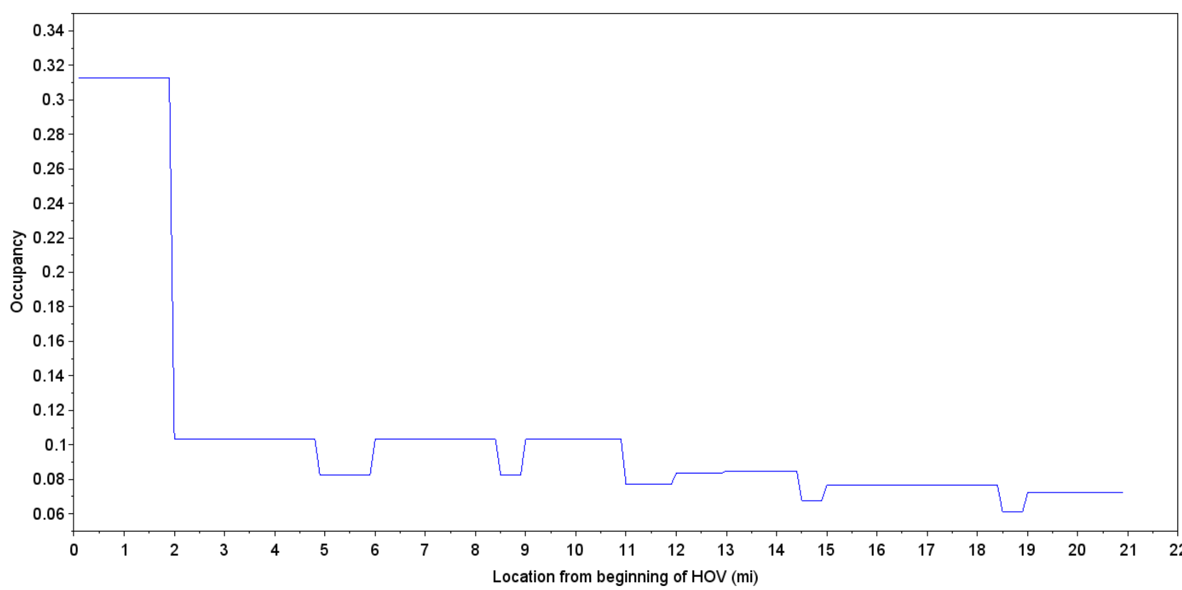


Figure D-20: Steady state occupancy as function of simulation time and location for southbound I-65 south of downtown Nashville and constant demand equal to 11% of AADT.

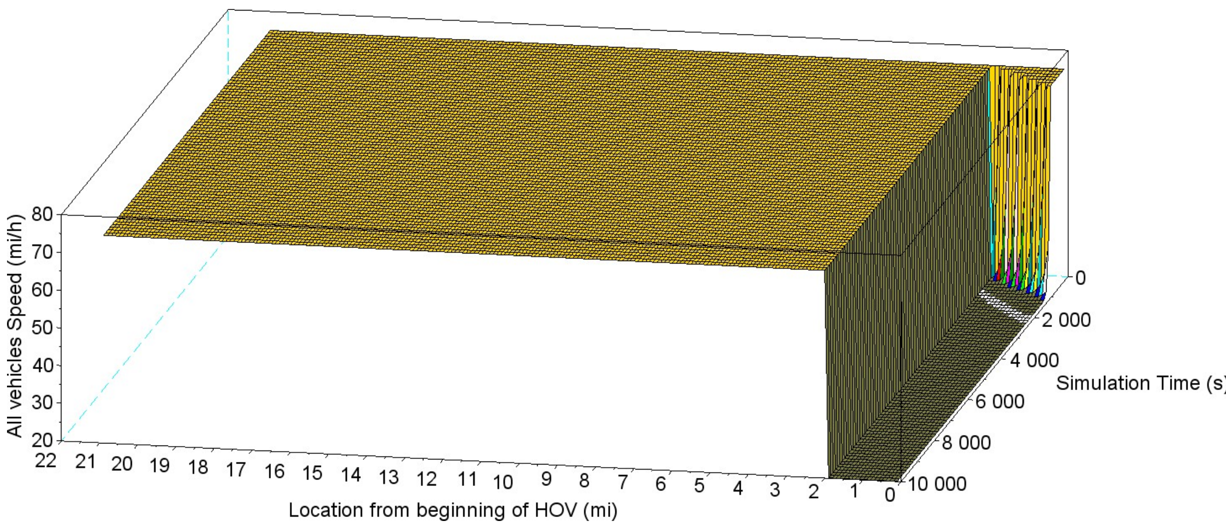


Figure D-21: Space mean speed of all vehicles as a function of simulation time and location for southbound I-65 south of downtown Nashville and demand equal to 11% of AADT.

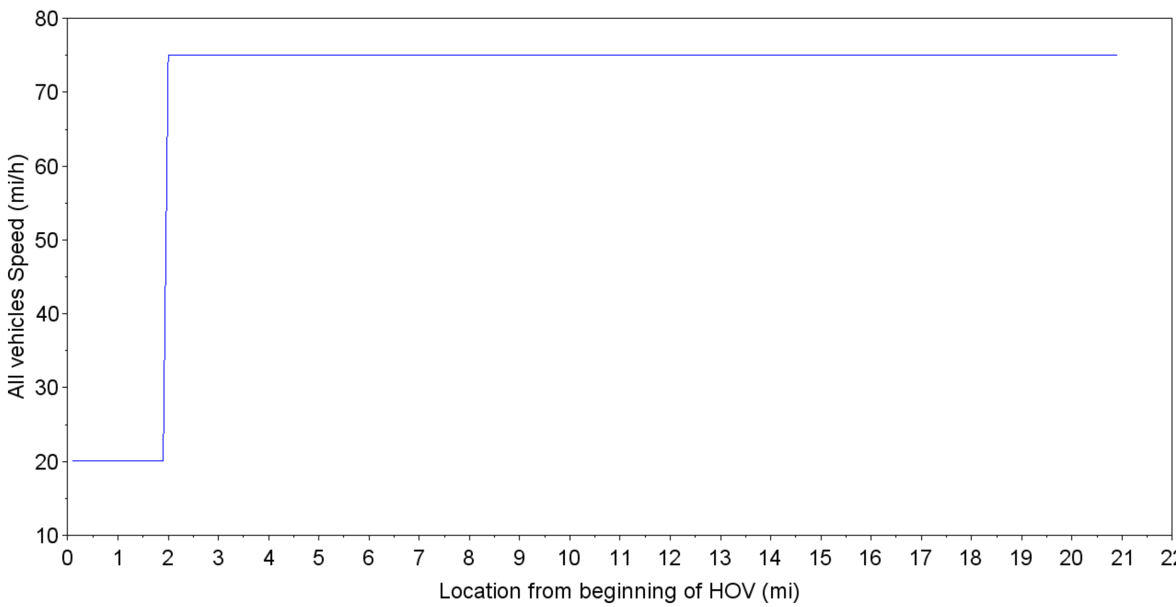


Figure D-22: Steady state space mean speed of all vehicles as function of simulation time and location for southbound I-65 south of downtown Nashville and constant demand equal to 11% of AADT.

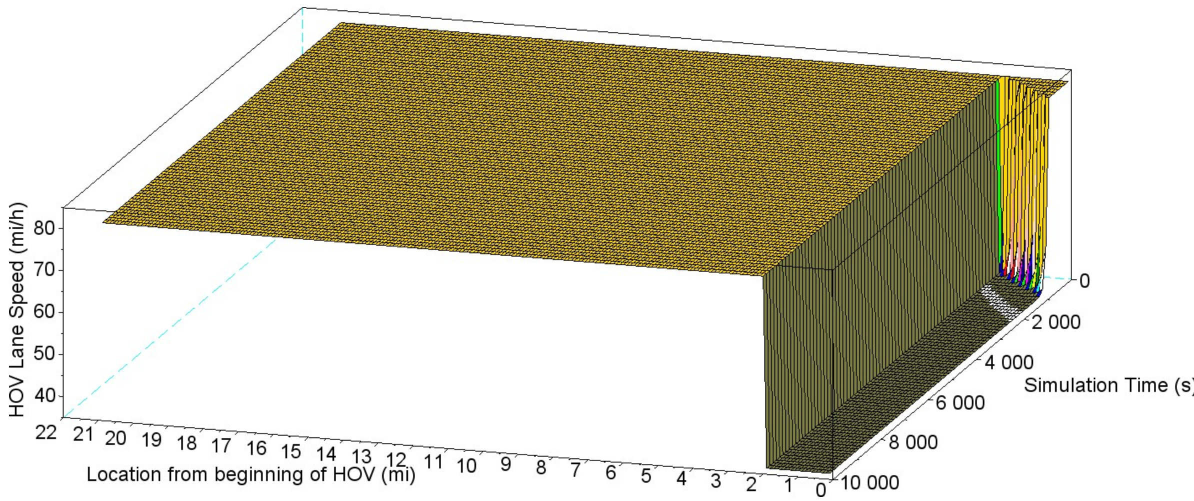


Figure D-23: Time mean speed of vehicles in HOV lane as a function of simulation time and location for southbound I-65 south of downtown Nashville and demand equal to 11% of AADT.

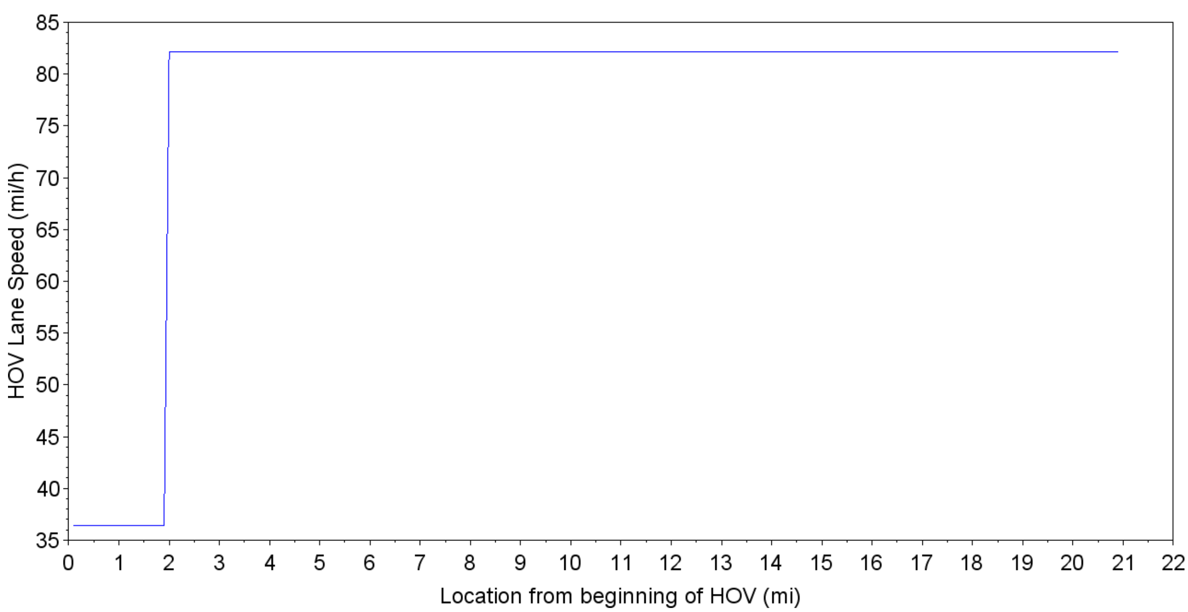


Figure D-24: Steady state time mean speed of vehicles in HOV lane as a function of simulation time and location for southbound I-65 south of downtown Nashville and demand equal to 11% of AADT.

***Results for K = 0.12***

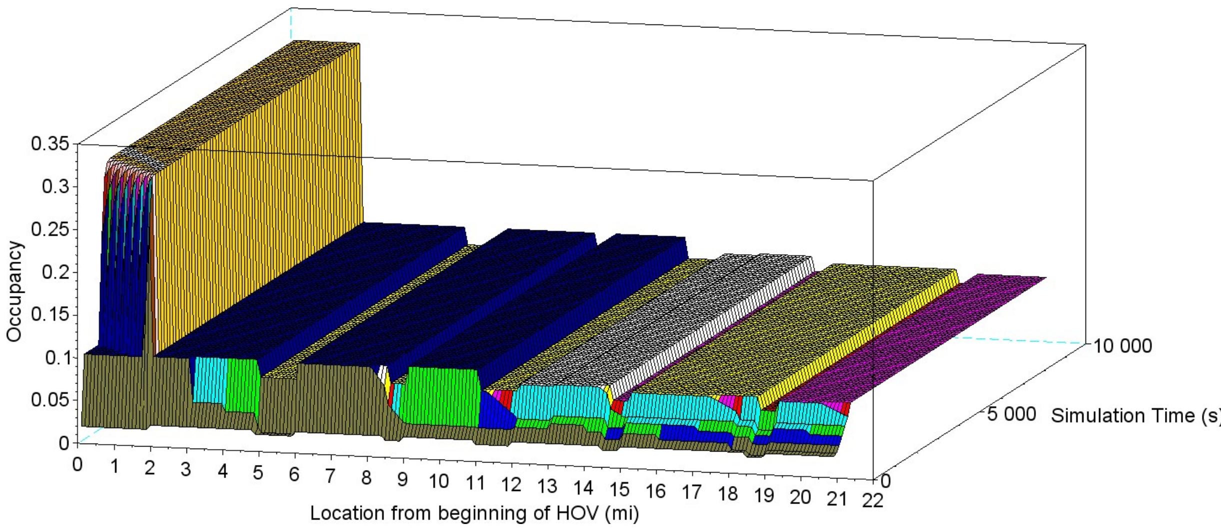


Figure D-25: Occupancy as function of simulation time and location for southbound I-65 south of downtown Nashville and constant demand equal to 12% of AADT.

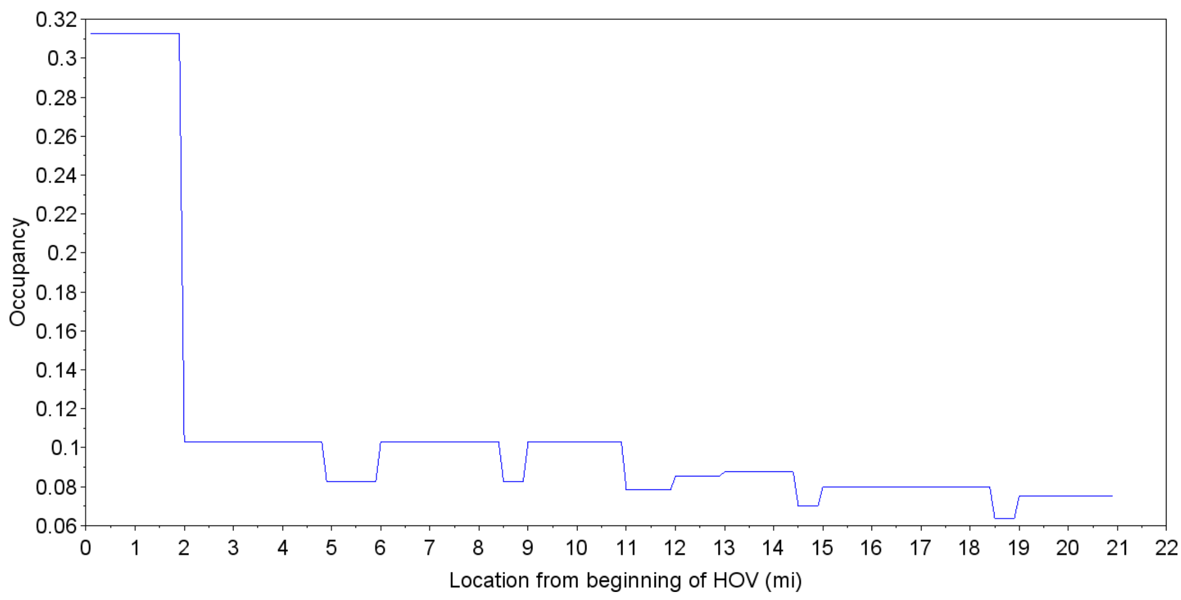


Figure D-26: Steady state occupancy as function of simulation time and location for southbound I-65 south of downtown Nashville and constant demand equal to 12% of AADT.

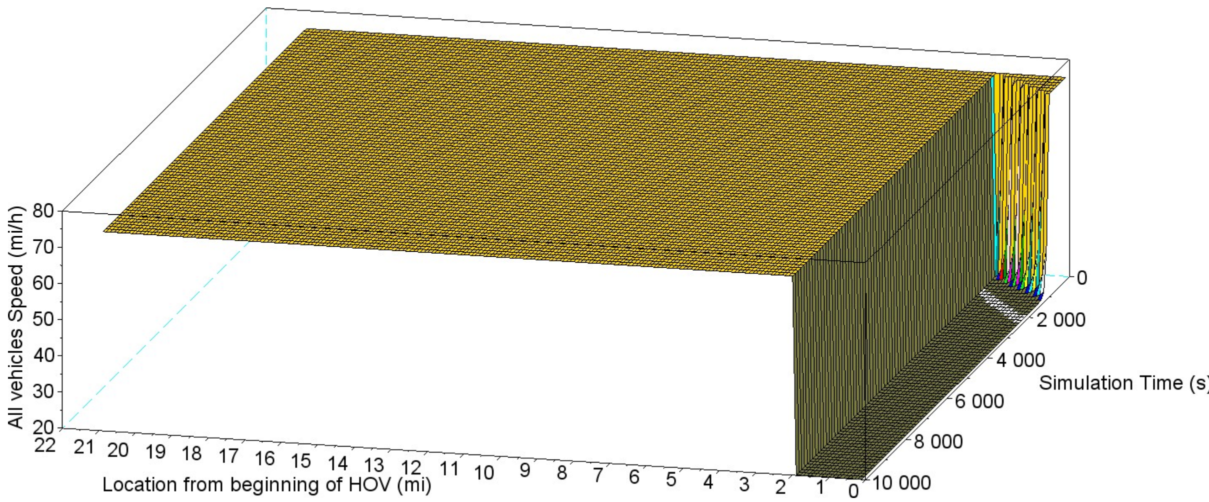


Figure D-27: Space mean speed of all vehicles as a function of simulation time and location for southbound I-65 south of downtown Nashville and demand equal to 12% of AADT.

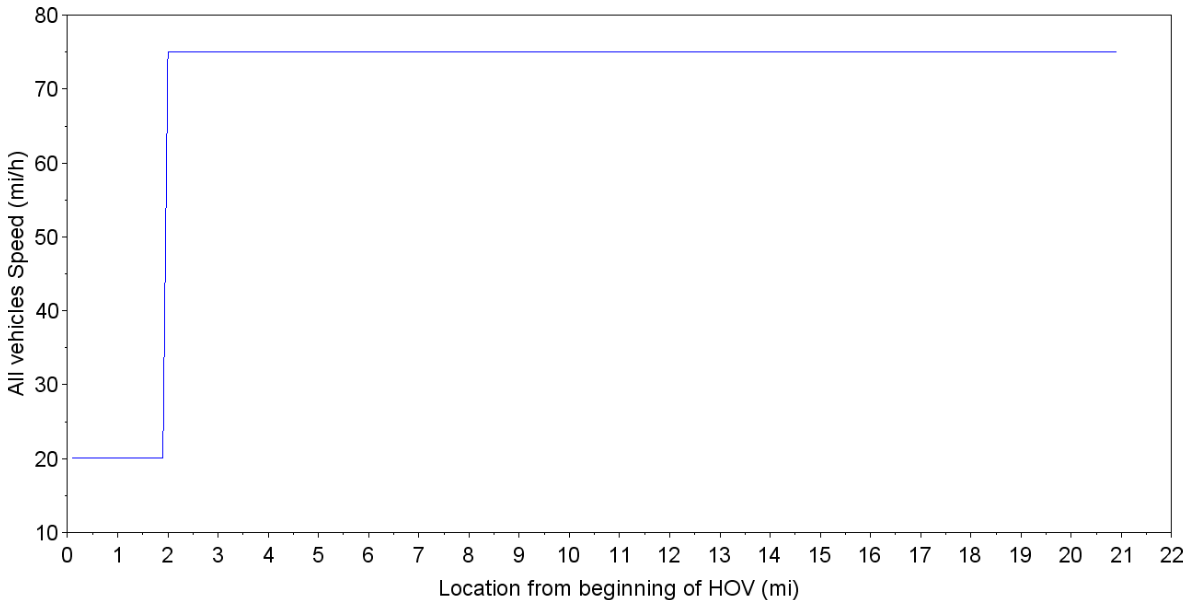


Figure D-28: Steady state space mean speed of all vehicles as function of simulation time and location for southbound I-65 south of downtown Nashville and constant demand equal to 12% of AADT.

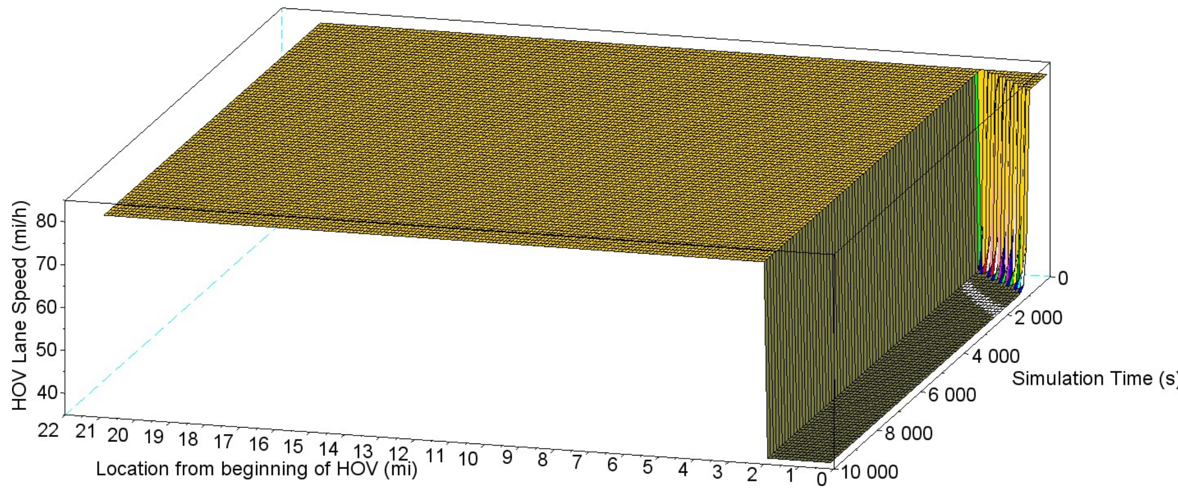


Figure D-29: Time mean speed of vehicles in HOV lane as a function of simulation time and location for southbound I-65 south of downtown Nashville and demand equal to 12% of AADT.

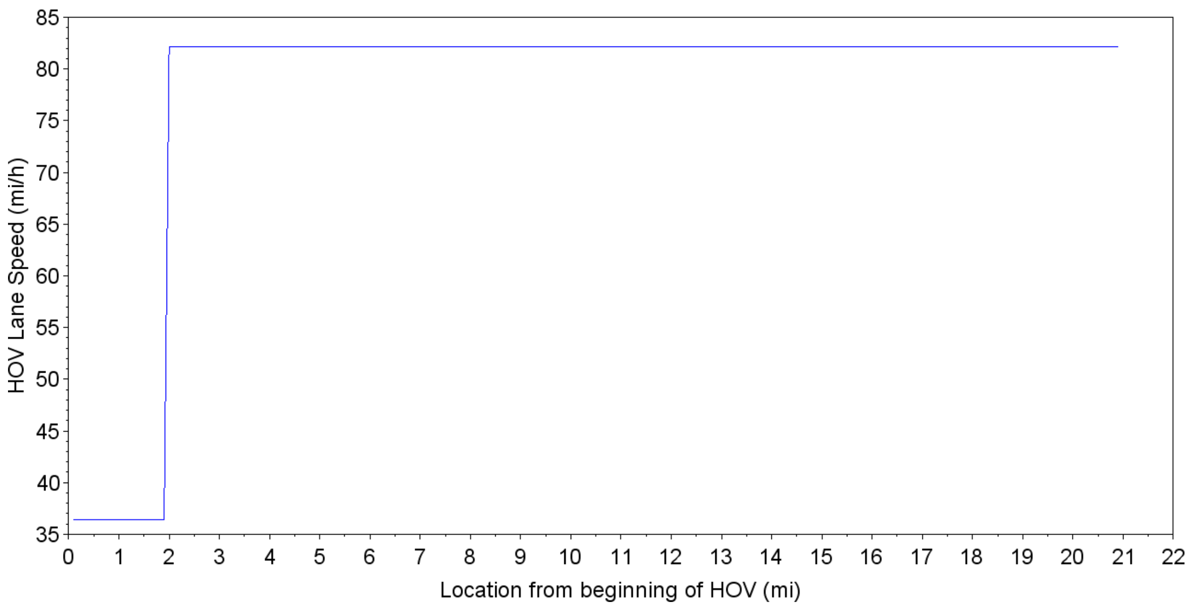


Figure D-30: Steady state time mean speed of vehicles in HOV lane as a function of simulation time and location for southbound I-65 south of downtown Nashville and demand equal to 12% of AADT.

# APPENDIX E: DATA COLLECTION POINT RESULTS FOR PEAK HOUR FOR SOUTHBOUND I-65 SOUTH OF NASHVILLE

Note: All level of service computations assume 1.1 passenger car equivalents per vehicle.

TABLE E.1: BASE YEAR DO NOTHING

| Data Collection Point | Flow (vph) | Space Mean Speed (mph) | Density (vpmpl) | Microsimulation Based LOS* |
|---|---|---|---|---|
| 1: MM 80 Ln 1 | 1085 | 10.6 | 112.6 | F |
| 2: MM 80 Ln 2 | 522 | 5.6 | 102.5 | F |
| 3: MM 80 Ln 3 | 791 | 9.6 | 91.1 | F |
| 4: MM 80 Ln 4 | 1185 | 15.1 | 86.6 | F |
| 5: MM 80 HOV | 838 | 64.1 | 14.4 | B |
| 6: 79 OFF | 266 | 34.8 | 8.4 | A |
| 7: 79 ON | 570 | 48.1 | 13.1 | B |
| 8: 78 OFF Ln 1 | 388 | 41.7 | 10.2 | A |
| 9: 78 OFF Ln 2 | 237 | 42.2 | 6.2 | A |
| 10: Harding Ln 1 | 802 | 63.5 | 13.9 | B |
| 11: Harding Ln 2 | 1092 | 67.0 | 17.9 | B |
| 12: Harding Ln 3 | 1562 | 69.7 | 24.6 | C |
| 13: Harding HOV | 449 | 72.4 | 6.8 | A |
| 14: 78 ON | 915 | 72.4 | 13.9 | B |
| 15: 74 A Ln 1 | 394 | 54.7 | 7.9 | A |
| 16: 74 A Ln 2 | 153 | 48.9 | 3.4 | A |
| 17: 74 B | 400 | 37.3 | 11.8 | B |
| 18: OHB Ln 1 | 929 | 45.2 | 22.6 | C |
| 19: OHB Ln 2 | 1199 | 46.9 | 28.2 | D |
| 20: OHB Ln 3 | 1232 | 53.2 | 25.5 | C |
| 21: OHB HOV | 958 | 67.8 | 15.5 | B |
| 22: 74 ON | 1038 | 15.1 | 75.5 | F |
| 23: 71 OFF | 370 | 35.2 | 11.6 | B |
| 24: Concord Rd Ln 1 | 946 | 15.9 | 65.6 | F |
| 25: Concord Rd Ln 2 | 1014 | 19.8 | 56.3 | F |
| 26: Concord Rd Ln 3 | 1483 | 26.6 | 61.3 | F |
| 27: Concord Rd HOV | 727 | 39.4 | 20.2 | C |
| 28: 69 Ln 1 | 570 | 40.7 | 15.4 | B |
| 29: 69 Ln 2 | 436 | 40.0 | 12.0 | B |
| 30: Moore's Ln 1 | 833 | 64.0 | 14.3 | B |
| 31: Moore's Ln 2 | 1081 | 67.2 | 17.7 | B |
| 32: Moore's Ln 3 | 1474 | 69.4 | 23.3 | C |
| 33: Moore's Ln HOV | 411 | 73.2 | 6.2 | A |
| 34: 69 ON | 693 | 73.1 | 10.5 | A |
| 35: 68 A | 460 | 59.6 | 8.5 | A |
| 36: 68 B | 248 | 38.5 | 7.0 | A |
| 37: 68 ON | 557 | 73.1 | 8.4 | A |
| 38: CSB Ln 1 | 255 | 39.7 | 7.0 | A |

| | | | | |
|---|---|---|---|---|
| 39: CSB Ln 2 | 1048 | 36.9 | 31.2 | D |
| 40: CSB Ln 3 | 971 | 39.6 | 27.0 | D |
| 41: CSB Ln 4 | 1324 | 46.3 | 31.5 | D |
| 42: CSB HOV | 465 | 60.7 | 8.5 | A |
| 43: 67 OFF Ln 1 | 307 | 49.1 | 6.9 | A |
| 44: 67 OFF Ln 2 | 118 | 46.1 | 2.9 | A |
| 45: McEwen Ln 1 | 862 | 62.6 | 15.2 | B |
| 46: McEwen Ln 2 | 1155 | 65.4 | 19.5 | C |
| 47: McEwen Ln 3 | 1517 | 68.4 | 24.4 | C |
| 48: McEwen HOV | 409 | 75.2 | 5.9 | A |
| 49: 67 ON | 432 | 75.0 | 6.4 | A |
| 50: 65 Ln 1 | 603 | 61.1 | 10.9 | A |
| 51: 65 Ln 2 | 500 | 60.8 | 9.0 | A |
| 52: Murfreesboro Ln 1 | 898 | 66.7 | 14.9 | B |
| 53: Murfreesboro Ln 2 | 829 | 71.3 | 12.8 | B |
| 54: Murfreesboro Ln 3 | 725 | 74.2 | 10.8 | A |
| 55: Murfreesboro Ln 4 | 677 | 76.7 | 9.7 | A |
| 56: Murfreesboro HOV | 149 | 80.8 | 2.0 | A |
| 57: 65 ON | 643 | 73.7 | 9.6 | A |
| 58: 61 OFF Ln 1 | 290 | 74.6 | 4.3 | A |
| 59: 61 OFF Ln 2 | 49 | 78.3 | 0.7 | A |
| 60: Peytonsville Ln 1 | 938 | 71.1 | 14.5 | B |
| 61: Peytonsville Ln 2 | 810 | 75.1 | 11.9 | B |
| 62: Peytonsville Ln 3 | 698 | 79.0 | 9.7 | A |
| 63: Peytonsville HOV | 119 | 84.0 | 1.5 | A |
| 64: 61 ON | 208 | 75.2 | 3.1 | A |
| 65: END Ln 1 | 997 | 71.8 | 15.3 | B |
| 66: END Ln 2 | 848 | 76.0 | 12.3 | B |
| 67: END Ln 3 | 788 | 79.7 | 10.9 | A |
| 68: END HOV | 131 | 84.3 | 1.8 | A |

TABLE E.2: BASE YEAR LANE REVERSION

| Data Collection Point | Flow (vph) | Space Mean Speed (mph) | Density (vpmpl) | Microsimulation Based LOS* |
|---|---|---|---|---|
| 1: MM 80 Ln 1 | 1054 | 10.1 | 114.3 | F |
| 2: MM 80 Ln 2 | 512 | 5.4 | 105.3 | F |
| 3: MM 80 Ln 3 | 790 | 9.2 | 94.6 | F |
| 4: MM 80 Ln 4 | 1245 | 14.1 | 96.9 | F |
| 5: MM 80 HOV | 1261 | 15.1 | 92.2 | F |
| 6: 79 OFF | 302 | 35.1 | 9.5 | A |
| 7: 79 ON | 570 | 57.2 | 11.0 | A |
| 8: 78 OFF Ln 1 | 426 | 41.3 | 11.3 | B |
| 9: 78 OFF Ln 2 | 271 | 41.8 | 7.2 | A |
| 10: Harding Ln 1 | 828 | 63.6 | 14.3 | B |
| 11: Harding Ln 2 | 1051 | 67.3 | 17.2 | B |
| 12: Harding Ln 3 | 1137 | 70.1 | 17.8 | B |
| 13: Harding HOV | 1488 | 70.6 | 23.2 | C |
| 14: 78 ON | 915 | 72.6 | 13.9 | B |
| 15: 74 A Ln 1 | 399 | 52.5 | 8.4 | A |
| 16: 74 A Ln 2 | 197 | 45.7 | 4.7 | A |
| 17: 74 B | 434 | 37.7 | 12.7 | B |
| 18: OHB Ln 1 | 862 | 54.1 | 17.5 | B |
| 19: OHB Ln 2 | 1032 | 56.7 | 20.0 | C |
| 20: OHB Ln 3 | 1108 | 62.6 | 19.5 | C |
| 21: OHB HOV | 1701 | 67.8 | 27.6 | D |
| 22: 74 ON | 1385 | 71.6 | 21.2 | C |
| 23: 71 OFF | 458 | 35.9 | 14.1 | B |
| 24: Concord Rd Ln 1 | 940 | 29.4 | 35.2 | E |
| 25: Concord Rd Ln 2 | 1099 | 37.6 | 32.2 | D |
| 26: Concord Rd Ln 3 | 1312 | 37.8 | 38.2 | E |
| 27: Concord Rd HOV | 1608 | 42.4 | 41.7 | E |
| 28: 69 Ln 1 | 615 | 40.6 | 16.7 | B |
| 29: 69 Ln 2 | 494 | 40.6 | 13.4 | B |
| 30: Moore's Ln 1 | 809 | 63.6 | 14.0 | B |
| 31: Moore's Ln 2 | 998 | 68.4 | 16.1 | B |
| 32: Moore's Ln 3 | 1063 | 72.0 | 16.3 | B |
| 33: Moore's Ln 4 | 1376 | 73.1 | 20.7 | C |
| 34: 69 ON | 693 | 73.2 | 10.5 | A |
| 35: 68 A | 508 | 58.9 | 9.5 | A |
| 36: 68 B | 271 | 36.4 | 8.1 | A |
| 37: 68 ON | 557 | 73.0 | 8.4 | A |
| 38: CSB Ln 1 | 226 | 37.1 | 6.7 | A |
| 39: CSB Ln 2 | 1020 | 34.8 | 32.2 | D |
| 40: CSB Ln 3 | 818 | 13.8 | 65.0 | F |
| 41: CSB Ln 4 | 974 | 42.2 | 25.4 | C |

| | | | | |
|---|---|---|---|---|
| 42: CSB HOV | 1385 | 50.8 | 30.0 | D |
| 43: 67 OFF Ln 1 | 327 | 47.9 | 7.5 | A |
| 44: 67 OFF Ln 2 | 128 | 45.8 | 3.1 | A |
| 45: McEwen Ln 1 | 842 | 62.3 | 14.9 | B |
| 46: McEwen Ln 2 | 1005 | 65.5 | 16.8 | B |
| 47: McEwen Ln 3 | 1044 | 69.4 | 16.5 | B |
| 48: McEwen HOV | 1379 | 69.9 | 21.7 | C |
| 49: 67 ON | 432 | 75.0 | 6.4 | A |
| 50: 65 Ln 1 | 632 | 62.0 | 11.2 | B |
| 51: 65 Ln 2 | 541 | 60.5 | 9.8 | A |
| 52: Murfreesboro Ln 1 | 922 | 66.9 | 15.2 | B |
| 53: Murfreesboro Ln 2 | 886 | 72.0 | 13.5 | B |
| 54: Murfreesboro Ln 3 | 746 | 75.2 | 10.9 | A |
| 55: Murfreesboro Ln 4 | 509 | 78.8 | 7.2 | A |
| 56: Murfreesboro HOV | 466 | 80.2 | 6.4 | A |
| 57: 65 ON | 643 | 73.6 | 9.6 | A |
| 58: 61 OFF Ln 1 | 284 | 75.3 | 4.2 | A |
| 59: 61 OFF Ln 2 | 59 | 78.4 | 0.9 | A |
| 60: Peytonsville Ln 1 | 946 | 71.3 | 14.6 | B |
| 61: Peytonsville Ln 2 | 810 | 75.1 | 11.9 | B |
| 62: Peytonsville Ln 3 | 553 | 79.4 | 7.7 | A |
| 63: Peytonsville HOV | 434 | 81.5 | 5.8 | A |
| 64: 61 ON | 208 | 75.2 | 3.1 | A |
| 65: END Ln 1 | 1025 | 71.6 | 15.7 | B |
| 66: END Ln 2 | 896 | 76.1 | 13.0 | B |
| 67: END Ln 3 | 590 | 80.9 | 8.0 | A |
| 68: END HOV | 426 | 84.3 | 5.6 | A |

TABLE E.3: BASE YEAR HEAVY ENFORCEMENT

| Data Collection Point | Flow (vph) | Space Mean Speed (mph) | Density (vpmpl) | Microsimulation Based LOS* |
|---|---|---|---|---|
| 1: MM 80 Ln 1 | 1038 | 10.7 | 106.4 | F |
| 2: MM 80 Ln 2 | 569 | 6.7 | 93.8 | F |
| 3: MM 80 Ln 3 | 756 | 9.4 | 88.3 | F |
| 4: MM 80 Ln 4 | 1467 | 16.6 | 97.5 | F |
| 5: MM 80 HOV | 243 | 73.3 | 3.6 | A |
| 6: 79 OFF | 262 | 35.2 | 8.1 | A |
| 7: 79 ON | 570 | 55.6 | 11.3 | B |
| 8: 78 OFF Ln 1 | 400 | 42.3 | 10.3 | A |
| 9: 78 OFF Ln 2 | 208 | 42.1 | 5.4 | A |
| 10: Harding Ln 1 | 854 | 63.2 | 14.9 | B |
| 11: Harding Ln 2 | 1131 | 66.5 | 18.7 | C |
| 12: Harding Ln 3 | 1709 | 69.3 | 27.2 | D |
| 13: Harding HOV | 128 | 76.6 | 1.9 | A |
| 14: 78 ON | 915 | 72.4 | 13.9 | B |
| 15: 74 A Ln 1 | 339 | 46.9 | 7.9 | A |
| 16: 74 A Ln 2 | 191 | 44.0 | 4.7 | A |
| 17: 74 B | 386 | 38.0 | 11.2 | B |
| 18: OHB Ln 1 | 1037 | 38.3 | 29.8 | D |
| 19: OHB Ln 2 | 1168 | 35.2 | 36.4 | E |
| 20: OHB Ln 3 | 1317 | 39.0 | 37.2 | E |
| 21: OHB HOV | 663 | 51.3 | 14.2 | B |
| 22: 74 ON | 1104 | 11.1 | 109.7 | F |
| 23: 71 OFF | 388 | 36.4 | 11.8 | B |
| 24: Concord Rd Ln 1 | 1049 | 18.1 | 63.9 | F |
| 25: Concord Rd Ln 2 | 1209 | 21.8 | 61.2 | F |
| 26: Concord Rd Ln 3 | 1814 | 19.5 | 102.2 | F |
| 27: Concord Rd HOV | 320 | 35.8 | 9.8 | A |
| 28: 69 Ln 1 | 601 | 41.5 | 16.0 | B |
| 29: 69 Ln 2 | 443 | 41.9 | 11.7 | B |
| 30: Moore's Ln 1 | 833 | 62.8 | 14.6 | B |
| 31: Moore's Ln 2 | 1143 | 64.5 | 19.5 | C |
| 32: Moore's Ln 3 | 1809 | 66.2 | 30.0 | D |
| 33: Moore's Ln HOV | 127 | 74.0 | 1.9 | A |
| 34: 69 ON | 693 | 73.0 | 10.5 | A |
| 35: 68 A | 468 | 58.9 | 8.8 | A |
| 36: 68 B | 249 | 40.4 | 6.8 | A |
| 37: 68 ON | 557 | 73.1 | 8.4 | A |
| 38: CSB Ln 1 | 204 | 41.8 | 5.4 | A |
| 39: CSB Ln 2 | 1105 | 40.6 | 30.0 | D |

| | | | | |
|---|---|---|---|---|
| 40: CSB Ln 3 | 1045 | 44.0 | 26.2 | D |
| 41: CSB Ln 4 | 1470 | 53.7 | 30.1 | D |
| 42: CSB HOV | 258 | 62.3 | 4.5 | A |
| 43: 67 OFF Ln 1 | 308 | 49.8 | 6.8 | A |
| 44: 67 OFF Ln 2 | 122 | 46.6 | 2.9 | A |
| 45: McEwen Ln 1 | 874 | 61.2 | 15.7 | B |
| 46: McEwen Ln 2 | 1258 | 63.9 | 21.7 | C |
| 47: McEwen Ln 3 | 1742 | 66.4 | 28.8 | D |
| 48: McEwen HOV | 115 | 75.3 | 1.7 | A |
| 49: 67 ON | 432 | 74.9 | 6.4 | A |
| 50: 65 Ln 1 | 603 | 62.4 | 10.7 | A |
| 51: 65 Ln 2 | 516 | 62.2 | 9.1 | A |
| 52: Murfreesboro Ln 1 | 854 | 66.3 | 14.2 | B |
| 53: Murfreesboro Ln 2 | 855 | 70.9 | 13.3 | B |
| 54: Murfreesboro Ln 3 | 766 | 73.3 | 11.6 | B |
| 55: Murfreesboro Ln 4 | 820 | 76.4 | 11.8 | B |
| 56: Murfreesboro HOV | 42 | 80.5 | 0.6 | A |
| 57: 65 ON | 643 | 73.6 | 9.6 | A |
| 58: 61 OFF Ln 1 | 283 | 74.5 | 4.2 | A |
| 59: 61 OFF Ln 2 | 57 | 77.8 | 0.8 | A |
| 60: Peytonsville Ln 1 | 954 | 71.3 | 14.7 | B |
| 61: Peytonsville Ln 2 | 820 | 75.0 | 12.0 | B |
| 62: Peytonsville Ln 3 | 755 | 77.9 | 10.7 | A |
| 63: Peytonsville HOV | 34 | 84.7 | 0.4 | A |
| 64: 61 ON | 208 | 75.0 | 3.1 | A |
| 65: END Ln 1 | 987 | 71.4 | 15.2 | B |
| 66: END Ln 2 | 887 | 75.4 | 13.0 | B |
| 67: END Ln 3 | 854 | 79.1 | 11.9 | B |
| 68: END HOV | 28 | 85.6 | 0.3 | A |

TABLE E.4: FUTURE YEAR DO NOTHING

| Data Collection Point | Flow (vph) | Space Mean Speed (mph) | Density (vpmpl) | Microsimulation Based LOS* |
|---|---|---|---|---|
| 1: MM 80 Ln 1 | 1015 | 9.6 | 116.8 | F |
| 2: MM 80 Ln 2 | 494 | 5.6 | 96.8 | F |
| 3: MM 80 Ln 3 | 770 | 7.2 | 118.1 | F |
| 4: MM 80 Ln 4 | 1229 | 15.4 | 87.8 | F |
| 5: MM 80 HOV | 792 | 65.0 | 13.4 | B |
| 6: 79 OFF | 270 | 34.3 | 8.7 | A |
| 7: 79 ON | 702 | 34.6 | 22.3 | C |
| 8: 78 OFF Ln 1 | 427 | 42.1 | 11.1 | B |
| 9: 78 OFF Ln 2 | 228 | 42.0 | 5.9 | A |
| 10: Harding Ln 1 | 844 | 63.0 | 14.7 | B |
| 11: Harding Ln 2 | 1129 | 66.3 | 18.7 | C |
| 12: Harding Ln 3 | 1650 | 69.6 | 26.1 | D |
| 13: Harding HOV | 498 | 73.3 | 7.5 | A |
| 14: 78 ON | 1134 | 71.9 | 17.4 | B |
| 15: 74 A Ln 1 | 326 | 40.2 | 8.9 | A |
| 16: 74 A Ln 2 | 185 | 36.3 | 5.6 | A |
| 17: 74 B | 356 | 36.4 | 10.8 | A |
| 18: OHB Ln 1 | 1104 | 18.1 | 67.2 | F |
| 19: OHB Ln 2 | 821 | 11.7 | 76.9 | F |
| 20: OHB Ln 3 | 1032 | 17.0 | 66.8 | F |
| 21: OHB HOV | 1058 | 25.1 | 46.4 | F |
| 22: 74 ON | 781 | 9.7 | 88.4 | F |
| 23: 71 OFF | 346 | 34.5 | 11.0 | B |
| 24: Concord Rd Ln 1 | 977 | 10.5 | 102.1 | F |
| 25: Concord Rd Ln 2 | 950 | 13.0 | 80.5 | F |
| 26: Concord Rd Ln 3 | 1366 | 23.3 | 64.5 | F |
| 27: Concord Rd HOV | 764 | 37.2 | 22.6 | C |
| 28: 69 Ln 1 | 579 | 41.7 | 15.3 | B |
| 29: 69 Ln 2 | 449 | 41.6 | 11.9 | B |
| 30: Moore's Ln 1 | 838 | 63.7 | 14.4 | B |
| 31: Moore's Ln 2 | 1100 | 67.0 | 18.0 | C |
| 32: Moore's Ln 3 | 1495 | 69.4 | 23.7 | C |
| 33: Moore's Ln 4 | 438 | 74.3 | 6.5 | A |
| 34: 69 ON | 891 | 72.8 | 13.4 | B |
| 35: 68 A | 489 | 55.4 | 9.7 | A |
| 36: 68 B | 263 | 37.0 | 7.8 | A |
| 37: 68 ON | 721 | 71.0 | 11.1 | B |
| 38: CSB Ln 1 | 290 | 27.4 | 11.7 | B |
| 39: CSB Ln 2 | 1017 | 24.3 | 46.0 | F |
| 40: CSB Ln 3 | 1009 | 25.6 | 43.3 | E |
| 41: CSB Ln 4 | 1305 | 35.0 | 41.0 | E |

| | | | | |
|---|---|---|---|---|
| 42: CSB HOV | 645 | 56.7 | 12.5 | B |
| 43: 67 OFF Ln 1 | 323 | 44.8 | 7.9 | A |
| 44: 67 OFF Ln 2 | 138 | 43.2 | 3.5 | A |
| 45: McEwen Ln 1 | 865 | 61.0 | 15.6 | B |
| 46: McEwen Ln 2 | 1203 | 63.9 | 20.7 | C |
| 47: McEwen Ln 3 | 1774 | 66.9 | 29.2 | D |
| 48: McEwen HOV | 484 | 75.1 | 7.0 | A |
| 49: 67 ON | 537 | 74.7 | 7.9 | A |
| 50: 65 Ln 1 | 620 | 60.9 | 11.2 | B |
| 51: 65 Ln 2 | 598 | 60.8 | 10.8 | A |
| 52: Murfreesboro Ln 1 | 913 | 66.3 | 15.2 | B |
| 53: Murfreesboro Ln 2 | 942 | 71.3 | 14.5 | B |
| 54: Murfreesboro Ln 3 | 822 | 74.0 | 12.2 | B |
| 55: Murfreesboro Ln 4 | 784 | 76.3 | 11.3 | B |
| 56: Murfreesboro HOV | 180 | 80.3 | 2.4 | A |
| 57: 65 ON | 803 | 73.1 | 12.1 | B |
| 58: 61 OFF Ln 1 | 311 | 74.2 | 4.6 | A |
| 59: 61 OFF Ln 2 | 68 | 78.3 | 1.0 | A |
| 60: Peytonsville Ln 1 | 948 | 70.5 | 14.9 | B |
| 61: Peytonsville Ln 2 | 951 | 74.3 | 14.1 | B |
| 62: Peytonsville Ln 3 | 890 | 77.1 | 12.7 | B |
| 63: Peytonsville HOV | 191 | 81.2 | 2.6 | A |
| 64: 61 ON | 256 | 74.6 | 3.7 | A |
| 65: END Ln 1 | 1023 | 70.9 | 15.8 | B |
| 66: END Ln 2 | 1022 | 75.1 | 15.0 | B |
| 67: END Ln 3 | 994 | 78.4 | 14.0 | B |
| 68: END HOV | 180 | 85.0 | 2.3 | A |

TABLE E.5: FUTURE YEAR LANE REVERSION

| Data Collection Point | Flow (vph) | Space Mean Speed (mph) | Density (vpmpl) | Microsimulation Based LOS* |
|---|---|---|---|---|
| 1: MM 80 Ln 1 | 1068 | 10.5 | 111.5 | F |
| 2: MM 80 Ln 2 | 537 | 5.7 | 104.2 | F |
| 3: MM 80 Ln 3 | 812 | 9.7 | 92.0 | F |
| 4: MM 80 Ln 4 | 1558 | 18.6 | 92.1 | F |
| 5: MM 80 HOV | 228 | 73.5 | 3.4 | A |
| 6: 79 OFF | 267 | 35.3 | 8.4 | A |
| 7: 79 ON | 702 | 38.2 | 20.2 | C |
| 8: 78 OFF Ln 1 | 403 | 42.9 | 10.3 | A |
| 9: 78 OFF Ln 2 | 219 | 42.3 | 5.7 | A |
| 10: Harding Ln 1 | 797 | 62.0 | 14.2 | B |
| 11: Harding Ln 2 | 1213 | 65.3 | 20.5 | C |
| 12: Harding Ln 3 | 1759 | 68.0 | 28.5 | D |
| 13: Harding HOV | 141 | 74.7 | 2.1 | A |
| 14: 78 ON | 1116 | 33.1 | 37.1 | E |
| 15: 74 A Ln 1 | 330 | 37.1 | 9.8 | A |
| 16: 74 A Ln 2 | 185 | 36.6 | 5.6 | A |
| 17: 74 B | 375 | 34.8 | 11.9 | B |
| 18: OHB Ln 1 | 1218 | 18.7 | 71.7 | F |
| 19: OHB Ln 2 | 846 | 11.0 | 85.0 | F |
| 20: OHB Ln 3 | 1088 | 15.7 | 76.3 | F |
| 21: OHB HOV | 921 | 25.4 | 39.9 | E |
| 22: 74 ON | 996 | 7.6 | 144.4 | F |
| 23: 71 OFF | 362 | 35.6 | 11.2 | B |
| 24: Concord Rd Ln 1 | 1068 | 11.2 | 104.7 | F |
| 25: Concord Rd Ln 2 | 1071 | 12.5 | 93.9 | F |
| 26: Concord Rd Ln 3 | 1677 | 25.0 | 73.9 | F |
| 27: Concord Rd HOV | 352 | 32.3 | 12.0 | B |
| 28: 69 Ln 1 | 611 | 42.4 | 15.8 | B |
| 29: 69 Ln 2 | 472 | 42.7 | 12.1 | B |
| 30: Moore's Ln 1 | 873 | 62.6 | 15.4 | B |
| 31: Moore's Ln 2 | 1218 | 64.8 | 20.7 | C |
| 32: Moore's Ln 3 | 1846 | 67.7 | 30.0 | D |
| 33: Moore's Ln HOV | 148 | 74.5 | 2.2 | A |
| 34: 69 ON | 891 | 72.7 | 13.4 | B |
| 35: 68 A | 511 | 52.8 | 10.7 | A |
| 36: 68 B | 263 | 41.4 | 6.9 | A |
| 37: 68 ON | 721 | 70.5 | 11.2 | B |
| 38: CSB Ln 1 | 245 | 32.4 | 8.4 | A |
| 39: CSB Ln 2 | 1075 | 34.6 | 34.2 | D |

| | | | | |
|---|---|---|---|---|
| 40: CSB Ln 3 | 1154 | 37.4 | 34.0 | D |
| 41: CSB Ln 4 | 1629 | 48.5 | 37.0 | E |
| 42: CSB HOV | 303 | 55.9 | 5.9 | A |
| 43: 67 OFF Ln 1 | 330 | 43.4 | 8.4 | A |
| 44: 67 OFF Ln 2 | 137 | 43.1 | 3.5 | A |
| 45: McEwen Ln 1 | 825 | 58.9 | 15.4 | B |
| 46: McEwen Ln 2 | 1305 | 60.8 | 23.7 | C |
| 47: McEwen Ln 3 | 2098 | 62.9 | 36.7 | E |
| 48: McEwen HOV | 159 | 74.3 | 2.3 | A |
| 49: 67 ON | 537 | 74.5 | 7.9 | A |
| 50: 65 Ln 1 | 644 | 62.1 | 11.4 | B |
| 51: 65 Ln 2 | 575 | 61.4 | 10.3 | A |
| 52: Murfreesboro Ln 1 | 919 | 66.7 | 15.2 | B |
| 53: Murfreesboro Ln 2 | 950 | 70.9 | 14.7 | B |
| 54: Murfreesboro Ln 3 | 807 | 73.3 | 12.1 | B |
| 55: Murfreesboro Ln 4 | 927 | 75.8 | 13.4 | B |
| 56: Murfreesboro HOV | 78 | 80.7 | 1.1 | A |
| 57: 65 ON | 803 | 73.0 | 12.1 | B |
| 58: 61 OFF Ln 1 | 329 | 75.4 | 4.8 | A |
| 59: 61 OFF Ln 2 | 49 | 78.7 | 0.7 | A |
| 60: Peytonsville Ln 1 | 961 | 70.3 | 15.1 | B |
| 61: Peytonsville Ln 2 | 961 | 73.7 | 14.3 | B |
| 62: Peytonsville Ln 3 | 1001 | 76.6 | 14.4 | B |
| 63: Peytonsville HOV | 54 | 80.8 | 0.8 | A |
| 64: 61 ON | 256 | 74.5 | 3.7 | A |
| 65: END Ln 1 | 1076 | 70.9 | 16.7 | B |
| 66: END Ln 2 | 1039 | 74.7 | 15.3 | B |
| 67: END Ln 3 | 1086 | 78.1 | 15.3 | B |
| 68: END HOV | 61 | 84.1 | 0.8 | A |

## TABLE E.6: FUTURE YEAR HEAVY ENFORCEMENT

| Data Collection Point | Flow (vph) | Space Mean Speed (mph) | Density (vpmpl) | Microsimulation Based LOS* |
|---|---|---|---|---|
| 1: MM 80 Ln 1 | 1068 | 10.5 | 111.5 | F |
| 2: MM 80 Ln 2 | 537 | 5.7 | 104.2 | F |
| 3: MM 80 Ln 3 | 812 | 9.7 | 92.0 | F |
| 4: MM 80 Ln 4 | 1558 | 18.6 | 92.1 | F |
| 5: MM 80 HOV | 228 | 73.5 | 3.4 | A |
| 6: 79 OFF | 267 | 35.3 | 8.4 | A |
| 7: 79 ON | 702 | 38.2 | 20.2 | C |
| 8: 78 OFF Ln 1 | 403 | 42.9 | 10.3 | A |
| 9: 78 OFF Ln 2 | 219 | 42.3 | 5.7 | A |
| 10: Harding Ln 1 | 797 | 62.0 | 14.2 | B |
| 11: Harding Ln 2 | 1213 | 65.3 | 20.5 | C |
| 12: Harding Ln 3 | 1759 | 68.0 | 28.5 | D |
| 13: Harding HOV | 141 | 74.7 | 2.1 | A |
| 14: 78 ON | 1116 | 33.1 | 37.1 | E |
| 15: 74 A Ln 1 | 330 | 37.1 | 9.8 | A |
| 16: 74 A Ln 2 | 185 | 36.6 | 5.6 | A |
| 17: 74 B | 375 | 34.8 | 11.9 | B |
| 18: OHB Ln 1 | 1218 | 18.7 | 71.7 | F |
| 19: OHB Ln 2 | 846 | 11.0 | 85.0 | F |
| 20: OHB Ln 3 | 1088 | 15.7 | 76.3 | F |
| 21: OHB HOV | 921 | 25.4 | 39.9 | E |
| 22: 74 ON | 996 | 7.6 | 144.4 | F |
| 23: 71 OFF | 362 | 35.6 | 11.2 | B |
| 24: Concord Rd Ln 1 | 1068 | 11.2 | 104.7 | F |
| 25: Concord Rd Ln 2 | 1071 | 12.5 | 93.9 | F |
| 26: Concord Rd Ln 3 | 1677 | 25.0 | 73.9 | F |
| 27: Concord Rd HOV | 352 | 32.3 | 12.0 | B |
| 28: 69 Ln 1 | 611 | 42.4 | 15.8 | B |
| 29: 69 Ln 2 | 472 | 42.7 | 12.1 | B |
| 30: Moore's Ln 1 | 873 | 62.6 | 15.4 | B |
| 31: Moore's Ln 2 | 1218 | 64.8 | 20.7 | C |
| 32: Moore's Ln 3 | 1846 | 67.7 | 30.0 | D |
| 33: Moore's Ln 4 | 148 | 74.5 | 2.2 | A |
| 34: 69 ON | 891 | 72.7 | 13.4 | B |
| 35: 68 A | 511 | 52.8 | 10.7 | A |
| 36: 68 B | 263 | 41.4 | 6.9 | A |
| 37: 68 ON | 721 | 70.5 | 11.2 | B |
| 38: CSB Ln 1 | 245 | 32.4 | 8.4 | A |
| 39: CSB Ln 2 | 1075 | 34.6 | 34.2 | D |
| 40: CSB Ln 3 | 1154 | 37.4 | 34.0 | D |
| 41: CSB Ln 4 | 1629 | 48.5 | 37.0 | E |

| | | | | |
|---|---|---|---|---|
| 42: CSB HOV | 303 | 55.9 | 5.9 | A |
| 43: 67 OFF Ln 1 | 330 | 43.4 | 8.4 | A |
| 44: 67 OFF Ln 2 | 137 | 43.1 | 3.5 | A |
| 45: McEwen Ln 1 | 825 | 58.9 | 15.4 | B |
| 46: McEwen Ln 2 | 1305 | 60.8 | 23.7 | C |
| 47: McEwen Ln 3 | 2098 | 62.9 | 36.7 | E |
| 48: McEwen HOV | 159 | 74.3 | 2.3 | A |
| 49: 67 ON | 537 | 74.5 | 7.9 | A |
| 50: 65 Ln 1 | 644 | 62.1 | 11.4 | B |
| 51: 65 Ln 2 | 575 | 61.4 | 10.3 | A |
| 52: Murfreesboro Ln 1 | 919 | 66.7 | 15.2 | B |
| 53: Murfreesboro Ln 2 | 950 | 70.9 | 14.7 | B |
| 54: Murfreesboro Ln 3 | 807 | 73.3 | 12.1 | B |
| 55: Murfreesboro Ln 4 | 927 | 75.8 | 13.4 | B |
| 56: Murfreesboro HOV | 78 | 80.7 | 1.1 | A |
| 57: 65 ON | 803 | 73.0 | 12.1 | B |
| 58: 61 OFF Ln 1 | 329 | 75.4 | 4.8 | A |
| 59: 61 OFF Ln 2 | 49 | 78.7 | 0.7 | A |
| 60: Peytonsville Ln 1 | 961 | 70.3 | 15.1 | B |
| 61: Peytonsville Ln 2 | 961 | 73.7 | 14.3 | B |
| 62: Peytonsville Ln 3 | 1001 | 76.6 | 14.4 | B |
| 63: Peytonsville HOV | 54 | 80.8 | 0.8 | A |
| 64: 61 ON | 256 | 74.5 | 3.7 | A |
| 65: END Ln 1 | 1076 | 70.9 | 16.7 | B |
| 66: END Ln 2 | 1039 | 74.7 | 15.3 | B |
| 67: END Ln 3 | 1086 | 78.1 | 15.3 | B |
| 68: END HOV | 61 | 84.1 | 0.8 | A |

# APPENDIX F: DATA COLLECTION POINT RESULTS FOR PEAK HOUR FOR NORTHBOUND I-65 SOUTH OF NASHVILLE

Note: All level of service computations assume 1.1 passenger car equivalents per vehicle.

TABLE F.1: BASE YEAR DO NOTHING

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| 1: END HOV | 1209 | 13.3 | 99.8 | F |
| 2: END Ln 5 | 1223 | 13.3 | 101.1 | F |
| 3: END Ln 4 | 1182 | 13.3 | 97.5 | F |
| 4: END Ln 3 | 1165 | 13.4 | 96.0 | F |
| 5: END Ln 2 | 1107 | 13.5 | 89.9 | F |
| 6: END Ln 1 | 1070 | 13.5 | 87.2 | F |
| 7: Interchang 79 HOV | 1368 | 62.2 | 24.2 | C |
| 8: Interchange 79 Ln 4 | 1401 | 63.0 | 24.4 | C |
| 9: Interchange 79 Ln 3 | 1337 | 63.0 | 23.4 | C |
| 10: Interchange 79 LN 2 | 1246 | 62.6 | 21.9 | C |
| 11: Interchange 79 Ln 1 | 1206 | 63.1 | 21.0 | C |
| 12: Interchange 78 HOV | 1505 | 65.3 | 25.4 | C |
| 13: Interchange 78 Ln 3 | 1461 | 64.9 | 24.8 | C |
| 14: Interchange 78 Ln 2 | 1439 | 64.8 | 24.4 | C |
| 15: Interchange 78 Ln 1 | 1437 | 65.1 | 24.3 | C |
| 16: Interchange 74 HOV | 1466 | 44.7 | 36.1 | E |
| 17: Interchange 74 Ln 4 | 1263 | 34.0 | 40.9 | E |
| 18: Interchange 74 Ln 3 | 1029 | 26.0 | 43.6 | E |
| 19: Interchange 74 Ln 2 | 1180 | 29.2 | 44.5 | E |
| 20: Interchange 74 Ln 1 | 131 | 46.7 | 3.1 | A |
| 21: Interchange 71 HOV | 1669 | 34.8 | 52.8 | F |
| 22: Interchange 71 Ln 4 | 1127 | 29.4 | 42.2 | E |
| 23: Interchange 71 Ln 3 | 755 | 23.6 | 35.2 | E |
| 24: Interchange 71 Ln 2 | 935 | 11.0 | 93.8 | F |
| 25: Interchange 71 Ln 1 | 541 | 10.0 | 59.5 | F |
| 26: Interchange 69 HOV | 636 | 72.1 | 9.7 | A |
| 27: Interchange 69 Ln 3 | 1656 | 68.6 | 26.6 | D |
| 28: Interchange 69 Ln 2 | 1381 | 63.6 | 23.9 | C |
| 29: Interchange 69 Ln 1 | 1322 | 63.5 | 22.9 | C |
| 30: Interchange 68 HOV | 632 | 63.0 | 11.0 | B |
| 31: Interchange 68 Ln 4 | 1482 | 44.5 | 36.6 | E |
| 32: Interchange 68 Ln 3 | 1119 | 27.0 | 45.7 | F |
| 33: Interchange 68 Ln 2 | 927 | 14.1 | 72.2 | F |
| 34: Interchange 68 Ln 1 | 1357 | 34.2 | 43.6 | E |
| 35: Interchange 67 HOV | 648 | 70.4 | 10.1 | A |
| 36: Interchange 67 Ln 3 | 1764 | 66.7 | 29.1 | D |
| 37: Interchange 67 Ln 2 | 1402 | 59.2 | 26.1 | D |

| | | | | |
|---|---|---|---|---|
| 38: Interchange 67 Ln 1 | 1339 | 59.1 | 24.9 | C |
| 39: Interchange 65 HOV | 518 | 71.4 | 8.0 | A |
| 40: Interchange 65 Ln 3 | 1398 | 65.0 | 23.6 | C |
| 41: Interchange 65 Ln 2 | 1152 | 60.5 | 20.9 | C |
| 42: Interchange 65 Ln 1 | 1085 | 59.4 | 20.1 | C |
| 43: Interchange 61 HOV | 405 | 74.2 | 6.0 | A |
| 44: Interchange 61 Ln 3 | 1062 | 72.9 | 16.0 | B |
| 45: Interchange 61 Ln 2 | 1208 | 72.2 | 18.4 | C |
| 46: Interchange 61 Ln 1 | 1134 | 70.5 | 17.7 | B |
| 47: BEGIN HOV | 421 | 76.0 | 6.1 | A |
| 48: BEGIN Ln 4 | 832 | 74.5 | 12.3 | B |
| 49: BEGIN Ln 3 | 882 | 74.0 | 13.1 | B |
| 50: BEGIN Ln 2 | 882 | 74.2 | 13.1 | B |
| 51: BEGIN Ln 1 | 865 | 74.5 | 12.8 | B |

TABLE F.2: BASE YEAR LANE REVERSION

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| 1: END HOV | 1204 | 13.3 | 99.3 | F |
| 2: END Ln 5 | 1213 | 13.4 | 99.6 | F |
| 3: END Ln 4 | 1188 | 13.3 | 98.3 | F |
| 4: END Ln 3 | 1147 | 13.5 | 93.7 | F |
| 5: END Ln 2 | 1127 | 13.4 | 92.4 | F |
| 6: END Ln 1 | 1096 | 13.5 | 89.4 | F |
| 7: Interchang 79 HOV | 1402 | 63.2 | 24.4 | C |
| 8: Interchange 79 Ln 4 | 1385 | 63.1 | 24.1 | C |
| 9: Interchange 79 Ln 3 | 1291 | 62.5 | 22.7 | C |
| 10: Interchange 79 LN 2 | 1249 | 62.5 | 22.0 | C |
| 11: Interchange 79 Ln 1 | 1246 | 62.8 | 21.8 | C |
| 12: Interchange 78 HOV | 1523 | 66.5 | 25.2 | C |
| 13: Interchange 78 Ln 3 | 1470 | 65.1 | 24.8 | C |
| 14: Interchange 78 Ln 2 | 1389 | 65.0 | 23.5 | C |
| 15: Interchange 78 Ln 1 | 1411 | 65.9 | 23.5 | C |
| 16: Interchange 74 HOV | 1497 | 33.4 | 49.3 | F |
| 17: Interchange 74 Ln 4 | 1320 | 28.5 | 51.0 | F |
| 18: Interchange 74 Ln 3 | 1138 | 22.0 | 56.8 | F |
| 19: Interchange 74 Ln 2 | 1302 | 23.6 | 60.6 | F |
| 20: Interchange 74 Ln 1 | 144 | 43.2 | 3.7 | A |
| 21: Interchange 71 HOV | 1801 | 33.5 | 59.1 | F |
| 22: Interchange 71 Ln 4 | 1231 | 28.4 | 47.6 | F |
| 23: Interchange 71 Ln 3 | 878 | 23.4 | 41.2 | E |
| 24: Interchange 71 Ln 2 | 1075 | 11.1 | 106.5 | F |
| 25: Interchange 71 Ln 1 | 611 | 9.9 | 67.8 | F |
| 26: Interchange 69 HOV | 1399 | 70.1 | 22.0 | C |
| 27: Interchange 69 Ln 3 | 1468 | 70.5 | 22.9 | C |
| 28: Interchange 69 Ln 2 | 1182 | 66.9 | 19.4 | C |
| 29: Interchange 69 Ln 1 | 1175 | 66.1 | 19.6 | C |
| 30: Interchange 68 HOV | 1611 | 48.6 | 36.5 | E |
| 31: Interchange 68 Ln 4 | 1212 | 44.1 | 30.2 | D |
| 32: Interchange 68 Ln 3 | 861 | 19.7 | 48.0 | F |
| 33: Interchange 68 Ln 2 | 827 | 13.6 | 66.9 | F |
| 34: Interchange 68 Ln 1 | 1218 | 28.4 | 47.2 | F |
| 35: Interchange 67 HOV | 1568 | 69.3 | 24.9 | C |
| 36: Interchange 67 Ln 3 | 1434 | 68.3 | 23.1 | C |
| 37: Interchange 67 Ln 2 | 1164 | 61.6 | 20.8 | C |
| 38: Interchange 67 Ln 1 | 1149 | 60.8 | 20.8 | C |
| 39: Interchange 65 HOV | 1201 | 71.1 | 18.6 | C |

| | | | | |
|---|---|---|---|---|
| 40: Interchange 65 Ln 3 | 1202 | 70.6 | 18.7 | C |
| 41: Interchange 65 Ln 2 | 934 | 65.5 | 15.7 | B |
| 42: Interchange 65 Ln 1 | 836 | 64.8 | 14.2 | B |
| 43: Interchange 61 HOV | 800 | 73.6 | 12.0 | B |
| 44: Interchange 61 Ln 3 | 978 | 74.1 | 14.5 | B |
| 45: Interchange 61 Ln 2 | 1028 | 73.0 | 15.5 | B |
| 46: Interchange 61 Ln 1 | 1002 | 70.7 | 15.6 | B |
| 47: BEGIN HOV | 735 | 74.6 | 10.8 | A |
| 48: BEGIN Ln 4 | 771 | 74.9 | 11.3 | B |
| 49: BEGIN Ln 3 | 793 | 74.8 | 11.7 | B |
| 50: BEGIN Ln 2 | 806 | 74.4 | 11.9 | B |
| 51: BEGIN Ln 1 | 777 | 74.3 | 11.5 | B |

## TABLE F.3: BASE YEAR HEAVY ENFORCEMENT

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| 1: END HOV | 1215 | 13.3 | 100.4 | F |
| 2: END Ln 5 | 1213 | 13.3 | 100.0 | F |
| 3: END Ln 4 | 1219 | 13.4 | 100.3 | F |
| 4: END Ln 3 | 1200 | 13.4 | 98.9 | F |
| 5: END Ln 2 | 1186 | 13.4 | 97.7 | F |
| 6: END Ln 1 | 1173 | 13.5 | 95.8 | F |
| 7: Interchang 79 HOV | 1483 | 61.3 | 26.6 | D |
| 8: Interchange 79 Ln 4 | 1408 | 61.1 | 25.4 | C |
| 9: Interchange 79 Ln 3 | 1295 | 61.2 | 23.3 | C |
| 10: Interchange 79 LN 2 | 1295 | 61.8 | 23.0 | C |
| 11: Interchange 79 Ln 1 | 1264 | 62.4 | 22.3 | C |
| 12: Interchange 78 HOV | 1530 | 67.1 | 25.1 | C |
| 13: Interchange 78 Ln 3 | 1440 | 66.3 | 23.9 | C |
| 14: Interchange 78 Ln 2 | 1357 | 65.9 | 22.7 | C |
| 15: Interchange 78 Ln 1 | 1394 | 66.6 | 23.0 | C |
| 16: Interchange 74 HOV | 1448 | 25.0 | 63.7 | F |
| 17: Interchange 74 Ln 4 | 1308 | 19.3 | 74.6 | F |
| 18: Interchange 74 Ln 3 | 1077 | 14.0 | 84.5 | F |
| 19: Interchange 74 Ln 2 | 1267 | 15.3 | 91.2 | F |
| 20: Interchange 74 Ln 1 | 167 | 39.1 | 4.7 | A |
| 21: Interchange 71 HOV | 1744 | 35.6 | 53.9 | F |
| 22: Interchange 71 Ln 4 | 1217 | 29.2 | 45.8 | F |
| 23: Interchange 71 Ln 3 | 831 | 22.9 | 39.9 | E |
| 24: Interchange 71 Ln 2 | 1018 | 11.0 | 101.8 | F |
| 25: Interchange 71 Ln 1 | 595 | 9.3 | 70.4 | F |
| 26: Interchange 69 HOV | 279 | 73.0 | 4.2 | A |
| 27: Interchange 69 Ln 3 | 1816 | 67.0 | 29.8 | D |
| 28: Interchange 69 Ln 2 | 1556 | 63.6 | 26.9 | D |
| 29: Interchange 69 Ln 1 | 1472 | 62.7 | 25.8 | C |
| 30: Interchange 68 HOV | 256 | 62.9 | 4.5 | A |
| 31: Interchange 68 Ln 4 | 1565 | 39.6 | 43.4 | E |
| 32: Interchange 68 Ln 3 | 1185 | 25.9 | 50.4 | F |
| 33: Interchange 68 Ln 2 | 1003 | 14.0 | 79.1 | F |
| 34: Interchange 68 Ln 1 | 1455 | 28.5 | 56.2 | F |
| 35: Interchange 67 HOV | 259 | 70.9 | 4.0 | A |
| 36: Interchange 67 Ln 3 | 1793 | 66.3 | 29.8 | D |
| 37: Interchange 67 Ln 2 | 1462 | 59.8 | 26.9 | D |
| 38: Interchange 67 Ln 1 | 1397 | 58.9 | 26.1 | D |
| 39: Interchange 65 HOV | 405 | 34.4 | 12.9 | B |

| | | | | |
|---|---|---|---|---|
| 40: Interchange 65 Ln 3 | 1385 | 19.2 | 79.4 | F |
| 41: Interchange 65 Ln 2 | 1253 | 16.8 | 82.2 | F |
| 42: Interchange 65 Ln 1 | 1210 | 16.7 | 79.6 | F |
| 43: Interchange 61 HOV | 254 | 59.2 | 4.7 | A |
| 44: Interchange 61 Ln 3 | 1337 | 24.4 | 60.3 | F |
| 45: Interchange 61 Ln 2 | 1255 | 20.8 | 66.5 | F |
| 46: Interchange 61 Ln 1 | 1207 | 25.0 | 53.2 | F |
| 47: BEGIN HOV | 230 | 75.8 | 3.3 | A |
| 48: BEGIN Ln 4 | 1099 | 55.0 | 22.0 | C |
| 49: BEGIN Ln 3 | 1159 | 50.0 | 25.5 | C |
| 50: BEGIN Ln 2 | 1097 | 56.8 | 21.2 | C |
| 51: BEGIN Ln 1 | 1129 | 55.1 | 22.5 | C |

## TABLE F.4: FUTURE YEAR DO NOTHING

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| 1: END HOV | 1225 | 13.4 | 100.8 | F |
| 2: END Ln 5 | 1235 | 13.3 | 101.9 | F |
| 3: END Ln 4 | 1228 | 13.3 | 101.3 | F |
| 4: END Ln 3 | 1204 | 13.4 | 99.1 | F |
| 5: END Ln 2 | 1188 | 13.5 | 97.2 | F |
| 6: END Ln 1 | 1185 | 13.4 | 97.6 | F |
| 7: Interchang 79 HOV | 1469 | 61.5 | 26.3 | D |
| 8: Interchange 79 Ln 4 | 1458 | 61.6 | 26.0 | D |
| 9: Interchange 79 Ln 3 | 1383 | 61.2 | 24.9 | C |
| 10: Interchange 79 LN 2 | 1288 | 61.1 | 23.2 | C |
| 11: Interchange 79 Ln 1 | 1268 | 61.4 | 22.7 | C |
| 12: Interchange 78 HOV | 1546 | 65.7 | 25.9 | C |
| 13: Interchange 78 Ln 3 | 1494 | 65.1 | 25.2 | C |
| 14: Interchange 78 Ln 2 | 1435 | 65.3 | 24.2 | C |
| 15: Interchange 78 Ln 1 | 1376 | 64.8 | 23.4 | C |
| 16: Interchange 74 HOV | 1321 | 19.0 | 76.4 | F |
| 17: Interchange 74 Ln 4 | 1292 | 18.4 | 77.3 | F |
| 18: Interchange 74 Ln 3 | 1166 | 14.7 | 87.5 | F |
| 19: Interchange 74 Ln 2 | 1273 | 16.5 | 84.8 | F |
| 20: Interchange 74 Ln 1 | 182 | 38.1 | 5.3 | A |
| 21: Interchange 71 HOV | 1774 | 34.2 | 57.0 | F |
| 22: Interchange 71 Ln 4 | 1239 | 29.1 | 46.9 | F |
| 23: Interchange 71 Ln 3 | 858 | 21.8 | 43.2 | E |
| 24: Interchange 71 Ln 2 | 1058 | 10.7 | 109.1 | F |
| 25: Interchange 71 Ln 1 | 600 | 9.3 | 71.1 | F |
| 26: Interchange 69 HOV | 748 | 71.3 | 11.5 | B |
| 27: Interchange 69 Ln 3 | 1720 | 67.2 | 28.1 | D |
| 28: Interchange 69 Ln 2 | 1513 | 63.5 | 26.2 | D |
| 29: Interchange 69 Ln 1 | 1369 | 62.5 | 24.1 | C |
| 30: Interchange 68 HOV | 702 | 60.3 | 12.8 | B |
| 31: Interchange 68 Ln 4 | 1529 | 39.0 | 43.2 | E |
| 32: Interchange 68 Ln 3 | 1073 | 23.4 | 50.5 | F |
| 33: Interchange 68 Ln 2 | 989 | 4.2 | 259.0 | F |
| 34: Interchange 68 Ln 1 | 1425 | 27.8 | 56.5 | F |
| 35: Interchange 67 HOV | 716 | 69.8 | 11.3 | B |
| 36: Interchange 67 Ln 3 | 1766 | 66.4 | 29.3 | D |
| 37: Interchange 67 Ln 2 | 1338 | 58.8 | 25.0 | C |
| 38: Interchange 67 Ln 1 | 1327 | 58.5 | 25.0 | C |
| 39: Interchange 65 HOV | 928 | 35.8 | 28.5 | D |

| | | | | |
|---|---|---|---|---|
| 40: Interchange 65 Ln 3 | 1278 | 14.7 | 95.6 | F |
| 41: Interchange 65 Ln 2 | 1210 | 17.2 | 77.5 | F |
| 42: Interchange 65 Ln 1 | 1117 | 16.5 | 74.4 | F |
| 43: Interchange 61 HOV | 584 | 72.8 | 8.8 | A |
| 44: Interchange 61 Ln 3 | 1513 | 57.8 | 28.8 | D |
| 45: Interchange 61 Ln 2 | 1319 | 57.4 | 25.3 | C |
| 46: Interchange 61 Ln 1 | 1258 | 57.2 | 24.2 | C |
| 47: BEGIN HOV | 542 | 75.9 | 7.9 | A |
| 48: BEGIN Ln 4 | 1070 | 73.9 | 15.9 | B |
| 49: BEGIN Ln 3 | 1089 | 73.2 | 16.4 | B |
| 50: BEGIN Ln 2 | 1093 | 73.4 | 16.4 | B |
| 51: BEGIN Ln 1 | 1094 | 73.7 | 16.3 | B |

TABLE F.5: FUTURE YEAR LANE REVERSION

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| 1: END HOV | 1232 | 13.4 | 101.1 | F |
| 2: END Ln 5 | 1227 | 13.4 | 101.0 | F |
| 3: END Ln 4 | 1225 | 13.4 | 100.8 | F |
| 4: END Ln 3 | 1202 | 13.4 | 98.7 | F |
| 5: END Ln 2 | 1189 | 13.4 | 97.9 | F |
| 6: END Ln 1 | 1173 | 13.4 | 96.4 | F |
| 7: Interchang 79 HOV | 1524 | 61.7 | 27.2 | D |
| 8: Interchange 79 Ln 4 | 1448 | 61.3 | 26.0 | C |
| 9: Interchange 79 Ln 3 | 1366 | 61.7 | 24.3 | C |
| 10: Interchange 79 LN 2 | 1269 | 61.6 | 22.6 | C |
| 11: Interchange 79 Ln 1 | 1245 | 62.2 | 22.0 | C |
| 12: Interchange 78 HOV | 1546 | 66.4 | 25.6 | C |
| 13: Interchange 78 Ln 3 | 1479 | 66.0 | 24.7 | C |
| 14: Interchange 78 Ln 2 | 1409 | 65.1 | 23.8 | C |
| 15: Interchange 78 Ln 1 | 1395 | 65.7 | 23.4 | C |
| 16: Interchange 74 HOV | 1315 | 20.9 | 69.3 | F |
| 17: Interchange 74 Ln 4 | 1311 | 19.9 | 72.5 | F |
| 18: Interchange 74 Ln 3 | 1195 | 16.9 | 77.9 | F |
| 19: Interchange 74 Ln 2 | 1285 | 18.2 | 77.8 | F |
| 20: Interchange 74 Ln 1 | 176 | 41.0 | 4.7 | A |
| 21: Interchange 71 HOV | 1805 | 34.2 | 58.0 | F |
| 22: Interchange 71 Ln 4 | 1231 | 28.3 | 47.8 | F |
| 23: Interchange 71 Ln 3 | 862 | 22.3 | 42.6 | E |
| 24: Interchange 71 Ln 2 | 1097 | 10.6 | 113.5 | F |
| 25: Interchange 71 Ln 1 | 621 | 9.4 | 72.7 | F |
| 26: Interchange 69 HOV | 1586 | 69.7 | 25.0 | C |
| 27: Interchange 69 Ln 3 | 1604 | 69.5 | 25.4 | C |
| 28: Interchange 69 Ln 2 | 1379 | 64.7 | 23.4 | C |
| 29: Interchange 69 Ln 1 | 1319 | 64.6 | 22.5 | C |
| 30: Interchange 68 HOV | 1765 | 44.9 | 43.2 | E |
| 31: Interchange 68 Ln 4 | 1322 | 37.3 | 38.9 | E |
| 32: Interchange 68 Ln 3 | 957 | 18.7 | 56.4 | F |
| 33: Interchange 68 Ln 2 | 825 | 11.2 | 81.2 | F |
| 34: Interchange 68 Ln 1 | 1361 | 25.8 | 58.0 | F |
| 35: Interchange 67 HOV | 1707 | 69.1 | 27.2 | D |
| 36: Interchange 67 Ln 3 | 1599 | 67.3 | 26.1 | D |
| 37: Interchange 67 Ln 2 | 1247 | 59.3 | 23.1 | C |
| 38: Interchange 67 Ln 1 | 1144 | 57.7 | 21.8 | C |
| 39: Interchange 65 HOV | 1232 | 18.7 | 72.5 | F |

| | | | | |
|---|---|---|---|---|
| 40: Interchange 65 Ln 3 | 1257 | 17.2 | 80.5 | F |
| 41: Interchange 65 Ln 2 | 1285 | 17.2 | 82.4 | F |
| 42: Interchange 65 Ln 1 | 1197 | 17.2 | 76.7 | F |
| 43: Interchange 61 HOV | 1119 | 72.3 | 17.0 | B |
| 44: Interchange 61 Ln 3 | 1268 | 72.8 | 19.2 | C |
| 45: Interchange 61 Ln 2 | 1236 | 71.2 | 19.1 | C |
| 46: Interchange 61 Ln 1 | 1154 | 69.7 | 18.2 | C |
| 47: BEGIN HOV | 940 | 73.5 | 14.1 | B |
| 48: BEGIN Ln 4 | 970 | 74.2 | 14.4 | B |
| 49: BEGIN Ln 3 | 998 | 74.2 | 14.8 | B |
| 50: BEGIN Ln 2 | 1014 | 73.9 | 15.1 | B |
| 51: BEGIN Ln 1 | 966 | 73.6 | 14.4 | B |

TABLE F.6: FUTURE YEAR HEAVY ENFORCEMENT

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| 1: END HOV | 1215 | 13.3 | 100.4 | F |
| 2: END Ln 5 | 1213 | 13.3 | 100.0 | F |
| 3: END Ln 4 | 1219 | 13.4 | 100.3 | F |
| 4: END Ln 3 | 1200 | 13.4 | 98.9 | F |
| 5: END Ln 2 | 1186 | 13.4 | 97.7 | F |
| 6: END Ln 1 | 1173 | 13.5 | 95.8 | F |
| 7: Interchang 79 HOV | 1483 | 61.3 | 26.6 | D |
| 8: Interchange 79 Ln 4 | 1408 | 61.1 | 25.4 | C |
| 9: Interchange 79 Ln 3 | 1295 | 61.2 | 23.3 | C |
| 10: Interchange 79 LN 2 | 1295 | 61.8 | 23.0 | C |
| 11: Interchange 79 Ln 1 | 1264 | 62.4 | 22.3 | C |
| 12: Interchange 78 HOV | 1530 | 67.1 | 25.1 | C |
| 13: Interchange 78 Ln 3 | 1440 | 66.3 | 23.9 | C |
| 14: Interchange 78 Ln 2 | 1357 | 65.9 | 22.7 | C |
| 15: Interchange 78 Ln 1 | 1394 | 66.6 | 23.0 | C |
| 16: Interchange 74 HOV | 1448 | 25.0 | 63.7 | F |
| 17: Interchange 74 Ln 4 | 1308 | 19.3 | 74.6 | F |
| 18: Interchange 74 Ln 3 | 1077 | 14.0 | 84.5 | F |
| 19: Interchange 74 Ln 2 | 1267 | 15.3 | 91.2 | F |
| 20: Interchange 74 Ln 1 | 167 | 39.1 | 4.7 | A |
| 21: Interchange 71 HOV | 1744 | 35.6 | 53.9 | F |
| 22: Interchange 71 Ln 4 | 1217 | 29.2 | 45.8 | F |
| 23: Interchange 71 Ln 3 | 831 | 22.9 | 39.9 | E |
| 24: Interchange 71 Ln 2 | 1018 | 11.0 | 101.8 | F |
| 25: Interchange 71 Ln 1 | 595 | 9.3 | 70.4 | F |
| 26: Interchange 69 HOV | 279 | 73.0 | 4.2 | A |
| 27: Interchange 69 Ln 3 | 1816 | 67.0 | 29.8 | D |
| 28: Interchange 69 Ln 2 | 1556 | 63.6 | 26.9 | D |
| 29: Interchange 69 Ln 1 | 1472 | 62.7 | 25.8 | C |
| 30: Interchange 68 HOV | 256 | 62.9 | 4.5 | A |
| 31: Interchange 68 Ln 4 | 1565 | 39.6 | 43.4 | E |
| 32: Interchange 68 Ln 3 | 1185 | 25.9 | 50.4 | F |
| 33: Interchange 68 Ln 2 | 1003 | 14.0 | 79.1 | F |
| 34: Interchange 68 Ln 1 | 1455 | 28.5 | 56.2 | F |
| 35: Interchange 67 HOV | 259 | 70.9 | 4.0 | A |
| 36: Interchange 67 Ln 3 | 1793 | 66.3 | 29.8 | D |
| 37: Interchange 67 Ln 2 | 1462 | 59.8 | 26.9 | D |
| 38: Interchange 67 Ln 1 | 1397 | 58.9 | 26.1 | D |
| 39: Interchange 65 HOV | 405 | 34.4 | 12.9 | B |

| | | | | |
|---|---|---|---|---|
| 40: Interchange 65 Ln 3 | 1385 | 19.2 | 79.4 | F |
| 41: Interchange 65 Ln 2 | 1253 | 16.8 | 82.2 | F |
| 42: Interchange 65 Ln 1 | 1210 | 16.7 | 79.6 | F |
| 43: Interchange 61 HOV | 254 | 59.2 | 4.7 | A |
| 44: Interchange 61 Ln 3 | 1337 | 24.4 | 60.3 | F |
| 45: Interchange 61 Ln 2 | 1255 | 20.8 | 66.5 | F |
| 46: Interchange 61 Ln 1 | 1207 | 25.0 | 53.2 | F |
| 47: BEGIN HOV | 230 | 75.8 | 3.3 | A |
| 48: BEGIN Ln 4 | 1099 | 55.0 | 22.0 | C |
| 49: BEGIN Ln 3 | 1159 | 50.0 | 25.5 | C |
| 50: BEGIN Ln 2 | 1097 | 56.8 | 21.2 | C |
| 51: BEGIN Ln 1 | 1129 | 55.1 | 22.5 | C |

# APPENDIX G: DATA COLLECTION POINT RESULTS FOR PEAK HOUR FOR SOUTHBOUND I-65 NORTH OF NASHVILLE

Note: All level of service computations assume 1.1 passenger car equivalents per vehicle.

TABLE G.1 BASE YEAR DO NOTHING

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| Begin HOV | 807 | 68.1 | 13.0 | B |
| Begin Lane 4 | 1213 | 28.1 | 47.6 | F |
| Begin Lane 3 | 1211 | 27.1 | 49.1 | F |
| Begin Lane 2 | 1269 | 26.9 | 51.8 | F |
| Begin Lane 1 | 1251 | 25.9 | 53.2 | F |
| Exit 92 HOV | 425 | 69.0 | 6.8 | A |
| Exit 92 Lane 3 | 977 | 58.0 | 18.5 | C |
| Exit 92 Lane 2 | 813 | 52.4 | 17.1 | B |
| Exit 92 Lane 1 | 753 | 51.4 | 16.1 | B |
| MM 90 HOV | 733 | 66.2 | 12.2 | B |
| MM 90 Lane 2 | 1919 | 35.9 | 58.8 | F |
| MM 90 Lane 1 | 1600 | 32.7 | 53.8 | F |
| End HOV | 766 | 46.0 | 18.3 | C |
| End Lane 2 | 1747 | 25.9 | 74.1 | F |
| End Lane 1 | 1735 | 25.9 | 73.6 | F |

TABLE G.2 BASE YEAR LANE REVERSION

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| Begin HOV | 1172 | 60.2 | 21.4 | C |
| Begin Lane 4 | 1172 | 50.4 | 25.6 | C |
| Begin Lane 3 | 1235 | 52.4 | 25.9 | C |
| Begin Lane 2 | 1234 | 61.2 | 22.2 | C |
| Begin Lane 1 | 1202 | 62.8 | 21.0 | C |
| Exit 92 HOV | 950 | 62.9 | 16.6 | B |
| Exit 92 Lane 3 | 796 | 59.2 | 14.8 | B |
| Exit 92 Lane 2 | 672 | 56.9 | 13.0 | B |
| Exit 92 Lane 1 | 585 | 56.2 | 11.5 | B |
| MM 90 HOV | 1383 | 70.4 | 21.6 | C |
| MM 90 Lane 2 | 1444 | 66.4 | 23.9 | C |
| MM 90 Lane 1 | 1405 | 63.6 | 24.3 | C |
| End HOV | 1339 | 30.4 | 48.5 | F |
| End Lane 2 | 1457 | 26.5 | 60.5 | F |
| End Lane 1 | 1423 | 26.3 | 59.5 | F |

TABLE G.3: BASE YEAR HEAVY ENFORCEMENT

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| Begin HOV | 294 | 73.8 | 4.4 | A |
| Begin Lane 4 | 1238 | 19.0 | 71.7 | F |
| Begin Lane 3 | 1176 | 16.6 | 77.9 | F |
| Begin Lane 2 | 1238 | 17.2 | 79.2 | F |
| Begin Lane 1 | 1268 | 18.8 | 74.0 | F |
| Exit 92 HOV | 151 | 69.3 | 2.4 | A |
| Exit 92 Lane 3 | 905 | 14.1 | 70.6 | F |
| Exit 92 Lane 2 | 725 | 10.4 | 77.0 | F |
| Exit 92 Lane 1 | 637 | 12.0 | 58.4 | F |
| MM 90 HOV | 204 | 66.1 | 3.4 | A |
| MM 90 Lane 2 | 1946 | 36.1 | 59.3 | F |
| MM 90 Lane 1 | 1582 | 31.8 | 54.7 | F |
| End HOV | 224 | 67.2 | 3.7 | A |
| End Lane 2 | 1787 | 25.9 | 75.9 | F |
| End Lane 1 | 1729 | 25.9 | 73.5 | F |

TABLE G.4: FUTURE YEAR DO NOTHING

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| Begin HOV | 887 | 63.6 | 15.3 | B |
| Begin Lane 4 | 1158 | 11.5 | 110.6 | F |
| Begin Lane 3 | 1067 | 12.0 | 97.7 | F |
| Begin Lane 2 | 1106 | 14.5 | 83.9 | F |
| Begin Lane 1 | 1021 | 10.0 | 111.9 | F |
| Exit 92 HOV | 468 | 59.2 | 8.7 | A |
| Exit 92 Lane 3 | 915 | 19.2 | 52.3 | F |
| Exit 92 Lane 2 | 803 | 14.6 | 60.3 | F |
| Exit 92 Lane 1 | 713 | 15.0 | 52.1 | F |
| MM 90 HOV | 677 | 63.3 | 11.8 | B |
| MM 90 Lane 2 | 1988 | 35.9 | 60.9 | F |
| MM 90 Lane 1 | 1545 | 31.8 | 53.4 | F |
| End HOV | 707 | 48.0 | 16.2 | B |
| End Lane 2 | 1783 | 25.9 | 75.8 | F |
| End Lane 1 | 1725 | 25.9 | 73.2 | F |

TABLE G.5: FUTURE YEAR LANE REVERSION

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| Begin HOV | 1005 | 16.0 | 69.2 | F |
| Begin Lane 4 | 1061 | 12.7 | 92.2 | F |
| Begin Lane 3 | 1076 | 12.2 | 97.2 | F |
| Begin Lane 2 | 1074 | 13.4 | 88.1 | F |
| Begin Lane 1 | 1026 | 14.5 | 77.6 | F |
| Exit 92 HOV | 966 | 59.0 | 18.0 | B |
| Exit 92 Lane 3 | 839 | 56.4 | 16.4 | B |
| Exit 92 Lane 2 | 720 | 50.5 | 15.7 | B |
| Exit 92 Lane 1 | 643 | 49.4 | 14.3 | B |
| MM 90 HOV | 1758 | 63.5 | 30.5 | D |
| MM 90 Lane 2 | 1586 | 57.8 | 30.2 | D |
| MM 90 Lane 1 | 1528 | 55.3 | 30.4 | D |
| End HOV | 1679 | 31.2 | 59.1 | F |
| End Lane 2 | 1630 | 26.5 | 67.6 | F |
| End Lane 1 | 1600 | 26.3 | 66.9 | F |

TABLE G.6: FUTURE YEAR LANE REVERSION

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| Begin HOV | 241 | 72.9 | 3.6 | A |
| Begin Lane 4 | 957 | 11.2 | 94.3 | F |
| Begin Lane 3 | 941 | 12.1 | 85.6 | F |
| Begin Lane 2 | 954 | 13.2 | 79.7 | F |
| Begin Lane 1 | 972 | 13.0 | 82.2 | F |
| Exit 92 HOV | 109 | 70.0 | 1.7 | A |
| Exit 92 Lane 3 | 697 | 30.0 | 25.5 | C |
| Exit 92 Lane 2 | 611 | 25.3 | 26.6 | D |
| Exit 92 Lane 1 | 578 | 25.2 | 25.2 | C |
| MM 90 HOV | 177 | 67.3 | 2.9 | A |
| MM 90 Lane 2 | 1970 | 36.4 | 59.5 | F |
| MM 90 Lane 1 | 1560 | 32.2 | 53.3 | F |
| End HOV | 192 | 59.2 | 3.6 | A |
| End Lane 2 | 1787 | 25.9 | 75.8 | F |
| End Lane 1 | 1726 | 25.9 | 73.2 | F |

# APPENDIX H: DATA COLLECTION POINT RESULTS FOR PEAK HOUR FOR NORTHBOUND I-65 NORTH OF NASHVILLE

Note: All level of service computations assume 1.1 passenger car equivalents per vehicle.

TABLE H.1: BASE YEAR DO NOTHING

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| 1: Begin HOV | 834 | 63.0 | 14.6 | B |
| 2: Begin Lane 6 | 511 | 8.0 | 70.2 | F |
| 3: Begin Lane 5 | 519 | 7.7 | 74.0 | F |
| 4: Begin Lane 4 | 509 | 6.8 | 82.2 | F |
| 5: Begin Lane 3 | 589 | 6.5 | 99.2 | F |
| 6: Begin Lane 2 | 801 | 10.1 | 87.2 | F |
| 7: Begin Lane 1 | 994 | 11.0 | 99.6 | F |
| 8: Exit 92 HOV | 842 | 63.0 | 14.7 | B |
| 9: Exit 92 Lane 4 | 534 | 6.6 | 89.0 | F |
| 10: Exit 92 Lane 3 | 573 | 8.6 | 73.7 | F |
| 11: Exit 92 Lane 2 | 451 | 9.8 | 50.8 | F |
| 12: Exit 92 Lane 1 | 311 | 3.4 | 100.3 | F |
| 13: Alta Loma HOV | 884 | 46.0 | 21.1 | C |
| 14: Alta Loma Lane 4 | 590 | 6.8 | 95.7 | F |
| 15: Alta Loma Lane 3 | 390 | 4.4 | 97.7 | F |
| 16: Alta Loma Lane 2 | 487 | 5.2 | 103.6 | F |
| 17: Alta Loma Lane 1 | 787 | 11.0 | 79.0 | F |
| 18: End HOV | 685 | 9.8 | 76.7 | F |
| 19: End Lane 4 | 636 | 5.4 | 130.8 | F |
| 20: End Lane 3 | 505 | 4.5 | 124.6 | F |
| 21: End Lane 2 | 580 | 5.1 | 124.6 | F |
| 22: End Lane 1 | 734 | 8.0 | 101.1 | F |

TABLE H.2 BASE YEAR LANE REVERSION

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| 1: Begin HOV | 594 | 10.8 | 55.1 | F |
| 2: Begin Lane 6 | 614 | 8.6 | 71.1 | F |
| 3: Begin Lane 5 | 642 | 9.2 | 69.6 | F |
| 4: Begin Lane 4 | 590 | 9.8 | 60.3 | F |
| 5: Begin Lane 3 | 681 | 8.4 | 81.3 | F |
| 6: Begin Lane 2 | 867 | 9.7 | 89.8 | F |
| 7: Begin Lane 1 | 1070 | 15.7 | 68.2 | F |
| 8: Exit 92 HOV | 556 | 8.5 | 65.3 | F |
| 9: Exit 92 Lane 4 | 556 | 6.2 | 89.5 | F |
| 10: Exit 92 Lane 3 | 613 | 10.1 | 60.5 | F |
| 11: Exit 92 Lane 2 | 534 | 10.7 | 50.0 | F |
| 12: Exit 92 Lane 1 | 393 | 4.0 | 99.5 | F |
| 13: Alta Loma HOV | 913 | 11.9 | 76.5 | F |
| 14: Alta Loma Lane 4 | 649 | 8.1 | 80.3 | F |
| 15: Alta Loma Lane 3 | 356 | 3.9 | 92.5 | F |
| 16: Alta Loma Lane 2 | 433 | 4.9 | 88.9 | F |
| 17: Alta Loma Lane 1 | 807 | 7.3 | 109.9 | F |
| 18: End HOV | 897 | 11.7 | 76.5 | F |
| 19: End Lane 4 | 573 | 3.7 | 153.6 | F |
| 20: End Lane 3 | 470 | 3.8 | 122.4 | F |
| 21: End Lane 2 | 555 | 5.3 | 105.1 | F |
| 22: End Lane 1 | 693 | 8.4 | 82.5 | F |

TABLE H.3: BASE YEAR HEAVY ENFORCEMENT

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| 1: Begin HOV | 594 | 10.8 | 55.1 | F |
| 2: Begin Lane 6 | 614 | 8.6 | 71.1 | F |
| 3: Begin Lane 5 | 642 | 9.2 | 69.6 | F |
| 4: Begin Lane 4 | 590 | 9.8 | 60.3 | F |
| 5: Begin Lane 3 | 681 | 8.4 | 81.3 | F |
| 6: Begin Lane 2 | 867 | 9.7 | 89.8 | F |
| 7: Begin Lane 1 | 1070 | 15.7 | 68.2 | F |
| 8: Exit 92 HOV | 556 | 8.5 | 65.3 | F |
| 9: Exit 92 Lane 4 | 556 | 6.2 | 89.5 | F |
| 10: Exit 92 Lane 3 | 613 | 10.1 | 60.5 | F |
| 11: Exit 92 Lane 2 | 534 | 10.7 | 50.0 | F |
| 12: Exit 92 Lane 1 | 393 | 4.0 | 99.5 | F |
| 13: Alta Loma HOV | 913 | 11.9 | 76.5 | F |
| 14: Alta Loma Lane 4 | 649 | 8.1 | 80.3 | F |
| 15: Alta Loma Lane 3 | 356 | 3.9 | 92.5 | F |
| 16: Alta Loma Lane 2 | 433 | 4.9 | 88.9 | F |
| 17: Alta Loma Lane 1 | 807 | 7.3 | 109.9 | F |
| 18: End HOV | 897 | 11.7 | 76.5 | F |
| 19: End Lane 4 | 573 | 3.7 | 153.6 | F |
| 20: End Lane 3 | 470 | 3.8 | 122.4 | F |
| 21: End Lane 2 | 555 | 5.3 | 105.1 | F |
| 22: End Lane 1 | 693 | 8.4 | 82.5 | F |

TABLE H.4: FUTURE YEAR DO NOTHING

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| 1: Begin HOV | 831 | 65.85 | 12.6 | B |
| 2: Begin Lane 6 | 495 | 6.33 | 78.2 | F |
| 3: Begin Lane 5 | 489 | 6.54 | 74.8 | F |
| 4: Begin Lane 4 | 494 | 7.92 | 62.4 | F |
| 5: Begin Lane 3 | 547 | 5.41 | 101.1 | F |
| 6: Begin Lane 2 | 815 | 7.58 | 107.5 | F |
| 7: Begin Lane 1 | 1047 | 10.95 | 95.6 | F |
| 8: Exit 92 HOV | 837 | 65.19 | 12.8 | B |
| 9: Exit 92 Lane 4 | 510 | 8.26 | 61.7 | F |
| 10: Exit 92 Lane 3 | 564 | 8.15 | 69.2 | F |
| 11: Exit 92 Lane 2 | 522 | 9.72 | 53.7 | F |
| 12: Exit 92 Lane 1 | 319 | 3.53 | 90.3 | F |
| 13: Alta Loma HOV | 917 | 29.03 | 31.5 | D |
| 14: Alta Loma Lane 4 | 621 | 6.21 | 100.0 | F |
| 15: Alta Loma Lane 3 | 432 | 5.07 | 85.2 | F |
| 16: Alta Loma Lane 2 | 498 | 6.24 | 79.8 | F |
| 17: Alta Loma Lane 1 | 862 | 11.42 | 75.4 | F |
| 18: End HOV | 719 | 10.13 | 70.9 | F |
| 19: End Lane 4 | 675 | 6.04 | 111.7 | F |
| 20: End Lane 3 | 557 | 4.84 | 115.0 | F |
| 21: End Lane 2 | 612 | 5.56 | 110.0 | F |
| 22: End Lane 1 | 766 | 9.02 | 84.9 | F |

TABLE H.5 FUTURE YEAR LANE REVERSION

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| 1: Begin HOV | 498 | 4.89 | 101.8 | F |
| 2: Begin Lane 6 | 582 | 6.96 | 83.6 | F |
| 3: Begin Lane 5 | 607 | 6.46 | 93.9 | F |
| 4: Begin Lane 4 | 547 | 6.47 | 84.5 | F |
| 5: Begin Lane 3 | 587 | 6.74 | 87.0 | F |
| 6: Begin Lane 2 | 858 | 10.83 | 79.2 | F |
| 7: Begin Lane 1 | 1077 | 10.74 | 100.2 | F |
| 8: Exit 92 HOV | 537 | 7.82 | 68.6 | F |
| 9: Exit 92 Lane 4 | 655 | 10.42 | 62.8 | F |
| 10: Exit 92 Lane 3 | 661 | 8.41 | 78.5 | F |
| 11: Exit 92 Lane 2 | 629 | 8.79 | 71.5 | F |
| 12: Exit 92 Lane 1 | 440 | 4.56 | 96.4 | F |
| 13: Alta Loma HOV | 1051 | 12.89 | 81.5 | F |
| 14: Alta Loma Lane 4 | 732 | 8.33 | 87.8 | F |
| 15: Alta Loma Lane 3 | 384 | 4.15 | 92.5 | F |
| 16: Alta Loma Lane 2 | 438 | 5.07 | 86.3 | F |
| 17: Alta Loma Lane 1 | 814 | 11.02 | 73.8 | F |
| 18: End HOV | 1107 | 11.87 | 93.2 | F |
| 19: End Lane 4 | 560 | 5.00 | 112.0 | F |
| 20: End Lane 3 | 464 | 4.51 | 102.8 | F |
| 21: End Lane 2 | 579 | 5.43 | 106.6 | F |
| 22: End Lane 1 | 724 | 8.15 | 88.8 | F |

TABLE H.6: FUTURE YEAR HEAVY ENFORCEMENT

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| 1: Begin HOV | 273 | 71.3 | 3.8 | A |
| 2: Begin Lane 6 | 571 | 7.75 | 73.6 | F |
| 3: Begin Lane 5 | 587 | 8.25 | 71.1 | F |
| 4: Begin Lane 4 | 621 | 7.71 | 80.5 | F |
| 5: Begin Lane 3 | 676 | 7.31 | 92.5 | F |
| 6: Begin Lane 2 | 907 | 8.60 | 105.5 | F |
| 7: Begin Lane 1 | 1097 | 12.71 | 86.3 | F |
| 8: Exit 92 HOV | 285 | 69.79 | 4.1 | A |
| 9: Exit 92 Lane 4 | 652 | 9.71 | 67.1 | F |
| 10: Exit 92 Lane 3 | 700 | 8.19 | 85.5 | F |
| 11: Exit 92 Lane 2 | 666 | 10.04 | 66.3 | F |
| 12: Exit 92 Lane 1 | 529 | 6.02 | 87.9 | F |
| 13: Alta Loma HOV | 281 | 66.55 | 4.2 | A |
| 14: Alta Loma Lane 4 | 940 | 12.01 | 78.3 | F |
| 15: Alta Loma Lane 3 | 670 | 7.23 | 92.7 | F |
| 16: Alta Loma Lane 2 | 608 | 7.38 | 82.4 | F |
| 17: Alta Loma Lane 1 | 913 | 8.74 | 104.4 | F |
| 18: End HOV | 271 | 20.77 | 13.0 | B |
| 19: End Lane 4 | 981 | 10.38 | 94.5 | F |
| 20: End Lane 3 | 720 | 7.27 | 99.0 | F |
| 21: End Lane 2 | 667 | 6.36 | 104.9 | F |
| 22: End Lane 1 | 756 | 9.44 | 80.1 | F |

# APPENDIX I: DATA COLLECTION POINT RESULTS FOR PEAK HOUR FOR EASTBOUND I-24

## TABLE I.1: BASE YEAR DO NOTHING

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| 1: Begin HOV | 607 | 69.3 | 9.6 | A |
| 2: Begin Lane 3 | 833 | 12.0 | 76.3 | F |
| 3: Begin Lane 2 | 922 | 9.3 | 109.3 | F |
| 4: Begin Lane 1 | 927 | 13.4 | 76.3 | F |
| 5: Exit 57 HOV | 547 | 55.8 | 10.8 | A |
| 6: Exit 57 Lane 3 | 988 | 16.1 | 67.5 | F |
| 7: Exit 57 Lane 2 | 990 | 13.5 | 80.5 | F |
| 8: Exit 57 Lane 1 | 913 | 13.6 | 74.0 | F |
| 9: Exit 59 HOV | 376 | 62.5 | 6.6 | A |
| 10: Exit 59 Lane 3 | 1061 | 57.7 | 20.2 | C |
| 11: Exit 59 Lane 2 | 944 | 50.5 | 20.6 | C |
| 12: Exit 59 Lane 1 | 874 | 50.0 | 19.2 | C |
| 13: Exit 60 HOV | 376 | 72.1 | 5.7 | A |
| 14: Exit 60 Lane 3 | 1102 | 67.5 | 18.0 | B |
| 15: Exit 60 Lane 2 | 938 | 63.0 | 16.4 | B |
| 16: Exit 60 Lane 1 | 873 | 61.8 | 15.5 | B |
| 17: Exit 62 HOV | 368 | 71.7 | 5.6 | A |
| 18: Exit 62 Lane 3 | 1027 | 67.8 | 16.7 | B |
| 19: Exit 62 Lane 2 | 875 | 61.2 | 15.7 | B |
| 20: Exit 62 Lane 1 | 839 | 60.9 | 15.2 | B |
| 21: Exit 64 HOV | 378 | 65.6 | 6.3 | A |
| 22: Exit 64 Lane 3 | 910 | 54.6 | 18.3 | C |
| 23: Exit 64 Lane 2 | 842 | 49.1 | 18.9 | C |
| 24: Exit 64 Lane 1 | 815 | 48.2 | 18.6 | C |
| 25: Exit 66 HOV | 373 | 66.6 | 6.2 | A |
| 26: Exit 66 Lane 3 | 904 | 52.7 | 18.9 | C |
| 27: Exit 66 Lane 2 | 804 | 47.1 | 18.8 | C |
| 28: Exit 66 Lane 1 | 698 | 45.7 | 16.8 | B |
| 29: Exit 70 HOV | 386 | 74.1 | 5.7 | A |
| 30: Exit 70 Lane 3 | 969 | 69.7 | 15.3 | B |
| 31: Exit 70 Lane 2 | 884 | 66.6 | 14.6 | B |
| 32: Exit 70 Lane 1 | 768 | 65.6 | 12.9 | B |
| 33: Exit 74 HOV | 435 | 71.8 | 6.7 | A |
| 34: Exit 74 Lane 3 | 1143 | 65.5 | 19.2 | C |
| 35: Exit 74 Lane 2 | 952 | 59.4 | 17.6 | B |
| 36: Exit 74 Lane 1 | 829 | 57.5 | 15.8 | B |
| 37: Exit 76 HOV | 356 | 74.2 | 5.3 | A |
| 38: Exit 76 Lane 3 | 1000 | 72.1 | 15.3 | B |
| 39: Exit 76 Lane 2 | 954 | 70.0 | 15.0 | B |

| | | | | |
|---|---|---|---|---|
| 40: Exit 76 Lane 1 | 764 | 69.9 | 12.0 | B |
| 41: Exit 78 HOV | 309 | 74.9 | 4.5 | A |
| 42: Exit 78 Lane 3 | 785 | 71.7 | 12.0 | B |
| 43: Exit 78 Lane 2 | 779 | 69.4 | 12.4 | B |
| 44: Exit 78 Lane 1 | 562 | 69.2 | 8.9 | A |
| 45: End HOV | 306 | 75.0 | 4.5 | A |
| 46: End Lane 3 | 869 | 73.9 | 12.9 | B |
| 47: End Lane 2 | 954 | 72.6 | 14.5 | B |
| 48: End Lane 1 | 911 | 71.5 | 14.0 | B |

TABLE I.2: BASE YEAR LANE REVERSION

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| 1: Begin HOV | 981 | 14.6 | 67.0 | F |
| 2: Begin Lane 3 | 901 | 9.4 | 96.0 | F |
| 3: Begin Lane 2 | 919 | 9.4 | 98.0 | F |
| 4: Begin Lane 1 | 990 | 13.2 | 75.1 | F |
| 5: Exit 57 HOV | 924 | 13.1 | 70.6 | F |
| 6: Exit 57 Lane 3 | 1010 | 14.4 | 70.2 | F |
| 7: Exit 57 Lane 2 | 970 | 12.6 | 77.2 | F |
| 8: Exit 57 Lane 1 | 825 | 9.6 | 85.8 | F |
| 9: Exit 59 HOV | 934 | 59.1 | 15.8 | B |
| 10: Exit 59 Lane 3 | 914 | 57.5 | 15.9 | B |
| 11: Exit 59 Lane 2 | 781 | 50.7 | 15.4 | B |
| 12: Exit 59 Lane 1 | 745 | 50.7 | 14.7 | B |
| 13: Exit 60 HOV | 1018 | 69.4 | 14.7 | B |
| 14: Exit 60 Lane 3 | 924 | 69.0 | 13.4 | B |
| 15: Exit 60 Lane 2 | 743 | 63.6 | 11.7 | B |
| 16: Exit 60 Lane 1 | 693 | 62.4 | 11.1 | B |
| 17: Exit 62 HOV | 847 | 69.7 | 12.1 | B |
| 18: Exit 62 Lane 3 | 791 | 68.6 | 11.5 | B |
| 19: Exit 62 Lane 2 | 668 | 61.9 | 10.8 | A |
| 20: Exit 62 Lane 1 | 666 | 62.3 | 10.7 | A |
| 21: Exit 64 HOV | 779 | 57.7 | 13.5 | B |
| 22: Exit 64 Lane 3 | 772 | 56.3 | 13.7 | B |
| 23: Exit 64 Lane 2 | 663 | 49.2 | 13.5 | B |
| 24: Exit 64 Lane 1 | 626 | 48.7 | 12.9 | B |
| 25: Exit 66 HOV | 807 | 53.7 | 15.0 | B |
| 26: Exit 66 Lane 3 | 761 | 52.0 | 14.6 | B |
| 27: Exit 66 Lane 2 | 636 | 45.7 | 13.9 | B |
| 28: Exit 66 Lane 1 | 543 | 44.1 | 12.3 | B |
| 29: Exit 70 HOV | 829 | 71.9 | 11.5 | B |
| 30: Exit 70 Lane 3 | 896 | 72.1 | 12.4 | B |
| 31: Exit 70 Lane 2 | 672 | 68.3 | 9.8 | A |
| 32: Exit 70 Lane 1 | 593 | 67.5 | 8.8 | A |
| 33: Exit 74 HOV | 1009 | 70.8 | 14.3 | B |
| 34: Exit 74 Lane 3 | 1024 | 70.2 | 14.6 | B |
| 35: Exit 74 Lane 2 | 705 | 64.3 | 11.0 | A |
| 36: Exit 74 Lane 1 | 616 | 63.4 | 9.7 | A |
| 37: Exit 76 HOV | 864 | 72.4 | 11.9 | B |
| 38: Exit 76 Lane 3 | 912 | 72.2 | 12.6 | B |
| 39: Exit 76 Lane 2 | 761 | 71.0 | 10.7 | A |

| | | | | |
|---|---|---|---|---|
| 40: Exit 76 Lane 1 | 610 | 70.0 | 8.7 | A |
| 41: Exit 78 HOV | 690 | 71.4 | 9.7 | A |
| 42: Exit 78 Lane 3 | 773 | 71.2 | 10.9 | A |
| 43: Exit 78 Lane 2 | 632 | 69.7 | 9.1 | A |
| 44: Exit 78 Lane 1 | 481 | 67.7 | 7.1 | A |
| 45: End HOV | 709 | 73.6 | 9.6 | A |
| 46: End Lane 3 | 835 | 73.3 | 11.4 | B |
| 47: End Lane 2 | 802 | 73.2 | 11.0 | A |
| 48: End Lane 1 | 827 | 71.6 | 11.5 | B |

# TABLE I.3: BASE YEAR HEAVY ENFORCEMENT

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| 1: Begin HOV | 215 | 74.7 | 2.9 | A |
| 2: Begin Lane 3 | 1054 | 15.8 | 66.5 | F |
| 3: Begin Lane 2 | 1141 | 15.4 | 74.2 | F |
| 4: Begin Lane 1 | 1267 | 18.3 | 69.2 | F |
| 5: Exit 57 HOV | 183 | 68.4 | 2.7 | A |
| 6: Exit 57 Lane 3 | 1143 | 19.3 | 59.2 | F |
| 7: Exit 57 Lane 2 | 1144 | 16.7 | 68.4 | F |
| 8: Exit 57 Lane 1 | 1081 | 15.1 | 71.7 | F |
| 9: Exit 59 HOV | 150 | 67.4 | 2.2 | A |
| 10: Exit 59 Lane 3 | 1175 | 57.6 | 20.4 | C |
| 11: Exit 59 Lane 2 | 1089 | 50.9 | 21.4 | C |
| 12: Exit 59 Lane 1 | 1022 | 50.6 | 20.2 | C |
| 13: Exit 60 HOV | 151 | 73.6 | 2.1 | A |
| 14: Exit 60 Lane 3 | 1224 | 66.3 | 18.5 | C |
| 15: Exit 60 Lane 2 | 1053 | 62.5 | 16.9 | B |
| 16: Exit 60 Lane 1 | 1007 | 62.2 | 16.2 | B |
| 17: Exit 62 HOV | 148 | 74.2 | 2.0 | A |
| 18: Exit 62 Lane 3 | 1141 | 67.6 | 16.9 | B |
| 19: Exit 62 Lane 2 | 965 | 61.7 | 15.6 | B |
| 20: Exit 62 Lane 1 | 900 | 60.7 | 14.8 | B |
| 21: Exit 64 HOV | 140 | 71.2 | 2.0 | A |
| 22: Exit 64 Lane 3 | 1055 | 55.1 | 19.1 | C |
| 23: Exit 64 Lane 2 | 931 | 49.2 | 18.9 | C |
| 24: Exit 64 Lane 1 | 896 | 48.7 | 18.4 | C |
| 25: Exit 66 HOV | 118 | 68.6 | 1.7 | A |
| 26: Exit 66 Lane 3 | 1011 | 53.1 | 19.0 | C |
| 27: Exit 66 Lane 2 | 935 | 48.9 | 19.1 | C |
| 28: Exit 66 Lane 1 | 761 | 46.5 | 16.4 | B |
| 29: Exit 70 HOV | 134 | 74.5 | 1.8 | A |
| 30: Exit 70 Lane 3 | 1041 | 69.1 | 15.1 | B |
| 31: Exit 70 Lane 2 | 1018 | 67.1 | 15.2 | B |
| 32: Exit 70 Lane 1 | 870 | 66.2 | 13.2 | B |
| 33: Exit 74 HOV | 150 | 72.7 | 2.1 | A |
| 34: Exit 74 Lane 3 | 1251 | 64.3 | 19.4 | C |
| 35: Exit 74 Lane 2 | 1087 | 60.8 | 17.9 | B |
| 36: Exit 74 Lane 1 | 955 | 59.1 | 16.2 | B |
| 37: Exit 76 HOV | 136 | 74.0 | 1.8 | A |

| | | | | |
|---|---|---|---|---|
| 38: Exit 76 Lane 3 | 1062 | 71.8 | 14.8 | B |
| 39: Exit 76 Lane 2 | 1051 | 69.3 | 15.2 | B |
| 40: Exit 76 Lane 1 | 864 | 69.3 | 12.5 | B |
| 41: Exit 78 HOV | 120 | 73.3 | 1.6 | A |
| 42: Exit 78 Lane 3 | 843 | 71.7 | 11.8 | B |
| 43: Exit 78 Lane 2 | 820 | 69.5 | 11.8 | B |
| 44: Exit 78 Lane 1 | 630 | 69.1 | 9.1 | A |
| 45: End HOV | 126 | 74.4 | 1.7 | A |
| 46: End Lane 3 | 954 | 73.2 | 13.0 | B |
| 47: End Lane 2 | 962 | 71.5 | 13.5 | B |
| 48: End Lane 1 | 987 | 71.4 | 13.8 | B |

TABLE I.4: FUTURE YEAR DO NOTHING

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| 1: Begin HOV | 599 | 68.9 | 8.7 | A |
| 2: Begin Lane 3 | 901 | 13.7 | 66.0 | F |
| 3: Begin Lane 2 | 891 | 11.0 | 81.2 | F |
| 4: Begin Lane 1 | 978 | 12.9 | 75.6 | F |
| 5: Exit 57 HOV | 540 | 58.5 | 9.2 | A |
| 6: Exit 57 Lane 3 | 1012 | 11.6 | 87.5 | F |
| 7: Exit 57 Lane 2 | 974 | 12.8 | 76.3 | F |
| 8: Exit 57 Lane 1 | 911 | 12.5 | 72.8 | F |
| 9: Exit 59 HOV | 413 | 63.5 | 6.5 | A |
| 10: Exit 59 Lane 3 | 1071 | 57.6 | 18.6 | C |
| 11: Exit 59 Lane 2 | 935 | 50.5 | 18.5 | C |
| 12: Exit 59 Lane 1 | 894 | 50.2 | 17.8 | B |
| 13: Exit 60 HOV | 395 | 70.9 | 5.6 | A |
| 14: Exit 60 Lane 3 | 1110 | 62.4 | 17.8 | B |
| 15: Exit 60 Lane 2 | 977 | 58.3 | 16.7 | B |
| 16: Exit 60 Lane 1 | 896 | 57.2 | 15.7 | B |
| 17: Exit 62 HOV | 383 | 69.9 | 5.5 | A |
| 18: Exit 62 Lane 3 | 980 | 68.0 | 14.4 | B |
| 19: Exit 62 Lane 2 | 841 | 62.3 | 13.5 | B |
| 20: Exit 62 Lane 1 | 804 | 62.2 | 12.9 | B |
| 21: Exit 64 HOV | 411 | 61.6 | 6.7 | A |
| 22: Exit 64 Lane 3 | 996 | 54.0 | 18.4 | C |
| 23: Exit 64 Lane 2 | 889 | 48.1 | 18.5 | C |
| 24: Exit 64 Lane 1 | 844 | 48.1 | 17.5 | B |
| 25: Exit 66 HOV | 416 | 62.9 | 6.6 | A |
| 26: Exit 66 Lane 3 | 961 | 49.9 | 19.3 | C |
| 27: Exit 66 Lane 2 | 867 | 44.9 | 19.3 | C |
| 28: Exit 66 Lane 1 | 777 | 43.7 | 17.8 | B |
| 29: Exit 70 HOV | 454 | 71.9 | 6.3 | A |
| 30: Exit 70 Lane 3 | 1084 | 68.4 | 15.8 | B |
| 31: Exit 70 Lane 2 | 944 | 64.8 | 14.6 | B |
| 32: Exit 70 Lane 1 | 884 | 64.3 | 13.8 | B |
| 33: Exit 74 HOV | 555 | 69.9 | 7.9 | A |
| 34: Exit 74 Lane 3 | 1345 | 62.0 | 21.7 | C |
| 35: Exit 74 Lane 2 | 1100 | 56.9 | 19.3 | C |
| 36: Exit 74 Lane 1 | 962 | 55.6 | 17.3 | B |
| 37: Exit 76 HOV | 448 | 72.3 | 6.2 | A |
| 38: Exit 76 Lane 3 | 1184 | 71.1 | 16.7 | B |
| 39: Exit 76 Lane 2 | 1053 | 68.5 | 15.4 | B |

| | | | | |
|---|---|---|---|---|
| 40: Exit 76 Lane 1 | 899 | 68.6 | 13.1 | B |
| 41: Exit 78 HOV | 344 | 72.5 | 4.7 | A |
| 42: Exit 78 Lane 3 | 941 | 70.2 | 13.4 | B |
| 43: Exit 78 Lane 2 | 866 | 67.2 | 12.9 | B |
| 44: Exit 78 Lane 1 | 666 | 65.9 | 10.1 | A |
| 45: End HOV | 363 | 74.1 | 4.9 | A |
| 46: End Lane 3 | 1042 | 73.5 | 14.2 | B |
| 47: End Lane 2 | 1086 | 71.8 | 15.1 | B |
| 48: End Lane 1 | 1095 | 71.1 | 15.4 | B |

TABLE I.5: FUTURE YEAR LANE REVERSION

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| 1: Begin HOV | 928 | 13.1 | 70.6 | F |
| 2: Begin Lane 3 | 928 | 12.7 | 72.8 | F |
| 3: Begin Lane 2 | 916 | 11.3 | 81.1 | F |
| 4: Begin Lane 1 | 899 | 11.4 | 79.1 | F |
| 5: Exit 57 HOV | 915 | 13.3 | 69.0 | F |
| 6: Exit 57 Lane 3 | 1021 | 12.5 | 81.6 | F |
| 7: Exit 57 Lane 2 | 992 | 12.3 | 80.5 | F |
| 8: Exit 57 Lane 1 | 774 | 10.6 | 72.7 | F |
| 9: Exit 59 HOV | 952 | 59.0 | 16.1 | B |
| 10: Exit 59 Lane 3 | 944 | 57.1 | 16.5 | B |
| 11: Exit 59 Lane 2 | 776 | 50.0 | 15.5 | B |
| 12: Exit 59 Lane 1 | 734 | 49.8 | 14.8 | B |
| 13: Exit 60 HOV | 992 | 68.6 | 14.5 | B |
| 14: Exit 60 Lane 3 | 961 | 68.3 | 14.1 | B |
| 15: Exit 60 Lane 2 | 799 | 63.2 | 12.6 | B |
| 16: Exit 60 Lane 1 | 733 | 62.3 | 11.8 | B |
| 17: Exit 62 HOV | 831 | 69.8 | 11.9 | B |
| 18: Exit 62 Lane 3 | 818 | 68.9 | 11.9 | B |
| 19: Exit 62 Lane 2 | 681 | 61.7 | 11.0 | B |
| 20: Exit 62 Lane 1 | 672 | 61.3 | 11.0 | A |
| 21: Exit 64 HOV | 809 | 56.1 | 14.4 | B |
| 22: Exit 64 Lane 3 | 800 | 54.8 | 14.6 | B |
| 23: Exit 64 Lane 2 | 738 | 48.4 | 15.3 | B |
| 24: Exit 64 Lane 1 | 641 | 48.0 | 13.4 | B |
| 25: Exit 66 HOV | 858 | 53.1 | 16.2 | B |
| 26: Exit 66 Lane 3 | 792 | 50.7 | 15.6 | B |
| 27: Exit 66 Lane 2 | 694 | 44.0 | 15.8 | B |
| 28: Exit 66 Lane 1 | 580 | 43.7 | 13.3 | B |
| 29: Exit 70 HOV | 914 | 70.2 | 13.0 | B |
| 30: Exit 70 Lane 3 | 906 | 70.1 | 12.9 | B |
| 31: Exit 70 Lane 2 | 737 | 66.1 | 11.1 | B |
| 32: Exit 70 Lane 1 | 672 | 64.7 | 10.4 | A |
| 33: Exit 74 HOV | 1171 | 66.1 | 17.7 | B |
| 34: Exit 74 Lane 3 | 1085 | 65.4 | 16.6 | B |
| 35: Exit 74 Lane 2 | 824 | 59.5 | 13.8 | B |
| 36: Exit 74 Lane 1 | 760 | 58.0 | 13.1 | B |
| 37: Exit 76 HOV | 1033 | 71.3 | 14.5 | B |
| 38: Exit 76 Lane 3 | 1006 | 71.1 | 14.1 | B |
| 39: Exit 76 Lane 2 | 823 | 69.2 | 11.9 | B |

| | | | | |
|---|---|---|---|---|
| 40: Exit 76 Lane 1 | 718 | 68.6 | 10.5 | A |
| 41: Exit 78 HOV | 840 | 69.8 | 12.0 | B |
| 42: Exit 78 Lane 3 | 858 | 69.8 | 12.3 | B |
| 43: Exit 78 Lane 2 | 668 | 67.0 | 10.0 | A |
| 44: Exit 78 Lane 1 | 570 | 66.3 | 8.6 | A |
| 45: End HOV | 846 | 72.7 | 11.6 | B |
| 46: End Lane 3 | 958 | 73.2 | 13.1 | B |
| 47: End Lane 2 | 899 | 73.4 | 12.2 | B |
| 48: End Lane 1 | 997 | 71.7 | 13.9 | B |

## TABLE I.6: FUTURE YEAR HEAVY ENFORCEMENT

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| 1: Begin HOV | 170 | 75.4 | 2.3 | A |
| 2: Begin Lane 3 | 948 | 14.9 | 63.5 | F |
| 3: Begin Lane 2 | 965 | 13.7 | 70.5 | F |
| 4: Begin Lane 1 | 1086 | 14.3 | 76.0 | F |
| 5: Exit 57 HOV | 158 | 72.0 | 2.2 | A |
| 6: Exit 57 Lane 3 | 1076 | 15.0 | 71.8 | F |
| 7: Exit 57 Lane 2 | 1100 | 16.1 | 68.2 | F |
| 8: Exit 57 Lane 1 | 996 | 13.6 | 73.1 | F |
| 9: Exit 59 HOV | 134 | 68.1 | 2.0 | A |
| 10: Exit 59 Lane 3 | 1182 | 57.4 | 20.6 | C |
| 11: Exit 59 Lane 2 | 1065 | 51.3 | 20.8 | C |
| 12: Exit 59 Lane 1 | 972 | 50.4 | 19.3 | C |
| 13: Exit 60 HOV | 146 | 72.4 | 2.0 | A |
| 14: Exit 60 Lane 3 | 1225 | 65.0 | 18.8 | C |
| 15: Exit 60 Lane 2 | 1044 | 59.7 | 17.5 | B |
| 16: Exit 60 Lane 1 | 977 | 58.9 | 16.6 | B |
| 17: Exit 62 HOV | 169 | 72.9 | 2.3 | A |
| 18: Exit 62 Lane 3 | 1161 | 67.0 | 17.3 | B |
| 19: Exit 62 Lane 2 | 1004 | 61.6 | 16.3 | B |
| 20: Exit 62 Lane 1 | 923 | 59.8 | 15.4 | B |
| 21: Exit 64 HOV | 166 | 70.1 | 2.4 | A |
| 22: Exit 64 Lane 3 | 1041 | 54.6 | 19.1 | C |
| 23: Exit 64 Lane 2 | 965 | 48.3 | 20.0 | C |
| 24: Exit 64 Lane 1 | 937 | 48.8 | 19.2 | C |
| 25: Exit 66 HOV | 164 | 69.9 | 2.3 | A |
| 26: Exit 66 Lane 3 | 1079 | 50.5 | 21.4 | C |
| 27: Exit 66 Lane 2 | 947 | 45.3 | 20.9 | C |
| 28: Exit 66 Lane 1 | 848 | 44.6 | 19.0 | C |
| 29: Exit 70 HOV | 175 | 74.8 | 2.3 | A |
| 30: Exit 70 Lane 3 | 1160 | 67.6 | 17.2 | B |
| 31: Exit 70 Lane 2 | 1079 | 64.4 | 16.8 | B |
| 32: Exit 70 Lane 1 | 929 | 63.0 | 14.7 | B |
| 33: Exit 74 HOV | 186 | 73.0 | 2.5 | A |
| 34: Exit 74 Lane 3 | 1399 | 57.8 | 24.2 | C |
| 35: Exit 74 Lane 2 | 1210 | 52.9 | 22.9 | C |
| 36: Exit 74 Lane 1 | 1080 | 50.7 | 21.3 | C |
| 37: Exit 76 HOV | 171 | 74.0 | 2.3 | A |
| 38: Exit 76 Lane 3 | 1236 | 70.1 | 17.6 | B |
| 39: Exit 76 Lane 2 | 1136 | 68.1 | 16.7 | B |

| | | | | |
|---|---|---|---|---|
| 40: Exit 76 Lane 1 | 995 | 68.0 | 14.6 | B |
| 41: Exit 78 HOV | 136 | 73.9 | 1.8 | A |
| 42: Exit 78 Lane 3 | 935 | 68.9 | 13.6 | B |
| 43: Exit 78 Lane 2 | 918 | 66.3 | 13.9 | B |
| 44: Exit 78 Lane 1 | 725 | 65.5 | 11.1 | B |
| 45: End HOV | 139 | 74.6 | 1.9 | A |
| 46: End Lane 3 | 1077 | 72.6 | 14.8 | B |
| 47: End Lane 2 | 1127 | 71.4 | 15.8 | B |
| 48: End Lane 1 | 1144 | 70.8 | 16.2 | B |

# APPENDIX J: DATA COLLECTION POINTS FOR PEAK HOUR FOR WESTBOUND I-24

Note: All level of service computations assume 1.1 passenger car equivalents per vehicle.

TABLE J.1: BASE YEAR DO NOTHING

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| 1: Begin HOV | 239 | 74.2 | 3.5 | A |
| 2: Begin Lane 3 | 1290 | 15.9 | 89.5 | F |
| 3: Begin Lane 2 | 1213 | 13.7 | 97.2 | F |
| 4: Begin Lane 1 | 1234 | 12.8 | 106.3 | F |
| 5: Exit 80 HOV | 212 | 72.6 | 3.2 | A |
| 6: Exit 80 Lane 3 | 1308 | 20.3 | 70.9 | F |
| 7: Exit 80 Lane 2 | 1310 | 19.0 | 75.9 | F |
| 8: Exit 80 Lane 1 | 1164 | 19.8 | 64.8 | F |
| 9: Exit 78 HOV | 208 | 67.1 | 3.4 | A |
| 10: Exit 78 Lane 3 | 1338 | 21.9 | 67.3 | F |
| 11: Exit 78 Lane 2 | 1286 | 21.7 | 65.3 | F |
| 12: Exit 78 Lane 1 | 1282 | 22.2 | 63.5 | F |
| 13: Exit 76 HOV | 199 | 70.9 | 3.1 | A |
| 14: Exit 76 Lane 3 | 1575 | 66.8 | 25.9 | C |
| 15: Exit 76 Lane 2 | 1235 | 59.5 | 22.8 | C |
| 16: Exit 76 Lane 1 | 1249 | 59.5 | 23.1 | C |
| 17: Exit 74 HOV | 221 | 69.5 | 3.5 | A |
| 18: Exit 74 Lane 3 | 1589 | 53.4 | 32.8 | D |
| 19: Exit 74 Lane 2 | 1343 | 45.9 | 32.2 | D |
| 20: Exit 74 Lane 1 | 1246 | 45.4 | 30.2 | D |
| 21: Exit 70 HOV | 252 | 70.5 | 3.9 | A |
| 22: Exit 70 Lane 3 | 1235 | 28.9 | 47.0 | F |
| 23: Exit 70 Lane 2 | 1107 | 25.4 | 48.0 | F |
| 24: Exit 70 Lane 1 | 1073 | 13.4 | 88.4 | F |
| 25: Exit 66 HOV | 255 | 70.2 | 4.0 | A |
| 26: Exit 66 Lane 3 | 1059 | 15.6 | 74.8 | F |
| 27: Exit 66 Lane 2 | 1046 | 14.0 | 82.0 | F |
| 28: Exit 66 Lane 1 | 1021 | 12.7 | 88.6 | F |
| 29: Exit 64 HOV | 250 | 68.5 | 4.0 | A |
| 30: Exit 64 Lane 3 | 1225 | 19.1 | 70.6 | F |
| 31: Exit 64 Lane 2 | 1236 | 16.1 | 84.7 | F |
| 32: Exit 64 Lane 1 | 1144 | 16.7 | 75.4 | F |
| 33: Exit 62 HOV | 240 | 69.3 | 3.8 | A |
| 34: Exit 62 Lane 3 | 1401 | 54.8 | 28.1 | D |
| 35: Exit 62 Lane 2 | 1239 | 50.6 | 26.9 | D |
| 36: Exit 62 Lane 1 | 1169 | 48.7 | 26.4 | D |
| 37: Exit 60 HOV | 276 | 67.7 | 4.5 | A |
| 38: Exit 60 Lane 3 | 1347 | 14.2 | 104.2 | F |
| 39: Exit 60 Lane 2 | 1290 | 16.9 | 84.1 | F |

| | | | | |
|---|---|---|---|---|
| 40: Exit 60 Lane 1 | 1233 | 17.7 | 76.5 | F |
| 41: Exit 59 HOV | 232 | 71.5 | 3.6 | A |
| 42: Exit 59 Lane 3 | 1493 | 65.1 | 25.2 | C |
| 43: Exit 59 Lane 2 | 1276 | 58.1 | 24.2 | C |
| 44: Exit 59 Lane 1 | 1202 | 57.7 | 22.9 | C |
| 45: Exit 57 HOV | 277 | 72.1 | 4.2 | A |
| 46: Exit 57 Lane 3 | 1619 | 59.0 | 30.2 | D |
| 47: Exit 57 Lane 2 | 1554 | 54.9 | 31.1 | D |
| 48: Exit 57 Lane 1 | 1525 | 54.9 | 30.5 | D |
| 49: End HOV | 417 | 10.9 | 42.0 | E |
| 50: End Lane 3 | 401 | 2.8 | 158.1 | F |
| 51: End Lane 2 | 934 | 12.8 | 80.3 | F |
| 52: End Lane 1 | 1816 | 23.6 | 84.6 | F |

TABLE J.2: BASE YEAR LANE REVERSION

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| 1: Begin HOV | 1250 | 72.9 | 18.9 | C |
| 2: Begin Lane 3 | 1239 | 72.7 | 18.8 | C |
| 3: Begin Lane 2 | 1327 | 72.6 | 20.1 | C |
| 4: Begin Lane 1 | 1327 | 72.8 | 20.0 | C |
| 5: Exit 80 HOV | 1401 | 70.8 | 21.8 | C |
| 6: Exit 80 Lane 3 | 1332 | 68.9 | 21.3 | C |
| 7: Exit 80 Lane 2 | 1191 | 60.2 | 21.8 | C |
| 8: Exit 80 Lane 1 | 1165 | 58.0 | 22.1 | C |
| 9: Exit 78 HOV | 1585 | 59.0 | 29.6 | D |
| 10: Exit 78 Lane 3 | 1423 | 56.8 | 27.6 | D |
| 11: Exit 78 Lane 2 | 1066 | 48.8 | 24.1 | C |
| 12: Exit 78 Lane 1 | 976 | 48.1 | 22.3 | C |
| 13: Exit 76 HOV | 1440 | 69.1 | 22.9 | C |
| 14: Exit 76 Lane 3 | 1346 | 67.4 | 22.0 | C |
| 15: Exit 76 Lane 2 | 1014 | 59.5 | 18.7 | C |
| 16: Exit 76 Lane 1 | 1030 | 59.5 | 19.1 | C |
| 17: Exit 74 HOV | 1412 | 55.9 | 27.8 | D |
| 18: Exit 74 Lane 3 | 1260 | 54.1 | 25.6 | C |
| 19: Exit 74 Lane 2 | 1031 | 46.8 | 24.2 | C |
| 20: Exit 74 Lane 1 | 912 | 45.8 | 21.9 | C |
| 21: Exit 70 HOV | 1391 | 67.3 | 22.7 | C |
| 22: Exit 70 Lane 3 | 1299 | 65.8 | 21.7 | C |
| 23: Exit 70 Lane 2 | 1090 | 58.7 | 20.4 | C |
| 24: Exit 70 Lane 1 | 1012 | 57.8 | 19.3 | C |
| 25: Exit 66 HOV | 1364 | 68.0 | 22.1 | C |
| 26: Exit 66 Lane 3 | 1351 | 66.8 | 22.2 | C |
| 27: Exit 66 Lane 2 | 1038 | 59.2 | 19.3 | C |
| 28: Exit 66 Lane 1 | 1032 | 60.2 | 18.9 | C |
| 29: Exit 64 HOV | 1101 | 20.4 | 59.4 | F |
| 30: Exit 64 Lane 3 | 1197 | 14.8 | 88.9 | F |
| 31: Exit 64 Lane 2 | 1170 | 16.9 | 76.1 | F |
| 32: Exit 64 Lane 1 | 1078 | 16.0 | 74.3 | F |
| 33: Exit 62 HOV | 1270 | 63.5 | 22.0 | C |
| 34: Exit 62 Lane 3 | 1194 | 62.0 | 21.2 | C |
| 35: Exit 62 Lane 2 | 1011 | 54.0 | 20.6 | C |
| 36: Exit 62 Lane 1 | 969 | 53.4 | 20.0 | C |
| 37: Exit 60 HOV | 1365 | 19.2 | 78.3 | F |

| | | | | |
|---|---|---|---|---|
| 38: Exit 60 Lane 3 | 1249 | 16.5 | 83.4 | F |
| 39: Exit 60 Lane 2 | 1100 | 15.1 | 80.0 | F |
| 40: Exit 60 Lane 1 | 1046 | 14.6 | 78.8 | F |
| 41: Exit 59 HOV | 1351 | 67.8 | 21.9 | C |
| 42: Exit 59 Lane 3 | 1256 | 65.9 | 21.0 | C |
| 43: Exit 59 Lane 2 | 1005 | 58.0 | 19.1 | C |
| 44: Exit 59 Lane 1 | 984 | 58.0 | 18.7 | C |
| 45: Exit 57 HOV | 1364 | 60.1 | 25.0 | C |
| 46: Exit 57 Lane 3 | 1410 | 59.5 | 26.1 | D |
| 47: Exit 57 Lane 2 | 1173 | 54.1 | 23.9 | C |
| 48: Exit 57 Lane 1 | 1147 | 54.7 | 23.1 | C |
| 49: End HOV | 1192 | 17.8 | 73.6 | F |
| 50: End Lane 3 | 398 | 2.8 | 156.9 | F |
| 51: End Lane 2 | 764 | 9.5 | 88.3 | F |
| 52: End Lane 1 | 1627 | 24.6 | 72.8 | F |

TABLE J.3: BASE YEAR HEAVY ENFORCEMENT

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| 1: Begin HOV | 272 | 74.59 | 4.0 | A |
| 2: Begin Lane 3 | 1503 | 29.38 | 56.3 | F |
| 3: Begin Lane 2 | 1528 | 30.78 | 54.6 | F |
| 4: Begin Lane 1 | 1516 | 30.83 | 54.1 | F |
| 5: Exit 80 HOV | 246 | 72.85 | 3.7 | A |
| 6: Exit 80 Lane 3 | 1627 | 31.27 | 57.2 | F |
| 7: Exit 80 Lane 2 | 1458 | 29.31 | 54.7 | F |
| 8: Exit 80 Lane 1 | 1314 | 27.65 | 52.3 | F |
| 9: Exit 78 HOV | 243 | 67.22 | 4.0 | A |
| 10: Exit 78 Lane 3 | 1410 | 24.12 | 64.3 | F |
| 11: Exit 78 Lane 2 | 1391 | 24.2 | 63.2 | F |
| 12: Exit 78 Lane 1 | 1377 | 24.9 | 60.8 | F |
| 13: Exit 76 HOV | 214 | 71.84 | 3.3 | A |
| 14: Exit 76 Lane 3 | 1617 | 66.82 | 26.6 | D |
| 15: Exit 76 Lane 2 | 1317 | 60.23 | 24.1 | C |
| 16: Exit 76 Lane 1 | 1273 | 59.54 | 23.5 | C |
| 17: Exit 74 HOV | 202 | 69.27 | 3.2 | A |
| 18: Exit 74 Lane 3 | 1568 | 53.21 | 32.4 | D |
| 19: Exit 74 Lane 2 | 1339 | 46.79 | 31.5 | D |
| 20: Exit 74 Lane 1 | 1229 | 45.15 | 29.9 | D |
| 21: Exit 70 HOV | 219 | 72.82 | 3.3 | A |
| 22: Exit 70 Lane 3 | 1522 | 55.04 | 30.4 | D |
| 23: Exit 70 Lane 2 | 1308 | 53.05 | 27.1 | D |
| 24: Exit 70 Lane 1 | 1311 | 53.58 | 26.9 | D |
| 25: Exit 66 HOV | 233 | 71.83 | 3.6 | A |
| 26: Exit 66 Lane 3 | 1154 | 19 | 66.8 | F |
| 27: Exit 66 Lane 2 | 1144 | 17.73 | 71.0 | F |
| 28: Exit 66 Lane 1 | 1065 | 17.43 | 67.2 | F |
| 29: Exit 64 HOV | 237 | 69.26 | 3.8 | A |
| 30: Exit 64 Lane 3 | 1186 | 18.89 | 69.1 | F |
| 31: Exit 64 Lane 2 | 1203 | 17.93 | 73.8 | F |
| 32: Exit 64 Lane 1 | 1146 | 13.68 | 92.1 | F |
| 33: Exit 62 HOV | 205 | 69.83 | 3.2 | A |
| 34: Exit 62 Lane 3 | 1375 | 61.86 | 24.5 | C |
| 35: Exit 62 Lane 2 | 1222 | 55.12 | 24.4 | C |
| 36: Exit 62 Lane 1 | 1202 | 55.08 | 24.0 | C |
| 37: Exit 60 HOV | 246 | 71.28 | 3.8 | A |
| 38: Exit 60 Lane 3 | 1503 | 30.71 | 53.8 | F |
| 39: Exit 60 Lane 2 | 1330 | 19.09 | 76.6 | F |

| | | | | |
|---|---|---|---|---|
| 40: Exit 60 Lane 1 | 1304 | 28.82 | 49.8 | F |
| 41: Exit 59 HOV | 233 | 72.26 | 3.5 | A |
| 42: Exit 59 Lane 3 | 1524 | 64.69 | 25.9 | C |
| 43: Exit 59 Lane 2 | 1292 | 57.95 | 24.5 | C |
| 44: Exit 59 Lane 1 | 1219 | 57.43 | 23.3 | C |
| 45: Exit 57 HOV | 249 | 70.4 | 3.9 | A |
| 46: Exit 57 Lane 3 | 1563 | 59.44 | 28.9 | D |
| 47: Exit 57 Lane 2 | 1496 | 55.96 | 29.4 | D |
| 48: Exit 57 Lane 1 | 1469 | 55.64 | 29.0 | D |
| 49: End HOV | 278 | 32.26 | 9.5 | A |
| 50: End Lane 3 | 394 | 2.73 | 158.8 | F |
| 51: End Lane 2 | 995 | 13.27 | 82.5 | F |
| 52: End Lane 1 | 1800 | 23.23 | 85.2 | F |

## TABLE J.4: FUTURE YEAR DO NOTHING

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| 1: Begin HOV | 758 | 65.3 | 12.8 | B |
| 2: Begin Lane 3 | 1200 | 14.1 | 93.4 | F |
| 3: Begin Lane 2 | 1108 | 9.1 | 133.9 | F |
| 4: Begin Lane 1 | 1166 | 14.0 | 91.6 | F |
| 5: Exit 80 HOV | 691 | 67.4 | 11.3 | B |
| 6: Exit 80 Lane 3 | 1203 | 17.7 | 74.7 | F |
| 7: Exit 80 Lane 2 | 1207 | 17.4 | 76.1 | F |
| 8: Exit 80 Lane 1 | 1065 | 16.2 | 72.3 | F |
| 9: Exit 78 HOV | 699 | 59.2 | 13.0 | B |
| 10: Exit 78 Lane 3 | 1184 | 16.4 | 79.5 | F |
| 11: Exit 78 Lane 2 | 1132 | 16.1 | 77.3 | F |
| 12: Exit 78 Lane 1 | 1164 | 19.3 | 66.2 | F |
| 13: Exit 76 HOV | 581 | 70.4 | 9.1 | A |
| 14: Exit 76 Lane 3 | 1469 | 67.5 | 23.9 | C |
| 15: Exit 76 Lane 2 | 1172 | 59.8 | 21.6 | C |
| 16: Exit 76 Lane 1 | 1178 | 59.7 | 21.7 | C |
| 17: Exit 74 HOV | 631 | 65.7 | 10.6 | A |
| 18: Exit 74 Lane 3 | 1439 | 53.0 | 29.9 | D |
| 19: Exit 74 Lane 2 | 1217 | 45.3 | 29.6 | D |
| 20: Exit 74 Lane 1 | 1136 | 44.6 | 28.0 | D |
| 21: Exit 70 HOV | 688 | 69.2 | 10.9 | A |
| 22: Exit 70 Lane 3 | 1417 | 47.0 | 33.1 | D |
| 23: Exit 70 Lane 2 | 1215 | 42.4 | 31.5 | D |
| 24: Exit 70 Lane 1 | 1157 | 42.4 | 30.0 | D |
| 25: Exit 66 HOV | 820 | 65.1 | 13.8 | B |
| 26: Exit 66 Lane 3 | 1024 | 15.6 | 72.2 | F |
| 27: Exit 66 Lane 2 | 1048 | 16.7 | 69.1 | F |
| 28: Exit 66 Lane 1 | 969 | 14.6 | 72.9 | F |
| 29: Exit 64 HOV | 876 | 60.6 | 15.9 | B |
| 30: Exit 64 Lane 3 | 1092 | 16.1 | 74.4 | F |
| 31: Exit 64 Lane 2 | 1053 | 15.3 | 76.0 | F |
| 32: Exit 64 Lane 1 | 1019 | 11.7 | 95.7 | F |
| 33: Exit 62 HOV | 617 | 64.7 | 10.5 | A |
| 34: Exit 62 Lane 3 | 1290 | 61.5 | 23.1 | C |
| 35: Exit 62 Lane 2 | 1104 | 54.3 | 22.4 | C |
| 36: Exit 62 Lane 1 | 1076 | 53.8 | 22.0 | C |
| 37: Exit 60 HOV | 911 | 54.0 | 18.6 | C |
| 38: Exit 60 Lane 3 | 1161 | 16.1 | 79.3 | F |
| 39: Exit 60 Lane 2 | 1030 | 13.8 | 82.2 | F |

| | | | | |
|---|---|---|---|---|
| 40: Exit 60 Lane 1 | 1033 | 13.9 | 81.9 | F |
| 41: Exit 59 HOV | 671 | 69.1 | 10.7 | A |
| 42: Exit 59 Lane 3 | 1355 | 65.1 | 22.9 | C |
| 43: Exit 59 Lane 2 | 1092 | 57.3 | 21.0 | C |
| 44: Exit 59 Lane 1 | 1072 | 57.4 | 20.5 | C |
| 45: Exit 57 HOV | 755 | 67.1 | 12.4 | B |
| 46: Exit 57 Lane 3 | 1492 | 56.5 | 29.0 | D |
| 47: Exit 57 Lane 2 | 1405 | 51.8 | 29.8 | D |
| 48: Exit 57 Lane 1 | 1305 | 51.4 | 27.9 | D |
| 49: End HOV | 839 | 35.7 | 25.9 | C |
| 50: End Lane 3 | 399 | 2.8 | 157.3 | F |
| 51: End Lane 2 | 840 | 10.3 | 90.0 | F |
| 52: End Lane 1 | 1783 | 23.5 | 83.5 | F |

TABLE J.5 FUTURE YEAR LANE REVERSION

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| 1: Begin HOV | 1350 | 12.14 | 122.3 | F |
| 2: Begin Lane 3 | 1355 | 15.04 | 99.1 | F |
| 3: Begin Lane 2 | 1240 | 14.35 | 95.1 | F |
| 4: Begin Lane 1 | 1291 | 14.5 | 97.9 | F |
| 5: Exit 80 HOV | 1315 | 26.42 | 54.8 | F |
| 6: Exit 80 Lane 3 | 1342 | 22.23 | 66.4 | F |
| 7: Exit 80 Lane 2 | 1246 | 21.97 | 62.4 | F |
| 8: Exit 80 Lane 1 | 1133 | 20.86 | 59.7 | F |
| 9: Exit 78 HOV | 1153 | 13.21 | 96.0 | F |
| 10: Exit 78 Lane 3 | 1163 | 17.62 | 72.6 | F |
| 11: Exit 78 Lane 2 | 1191 | 17.86 | 73.4 | F |
| 12: Exit 78 Lane 1 | 1169 | 20.01 | 64.3 | F |
| 13: Exit 76 HOV | 1418 | 69.09 | 22.6 | C |
| 14: Exit 76 Lane 3 | 1315 | 68.02 | 21.3 | C |
| 15: Exit 76 Lane 2 | 1041 | 59.38 | 19.3 | C |
| 16: Exit 76 Lane 1 | 1029 | 59.83 | 18.9 | C |
| 17: Exit 74 HOV | 1483 | 55.42 | 29.4 | D |
| 18: Exit 74 Lane 3 | 1355 | 53.11 | 28.1 | D |
| 19: Exit 74 Lane 2 | 1094 | 45.08 | 26.7 | D |
| 20: Exit 74 Lane 1 | 1028 | 45.53 | 24.8 | C |
| 21: Exit 70 HOV | 1528 | 66.71 | 25.2 | C |
| 22: Exit 70 Lane 3 | 1389 | 65.31 | 23.4 | C |
| 23: Exit 70 Lane 2 | 1141 | 56.04 | 22.4 | C |
| 24: Exit 70 Lane 1 | 1127 | 55.61 | 22.3 | C |
| 25: Exit 66 HOV | 1113 | 17.52 | 69.9 | F |
| 26: Exit 66 Lane 3 | 1181 | 19.23 | 67.6 | F |
| 27: Exit 66 Lane 2 | 1077 | 18.34 | 64.6 | F |
| 28: Exit 66 Lane 1 | 981 | 17.9 | 60.3 | F |
| 29: Exit 64 HOV | 1074 | 17.47 | 67.6 | F |
| 30: Exit 64 Lane 3 | 1141 | 17.3 | 72.5 | F |
| 31: Exit 64 Lane 2 | 1111 | 15 | 81.5 | F |
| 32: Exit 64 Lane 1 | 1077 | 14.23 | 83.3 | F |
| 33: Exit 62 HOV | 1249 | 63.79 | 21.5 | C |
| 34: Exit 62 Lane 3 | 1179 | 61.69 | 21.0 | C |
| 35: Exit 62 Lane 2 | 1019 | 54.17 | 20.7 | C |
| 36: Exit 62 Lane 1 | 962 | 53.18 | 19.9 | C |
| 37: Exit 60 HOV | 1263 | 17.17 | 80.9 | F |
| 38: Exit 60 Lane 3 | 1112 | 14.59 | 83.8 | F |
| 39: Exit 60 Lane 2 | 994 | 12.92 | 84.6 | F |

| | | | | |
|---|---|---|---|---|
| 40: Exit 60 Lane 1 | 950 | 14.04 | 74.4 | F |
| 41: Exit 59 HOV | 1268 | 67.56 | 20.6 | C |
| 42: Exit 59 Lane 3 | 1183 | 65.88 | 19.8 | C |
| 43: Exit 59 Lane 2 | 998 | 57.87 | 19.0 | C |
| 44: Exit 59 Lane 1 | 938 | 57.16 | 18.1 | C |
| 45: Exit 57 HOV | 1387 | 60.57 | 25.2 | C |
| 46: Exit 57 Lane 3 | 1376 | 60.1 | 25.2 | C |
| 47: Exit 57 Lane 2 | 1229 | 56.24 | 24.0 | C |
| 48: Exit 57 Lane 1 | 1140 | 56.03 | 22.4 | C |
| 49: End HOV | 983 | 13.9 | 77.8 | F |
| 50: End Lane 3 | 393 | 2.8 | 154.4 | F |
| 51: End Lane 2 | 1012 | 13.87 | 80.3 | F |
| 52: End Lane 1 | 1619 | 25.81 | 69.0 | F |

## TABLE J.6: FUTURE YEAR HEAVY ENFORCEMENT

| Data Collection Point | Flow (veh/h) | Space Mean Speed (mph) | Density (pcpmpl) | LOS |
|---|---|---|---|---|
| 1: Begin HOV | 239 | 74.2 | 3.5 | A |
| 2: Begin Lane 3 | 1290 | 15.9 | 89.5 | F |
| 3: Begin Lane 2 | 1213 | 13.7 | 97.2 | F |
| 4: Begin Lane 1 | 1234 | 12.8 | 106.3 | F |
| 5: Exit 80 HOV | 212 | 72.6 | 3.2 | A |
| 6: Exit 80 Lane 3 | 1308 | 20.3 | 70.9 | F |
| 7: Exit 80 Lane 2 | 1310 | 19.0 | 75.9 | F |
| 8: Exit 80 Lane 1 | 1164 | 19.8 | 64.8 | F |
| 9: Exit 78 HOV | 208 | 67.1 | 3.4 | A |
| 10: Exit 78 Lane 3 | 1338 | 21.9 | 67.3 | F |
| 11: Exit 78 Lane 2 | 1286 | 21.7 | 65.3 | F |
| 12: Exit 78 Lane 1 | 1282 | 22.2 | 63.5 | F |
| 13: Exit 76 HOV | 199 | 70.9 | 3.1 | A |
| 14: Exit 76 Lane 3 | 1575 | 66.8 | 25.9 | C |
| 15: Exit 76 Lane 2 | 1235 | 59.5 | 22.8 | C |
| 16: Exit 76 Lane 1 | 1249 | 59.5 | 23.1 | C |
| 17: Exit 74 HOV | 221 | 69.5 | 3.5 | A |
| 18: Exit 74 Lane 3 | 1589 | 53.4 | 32.8 | D |
| 19: Exit 74 Lane 2 | 1343 | 45.9 | 32.2 | D |
| 20: Exit 74 Lane 1 | 1246 | 45.4 | 30.2 | D |
| 21: Exit 70 HOV | 252 | 70.5 | 3.9 | A |
| 22: Exit 70 Lane 3 | 1235 | 28.9 | 47.0 | F |
| 23: Exit 70 Lane 2 | 1107 | 25.4 | 48.0 | F |
| 24: Exit 70 Lane 1 | 1073 | 13.4 | 88.4 | F |
| 25: Exit 66 HOV | 255 | 70.2 | 4.0 | A |
| 26: Exit 66 Lane 3 | 1059 | 15.6 | 74.8 | F |
| 27: Exit 66 Lane 2 | 1046 | 14.0 | 82.0 | F |
| 28: Exit 66 Lane 1 | 1021 | 12.7 | 88.6 | F |
| 29: Exit 64 HOV | 250 | 68.5 | 4.0 | A |
| 30: Exit 64 Lane 3 | 1225 | 19.1 | 70.6 | F |
| 31: Exit 64 Lane 2 | 1236 | 16.1 | 84.7 | F |
| 32: Exit 64 Lane 1 | 1144 | 16.7 | 75.4 | F |
| 33: Exit 62 HOV | 240 | 69.3 | 3.8 | A |
| 34: Exit 62 Lane 3 | 1401 | 54.8 | 28.1 | D |
| 35: Exit 62 Lane 2 | 1239 | 50.6 | 26.9 | D |
| 36: Exit 62 Lane 1 | 1169 | 48.7 | 26.4 | D |
| 37: Exit 60 HOV | 276 | 67.7 | 4.5 | A |
| 38: Exit 60 Lane 3 | 1347 | 14.2 | 104.2 | F |

| | | | | |
|---|---|---|---|---|
| 39: Exit 60 Lane 2 | 1290 | 16.9 | 84.1 | F |
| 40: Exit 60 Lane 1 | 1233 | 17.7 | 76.5 | F |
| 41: Exit 59 HOV | 232 | 71.5 | 3.6 | A |
| 42: Exit 59 Lane 3 | 1493 | 65.1 | 25.2 | C |
| 43: Exit 59 Lane 2 | 1276 | 58.1 | 24.2 | C |
| 44: Exit 59 Lane 1 | 1202 | 57.7 | 22.9 | C |
| 45: Exit 57 HOV | 277 | 72.1 | 4.2 | A |
| 46: Exit 57 Lane 3 | 1619 | 59.0 | 30.2 | D |
| 47: Exit 57 Lane 2 | 1554 | 54.9 | 31.1 | D |
| 48: Exit 57 Lane 1 | 1525 | 54.9 | 30.5 | D |
| 49: End HOV | 417 | 10.9 | 42.0 | E |
| 50: End Lane 3 | 401 | 2.8 | 158.1 | F |
| 51: End Lane 2 | 934 | 12.8 | 80.3 | F |
| 52: End Lane 1 | 1816 | 23.6 | 84.6 | F |

## APPENDIX K: PUBLIC SURVEY INSTRUMENT AND RESPONSE SUMMARY

Each survey question (boldface) has been appended with the respective responses.

1. **What is your age?**
   a. **Under 20** (13 / 2.73%)
   b. **21 – 29** (214 / 44.96%)
   c. **30 – 39** (119 / 25.00%)
   d. **40 – 49** (63 / 13.24%)
   e. **50 – 59** (35 / 7.35%)
   f. **60+** (32 / 6.72%)

2. **What is your gender?**
   a. **Male** (108 / 22.64%)
   b. **Female** (366 / 76.73%)
   c. **Prefer not to answer** (3 / 0.63%)

3. **What is your race?**
   a. **Caucasian or White** (414 / 87.0%)
   b. **Hispanic or Latino** (14 / 2.9%)
   c. **Black or African American** (24 / 5.0%)
   d. **Asian or Pacific Islander** (7 / 1.5%)
   e. **Native American** (1 / 0.2%)
   f. **Other** (9 / 1.9%)
   g. **Prefer not to answer** (7 / 1.5%)

4. **How many people live in your household? (open ended)** (frequency distribution shown on page 87 of the report)

5. **How many members of your household drive a vehicle? (open ended)** (frequency distribution shown on page 88 of the report)

6. **What is the highest level of education that you have completed?**
   a. **No schooling completed** (1 / 0.2%)
   b. **High school graduate or GED** (41 / 11.3%)
   c. **Associate degree** (19 / 5.3%)
   d. **Bachelor's degree** (243 / 67.1%)
   e. **Master's degree** (10 / 2.8%)
   f. **Professional degree** (48 / 13.3%)
   g. **Doctorate degree** (0 / 0.0%)

7. **What was your total household income before taxes during the past 12 months?**
   a. **Less than $25,000** (47 / 10.4%)
   b. **$25,000 to $34,999** (41 / 9.1%)

c. **\$35,000 to \$49,999** (60 / 13.3%)
d. **\$50,000 to \$74,999** (78 / 17.3%)
e. **\$75,000 to \$99,999** (87 / 19.3%)
f. **\$100,000 to \$149,999** (88 / 19.5%)
g. **\$150,000 or more** (51 / 11.3%)

8. **How far do you drive (each way) to get to your place of employment or school?**
   a. **10 miles or less** (154 / 32.4%)
   b. **11-25 miles** (216 / 45.4%)
   c. **26-40 miles** (84 / 17.7%)
   d. **40-59 miles** (13 / 2.7%)
   e. **60+ miles** (9 / 1.9%)

9. **How many of these miles are on the interstate?**
   a. **0-4 miles** (160 / 33.6%)
   b. **5-9 miles** (94 / 19.8%)
   c. **10-19 miles** (134 / 28.2%)
   d. **20-29 miles** (58 / 12.2%)
   e. **30 – 39 miles** (21 / 4.4%)
   f. **40+ miles** (9 / 1.9%)

10. **On average, how many hours do you spend in your vehicle per day?**
    a. **1 hour or less** (177 / 37.2%)
    b. **1-3 hours** (284 / 59.7%)
    c. **3-6 hours** (13 / 2.7%)
    d. **6 or more hours** (2 / 0.4%)

11. **Which of the following best describes your primary vehicle that you use for commuting to and from work and/or school?**
    a. **Gasoline engine** (447 / 93.9%)
    b. **Diesel engine** (1 / 0.2%)
    c. **Hybrid engine** (18 / 3.8%)
    d. **Electric** (6 / 1.3%)
    e. **Other** (4 / 0.8%)
    e. **I don't know** (0 / 0.0%)

12. **Do you own or lease your primary vehicle?**
    a. **Own** (430 / 90.3%)
    b. **Lease** (38 / 8.0%)
    c. **Don't have a vehicle or don't know** (8 / 1.7%)

13. **How many vehicles are you in your household?**
    a. **0** (2 / 0.4%)
    b. **1** (112 / 23.5%)
    c. **2-3** (321 / 67.4%)
    d. **4-5** (40 / 8.4%)
    e. **6+** (1 / 0.2%)

**14. Do you drive on Interstate 24 or Interstate 65 going in or out of Nashville?**

- **a. Yes, I 24** (56 / 11.8%)
- **b. Yes, I 65** (158 / 33.2%)
- **c. Yes, both** (157 / 33.0%)
- **d. No** (105 / 22.1%)

**15. What are your primary entrance and exit locations onto the interstate? For example, "I enter I-65 from Saturn Parkway" or "I exit I-65 on 440 W". (open ended)**

**16. Do you typically drive during rush hours (7am – 9am inbound to Nashville, 4pm – 6pm outbound from Nashville, M-F)?**

- **a. Yes** (262 / 55.4%)
- **b. No** (118 / 24.8%)
- **c. Sometimes** (96 / 20.2%)

**17. Do you know what a High Occupancy Vehicle (HOV) lane is?**

- a. **Yes** (449 / 94.3%)
- **b. No** (17 / 3.6%)
- **c. Maybe** (10 / 2.1%)

**18.** I**f familiar with HOV lanes, do you recall seeing signs regarding lane restrictions while driving?**

- a. **Yes** (438 / 92.0%)
- b. **No** (20 / 4.2%)
- **c. Unsure** (18 / 3.8%)

**19. Which of the following are examples of a low emission vehicle which would qualify for HOV lane usage at any time? (check all that apply)**

- **a. Hybrid**
- **b. Normal, sedan**
- **c. Economy sized vehicle**
- **d. SUV**
- **e. Diesel pickup truck**
- **f. Motorcycle**
- **g. None of the above**
- **h. All of the above**
- **i. Unsure**

**20. Do you or have you ever used the HOV lane?**

- **a. Yes** (393 / 82.6%)
- **b. No** (83 / 17.4%)

**21. If "No", why?**

- **a. I drive a single occupancy vehicle** (53 / 34.4%)
- **b. I typically don't drive during rush hour** (22 / 14.3%)
- **c. I'm rarely in a hurry, so don't see the need** (5 / 3.3%)
- **d. I don't want to risk getting a fine/pulled over** (21 / 13.6%)

**e. I choose to adhere to the posted rules** (32 / 20.8%)
**f. I don't want to have to change 2+ lanes in busy traffic** (10 / 6.5%)
**g. Other (explain)** (11 / 7.1%)

**22. If "Yes", how often?**
**a. Every day** (88 / 22.5%)
**b. Once a week** (106 / 27.0%)
**c. Once a month** (134 / 34.2%)
**d. Only in an emergency or when I'm in a hurry** (64 / 16.3%)

**23. What are your preferred hours for HOV lane usage? (choose all that apply)**
a. **Prior to 6 am** (33 / 8.4%)
b. **6 am- 10 am** (209 / 53.2%)
c. **10 am- 1 pm** (71 / 18.1%)
d. **1 pm - 4 pm** (102 / 26.0%)
e. **4 pm - 7 pm** (234 / 59.5%)
f. **7 pm or later** (96 / 24.4%)
g. **Never** (21 / 5.3%)

**24. How often have you violated the HOV lane use rules?**
**a. Never** (112/28.50%)
**b. Rarely** (135/34.35%)
**c. Sometimes** (78/19.85%)
**d. Often** (46/11.70%)
**e. Always** (22/5.60%)

**25. What percentage of time driving on I-24 or I-65 do you violate the HOV lane use rules?**
**a. Under 10% of the time** (287 / 73.2%)
**b. 11-25% of the time** (35 / 8.93%)
**c. 26-50% of the time** (26 / 6.63%)
**d. 51-75% of the time** (16 / 4.08%)
**e. 76-90% of the time** (20 / 5.10%)
**f. More than 90% of the time** (8 / 2.04%)

**26(A). If "Never" or "Rarely" to #24, Why do you comply with the HOV lane use rules? (choose all that apply)**
**a. I carpool** (55 / 22.26%)
**b. I don't typically drive during rush hour** (94 / 38.05%)
**c. I don't want to risk getting a fine/pulled over** (128 / 51.82%)
**d. I choose to adhere to the posted rules** (144 / 58.29%)
**e. I don't want to have to change 2+ lanes in busy traffic** (31 / 12.55%)
**f. Other** (18 / 7.28%)

**26(B). If "Sometimes," "Often" or "Always" to question 24, why do you not comply with the HOV lane rules? (choose all that apply)**
a. **I'm perpetually late and need to get somewhere quickly** (38 / 26.02%)
b. **I don't believe I will get a ticket/pulled over** (61 / 41.78%)
c. **I don't like or agree with the rules, so I choose not to follow them** (10 / 6.85%)

d. **I don't think the usage of HOV lanes to be an environmental concern** (24 / 16.44%)
e. **I don't understand or didn't know the rules** (11 / 7.53%)
f. **I'm typically frustrated with other drivers and am trying to get around them** (83 / 56.85%)
g. **Other** (18/12.32%)

**27. If "Sometimes", "Often", or "Always" to #24, what would need to change for you to follow the rules?**

a. **Clearer rules and punishments** (31 / 21.22%)
b. **Stronger enforcement/fines** (53 / 36.3%)
c. **Better traffic conditions** (125 / 85.61%)
d. **Nothing** (6 / 4.11%)
e. **Other** (5 / 3.42%)

**28. Assuming that you are driving as a single-occupancy vehicle, you could save 15 minutes by traveling in the HOV lane on your morning commute. What dollar amount of a toll would you be willing to pay to drive legally in the HOV lane? (open ended)**

**29. Assuming that you are driving as a single-occupancy vehicle, if the fine for driving in an HOV lane is <$50, $100, $500> and enforcement is done automatically, how many minutes in time savings that would be required before you'd be willing to violate the HOV lane rules? (open ended)**

**30. Assuming that you are driving as a single-occupancy vehicle, if the toll for driving in an HOV lane is $1 and enforcement is done <automatically, manually by police>, how many minutes in time savings that you would require before being willing to pay the toll to use the HOV lane? (open ended)**

**31. What are the chances that you would create a carpool or use other ecofriendly modes of transportation to legally use the HOV lane?**

a. **High** (38 / 8.0%)
b. **Medium** (88 / 18.5%)
c. **Low** (324 / 68.1%)
a. **I already do** (26 / 5.5%)

**32. Is gaining access to the HOV lane a motivating factor to create a carpool?**

a. **Yes** (73 / 15.3%)
b. **No** (307 / 64.5%)
c. **Maybe** (96 / 20.17%)

**33. If Yes or Maybe to Q32: How much time savings would motivate you to form a carpool lane if the HOV lanes were enforced and fined? (open ended)**

**34. If not, what would be your motivating factors to create a carpool? (open ended)**

# APPENDIX L: PARTICIPANT RESPONSES TO QUESTION 35

**What could be done to make carpooling a more enticing option?**

| |
|---|
| I don't live by anyone that works in the same area as me, so even if it's enticing, it's not possible. And I'm not riding with complete strangers. |
| Employee benefits for those who work at the same place |
| The ability to get to work faster. |
| None, I like coming and going as I please and I take my dogs to doggy daycare on the way to work. |
| Better car pool meet up locations and better advertising |
| It doesn't matter traffic is traffic |
| Carpooling is not a feasible option for my job as a caseworker |
| Tax benefits, more convenient parking/bus locations |
| Does not apply to me. Carpooling is not viable with my work schedule. |
| Enforcement of use of the carpooling lane to ensure time will be saved. |
| This is not an option for me because there is no one in my neighborhood |
| It's not that I don't want to carpool, but that I don't have anyone to carpool with |
| Nothing |
| Easy meetup/signup process |
| You get to where you need to be faster and switching drivers, things of that nature. |
| Discount of some sort |
| Isnt applicable to me because I require a hogher level of independence |
| Enforcing stricter laws on the occupancy of vehicles, charging higher fines |
| Nothing |
| Celebrity drivers |
| I don't know |
| none, I like to come and go as I please. |
| more HOV lanes |
| Making sure those who break the rules are fined |
| More organized ways to find people to carpool with |
| Some of these questions are phrased in a confusing way. I can handle my commute without an HOV lane. Sure, it would be great if we could improve traffic conditions so that commuting during rush hour took less time -- but I don't see a scenario in which I would pay money to use an HOV lane. If the penalties/fees were automatically enforced, I would not violate them. I would have to be rich before I would pay for an HOV lane. I feel like there are better solutions for traffic regulation. I think carpooling would be great, but I don't know anyone who needs to commute along the same route as me, and I don't wish to commute with strangers/community members. I would also rather pay for gas, which is cheaper than taking an Uber. |
| Make it go faster |
| .na |
| Meet up locations, networking services. |
| if the HOV lane was actually quicker. |
| Having someone near me who works where I work |
| Word of mouth. |

| |
|---|
| Safety |
| I have no interest in carpooling. I hate relying on othr people especially when job and money are on the line. Every so often is fine as a favor. I would never otherwise. |
| Cash incentives |
| The HOV lanes actually have to move significantly faster. |
| Make my friends need to go where I need to go at about the same time that I need to go there. |
| Gas cost reimbursement |
| Park and rides for meeting spots, better bus system. |
| I don't think people want to do that. I can't speak to this question. |
| I do not know - I like driving my own car and having my car to drive to places whenever i need it instead of depending on someone to pick me up or drop me off places. I like carpooling sometimes, but not all the time because I don't like to be on other people's schedules. |
| Have coworkers who live near me and work the same hours |
| Nothing |
| Tax credit or free parking vouchers |
| convenience |
| More park and ride options |
| Not sure |
| Not sure |
| You have to have friends in order to carpool |
| Just make it available |
| not sure |
| No one I work with is in my direction and I don't use the interstate to get to work |
| Unsure |
| ? |
| Making participants (drivers and passengers) go through basic background checks, or even just fill out surveys to be paired with similar people. I'm thinking more about age/ gender and how big differences in these might cause some passengers to feel uncomfortable. |
| riding with friends |
| Nothing. I would prefer to travel alone. |
| N/A |
| Nothing |
| flexible work schedules that allow commuters to drop off and pick up one another. On site dining facilities. Affordable local commuting options once in Nashville that don't center around waiting for a bus if it's even in the area. |
| More time saved or discounted group rides on lyft |
| carpool lots to meet at and tax breaks |
| Greater enforcement of rules and regulations |
| Less time driving. |
| Unsure |
| Not sure |
| Nothing |

| |
|---|
| Pay me |
| Nothing. |
| My schedule is too busy and packed to be able to carpool with anyone. Most of the people I know live closer to Nashville and don't take my route. |
| Nothing, honestly. Would have to be coworkers. |
| Nothing |
| Nothing |
| I don't live near anyone with the same destinations as me. |
| Not a possibility with my current life. |
| Nothing |
| N/A |
| Gas giftcards or discounts for people who are legally using the HOV lane by carpooling |
| Having more HOV lanes. |
| Gas cards |
| Emphasis on money Being saved as not using as much gas |
| if we had singalongs, stopped for coffee/donuts/breakfast, and if we took turns driving |
| Not sure. I don't really like to depend on other people to take me places. I was taught growing up that being 10-15 mins early was being on time and I don't like being late. Carpooling could increases the chances of being late because other people would be involved and I can't control other people. |
| Nothing for me because I do not know many people going in my same direction. |
| Being able to trust other human beings, secure places to park cars |
| Having people I could easily carpool with. |
| At least save 30 mins of commute time. |
| tax deduction |
| Apps that pay you each mile that you share a ride. |
| I already carpool as a Lyft driver. I don't have similar destinations with people that I live near who I actually know and communicate with regularly. |
| n/a |
| Faster transportation in HOV lane during rush hours. |
| I already carpool by bringing a child to school each day, but we don't drive interstate |
| I would need to be able to go directly to or from home each day which isn't a usual occurrence. |
| I don't live near anyone coming to LU |
| Convenience |
| tax benefit, parking benefit, lane benefit |
| Perhaps a points system - points redeemable in cash or gift cards or other benefits (think loyalty program) |
| Not interested |
| unsure |
| Not an option with my job |
| Very little |
| Employer incentives |

| |
|---|
| Nothing |
| Free car service/gas |
| I am already carpooling |
| The loss of flexibility in commute arrival/departure makes carpooling not attractive. |
| Knowing who would carpool with you |
| Multiple car seats in my car keep my from being able to carpooling, |
| Carpooling is challenging in our current environment, especially for professionals. My schedule is not consistent from day to day because it fluctuates with my workload. If you don't have a consistent schedule that matches with your carpool buddies, it's not feasible. |
| Would have to be with colleagues I am familiar with. |
| Nothing. I like the freedom of having my vehicle. |
| Networking with people who have similar schedules. |
| I can't think of anything |
| We would have to work at the same place of Business. |
| Nothing I can think of. I need a vehicle for other meetings during the day. |
| Finding drivers convenient to me who were willing to commute on my schedule and could accommodate my extra-curricular needs |
| I would be happy to carpool, but no one else from the University lives in my area. |
| Nothing. I am not interested in carpooling from Mount Juliet. |
| I'm just not sure Nashvillians are frustrated enough to pursue carpooling. HOV lanes for been around for years and commuters still haven't bought into the idea of carpooling. |
| More people Move To Dickson? |
| Knowing people who live near me who also work where I work. |
| Carpooling would not work for me, as my hours and destinations differ from day to day. |
| Hytch app is a motivator |
| N/A |
| Nothing for me. |
| benefits from your work. realistically nobody wants to spend more time with people on their commute when they are going to spend 8-10 hrs around ppl all day at work. isn't it nice having time to yourself on your way in and out of work. benefits from the work place will entice people to make the switch. |
| My job requires that I drive throughout the middle Tennessee area several times per week during the work day, so I must have my own vehicle accessible. |
| I would need to find people who have a flexible commute schedule |
| It's difficult for me to agree to carpool because my arriving/leaving hours tend to be fluid by the nature of my work. |
| Reduced toll |
| Improving arrival times to final destinations, something carpooling can't guarantee. |
| because I frequently have errands and appointments in the afternoons, I would not normally choose to carpool. |
| In a city like Nashville, I'm not sure anything would make it more enticing. Too spread out--both residences and workplaces. |
| Have people who live near me and have a similar schedule. |

| |
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| ENFORCEMENT!!!! I already drive to and from Nashville with 2 people in my car everyday. I do NOT use the HOV lane because it is NOT enforced and is basically a free-for-all. I drive with a child and feel unsafe driving in the HOV lane because of 'violators' who tailgate and jump in front. It is also difficult to cross 3 lanes of heavy traffic to exit the interstate. |
| Live and work where others are using the same route. |
| A rotating group of cars from which to choose. |
| Others would need the same schedule as me for after school duties. Since my days are long with several after school duties, it would be difficult to form a carpool. |
| Actually enforcing people who are single lane drivers with tickets. |
| Nothing, I like to have my own vehicle to come and go as I please. |
| Parking lots with no fee that you can leave your car at overnight. |
| Better parking options for wherever the destination is, and maybe some statewide incentives to carpooling, like tax breaks or refunds or something. |
| Parking privileges; economic incentives (discounted gas prices / tax break) - but I recognize the difficulty of monitoring and distribution |
| Nothing |
| an enforced HOV lane/violations |
| ensure safety of strangers |
| It does not interest me at all. I would not engage in carpooling. |
| more HOV lanes |
| Unsure |
| Nothing, I live too far from carpool options |
| Coordination and easy meeting location |
| $5/gal gas tax |
| If many people work in the same location, at the same times, for the same number of hours per day, and live in the same area, and are willing to carpool. |
| I have a wacky schedule with multiple appointments after work, so carpooling is not a good option for me. |
| Shorter commute time |
| tax deduction or some form of bonus |
| Speed and time savings |
| Weekly bonus |
| Convenience |
| unsure |
| with my family requirements, carpooling is not enticing to me. having flexible work from home arrangements would be more enticing for my current situation. these were used at my former employers and were appreciated. It also saves office space if the spaces are shared. |
| It is too complicated in my situation to carpool. |
| I don't think it can. Its too hard to coordinate schedules much less find someone who actually drives to the same area. |
| Proximity and relationships with those riding with |
| Save time & money ... splitting HOV charges with carpool |
| Ease of use (more people at my time) |

| |
|---|
| Other than monetary rewards, not much. |
| fun people and direct money savings |
| Not having to drive my own vehicle. Riding in a luxury car. Riding with people that I already know. |
| I like having my own car so I can run errands during lunch or on the way home |
| FInding someone in my area to carpool with |
| Some sort of incentive to the driver. Hard to prove to the source that you earned the incentive. Maybe a type of tax break? |
| I live in a rural area where few other staff members live and I work odd hours. Carpooling is not an option. |
| The HOV lane is too busy with traffic (possibly with violators) to save any time currently. If I could actually save more than 10 min. of drive time each way to work than I might be enticed to have a carpool. |
| I don't mind carpooling if I had someone to carpool with. |
| Flex work hours |
| Nothing. I like the flexibility to come and go when I please. If I must do something different, then I would. |
| Shorter commute time |
| I don't think anything. |
| Unsure |
| More predictable working hours. It is difficult to carpool when you regularly work late unexpectedly. |
| convenient |
| People live close to you. Or easy places to meet up |
| Having someone at work live in my area |
| Nothing |
| Not sure, not useful for me |
| Ease of finding people coming to and from the same or close location |
| Save time |
| N/A |
| Make people more tolerable. |
| If friends / coworkers did it. |
| Better campaign, enforcement, better roads |
| Living in the same part of town with coworkers on same schedule |
| Nothing |
| Other incentives |
| Not sure |
| Time saving, logistics |
| Nothing - I enjoy my few minutes to myself in the morning and afternoon. |
| Faster, more efficient |
| It will never be enticing. It's also not practical for me. |
| Having someone that actually makes the same drive as I do |

| |
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| Nothing |
| Encourage it |
| Apps |
| Make set up easier via app- kind of like Uber or Lyft |
| I am not interested in carpooling because I live far away from my work and do not have friends/colleagues who live along my route. |
| A carpooling service or better information on ways to carpool |
| I don't know |
| Not sure |
| I drive a lot for work around Nashville at various times of day. Carpooling is not an option because I spend so much time out of my office. |
| I carpool when it is convenient to do so and if I know other people who are traveling to the same location. |
| I don't want to ride with people I don't know in a carpool. Maybe if it was done through more official channels and there was a designated person driving. |
| Tax break |
| Nothing. I need the flexibility of having my own ride |
| Having coworkers who live near me to carpool with. This currently is not the case. |
| Have more friends who live in the same place & work together |
| Carpooling isn't an option for my line of work. I'm a children's mental health case manager, so I'm constantly going to schools and homes to conduct visits. Each case manager needs their own care to conduct their own scheduled day. |
| Financial incentives to participants |
| Discount on registration each year |
| I don't know |
| I have a busy schedule that varies and I'm never able to carpool with people at work because we work at different times and live far away from each other. |
| If people I went to my internship site with lived closer and had the same schedule that I did. |
| If people I went to my internship site with lived closer and had the same schedule that I did. |
| Better infrastructure in Nashville |
| I don't find carpooling enticing, I find it inconvenient. |
| Monetary incentives |
| Nothing. I don't carpool. |
| Nothing |
| IDK |
| Convenience |
| Convenience |
| Convenience |
| Convenience |
| Convenience |
| Incentives |
| Nothing. I prefer to drive alone instead of waiting/picking up others |

| |
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| I have no need to carpool. No one lives close to me that could carpool with me. I don't usually drive on the interstate during rush hour traffic. |
| uber like service, that would have people pay you for driving them to the same location or a spot on the way if you agreed. |
| faster arrival to work |
| working with people who live in similar neighborhoods |
| If I were traveling into the city during rush hour times, I think carpooling would be my only option as the traffic I see is unbearable. However, I am traveling opposite of traffic most days and do not have an issue with other cars on the road during my commute. |
| Perks |
| Convenient parking at centralized pick-up points on the perimeter |
| Better carpool options & better ways of finding people to carpool with |
| Nothing. I work strange hours and carpooling would not work. |
| Not sure |
| Nothing, carpooling gets complicated... |
| I don't see it as reasonable, since work schedules are not always set or in line with others driving the same direction. I don't want to be tied to someone else's schedule for getting me to/from work. |
| I don't know |
| none I would not carpool unless I had a need |
| N/A. My job requires driving to meet customers occasionally. I meet some on the way to work and some on the way home. Would possibly be required to back track to pick up fellow riders. Carpooling not an option. |
| Co-workers who lived in a convenient area. |
| I'm not sure. |
| Coworkers having my same schedule, as I work unusual hours (6 hrs a day 5 days a week currently) |
| Carpooling would be more enticing if the HOV lane was either larger or the exits I normally take on the highway would be accessible from the HOV lane. |
| Reward systems |
| Incentives |
| Nothing for my job |
| I don't like being stuck at work dependent on someone else |
| I don't like being stuck at work dependent on someone else |
| I don't like being stuck at work dependent on someone else |
| I don't work at traditional times. Nor do I live close to fellow employees |
| Actually enforce the carpool lanes and fine violators excessively. I know that in California the posted fine was almost $300 for violating the HOV rules. |
| Not sure. Too inconvenient. |
| Networking opportunities with individuals who work in similar areas |
| nothing. drive time is personal time away from other people |
| Have park and ride options where people can meet to drive to work together. Have a van provided by the city/county, etc. |

| |
|---|
| hard to find people you trust to make it into work every workday |
| Free tolls |
| i dont know anyone to carpool with and theres only 3 people at my job so there wouldn't be such a thing |
| Higher policing on interstates |
| Everyone splits gas and doesn't talk on their phone |
| N/A |
| I drive Uber and can't have no fares in my car. |
| A reasonable amount of decreased travel time. |
| Having better options to meet people coming/going from the same general destinations |
| more incentives available to motorists |
| I don't think many are apt to do this unless they work together/live in the same complex |
| Unsure |
| Making it easier to know who in your area wants to carpool to the same place |
| Time saving incentives and regulating who is using the hov lane. |
| High tolls |
| More frequency and availability |
| Get paid for doing carpool. I carpool every day from Kentucky to Nashville and use Hytch to get money for carpool. |
| N/A |
| Knowing the people you were carpooling with |
| Na - already carpool with husband |
| Tax bonus or something |
| I would not carpool with people I don't know |
| easier road access |
| Nothing, people want to stick to their own schedule and not work around trying to find another person to go somewhere |
| Communal drop-off/pick-up points (park & ride, etc) |
| Unsure |
| An app designed specifically for carpooling within Nashville area |
| Better places to meet the other person to carpool in the area. It is terrible finding places to park your car and meet someone any where. |
| Not much. For me, carpooling doesn't work because I often go somewhere on my way home - either grocery shopping or out with friends. |
| Nicer people |
| tax breaks |
| An app with other local commuters going in the same direction willing to carpool |
| Make it easier to find groups and people |
| A functional and updated carpool matching website |
| Money |
| Not sure |
| Money |

| |
|---|
| unsure |
| Not sure |
| If I had a longer drive |
| Improvement of public transportation system |
| I don't have the ability to carpool. My job requires my personal vehicle at various points during the day. |
| Gas gift cards |
| Saving more money |
| Every time I drive in 65 during rush hour most of the cars in the gov only have 1 person in them and the lane doesn't seem to be moving faster than traffic. It needs to be more heavily enforced to have any real benefit to those wanting to start carpooling |
| Quicker time arrivals |
| No ticket for driving 10 miles over the speed limit. |
| Having an online board to meet people going to a similar destination. I don't know anyone with my same commute. |
| I like to travel alone |
| Benefits |
| Charging people in the carpool lane kind of defeats the purpose and will make people do the opposite of carpooling |
| Working in the same building or area as a friend or roommate |
| Already enticing |
| Finding people to carpool with |
| It's not. I have to be at work earlier than most people, and no one i work with lives near me |
| Shorter commute |
| Shorter commute |
| Get paid |
| More people going to the same part of town for work |
| I dont live near anyone I know going to work |
| Idk |
| Carpool apps |
| Random |
| Reward w lower insurance rates |
| Reward w lower insurance rates |
| None |
| Tax deduction |
| I can't really think of anything at this time except perhaps to have a close friend or coworker who lives/works very close to where I do. It's more about the people than the rules. |
| Nothing |
| Don't know |
| Actually having people I know going to the same place I am. |
| Parking lots |
| Don't know |

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| It's not possible for my work situation |
| Carpool parking lots |
| More time savings- better enforcement |
| Public transport |
| Nothing |
| Nothing. No one lives near me that I work with. |
| Advertise the benefits of it more |
| Less commute times |
| Adding park and rides where people can easily meet and park their cars for free would encourage people to actually do it. They have these back in Ca where I'm from so I've used them often prior to moving here. |
| Safer places to find someone |
| No toll |
| Just not an option with my random schedule |
| Unsure. I don't have a long commmute, but I would want the freedom to do as I please after work rather than having to have my schedule set my the carpool, |
| It doesn't make sense for me as my work is literally 5 min from my house |
| I don't drive to work, I bike |
| Website where people could communicate so you could determine other ppl going to the same area at the same time. |
| Nothing. I drive alone. |
| Easier access to find others to carpool with |
| Doesn't appeal to me. I want to be able to have my own vehicle before, after, or during the workday, and I don't want to spend time getting to a carpool and then going to multiple locations to drop people off and get to work in the morning. |
| I don't know. I don't use it |
| Not sure. |
| Apps that give you savings for car pooling |
| Safe |
| Syncing up with other people is more hassle than it's worth. |
| Carpool advertisements |
| Continue to create incentives for employees to carpool, vanpool, or ride the bus or train from employers. The State of Tennessee does this already and I take full advantage of it by using my bus pass. |
| save gas |
| Make HOV hours longer so only they could drive on it always. |
| Not much/ people like their alone time in their cars. |
| Not having to pay a toll |
| I don't have anyone I can carpool with or vise versa. |
| Have an app for carpooling, connecting nearby neighbors so they can share rides |
| Advertisement |
| N/A |
| I do not know. I work in a small office, and no one lives on my side of town. |

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| Too hard to manage different schedules and find reliable people. Honestly, I'd prefer a train to carpooling. |
| More people that work in the same area would need to live in the same area as me. |
| I don't use the interstate for getting to work, so it is not a top priority to use the HOV lane. |
| My job and hours prevents the use of carpooling as they are too unpredictable. |
| I would have to see a major reduction in travel time. It routinely takes me one hour to travel 15 miles from Antioch to the downtown area. HOV lanes would also have ti be 24 hours (not just restricted times) for me to do this. Honestly, I want to see all HOV lanes in the metro Nashville area a 24-hour rule. Rush hour begins before 7 AM and before 4 PM. Every other major city I've traveled to has HOV lanes that don't have time restrictions. I would seriously carpool if HOV lanes were ALWAYS HOV lanes. |
| nothing at this point. |
| Don't konw |
| Reduction in car insurance |
| Convenience |
| If we got tax break or paid to do it. |
| Have a regular work schedule start/end time with no need to leave the office during the day for appointments. |
| Y |
| Tax Breaks, seeing others doing the same (one carpool is not going to help fix traffic) |
| none. I am from Houston and traffic here is not even close to as bad as it was there. I don't mind waiting fro the traffic. It at least moves. |
| Ticket all the people in the HOV lane illegally, I often count the cars passing me in the HOV lane and it has never been less that 70% single occupant/non low emissions vehicles, usually more. |
| In my line of work which requires being in the car for many miles most days, a carpool is not something that would work. |
| Nothing. Too hard with after work commitments. |
| Better traffic flow of our highways. |
| similar start and end locations |
| N/a |
| More park n ride type locations |
| Being more of a morning person ;) But, in all seriousness, carpooling is, overall, a great option. |
| Carpooling doesn't work for me due to my work hours. |
| Move someone that I work with next door to me. |
| Make it where women feel safe from harm. The idea of carpooling with a stranger (because no one I know works around me or lives around me). |
| nothing |
| For me- nothing. My work hours are flexible making it difficult to carpool |
| Idk |
| Idk |
| Make more friends |
| To create a sort-of incentive, maybe. If you could prove that you do use carpooling for your daily commute, you could earn some kind of gas stipend. |

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| I have no issue with carpooling, but my coworkers not classmates live in the area that i live in, so it would not make sense to commue. |
| Never having to pay for gas |
| I think carpooling would be more enticing if there were some rewards involved. One reward could be some sort of discount on gasoline for drivers that do carpool. |
| Having more than one HOV lane, because currently that one HOV lane gets backed up too in Nashville. Or maybe the HOV lane being closer to the exit side of the interstate because I hate having to cross 5 lanes of traffic to get to the exit. |
| I would not carpool because of schedule conflicts that could arise. |
| I think its a matter of having people who live in the same vicinity who are heading to the same area as you to make a carpool work efficiently. |
| I would personally just need to live closer to people I could carpool with. Maybe having some type of rewards program if you could prove you carpool. |
| uncertain |
| I would carpool but there's no one going my direction for work. |
| Nothing. Not enticing at all. |
| Nothing needed. |
| Regularly scheduled hours of work. My hours are too flexible. I like my flexible hours. |
| Nothing |
| Access to carpool, parking, willingness on part of participants. |
| Publicize ride-sharing/carpooling apps with testimonials about how safe and effective they are. |
| No idea. |
| I don't work a job or in an office where carpooling is feasible. I would be more likely to use public transportation if it were convenient to me. |
| Unsure |
| Using the HOV lane isn't a priority for me. I carpool because it's the right thing to do. |
| Not sure since I don't use it when timing is enforced |
| make the cars party cars with food and nice people. |
| Free parking by employer. If tolls are created a reduction or no toll for multiple occupancy. |
| It already is |
| Sharing wear and tear on my car |
| Nothing |
| Nothing |
| Knowing people from work who live closer to me so carpooling isn't inconvenient |
| Nothing |
| Does not apply due to my work schedule. |
| Not sure- I am retiring |
| Connect people with other people who are willing to carpool. |
| It would be enticing if the HOV lane was actually enforced. At this time, it doesn't seem that there is any enforcement of the HOV lane, so there are many people who drive every type of vehicle as single occupant drivers in the HOV lane. So, there is no motivating factor to create a carpool. If the lane was actually enforced, then that would greatly increase motivation to be able to access it. |

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| Tax breaks |
| Lots to park cars |
| I don't carpool |
| It is a joke as far as I can tell; hardly anyone pays any attention to the rules. If the law were enforced, maybe people who are actually qualified to be using the lane would. So, I believe simply enforcing the law would encourage those who can use the HOV to do it. |
| If I used the interstate during rush hour |
| I would not carpool because my schedule is different every day |
| Offer discounted Ubers |
| Park and ride areas |
| 0 |
| ? |
| ? |
| when my car is not working. |
| It just depends on if you have people you can carpool with |
| N/A |
| no option |
| faster commute, money |
| - |
| Nothing, I believe you should be allowed to use the HOV lane as a single driver. It is ridiculous to ask people to carpool when most of us drive alone. |
| Offer an incentive |
| more HOV lanes |
| I have no clue |
| It's just unlikely that I would carpool, regardless. |
| If it were easier to organize carpooling and if there were more benefits to carpooling. |
| Make people less annoying. |
| I dont think that there is much that can be done. we are in the south, driving is a big part of the culture. I was born and raised here, I dont use the HOV section, but I do use that lane when the sign say HOV is over. I have been driving since I was 14, so to most people down here your vehicle is a private space and important to you, which is why it is hard to get people to car pool, its southern culture to take pride in your vehicle. |
| I carpool when there are multiple people who need to be at the same place at the same time but otherwise it seems inefficient. |
| More obvious increase in time benefits. |
| N/a |
| Nothing |
| monetization, such as apps paying users to carpool such as waze-carpool app |
| Having people to live around me to ride with |
| Not sure |
| Employer gas funding |
| More carpool lanes |

# APPENDIX M: RESPONSES TO SURVEY QUESTION 38

**Would you be willing to participate in a peer-reported enforcement system for HOV lane usage? (Reporting illegal lane usage by reporting the vehicle's make/model and license plate to a hotline). If yes or maybe, why?**

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| Because it's the law |
| Depends on time line |
| Not sure |
| I would rather not have to call while I am driving, it would be distracting |
| Why not |
| If it is helpful and needed, I will consider it |
| I like rules |
| I'm a rule follower |
| I see everyone violate it every day |
| I do not like it when people are rude and break the rules on the road. Everyone feels entitled to break rules if it benefits them, but take great offense when others speed, cut you off, etc. Peer reporting would be good but also be distracting to call while driving. |
| I follow rules, so everyone else should too. |
| I don't need additional distractions while driving and it would have to be blatant and repeat offenders for me to call. |
| Because people are usually speeding in that lane in order to bypass everyone else and aren't being safe behind the wheel. |
| It's a good idea, but I'm think that this would be a bit of a distraction as a driver, if I'm trying to gauge every car in the HOV lane. |
| i like people to follow the rules |
| I need to focus on my own driving and would not want to use the phone while driving. |
| It depends if it's anonymous or not |
| Takes more time, distracted driving to report/keep track of vehicles |
| I use the HOV lane too, so it would feel unfair |
| because I believe peer reporting is effective.. |
| I prefer not to participate. |
| Not sure what a peer reported system would require of me. But I believe in carpooling and HOV lane ethics |
| Because we all should respect the law |
| Misuse of the HOV lane is frustrating, especially during rush hour. It's not enforced. I do what I can to abide by the rules even though I know most people won't. |
| catch those who cheat |
| HOV is not enforced now. |
| Sense of fairness |
| Because the HOV only works if there is compliance and I'm just a dirty snitch. |

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|---|
| I often see more single occupancy vehicles in the HOV lane, which as a person who regularly adheers to the HOV rules, bothers me. I would like to report those people violating the rules;however, Nashville traffic is often so bad, I find myself using the HOV lane to pass slower vehicles on occasion. I would not want to be reported or penalized for passing another vehicle momentarily in the HOV lane. |
| violators are cheating |
| I would be uncomfortable reporting offenders. |
| Rules should be followed and would improve traffic flow |
| Everyone needs to follow the traffic rules. |
| I might call in if I was asked to be on the look out for that type of thing. |
| There are those that take advantages of HOV lane consistently. A fine is probably the only deterrent to the action. |
| I don't view the HOV lanes as being beneficial because I observe so much abuse of this lane by single-occupancy vehicles. Other states consistently monitor HOV lane use and issues fines accordingly. This accountability has made the HOV lanes more beneficial in my own experience. |
| Wouldn't want it to distract from driv Ng |
| I would be willing to participate to increase accountability of those choosing to not follow the law. |
| Because the HOV lane needs enforced and if the police aren't going to do it then someone should. However, I am not thrilled with having to spend more of my day on traffic-related issues. I lived in the Baltimore/DC metro area before relocating to Nashville. There the HOV lanes are strictly enforced and actual work how they are intended - to save time and reduce congestion. Cameras could be installed to automatically take pictures of vehicle occupants and license plates. |
| If it would improve traffic and time issues, I might report. |
| I like rules and the HOV lane is there for a reason. Also, I know the state takes federal highway money to have that lane, so people should follow the rules. |
| Because part of being a citizen and forming community is establishing community standards; civic duty |
| I'm a rule follower and I don't like when others don't follow rules |
| it would be difficult to note the driver/car info and call this in while driving. |
| Because people should follow the rules |
| Because it annoys me to see car after car go by in the HOV lane that all have one person in the car. |
| Even though I don't always follow the rules, I do believe that if everyone did, traffic would be better. If there was enforcement, I'd be more likely to use it. |
| We would all be looking out for each other. |
| Makes the HOV effective. Right now, everyone uses it. |
| While I have been known to call the cops on people, if I'm driving it rarely happens because I don't want to pick up my phone to dial a new number, take a picture of the license plate, etc. Would hate to report wrong license. |
| I don't know if I would bother calling in violators. It probably wouldn't be worth my time. |
| Because people need to follow the laws weather they are being watched or not |

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| I do it myself sometimes. |
| It would keep the HOV for what it's intended for |
| Because I see this all the time and it frustrates me. I'd gladly report violators if it improved the usage. |
| Prospect Theory |
| Cops aren't always around and people take advantage of that with breaking rules and rising over there when they shouldn't |
| Keeps us and others accountable to each other |
| Need people to obey laws. |
| Hard to drive and get vehicle info while calling safely |
| Less people would violate if they felt as if they could be caught at any time by their peers |
| This would be hard to do while driving |
| I wouldn't want police to enforce improper HOV usage during rush hour, but a fine reporting system would be more appropriate so as to not slow down traffic further. |
| I would only do so if someone is blatantly violating rules or is driving aggressively. |

# APPENDIX N: RESPONSES TO SURVEY QUESTION 39

**Would you be willing to participate in a peer-reported enforcement system for HOV lane usage? (Reporting illegal lane usage by reporting the vehicle's make/model and license plate to a hotline). If not, why?**

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| I'm not tattling on others. And I don't want to take the time out of my already busy day. |
| I would never do that; people don't like to feel like they 'told on' someone. |
| I use it illegally already. Why would I report others? |
| Too many people trying to get tag numbers during rush hour will just cause more wrecks |
| That would add to distractions on the road |
| It is not my job to make assumptions about other vehicles and the people in them. I wouldn't be able to tell if the persons in question had their own emergencies to contend with, and I doubt I would make a call if I noticed anyone in violation, being that talking on the phone while driving is illegal in itself. I believe it is the responsibility of the police and other DOT officials to enforce the rules of the road. |
| I feel like that would create a lot of issues for false reports. This would best be handled by law enforcement or traffic camera footage. |
| That could potentially be distracting while driving on an already busy and dangerous interstate. |
| It would involve texting and driving |
| Don't have time for that |
| I probably wouldn't want to take the time to report |
| I wouldn't be able to concentrate on the road if I was taking down plate numbers. I don't like to be on the phone while driving. |
| To dangerous to remember tag number drive and call at same time. |
| Don't have time |
| don't want to spend my time on the road acting as police. |
| Time restraints |
| too much effort. Not concerned enough |
| Snitches. Also, this seems like a waste of my personal time. Also, the requirements for making such a call (having to look up the number, remember the person's plate number, or follow closely behind them in order to accurately report the plate number) seems unsafe. |
| Dont want to rat people out/take the time |
| Don't drive it often. |
| Unsafe to call while driving and a hassle. |
| I wouldn't trust it |
| I don't have time and don't want to have distractions while driving |
| This concept isn't for me. |
| It doesn't bother me that much that other people would use the HOV lane. I only use it when I'm able to, but I don't really care if others do. Also I don't know how accurate I would be if I tried to participate. |
| I don't want to be on my phone while driving |

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| Time consuming, takes attention off safety and driving, don't care enough what other people are doing. |
| Because the human error rate would be too high. I pay 200+ a month to drive a prius in those lanes and is someone reported me because they didn't see my sticker- the police would not be happy someone wasted their time. |
| I would be the one being reported not doing the reporting |
| That would distract me too much while driving |
| Lack of time. |
| I don't drive during rush hour if I can avoid it. |
| distracted driving |
| Too busy |
| I'm worried about getting to and from work. Not if someone else is violating the job lane |
| I don't like making calls |
| bc i violate the rules too |
| Because it's silly. No one obeys the rule and not enough ppl carpool or have hybrid cars to make sense. It just slows down the flow of traffic and still wouldn't be obeyed. Traffic is bad enough now. Thankfully I don't need to use highways to get to work or back home and work nights. Traffic is a huge reason why |
| Because I don't want to |
| ? |
| do not have time |
| I'm not a nark |
| Because I would be busy driving |
| That's petty. The other person is not putting anyone in danger by breaking the rule. |
| This seems difficult to do while driving, especially during high traffic times |
| I wouldn't feel comfortable with that. |
| Snitches get stitches |
| I don't care if they use it illegally |
| I don't have have time |
| Don't want to do that while driving. |
| No |
| Not my business |
| This seems extreme, and it would be hypocritical considering that I use the lane from time to time myself. Also, trying to take note of the make/model and license plate of a car while driving during rush hour could be dangerous; I'd only do this in a case of emergency (suspicion of drunk driving & etc.) |
| It is distracting while driving. |
| I believe that is the job of the traffic enforcers. |
| N/A |
| Because I also sometimes use the HOV illegally and would not want it to happen to me. |

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|---|
| I am suppose to driving without distractions. Not writing down a another person's make/model of their vehicle to report and I could potentially get pull over myself by being 'peer- Reported enforcement system' |
| I don't want to be a snitch. It's not really a big deal. |
| There are bigger issues that need to be addressed right now and this does not feel like a high priority to me honestly. |
| First it's the police's job to give people tickets for not adhering to the rules of the road. Second this would be a distraction and people already don't pay enough attention when driving. |
| Using my phone on the interstate is a distraction |
| I don't feel it is my business to report someone else's wrong behaviors. I also wouldn't want it done to me. |
| Too dangerous while driving. |
| These individuals might have a good reason for violating the rules of the HOV lane. |
| i dont care enough |
| I don't want to report anyone. |
| It's distracting to do while driving in traffic for something that minor. |
| Just want to get to work |
| Not interested in monitoring illegal peer HOV lane use |
| too much time required |
| Too dangerous to call while driving |
| Not willing to live in a police state |
| Not a rat. |
| I do not agree that reserving one lane of a severely over crowded interstate for HOV is the best use of available road space. |
| Too time consuming |
| I am not interested. |
| If these peer reports cannot be independently verified by law enforcement, I would not be in favor. It would be too simple for a frustrated driver or bored motorist to call in a false report. |
| I don't drive the interstate often enough to work to do this. |
| This would be distracting and could lead to false reports. |
| Would result in distracted driving |
| Cell phone use while driving isn't a great idea. |
| Creating a lane restriction at the imposed time would increase my driving time by removing a viable lane necessary to accommodate unforeseen problems such as breakdowns, wrecks, infrastructure work, etc. |
| Doesn't seem very safe when I'm supposed to be paying attention to the road. |
| I am concerned about how safe this would be. |
| It should be important enough for law enforcement/local government to figure out a way to enforce the law. Having motorists to this while driving would simply be a safety hazard. |
| Wouldn't want to take the time |
| Too potentially dangerous while driving; lack of time. |

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| Not worth the bother |
| I have to pay attention to my driving and the idiots around me. Reporting illegal lane usage would be a distraction. |
| nobody got time for that, shouldn't there be jobs created for enforcing this. Additionally, everyone getting on their phones to report people will create more distraction and increase wrecks. |
| I drive infrequently on the highway |
| The distraction of trying to get someone else's plate number while driving in a separate lane, most likely, is not the best way for me to be a safe driver. |
| I was erroneously turned in for throwing a cigarette butt out of my window. I don't smoke and I have never thrown any type of trash out of my window. People make mistakes. |
| I don't know how this could safely be done from a moving vehicle if I'm driving. |
| I'm not a tattletale. I'd love to get to work faster, but more than that I'd love to have a schedule that would allow me to work from home some. My job duties do not require daily presence at the job site. |
| It does not matter to me who uses HOV lanes. I think that they should be open to everyone. |
| That seems like a petty waste of time & dangerous. |
| I think this would be a distraction to already distracted drivers and create an even more dangerous situation. |
| I'm not a snitch :) This feels like communist China type of stuff. |
| I do not care enough to make that call. People need to get where they need to go, so why am I going to make their life harder and inconvenience them by going out of my way to call and make sure they get fined for something that doesn't even remotely affect me? Also, why would I inconvenience myself by going out of my way to make that call? I could mind my own business for free. Lastly, and most importantly, I shouldn't be making any calls while driving. |
| I just like to get home and would not like something else to think about when trying to relax |
| If not causing harm, I do not see a reason to tell on someone. |
| It's not important to me to take the time to call into a hotline, especially since I violate the HOV rulings. |
| Violation of privacy |
| People lie |
| Would not take the time |
| time commitment |
| Frankly I do not think we need a HOV lane. Traffic is busy enough as it is and we need all the lanes we can get. Peer reporting is very 'petty' and I do not think violated the hov lane is a big enough deal for me to take the time to report it. |
| Don't trust people |
| I focus on driving. |
| would not feel comfortable doing this while driving |
| I do not have time. |
| I can't do that and drive down the interstate. |
| Not interested in reporting others |

| |
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| Not my job to report people |
| I'm not interested in reporting other drivers. I'm spending my time paying attention to the traffic and roads and don't have time to monitor anyone else; besides, I don't like the idea of reporting on someone else for a violation of HOV lanes - I don't consider that a serious issue and it's creepy. Way too '1984' for me. |
| I am not a snitch. |
| It is too busy to making phone calls and remembering license plates while I am driving. |
| hard enough to navigate traffic without trying to report offenders |
| It's not my call to judge what other cars are doing. If a car is in an HOV lane and are going to an emergency, I do not want to penalize them. |
| Now you're asking me to pay more attention to monitoring the HOV lane than my own driving! I want reasons to pay more attention to my driving and LESS to my phone! |
| I don't have time for that. I really don't see the HOV lane as helping out on the interstates except it allows people to break the rules. |
| just don't have time to do that. |
| Because I don't travel early enough in the morning nor travel enough during rush hour in the evening to do it and I do not want to alter my times because of the flexibility that I have. |
| Unwilling to do this; System could be abused |
| Not interested |
| Not taking the time to do the police's job. |
| Waste of time |
| Not worth the work of writing down lisence plate numbers |
| Unless there was an incentive for me, I don't have time to report other people's violations |
| Idk |
| It doesn't bother me if people use it |
| Too much trouble. |
| Don't want to |
| I don't feel comfortable |
| No time |
| Seattle has something similar, and people abuse it. |
| I don't want more distracted people on the road trying to fumble around with their phone to report someone. That would cause slower traffic and more distracted drivers. |
| It's skeezy, don't want to be fake reported if the person behind you is upset or something bc of road rage. Dangerous bc driving |
| N/A |
| Don't like throwing others under the bus |
| I'm not a snitch |
| Too much time, too difficult |

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|---|
| This seems ridiculous to me. HOV lanes are fine how they are now -- I would not pay to use an HOV lane and think it is unsafe to have peer-reporting. If I see someone violate an HOV rule, I then have to look up the phone number, tailgate them to get their make/model/plate number, and talk on the phone while driving. These risks seem unnecessary for reporting an HOV violation. Also, what if someone reports you inaccurately due to roadrage, miscalculating how many people are in the car, etc.? This is a ridiculous idea. |
| I don't have issues with people violating HOV usage. |
| If there is no other way to prove the violation happened, I would not trust others to properly call this in. Anyone could claim someone else violated the HOV rules, maybe if they were angry with them related to road rage, etc. This could also lead to more distracted driving accidents while people take down plate numbers. |
| Because I wouldn't call while driving. |
| Because that's ridiculous. Our lanes our so congested that if the rules were followed it would make things so much worse. 65 is almost a parking lot in the morning as it is |
| This is not my job to enforce. Additionally, I like having all lanes of traffic distributed evenly and using a lane that might otherwise be empty (the HOV lane if no carpoolers, hybrids, etc). |
| Too much work |
| No time and dangerous while I'm trying to drive |
| Not a good use of my time. |
| I don't care enough to call and make a report just because someone else is being a jerk. Doesn't effect me and in this case, isn't a big enough deal. |
| N/A |
| too much effort |
| I am not going to introduce an additional stress into my commute. |
| I don't have time. |
| That would involve being distracted while driving |
| I don't care enough. |
| I would have to report myself and it would take up too much time. |
| It wouldn't help and I don't think that kind of regulation would be beneficial because how do you prove it? |
| I feel it is unnecessary. Anyone should be allowed to use the hov lane |
| I'm not usually on the interstate during rush hour traffic and when I am, I usually use the interstate to go around street traffic. I am on and off very quickly. |
| Tattling is not cool. |
| Peer report seems to over-police offenders and although I do not break the HOV rules often, I do sometimes and do not want to get in trouble myself. |
| I'm not a tattle teller & I mind my own business. |
| Too much work; I'm also not a tattletale |
| No time to participate |
| Because i'd rather mind my own business |
| It feels wrong. |
| It's none of my business if others violate the HOV lane rules. |

| |
|---|
| That is not my job and I do not want that responsibility |
| That would be a waste of my time. My eyes should be on the road in front of me not on the HOV lane. |
| I would only feel obligated to report if the vehicle was being driven erratically. ie Speeding, swerving |
| Seems like a hassle to do while I'm driving. |
| I mind my own business. |
| It's not up to me to enforce traffic rules to other citizens. I do not have the time or the energy for it. |
| I don't like being on the phone or writing down notes when I am driving. I also do not like constantly peering into other people's cars. |
| This system could be taken advantage of. |
| Not safe. Too prone to errors |
| Because I use the HOV lane so I'm not going to turn others in for doing what I'm doing |
| It would require too much effort. |
| I don't care that much |
| who am I to judge who uses the lane. There are not an abundance of qualified people in the lane, and when traffic is slower, there is a wide open lane to ease the pressure traffic. seems silly to waste a perfectly good road because it is deemed only for consumption of a certain qualified car or passenger limit. |
| It would cause me to not pay attention and cause me to violate cell phone laws. |
| i aint no snitch |
| thats distracted driving. people already cant drive here, now you want them to get even more distracted? |
| Dont see the need for it |
| Too much effort |
| Quite busy/not much free time in my schedule |
| I'd feel like a narc |
| I don't think that people who use the HOV lane illegally are hurting anyone |
| It's unecessary, unless the city is willing to pay me to do that. The city should regulate the HOV lane, not ask me to police it for them. |
| Take attention off road |
| Its not up to me to decide another person's choices for breaking the rules |
| I don't have a lot of time. |
| I wouldn't want people calling on mw |
| I feel that would encourage phone usage while driving |
| Recording & calling in offenders would lead to distracted driving, and thus accidents. Seems like a bad idea. I wouldn't risk it while driving. |
| The potential for abuse is too great. |
| Everybody should be paying attention to the road and driving not to other person license plates/vehicle models descriptions. They can eaaily install cameras. |
| No |
| Don't care enough |

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| N/a |
| Not my style |
| Don't like to report on other people |
| Snitches get stitches. |
| I don't trust other people to enforce the laws unless they are certified to do so. |
| I don't drive on the interstate on way to work, I wouldn't qualify |
| Not in position |
| You want me to call a hotline while I'm driving??? Unsafe |
| I don't want to police other people when I'm driving to work. |
| I'm not a snitch? I also don't have time for that during rush hour haha. |
| Dont have time to worry about other people |
| 0 |
| I think people would start doing it out of spite not because someone is actually using it wrong. Also that's not our job to police the HOV lanes. Atlanta does a great job at it. I also believe that would DEFINITELY cause more accidents. |
| There are bigger issues |
| Distraction |
| I am too busy trying to get to work or school to snitch on other people also trying to get on work on time. |
| Seems like a waste of my time. |
| I don't really think violating that rule is a huge deal, and I don't want to get someone in trouble for doing it |
| I am paying more attention to my driving and not how many people are in another car. I feel like this could cause accidents. |
| Not interested |
| Not interested |
| It's petty, there are WAY bigger issues to worry about, and I'm focused on operating my vehicle and reaching my destination |
| Using phone wil driving is unsafe. Not my business. Feel like a narc |
| We shouldn't be driving and using our phones at the same time. |
| I don't have time for that and it would be difficult to get plate info down while I'm also driving. |
| Time consuming |
| I don't want to try to do that while I'm driving in traffic |
| How do you regulate that? |
| It would involve using my phone when driving. |
| Don't care. Ppl driving in HOV Lane are not in my Lane. |
| Always the driver, wouldn't be able to write down numbers |
| I don't use the HOV lane at all. |
| Miss use of authority |
| It doesn't seem safe for me to do this while driving. |
| Too much work for something I don't care about very much. |

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| Because I don't know the other persons circumstance and why they are using it. There could be someone else in the car that I can't see or it's an emergency |
| I don't have time to tattle tale on people. |
| Would not want to report |
| N/A |
| Not safe while driving |
| Seems like a tattle-tale/bad idea scenario. I don't want to be law enforcement. |
| I feel like people could abuse this and call in cars they are frustrated with. |
| Do you want me to use my phone while driving?! Seems like a bad idea. I'm not going to memorize a make and model and license plate and remember that until I get to my destination to then make a phone call to report someone. |
| It is not my responsibility to enforce the law. |
| It's not my responsibility to 'patrol' others. |
| Not interested in taking responsibility for others' driving choices |
| Only if it effected me daily, it does not. |
| Already too much device usage on the roads. |
| N |
| Not interested. |
| You really want someone to take down a license plate number while driving!?! |
| You should be focused on driving. Not watching out for illegal use of the HOV |
| time consuming, distracting |
| Snitches get stitches |
| We all are trying to get downtown on time. What benefit is it if we have an extra lane, yet it is restricted to certain kinds of vehicle? It just slows down traffic (assuming we all abide by the law). In my opinion, I don't think people really understand what an HOV lane is for, and if they did, they would say, 'rubbish.' Just provide us with enough lanes or alternate routes to accommodate all the traffic. |
| I don't trust citizens to use this in an honest way. What prevents me from calling and reporting someone just because they cut me off, or I didn't like they way they were driving? |
| That is a lot of work that I think would contribute to distracted driving. |
| i don't want to be big brother. |
| Don't have time |
| Because first of all, it's none of my business, and second of all, no one has time for that, and third of all, that is the job of the police not citizens. |
| I try not to use my phone while driving. I think it would be riskier to try and pick up my phone on a busy highway, especially 65. |
| It would be more dangerous getting out your phone and trying to copy down the license plate/call |
| I don't feel that I drive on Nashville's interstates enough to be able to participate in this. Because I live on campus, I hardly ever drive during rush hour. |
| I do not use the interstate enough to provide any sufficient data. |
| I would not advocate for other drivers to preoccupy themselves with trying to drive while reporting information on cell phone for something as insignficant as driving in the HOV. |

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| It's not safe for me to be paying more attention to another car's plate and dialing a number just to tattle on them than on my own driving. |
| Waste of time. Besides it's unsafe to be on the phone or writing stuff down while driving and that's exactly what would have to be done unless we all get police radios. |
| Because snitches get stitches. Nobody likes a rat. |
| Too much work. |
| I like to leave other people alone |
| I feel that is better suited for law enforcement to monitor. |
| I don't like throwing people under the bus, everyone has their reasons for doing what they do, why would I assume something and tell on them. plus I hope people wouldn't do that to me! |
| I do not have a car |
| How would we monitor this? What if I accidentally cut someone off in traffic so they called me in as a violation because they were upset even if I did not violate the HOV lane rules |
| Not interestedly |
| Offenders could be violent if they believe you are recording their tag number. |
| Ain't nobody got time for that. |
| Not interested |
| I don't care enough to call out other people. |
| only me in the car so i don't normally use HOV |
| Takes up time. |
| Could have serious repercussions Job of law enforcement |
| I am retired |
| Inconsistent |
| Would not want to report other people |
| not an frequent issue with us |
| That's a lot of double tasking right there |
| not interested, does not effect me |
| I am not a rat |
| It's too much trouble, and I don't know why they're using the lane. It may be an emergency |
| That's lame |
| Snitches get stitches. |
| If the lane is saving me time I would rather not be reported. |
| I don't want to spend time doing that and I rarely use the interstate. |
| That's tattletelling |
| Because I think the amount of traffic is ridiculous and sometimes you are stuck in traffic for hours even when you left in plenty of time I get why people use that lane and I am not ratting them out for it |
| Time |
| Do not have the time / energy to ruin someones day for doing something they may have done accidentally with no negative consequences |
| Let the police enforce traffic laws. If they don't catch someone don't worry about it. |

# APPENDIX O: SCHEDULE OF INTERCHANGES/ENTRANCES/EXITS

## SCHEDULE OF I-24 INTERCHANGES / ENTRANCES / EXITS:

| EXIT | DESCRIPTION | MILE MARKER (MM) |
|---|---|---|
| 54 | TN 155; Briley Parkway | 53.4 |
| 56 | TN 255; Harding Place | 55.7 |
| 57 | Haywood Lane | 56.8 |
| 59 | TN 254; Bell Road | 59.4 |
| 60 | Hickory Hollow Parkway | 60.3 |
| 62 | TN 171; Old Hickory Boulevard | 62.3 |
| 64 | Waldron Road | 64.5 |
| 66 | TN 266; Sam Ridley Parkway | 66.1 |
| 70 | TN 102; Lee Victory Parkway/Almaville Road | 69.7 |
| 74 | I-840 West/East | 74.3 |
| 76 | Fortress Boulevard/Medical Center Parkway | 75.9 |
| 78 | TN 96 | 77.7 |
| 80 | TN 99 | 79.6 |
| 81 | US 231/TN 10 | 80.9 |

## SCHEDULE OF I-65 INTERCHANGES / ENTRANCES / EXITS:

| EXIT | DESCRIPTION | MILE MARKER (MM) |
|---|---|---|
| 53 | TN 396; Saturn Parkway | 53.18 |
| 59A-B | I-840 West/East | 59.15 |
| 61 | TN 248; Goose Creek Bypass/Peytonsville Road | 61.81 |
| 65 | TN 96; Murfreesboro Road | 65.64 |
| 67 | McEwen Drive | 67.05 |
| 68 | Cool Springs Boulevard | 68.01 |
| 69 | TN 441; Moores Lane | 69.34 |
| 71 | TN 253; Concord Road | 71.60 |
| 74 | TN 254; Old Hickory Boulevard | 74.73 |
| 78 | TN 255; Harding Place | 78.01 |
| 79 | Armory Drive | 79.33 |
| 90A | US 31W/US 41/TN 11; Dickerson Pike | 90.71 |
| 90B | TN 155; Briley Parkway | 91.11 |
| 92 | TN 45; Old Hickory Boulevard | 93.03 |
| 95 | TN 386; Vietnam Veterans Boulevard | 96.32 |