METHODOLOGY FOR COLLECTING VEHICLE OCCUPANCY DATA ON MULTI-LANE INTERSTATE HIGHWAYS: A GA 400 CASE STUDY

A Thesis
Presented to
The Academic Faculty

By

Katherine T. D'Ambrosio

In Partial Fulfillment
Of the Requirements for the Degree
Master of Science in the
School of Civil & Environmental Engineering

Georgia Institute of Technology
August 2011

METHODOLOGY FOR COLLECTING VEHICLE OCCUPANCY DATA ON MULTI-LANE INTERSTATE HIGHWAYS: A GA 400 CASE STUDY

Approved by:

Dr. Randall L. Guensler, Co-Advisor
School of Civil & Environmental Engineering
Georgia institute of Technology

Dr. Michael P. Hunter, Co-Advisor
School of Civil & Environmental Engineering
Georgia Institute of Technology

Dr. Michael D. Meyer
School of Civil & Environmental Engineering
Georgia Institute of Technology

Date Approved: July 8, 2011

“HERE’S TO THE NIGHTS THAT TURNED INTO MORNINGS,
THE FRIENDS THAT TURNED INTO FAMILY,
AND THE DREAMS THAT TURNED INTO REALITY”
-UNKNOWN-

ACKNOWLEDGEMENTS

I would first like to thank my parents, who have been supportive of me throughout my entire life and encouraged me to succeed in everything I attempt. I am deeply indebted to them for their continued support, love and generosity.

I would like to express my sincere gratitude to Dr. Randall Guensler who provided the opportunity to pursue a graduate degree and for his support and patience throughout the project. I am also grateful to Dr. Michael Hunter for his encouragement and advisement beginning during my undergraduate research and continuing through my graduate studies. I must thank Dr. Michael Meyer, Dr. Guensler and Dr. Hunter for their review of this thesis.

A very special thanks goes out to my fellow graduate research assistants who were all involved with the numerous data collection sessions: Stephanie Box, Felipe Castrillon, Chris Rome, Adnan Sheikh, Chris Toth, Sam Vedala, and Trung Vo. I must also acknowledge Vetri Elango, Angshuman Guin and Lakshmi Peesapati, for their roles in the project. I would particularly like to extend my sincerest gratitude to Katie Smith who not only took part in the data collection deployments but also assisted me in the data processing of the GA 400 data for this thesis as well as partnering with me to present preliminary findings from GA 400 at a conference in San Antonio.

Finally, I must express my gratefulness to my friends, especially those I met at Georgia Tech, who have always encouraged me to accomplish my goals and for their constant acceptance, and I would not be where I am without them.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Georgia Tech	Georgia Institute of Technology
GP	General Purpose (Lanes)
GRA	Graduate Research Assistant
HD	High Definition
HDV	Heavy Duty Vehicle
HOT	High Occupancy Toll
HOV	High Occupancy Vehicle
L#	Lane Number (1, 2, 3) – Lanes at Downstream Site
LDV	Light Duty Vehicle
LP	License Plate
ML	Managed Lanes
SUV	Sports Utility Vehicle
TL#	Toll Lane Number (1, 2, 3, 4, 5, 6, 7) – Lanes at Toll Plaza
URA	Undergraduate Research Assistant

SUMMARY

A before and after comparison of vehicle occupancy distributions for the Atlanta, GA I-85 HOV to High Occupancy Toll (HOT) lane conversion scheduled for summer 2011, will assess the changes in vehicle and passenger throughput associated with lane conversion. The field deployment plans and data collection methodologies developed for the HOT evaluation were the result of a comprehensive literature review, an examination of previous data collection methods, an evaluation of the physical characteristics of the I-85 corridor, and the testing of a variety of equipment/manpower strategies.

The case study in this thesis evaluates the established vehicle occupancy methodology for consistency across multiple observers during parallel data collection efforts. The differences noted in exact matches and consistency across the use of the "uncertain" values developed for field implementation is specifically assessed. Results from this study are the first step in assessing the validity of the data collection methods used on the HOT corridor and will yield recommendations for improving the methodology for future occupancy studies. A separate assessment of the accuracy of the methodology is also being conducted by the research team and will be published under a separate cover.

CHAPTER 1: INTRODUCTION

The collection of vehicle occupancy and license plate data can provide valuable demographic data about the users of a specific transportation corridor for transportation planning purposes. In the case of a High Occupancy Vehicle (HOV) lane conversion to a High Occupancy Toll (HOT) lane in Atlanta, GA, occupancy data are being collected to assess the impacts of the HOT lane on carpooling and commute-shed activity patterns. The thesis presents the development and case study based calibration and validation of a methodology to determine vehicle occupancy on multi-lane fully controlled access facilities.

Existing methodologies for collecting vehicle occupancy range from manual methods to automated technologies, and numerous hybrid variations. This research examined the advantages and disadvantages associated with each that led to the development and implementation of the Georgia Institute of Technology (Georgia Tech) methodology for the collection of data on the Atlanta I-85 HOV-to-HOT conversion corridor. The use of a variety of technologies to improve the accuracy and organization of the data are discussed, as well as the adjustments to specific procedures as the methodologies were field tested. A controlled test deployment on a local toll road allowed for assessment of consistency in parallel observations. The conclusion discusses the results of the field tests, the limitations of the chosen methodology and identifies improvements to be tested and implemented in the future.

The next chapter discusses the overall HOV-to-HOT corridor analysis project and the data collection requirements in order to monitor the HOT lane effectiveness.

Chapters 3 and 4 provide the methodology literature review, site selection and data collection processes for I-85 based upon the literature review findings. The methodology for collecting license plates along the HOT corridor for us in data matching is discussed in Chapter 5. Chapter 6 focuses on the vehicle occupancy methodology that was established for this project. Chapter 7 presents the preliminary occupancy results from I-85 for three quarterly data collection efforts. Chapter 9 reports the case study designed to assess the consistency of parallel data collection and distributions of "uncertain" values across multiple data collectors. Conclusions, recommendations and potential future research opportunities are reported in the Chapter 10.

CHAPTER 2: OVERVIEW OF THE HOV-TO-HOT PROJECT

The Atlanta HOV-to-HOT conversion project is funded by the United States Department of Transportation (USDOT) Congestion Reduction Demonstration Program Grant that was awarded to the Georgia Department of Transportation (GDOT) in November of 2008. The demonstration project is scheduled to convert a approximately 16 mile segment of the HOV lanes on I-85, from Chamblee Tucker Road to Old Peachtree Road, into HOT lanes by the end of summer 2011.

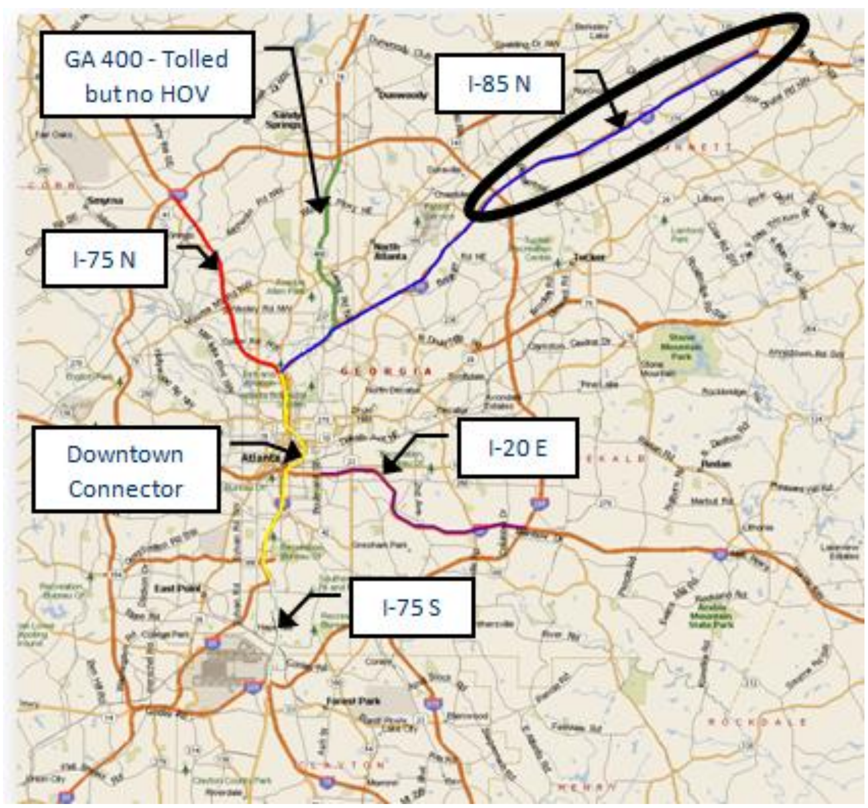


Figure 1: Proposed HOT Lane (circled) and All HOV Corridors in Atlanta, GA

A two year performance evaluation of the HOT lane is being conducted by a team from the Georgia Tech School of Civil and Environmental Engineering to assess the impacts of the HOT lane on carpooling and commute-shed [1] [2] activity patterns. In this work, "vehicle occupancy" is defined as the number of passengers in a vehicle. Quarterly vehicle occupancy (persons/vehicle) and license-plate-based demographic data are being collected for one year before and one year after the HOT lane is implemented. The methodologies for collecting vehicle occupancy and license plate data were initially established in the summer of 2010 after an analysis of the data collection sites along the corridor, a comprehensive literature review and the assessment of possible equipment available for the project. Adjustments to the initial methodologies were made when necessary based on field observations and after processing data back in the laboratory.

The collected data will be utilized in the evaluation of the effectiveness of the HOT lane and to aid in the assessment of whether the HOT lanes should be expanded to other corridors in the Atlanta area. While the project scope for the Georgia Tech team includes a full analysis of a variety of performance assessments; this report focuses on the methodology for collecting vehicle occupancy along the proposed HOT corridor, including an analysis of consistency and limitations of the chosen methodology.

Presently, an Atlanta HOV lane allow access to carpool vehicles with two or more passengers and is intended to restrict single occupant vehicles (SOVs) use. The proposed HOT lanes will allow free access to vehicles with three or more occupants (HOV-3 vehicles), while also allowing SOVs and two-person carpools to use the lane if they pay a toll. Since it is more difficult for users to form 3-person carpools, the increase in the minimum number of occupants for free lane access will likely decrease demand for use of the lane. SOVs and 2-person carpools will be charged for usage of the HOT lane based on a variable toll pricing system which will set the fee based on current demand for the lane in order to maintain free-flowing traffic throughout the HOT corridor. As congestion increases in the HOT lane, particularly during peak periods, the fee for non-HOV-3 carpools will increase to reduce demand. Alternatively, during off-peak times or when demand is low, the fee will be lowered to a minimum value.

By controlling demand, the periods of congestion on the lanes should be minimal (unavoidable congestion may occur due to incidents) and those that choose to pay to use the HOT lane will be paying for a reliable trip through the corridor. The overarching demonstration project analysis will assess whether demand can be sufficiently influenced as to eliminate demand based congestion in an environment with some of the worst freeway traffic congestion. According to Forbes.com, for example, Atlanta ranks number 1 in the list for worst cities for commuters where people spend at least 60 hours a year stuck in traffic. [3]

CHAPTER 3: LITERATURE REVIEW OF VEHICLE OCCUPANCY METHODOLOGY

The methodology developed for collecting vehicle occupancy on the HOV-to-HOT conversion corridor was based on a comprehensive literature review of previous methods used, the constraints and characteristics of the sites selected along the study corridor, and the capabilities of equipment and manpower available for the project.

A literature review was compiled on the methodologies for collecting vehicle occupancy, particularly on managed lanes. Few reports have been published on analyzing different methods for this type of data collection. A majority of the reports found were either repetitive, dealt with the monitoring of violation rates of HOV lanes, or reported the results of the occupancy data collection in the studied area without significant discussion of the data collection methods. The next sections of this thesis summarize the information learned through the literature reviews that was applied in developing the vehicle occupancy data collection methodologies for the HOV-to-HOT conversion corridor analysis.

3.1 Summary of Existing Methods for Collecting Vehicle Occupancy

The most comprehensive document found on methodologies for collection vehicle occupancy was released by the Federal Highway Administration (FHWA) Office of Highway Information Management [4]. The report examines the five most recognized methods of occupancy data collection that currently exist: roadside/windshield, carousel observation, photographic and video surveillance, accident data extraction, and mail-out survey.

The roadside/windshield method is generally recommended over other methods for before and after studies. The next five subsections provide a brief overview of the roadside/windshield method as well as the four other existing alternative methods for collecting vehicle occupancy data. This is followed by additional detail on the roadside/windshield method as this is utilized in the HOV-to-HOT conversion corridor data collection.

3.1.1 Roadside /Windshield Method

The traditional roadside/windshield method is the most commonly used method to collect data because of its simplicity and low equipment requirements. With this method, a data collector is positioned such that they can see through a passing vehicle's windshield and windows to visually count the number of occupants. The occupancy value is then recorded using an electronic counter or on a worksheet, limiting the equipment required and the effort to transport to and from the site. Strengths of using this method are the minimal equipment required, the ease to implement, and the high percentage of collected data for passing vehicle, usually in the 75-90% range. However, there are several limitations to this method including a short view time into the vehicle (particularly at high speeds), data collection can only be conducted during daylight hours only, and concerns with balancing the safety of the observer with the ideal perspective for viewing inside the vehicle. Another notable limitation is the labor intensiveness of this method which tends to degrade the observer's performance over time.

3.1.2 Carousel Method

The carousel method positions observers in probe vehicles that travel through the observation corridor at 10-15 mph slower than the present traffic in order to collect the vehicle occupancy of neighboring vehicles. This method improves the accuracy of the collected data, especially for vehicles with passengers in the back seats, since the observer is located less than 10 feet away. The strengths of this method are mainly in the observers viewing time and angle which improves the accuracy of the collected data as well as the improved safety of the observer, now located inside a vehicle. Limitations of this method include the requirement of continuously moving traffic, data collection only on multi-lane roadways, potential obstruction of existing traffic, daylight operation providing the best results, required coordination if multiple vehicles are used to record separate samples of traffic, and most significantly, a success rate that is much lower than other methods, averaging at only 25% of the total traffic volume.

3.1.3 Photographic/Video Surveillance Methods

Existing technologies for photographic and video surveillance methods for collecting vehicle occupancy are not at a point of development that they could be used in this project. Given the time required for extracting the data from the recordings as well as for the installation and removal of equipment, the FHWA does not recommend the use of this method for the collection of vehicle occupancy data. When the technology is used, its advantages would include minimal observer fatigue in the field and creating a permanent record of all passing vehicles that allows for review of the data, collection of additional types of data for each vehicle and the use of a variety of sampling strategies. The currently available equipment, however, is extremely expensive, can be limited by the stationary view, might accidently record external factors that hinder observations such as glare, and requires extensive training for equipment use and for the processing of data.

3.1.4 Mail Out or Telephone Surveys

A mail out or telephone survey can obtain valuable information for a region by sampling a small percentage of the area's population. While the survey participants can provide averaged information about vehicle occupancy, when looking at a specific corridor this method will be inadequate unless specific users of that corridor are identified and data are specified about that location. Limitations include a lack of detailed information, the expense for a large survey, and the typically low response rate on the order of 1% of the population. Advantages of this method are that little to no training required for collection, other types of information can also be obtained, and there are no physical safety concerns.

3.1.5 Accident Data Extraction

The accident-data extraction method is a relatively new method that estimates average occupancy for a defined area from police accident reports in the study area. The advantages of this method are that it requires no field collection effort, is low cost, provides good regional samples, records can contain other valuable information, and new data can be collected as new reports are submitted. This method works well for identifying trends in a larger area, but can be limited or biased by a small number of records when considering a single corridor. Specifically it was noted in the report that HOV lanes are generally underrepresented in accident reports and may not necessarily represent an average sample of the driving population.

3.1.6 Variations in Data Collection using Roadside/Windshield Methods

A report distributed by the Florida Department of Transportation (FDOT) [5] presents the results of a study to assess the efficiency of several methods, including the roadside/windshield method, for collecting and analyzing vehicle occupancy. The study included over 2,000 hours of data collected from 21 different sites, varying in type of facility, travel lane, direction, time of day, day of week, and month of year. The roadside/windshield method was used for all of the field data collection; other methods were analyzed in the report but will not be discussed here. An emphasis is made on the importance to tailor a study to the specific corridor and final objectives of the study.

Several components were identified from the FDOT study about vehicle occupancy under different collection circumstances. Hourly variation showed that occupancy rates began very low in the morning, increased throughout the day until the afternoon peak, then maxed out after the evening rush. This is easily explained by the morning work trips, followed by errands or lunch trips during the middle of the day, then dipping back down for the evening work-to-home trips and finally peaking with family trips in the evening. Occupancy variation over lanes was also analyzed by the FDOT project, which concluded that a variation in occupancy did exist over several lanes and that estimating occupancy from only one lane would not be accurate. Similarly, a variation was found between opposing directions indicating that data collected from one direction of travel does not necessarily mimic the data in the opposite direction of travel. In terms of the schedule of collecting data, the analysis showed that variations were the most extreme in data collected on Mondays and Fridays and concluded in the report that those two days should be avoided for occupancy collection studies in the future. A look at the monthly variation advises future studies to take into account the schedules of schools in the surrounding area which can greatly affect both the traffic volumes and the number of occupants.

Important methodology guidelines can be taken from this report and applied to future studies. In particular, it was found that counts of 1-2 hours will produce data with sufficient accuracy and precision for most purposes. Also, it is necessary to record data from all lanes in both directions or at least in the peak direction to achieve accurate results. The study also advises that a police officer be present at the data collection site to ensure that there are no traffic problems and so other officers do not stop to inquire about observers' actions.

3.1.7 Factors Affecting Accuracy when Using Roadside/Windshield Methods

Another important report reviewed was "Accuracy and Other Factors Affecting a Continuous Vehicle Occupancy Monitoring Program" [6]. This study focused on three main objectives: motivations of observers to stay alert, optimal field conditions for observation, and the level of accuracy that can be expected. The described methodology used portable computers in the field to minimize human error, decrease transcription errors, conduct consistency checks, and minimize post-processing. A parallel study was conducted that deployed three people to each site to collect the same occupancy data which were later compared for discrepancies and to assess the accuracy of the collected data. This report identifies five important factors to take into account when creating a deployment plan and selecting sites for data collection.

- Weather: it can be difficult for observers to collect data during sunny days because glare on the vehicle makes it difficult to see inside.
- Time of Day: the most accurate counts occurred in the morning hours when observers were fresh and alert.

- Speed Limit: the faster the traffic, the more likely observers were to miss vehicles or record vehicles that did not exist.
- Observer Comfort: fewest errors made when conditions were most uncomfortable, generally when the observer was forced to stand.
- Traffic Density: heavier traffic conditions tended to focus the observer's attention more, thus improving the accuracy of the data.

The study also lists insignificant factors identified by this study for the accuracy of the occupancy data as the length of time counting, average occupancy, and the light levels at the site (as long as the observer can see). A list of criteria for site selection defining the best vantage point included: use of 10-20 ft above the roadway; distances between 10 and 50 ft from the roadway; located where observers will not distract drivers; convenient parking and access to the site; minimal expected weaving movements in observed traffic; and located to minimize glare given the angle of the sun.

3.1.8 Case Studies Using Roadside/Windshield Methods

3.1.8.1 FDOT – 2005

A 2005 FDOT report [7] identifies new technologies that could provide new methods of data collection as well as recommending a set of guidelines and tools to enhance occupancy study collections. The set of study guidelines for manual counting methods address issues related to scheduling, data sampling, training, equipment, deployment plans and data analysis.

The key aspect of this report for the I-85 study is the use of a handheld Pocket PC in the vehicle occupancy data collection methodology. This equipment allows the data collector to input data in a quick and simple way using a predefined script for data imputation. In the FDOT study, several variations of data imputation screens were developed. The first screen predefines either the lane number or the vehicle classification being observed and then only requires the observer to input an occupancy value and to save the record. The second and third variations require the observer to select a vehicle classification or a lane number respectively and then to input an occupancy value before saving the record. The most complicated of the variations required the observer to first choose a lane (lane 1-4), to then designate a classification (Car, Truck, Bus, or Other), to input an occupancy value using a keypad interface with all ten numbers (0-9) and then to hit a save button to record the data into a file.

The report does not discuss the differences in accuracy and percentage of vehicle classifications collected of the varying imputation screens. A short paragraph in the report does indicate that the study analyzed the possibility of using voice recognition software in conjunction with the touch input, but that the option was found impractical because of lack of the appropriate software for the Pocket PC and unreliability due to interference from nearby traffic noises.

3.1.8.2 Washington State DOT (WSDOT) – 1994

The objective of the WSDOT report, “HOV Monitoring and Evaluation Tool,” was to identify which methods of collecting vehicle occupancy, travel time, and public opinion are the most effective [8]. Occupancy data were collected by human observers with portable computers standing on an overpass or an access ramp at 48 sites around the Seattle area. A FORTRAN program was developed for the project which allowed observers to record their location, date and time of session, type of session, direction of traffic, and comments of observation conditions. The report explains the procedures used to select sites, how the observers traveled to the site, how equipment use was determined and how information was transferred back for analysis. The preparation of field kits and the process of quality assurance were also described, which is extremely useful in the initial set-up of the field deployment. This report is one of few that explain in detail the entire process followed for an occupancy study and analysis.

Several lessons from this study can be learned and applied to future studies, including the use of a similar tool as described in the FDOT study - a specifically developed script that allowed imputation of particular data required for analysis. This study deployed observers for three to five 30 min counts with a 5-10 minute break between each count. For classifying vehicles and recording occupancy, the observers used a key-pad (0-9) with the following designations: 1-4 person passenger vehicle, 5 = vanpool, 6 = transit bus, 7 = other bus, 8 = 2-axle truck, 9 = 3-axel truck, 0 = motorcycle. An interesting aspect of this method is that occupancy and vehicle classification were defined in one button instead of separately. This limited the occupancy information recorded to only the passenger vehicles while only collecting traffic counts for all other classifications. A statement in this report that appears obvious but is generally overlooked in other studies is that because every car must have a driver, it is more important to position observers to see the passenger side of the vehicle.

3.1.9 Other Case Studies

Several other case studies were analyzed during the literature review for developing occupancy data collection methodologies for the HOV-to-HOT conversion corridor analysis. Previous studies included multiple cities in California from 1988-1994 [9], the City of Lincoln, NE in 2006 [10], Richmond, VA in 2007 [11], and a report that analyzed monitoring programs of HOV lanes in Virginia, California, Texas, Oregon, New Jersey and Washington State [12]. These readings provided background information on the collection and monitoring of vehicle occupancy but did not provide insight beyond what has already been discussed or would be relevant to developing the methodology for collecting vehicle occupancy for the HOV-to-HOT project.

CHAPTER 4: DEPLOYMENT PLAN FOR DATA COLLECTION ON HOV-TO-HOT CORRIDOR

4.1 Site Selection

As stated, the HOV-to-HOT conversion corridor stretches for approximately 16 miles along I-85 north of the city of Atlanta beginning just inside the I-285 perimeter at Chamblee Tucker Road and ending just past the exit for Old Peachtree Road. The objective of the effort being reported in this thesis is the collection of occupancy and license plate data, as part of the broader HOV-to-HOT evaluation project. In surveying the study, corridor data collection was deemed feasible from several overpasses and interchange gore areas along the corridor. While the viewing angle for license plate data collection tends to be acceptable from overpass location, previous studies for collecting data similar data from an overpass [1][2] concluded that the use of spotting scopes or binoculars are required to collect the data. The main concern with collecting vehicle occupancy from the overpass is the viewing angle into the vehicle, which is limited by the vehicle roof and the pillars. To gain a more direct view into moving vehicles, and to eliminate the need for a spotting scope which increases the difficulty in tracking a vehicle, it was postulated that data collectors could be positioned in the gore area between the freeway and a ramp, for the collection of vehicle occupancy.

In selecting sites for collecting vehicle occupancy and license plate data, the following criteria were established:

1. An overpass for the best view of the back of the vehicles required to collect vehicle license plates

2. Occupancy methodology may require the use of gore area (located between off ramp and freeway)
3. The safety of the data collection teams: both to access the site from parking are and while collecting data

With these criteria in mind, each of the 15 overpasses within the corridor were visited and assessed for data collection capabilities and safety. Four sites were initially selected for the data collection effort that satisfied the criteria as well as allowing sampling distributed throughout the approximately 16 mile corridor. Before the data collection began, an additional northbound traffic monitoring site at the southern tip of the corridor was included to collect a data set for vehicles entering the HOT corridor. The following sites were used in the data collection for the HOV-to-HOT effectiveness analysis:

- Chamblee Tucker Road (Exit 94)
- Jimmy Carter Boulevard (Exit 99)
- Beaver Ruin Road (Exit 102)
- Pleasant Hill Road (Exit 104)
- Old Peachtree Road (Exit 109)

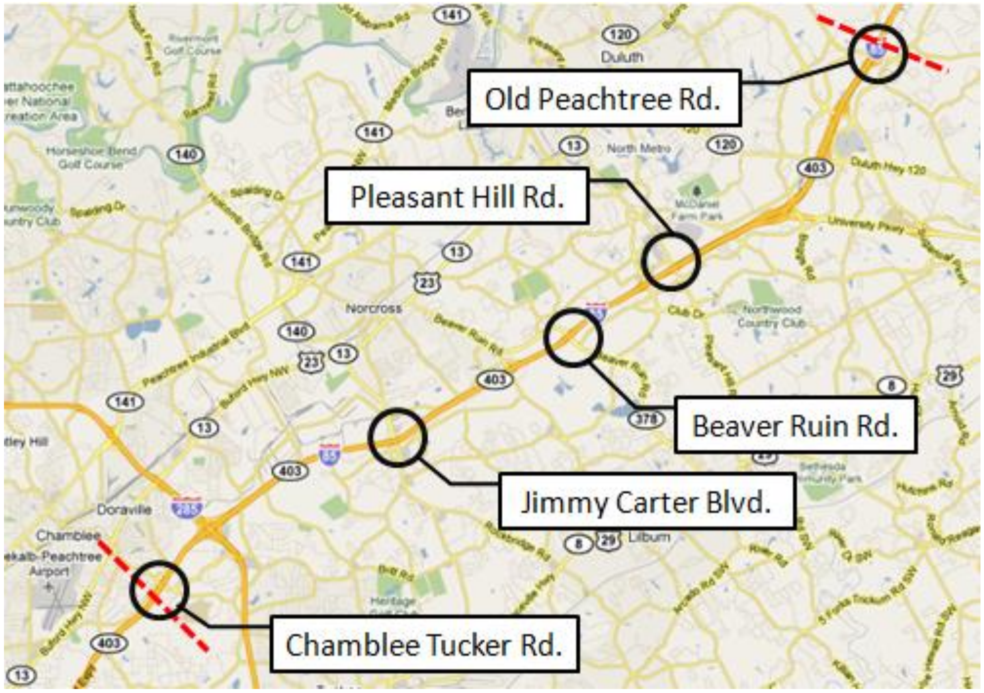


Figure 2: Data Collection Sites on Proposed HOT Corridor

A data collection safety plan for the collection of data at each site is in Appendix A. The safety plan describes the access, parking and safety measures to be followed at each data collection site. Fencing on the bridge was seen as undesirable as it was a hindrance for the license plate collection, where video cameras would then have to be carefully positioned to capture the lanes without including the fencing in the view. Further discussion of the license plate collection methodology can be found in Chapter 5.

4.1.1 Chamblee Tucker Road (Exit 94)

Chamblee Tucker Road is the southern-most site of the HOV-to-HOT conversion corridor and is located just inside the I-285 perimeter of Atlanta, GA. Upon visiting the site, the team determined that a U-turn bridge for I-85 located on the south side of the overpass would interfere with any cameras positioned on the bridge to collect southbound traffic. This site was thus not included among the initial four sites because of this inability to collect southbound data. Because the next site was five miles into the proposed corridor, Chamblee Tucker was added to the data collection schedule for recording only northbound traffic during the PM-peak to monitor the entrance into the proposed HOT corridor. This site also had sidewalks and crosswalks; there is no fencing on the bridge and the northeast quadrant at this site has sufficient room for a team to observe and record vehicle occupancy data.

4.1.2 Jimmy Carter Boulevard (Exit 99)

Jimmy Carter Boulevard was the second selected site driving northbound through the corridor. This site includes both crosswalks and sidewalks, does not have a chain-link fence on the bridge, and has available gore areas in all four quadrants for occupancy data collection. The high traffic volume at this site and the narrow sidewalks along the overpass were potential concerns for the safety of the data collection team; hence, detailed safety training was conducted.

4.1.3 Beaver Ruin Road (Exit 102)

The Beaver Ruin Road site is located midway through the corridor at mile marker 102. Data were collected at this site previously for another Georgia Tech study [1][2] allowing for comparison with past data. The site had crosswalks and sidewalks, as well as available gore areas in all four quadrants; and no fencing on the overpass.

4.1.4 Pleasant Hill Road (Exit 104)

Pleasant Hill Road is the fourth selected site. Its location is the closest to the major interchange of GA-316 and I-85 where a team could safely and accurately collect data. It is important for data to be collected just before and after the GA-316 interchange to quantify the volume of vehicles using the HOT corridor to and from GA 316. The Pleasant Hill site includes crosswalks and sidewalks for travel from the parking area, no fence on bridge for improved video collection, and gore areas available in all four quadrants of the interchange.

4.1.5 Old Peachtree Road

The Old Peachtree Road site is the northern-most site in the HOV-to-HOT corridor and was the most difficult to configure for data collection needs. It was necessary to choose this site because it was the northern bound of the data collection corridor and it was the only site with an overpass north of the GA 316 interchange. Due to recent intersection improvements along Old Peachtree Road, improved safety at this site was provided by crosswalks and sidewalks. However, a major concern with this site was the presence of access roads running parallel to both sides of I-85 that continue through the overpass at Old Peachtree Road. These access roads separate the gore area from the I-85 lanes by an extra 100 ft, which greatly hinders the occupancy collection. For that reason, the occupancy teams had to be relocated to different locations further upstream from the gore to improve the viewing angle.

4.2 Lane Numbering At Sites

For ease in organizing data, the lanes at each site are numbered from the inside lane and counting up from "0" for the managed lane (HOV or HOT lane). The lane directly to the right of the managed lane is then labeled “1”, then “2”, “3”, etc. with the outside lane numbered the highest (see Figure 3). Because the Atlanta area only has single HOV lanes on any facility, this method can be used at any location around the Atlanta area; a site without an HOV lane would begin with lane numbering at “1”.

For the selected sites described above (3.1-3.5), all but Old Peachtree Road have 1 managed lane and 5 general purpose lanes which translates to data being recorded on lane “0”, “1”, “2”, “3”, “4” and “5”. At Old Peachtree, there is 1 managed lane and only 4 general purpose lanes which translates to data being recorded on lane “0”, “1”, “2”, “3”, and “4”.

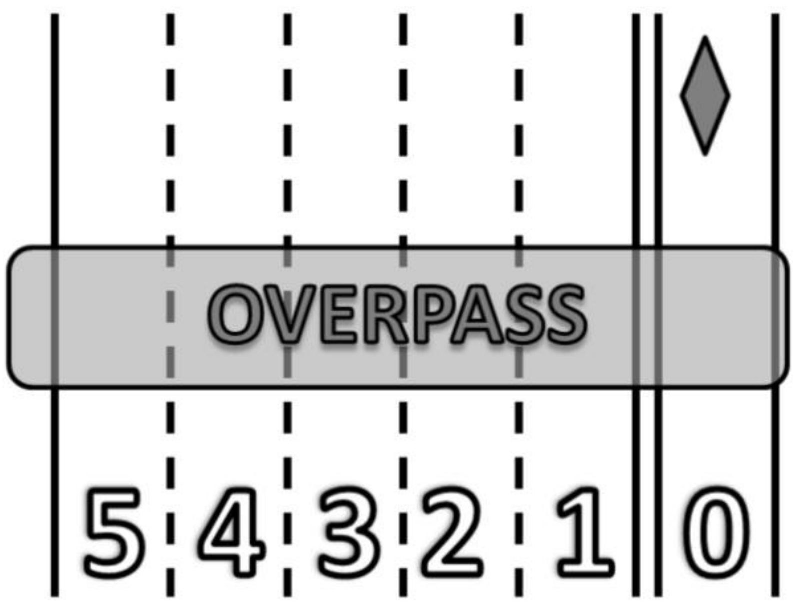


Figure 3: Lane Numbering Scheme

4.3 Data Collection Schedule

For the purposes of the before and after study, quarterly data are being collected over a two-year period at the five selected sites on I-85. A total of eight deployments will occur for this analysis: fall 2010, winter 2010, spring 2011, summer 2011, fall 2011, winter 2011, spring 2012, and summer 2012. During each quarter a team visits each of the five selected sites during one week to collect vehicle occupancy and license plate data for both the AM and PM peak traffic times (except Chamblee Tucker, for which only PM-peak data are collected). Each peak session collects data for two hours: 7am-9am for the AM-peak and 4:30pm-6:30pm for the PM-peak. Because traffic around the Atlanta area enters the city in the morning and exits the city in the afternoon, the AM-peak sessions observe the southbound traffic while the PM-peak sessions observe the northbound traffic.

Before the data collection began, the team decided to collect a minimum of three AM sessions and three PM sessions at each site for data analysis. The fall 2010 data collection schedule assigned teams for each peak time for Monday through Thursday with the idea that the Tuesday, Wednesday, and Thursday data would be used for analysis and the Monday data could be used in case a data collection session was canceled due to unforeseeable circumstances. After the fall 2010 collection, the schedule was reduced to only the Tuesday, Wednesday, and Thursday sessions with make-up sessions being undertaken at the end of the quarterly deployment.

4.3.1 Limitations in the Data Collection Schedules

The first notable limitation in the data collection schedule is that it has to be developed around the schedule of the data collectors hired for the project. The data collection teams are predominantly undergraduate research assistants (URAs) who are working for the project at the same time as completing their undergraduate degrees at Georgia Tech. Hence, data collection during finals week and scheduled holidays, (especially winter break), is impractical. To that end, the data collection schedules do reflect the Georgia Tech calendar.

A second limitation is that data collection sessions must be canceled during inclement weather conditions because of the electronic equipment used in the established methodologies for this project (discussed in later chapters). While the data collected does not allow for a determination of potential differences in vehicle occupancy during inclement weather, the data does ensure a comparison of consistent weather conditions across data collection periods

CHAPTER 5: LICENSE PLATE DATA COLLECTION

5.1 License Plate Collection Methodology

A methodology for collecting license plates on a high speed freeway had been established by a previous Georgia Tech Graduate Research Assistant, Jennifer Nelson, for a similar data collection effort in summer 2006 [1]. This methodology included the use of spotting scopes, voice recorders, and video recorders in the collection of license plates of general purpose lanes from an overpass. In a report by Nelson, only about 25-30% of the passing vehicle license plates were collected using this methodology and the data collection conditions were described as “strenuous” for the field observers. For purposes of the analysis of the HOV-to-HOT conversion corridor, a higher percentage of license plates were desired so the team sought to improve upon this methodology.

At first, slight adjustments to Nelson’s methodology were analyzed to help improve the percentage of collected license plates. The use of a voice recognition program, Dragon Naturally Speaking, was assessed in an effort to improve the accuracy of transferring of the spoken license plate to an electronic document. It was eventually determined that vocalizing the license plates in the field was the limiting factor in collecting the data, requiring that alternative strategies be identified. The prospects of video recognition technologies were evaluated, but the available options did not provide an acceptable level of performance for this study.

Due to advancements in video camera quality in cameras at a reasonable price, the collection of license plates using high-definition video was investigated for potential application to the HOV-to-HOT corridor. After researching and initial testing of camera capabilities, the Panasonic-HDC-TM700 Hi-Def-Camcorder was selected for collecting vehicle license plates. When set up properly, the high definition capabilities of this equipment can record two lanes of traffic to be simultaneously recorded from the overpass with sufficient clarity to read the license plates of passing vehicles. After recording the data in the field, the video is then manually processed using a proprietary video processing program developed at Georgia Tech. The processed output file includes date, timestamp, frame number, license plate number, license plate state, vehicle classifications (Appendix D), lane number, comments, name of personnel conducting the video data reduction, and when the processing was completed. With this methodology, vehicle license plate identification rates range from a low of 50% under poor lighting conditions to a high of 95% under ideal conditions. During data collection periods with reasonable lighting, typical capture rates are on the order of 70% to 80%. Reasons for the failure to record some license plates are discussed in the following section.

5.2 Limitations of the License Plate Data Collection Methodology

The limitations of the video-based license plate data collection methodology can be divided into two categories: environmental and human. The most notable environmental limitations are during the fall and winter data collections when sunrise and sunset occur during the peak-traffic periods and thus conflict with the data collection schedules. The low light levels at the beginning and end of these data collection sessions affect the camera recordings and hinder the processing of the license plate recognition during video data reduction. Other environmental limitations occur when congestion allows vehicles to tailgate enough to occlude the license plate during the recorded view. Human error has also been a concern when setting up the cameras to collect the field data. Through analysis of the fall 2010 video, a specific angle and zoom was established to maximize the quality of the video collected. Failure to utilize optimal camera settings can result in lower license plate capture rates.

In addition, at two of the data collection sites, a chain-link fence surrounds the bridge, requiring extensive training for the observers to ensure proper video camera setup. The lens must be placed very close to the chain-link fence, and the zoom and focus must be checked to ensure that the camera view is trained upon the passing traffic and not on the fence.

5.3 License Plate Data Collection

For the selected sites the license plate field data collection requires the use of four cameras positioned on the overpass. A camera is set up to record lanes "0/1" (the managed lane and the lane adjacent), "2/3" and "4/5". At Old Peachtree Road where there is not a lane "5", the camera only records lane "4". Each camera is positioned on a tri-pod and tethered to the bridge (Appendix A). When positioning the cameras for recording, the lens is zoomed all the way out and then the camera is angled such that the skip line separating the two lanes of interest is vertical in the center of the display and the outside lane lanes appear approximately half way up the screen (see Figure 4). After analysis of previously recorded videos, the team determined that this set-up provides the best recording quality and maximizes the length of time that each license plate is readable on the screen for improved video reduction processing.

Figure 4: Screen Shot from License Plate Video Collection (Plate Numbers Removed)

5.4 License Plate Video Processing

After the data collection sessions, the video files are transferred to a common drive and then the license plate video recordings of the vehicles through each lane in the field are sent through a proprietary video processing program developed at Georgia Tech. To use the video processing system, the videos are reduced to screen shots of every 30th frame (2 frames per second) to keep the program and computer drive from being overwhelmed by the size of the two-hour, high definition video files as well as allowing the student observers to tab through images rather than try to pause the video to read the license plate. Once the video processing program is opened, student video processors tab through images and manually input the following information to the best of their ability: license plate number, vehicle classification, and license plate state. Vehicle classification and state are only defined if the plate is not registered in the state of Georgia. If the license plate is unreadable, the processor records the vehicle as miss to allow for an accurate vehicle count.

5.4.1 Reasons for a Missed License Plate in Video Processing

There are several factors that can create a missed record while the video is being processed. Low light levels, video blurriness, tailgating, towing, and lane changes are the most common reasons for a recorded missed license plate. During the fall and winter quarters, sunset and sunrise occur during the data collection sessions causing low light levels to occur, which affects the quality of the HD recording and thus the visibility of the license plate. The two main causes of short term video blurriness are from shaking of the bridge where the cameras are set up due to large trucks and from the auto-focusing of the camera as an object enters the view. Long term video blurriness is usually explained by setting up the camera incorrectly; in particular when a chain link fence is involved, the camera may auto-focus on the chain link fence at some point during the two-hour data collection period if it is in the camera view and fail to record the license plates in the HD quality. At this point, no improvements to the methodology have been identified to reduce these factors (other than further training of the individuals who set up the cameras). Alternatively, driver behavior such as tailgating and lane changes, are a minimal factor in the missed records but are unpredictable and unavoidable in the data collection effort.

5.4.2 Variations in License Plate Recordings

Several number-letter variations have been identified during the translation of the license plate from the images to the output file. The most common character transposition is 8 vs. 0. Table 1 displays the 25 most frequent occurring variations of a two day data set of 464 character variations. There are three main groupings that can be noted based on the highest occurring variations. First, the rounded characters which includes 0, 8, 6, 9, O, D, Q. The second grouping is with M, W, and N which have angled features that are difficult to pick up, even with the HD video camera. The third grouping is with between specific characters that have similar features: examples include 5 vs. 6, 6 vs. G, 1 vs. I, 1, vs. 7, 2 vs. Z, B vs. D, and V vs. Y.

Table 1: Variations in License Plate Video Processing Characters

Order	Variations		Count
1	**0**	**8**	52
2	**M**	**W**	43
3	**5**	**6**	42
4	**8**	**9**	27
5	**8**	**B**	22
6	**6**	**G**	18
7	**0**	**O**	18
8	**0**	**9**	17
9	**6**	**8**	15
10	**0**	**D**	13
11	**M**	**N**	12
12	**1**	**I**	11
13	**6**	**9**	10
14	**0**	**Q**	10
15	**1**	**7**	8
16	**2**	**7**	8
17	**5**	**8**	8
18	**2**	**Z**	8
19	**0**	**6**	7
20	**B**	**D**	7
21	**V**	**Y**	7
22	**3**	**8**	6
23	**5**	**S**	5
24	**N**	**W**	5
25	**0**	**1**	5

CHAPTER 6: VEHICLE OCCUPANCY METHODOLOGY FOR HOV-TO-HOT CONVERSION CORRIDOR DATA COLLECTION

The vehicle occupancy methodology for the HOV-to-HOT project was based on the literature review, data requirements for analyzing the effectiveness of the HOT lane and an examination of the physical characteristics of the project corridor. The roadside/windshield method described in the literature was selected for the HOT corridor because of the desired high percentage of collected vehicle occupancy data, the before and after nature of the study, and the features of the available sites.

6.1 Data Requirements

Several pieces of information needed to be collected both in the lab and in the field for each data collection session. For the preliminary information collected before each session, a worksheet (Appendix B) is filled out which includes up-to-date data on the temperature, sunrise/sunset times, gas prices, any construction or accidents in the study corridor and notes about the schedules of surrounding public schools. All of this preliminary information can be used to help explain any discrepancies found in the data. For example, if the traffic volumes and thus the occupancy records are particularly low during a day or a week, the worksheet could indicate that local schools were implementing a teacher-workday that allowed students to stay at home.

Once in the field, it is necessary for the observer to record both a vehicle classification and a vehicle occupancy value for a passing vehicle. Each of the records is also defined by a site name, the data type, the peak-time period, the direction being observed, a lane number and a date of observation. All of these pieces of data are imputed as the file name of the occupancy file that is created at each session.

6.1.1 File Name Convention

A file name convention was established in order to keep all of the files organized throughout the two year study. For each quarterly collection, a total of 156 occupancy files will be collected and stored for the pending before and after analysis. After the eight quarters there will be at least 1,248 files on record. The following name convention provides all key pieces of information about the file in one line:

[Site]_[Data Collected]_[Peak Time]_[Direction]_[Lane #]_[Date].[File Type]

Table 2: File Name Convention for HOV-to-HOT Data

Site		Data Type	Peak Time	Direction	Lane #	Date
CTR	(Chamblee-Tucker Rd)	VO	AM	NB	0	mmddyy
JCB	(Jimmy Carter Boulevard)	LP	PM	SB	1	
BRR	(Beaver Ruin Rd)				2	
PHR	(Pleasant Hill Rd)				3	
OPR	(Old Peachtree Rd)				4	
					5	

The table above references the different options for each variable. After the site is selected, the type of data, either vehicle occupancy (VO) or license plate (LP) data is labeled, followed by the time, direction, observed lane and the date.

6.1.2 Equipment

An electronic method for recording the data was desired to improve both the accuracy and percentage of recorded data. Building on the literature review, and from both the FDOT and WSDOT studies, an electronic recording device with a script, created specifically for this project, was developed and implemented in the methodology. A netbook (ASUS EeePC) was purchased for use in each of the observed lanes. Observers need to have the flexibility to find the best viewing angle for their lane, so an external key-pad is used to relay the collected data back to the netbook for recording and storage. The netbook can then be closed and stored in a drawstring backpack worn by the observer. While in the field, observers record a vehicle classification and occupancy value for passing vehicles in the assigned lane.

6.1.3 External Key-pad

The external key pads used for vehicle classification have all been refaced to clarify for the observer exactly what data they are recording (Figure 5). Upon creating a record, the observer is required to first select a vehicle classification and then to identify an occupancy value. To reduce the complexity for the data collectors and improve the percentage of vehicles recorded in the field, vehicles were divided into only three classifications:

- HDV – Heavy Duty Vehicle (ex: large truck, non-passenger owned vehicles, 3+-axle vehicles)
- SUV – Sports Utility Vehicle (includes pick-up trucks, minivans, and station wagons)
- LDV – Light Duty Vehicle (e.g. sedans, two-seaters, and crossover vehicles)

After recording the vehicle classification, the observer selects an occupancy value. There are seven options for occupancy values displayed on the keypad: 1, 1+, 2, 2+, 3, 3+, and 4+. The yellow buttons on the far left (1, 2, 3, 4+) are used when the observer is confident that they can see all occupants in the vehicle. Alternatively, the column of orange buttons to the right (1+, 2+, 3+) can be used if external factors hinder the observer's ability to accurately quantify the occupancy. For example, rear tinted windows often prevent the observer from seeing whether passengers are present in the rear seat. Further explanation and use of the orange buttons is discussed in section 7.2.

There are also two red buttons included in the re-facing of the keypad. The "C", for "clear", button located at the top of the keypad is used to mark the previously created record as incorrect. As vehicles are speeding past the observer, the field team found that observers could accidently press the wrong button and create a false record. With the "C" button, the observer can then mark that record as incorrect so that it will not be used in any analysis. The second red button, "MISS", was added to the script as a way to record a passing vehicle that the observer was unable to create a record for. By recording all of the missed vehicles, estimated traffic counts can be obtained at the same time occupancy data are collected. However, with placement of a camera on the overpass recording video for all lanes and post processing the video for high traffic volumes, the

"MISS" button became unnecessary in the HOV-to-HOT data collection and is only used if desired by the observer. Rather than creating a record for the most vehicles, all observers are instructed that an accurate vehicle occupancy record of fewer vehicles is more important for the study.

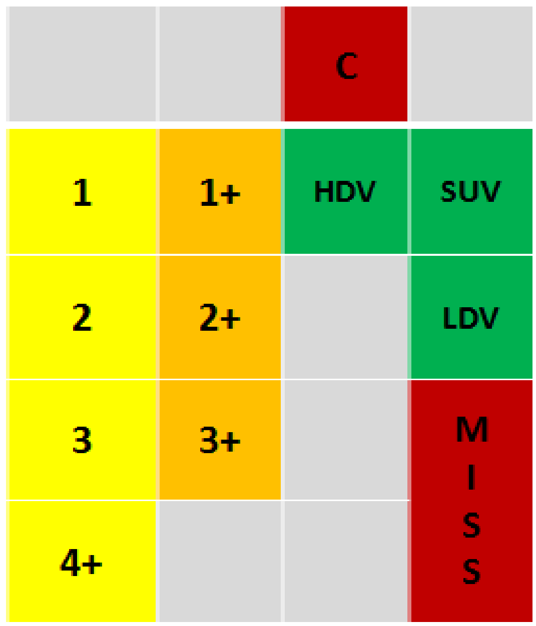


Figure 5: Refaced External Keypad for Occupancy Data Collection

6.1.4 Equipment Failure

In case of equipment failure during a deployment, an extra netbook and keypad are contained in the field kit. Printed occupancy worksheets and pens are also in the field kit for should multiple equipment failures occur during a data collection period. For the first three quarters, there has never been a need for the occupancy worksheets.

6.2 Definition and use of "Uncertain" Values

One of the limitations of the roadside/windshield method discussed in the literature review was light levels, particularly on sunny days, when glare can be a major issue, and in the early morning hours where there is not enough light to see all vehicle occupants. In addition to the hindrance of light level, field observers have noted a significant number of vehicles with deeply tinted back and rear windows. These and other factors such as vehicle speed were motivators for creating an ability for observers to be able to record their uncertainty when in the field. To accomplish this, the "X+" column of keys (orange keys, second column) on the keypad indicate that the observer is confident that there is at least 1, 2, or 3 occupants in the vehicle (1+, 2+, 3+), but there could be more unseen passengers due to external conditions hindering the view. A distribution of the uncertain values for analysis purposes is quantified by a separate study discussed in Chapter 9.1.

6.3 Changes to the Initial Methodology

Several updates to the initial methodology have been made to improve the accuracy of the collected data and simplify processes. The notable changes to keypads, auditory alerts and other elements are discussed in the following sections.

6.3.1 Keypads

Initially, wireless external keypads were chosen because of the expected ease of plugging the wireless USB transmitter into the netbook and then walking away with the keypad to collect data. This equipment was quickly eliminated when the field team noted crosstalk occurring between keypads and other netbooks. Because the netbooks are generally operated with the screen closed during data collection, it was not possible for a data collector to know whether the data they were collecting was being accurately recorded by their corresponding netbook. The wireless keypads were replaced with wired keypads, which connect to the netbook, snake out of the drawstring back-pack and are held by the observer.

6.3.2 Off-Pattern Beep Added to Script

A few files from the data collected in fall, 2010 showed that the observer was getting off-pattern when recording the data. The script requires the entry of a classification value followed by an occupancy value to create a record. When an occupancy value is pressed first, or two classifications are pressed in a row, the script rejects the record and records the reading as a miss. With the netbooks closed, there was no way for the observer to know if they were off pattern. A beeping alert noise was added to the script to alert the observer when they are off-pattern and to start their next record with a classification followed by an occupancy value. To hear the beep over the traffic noises, headphones are used.

6.3.3 Binoculars

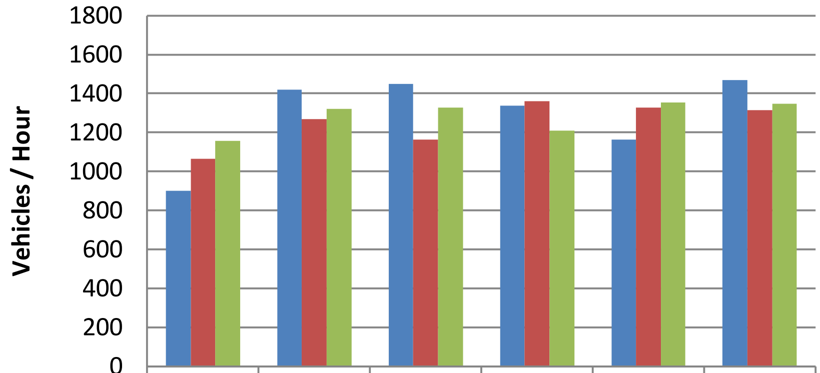
The initial plans included the use of binoculars to improve the viewing for the occupancy recorders. Upon testing this method in the field, it was found that the binoculars were not required to view into the vehicle and could actually impair the observer's vision by requiring a longer focus time. A set of binoculars was kept in the field kit for the fall 2010 data collection deployment, but was never used and have been removed from the equipment list.

6.4 Summary of Vehicle Occupancy Methodology for HOV-to-HOT Conversion Corridor Analysis

In summary, the methodology for collecting vehicle occupancy along the Atlanta I-85 HOV-to-HOT conversion corridor records a vehicle classification (HVD, SUV and LDV) and a vehicle occupancy value (1, 1+, 2, 2+, 3, 3+, 4+) for a specified lane using a netbook, external wired keypad and pre-configured computer script. Uncertain values such as 1+, 2+, and 3+ are used to indicate that a minimum number of 1, 2, or 3 persons was observed, but that external factors (such as glare, window tint, vehicle speed, etc.) obscured the view into the vehicle, making it impossible to establish an upper boundary of passengers. Observers are positioned in the gore area adjacent to the direction of travel being observed. With the netbook closed and secured in a backpack, observers can move around the gore are to find the best viewing angle for their assigned lane. A field session checklist was established for the supervisors to ensure that every aspect of the methodology was completed correctly and safely. A copy of this checklist can be found in Appendix C.

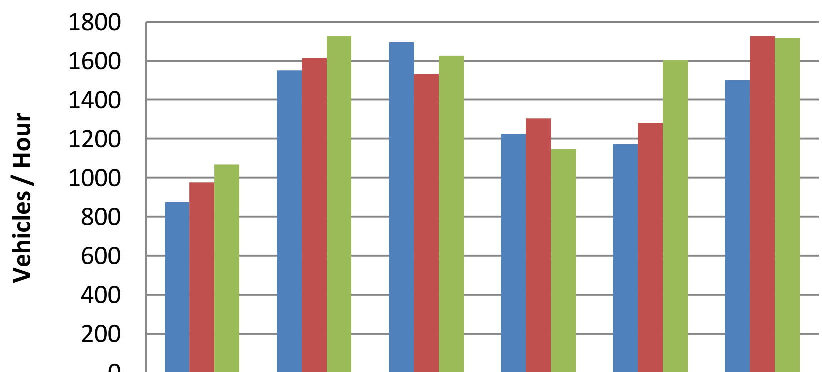
CHAPTER 7: RESULTS OF OCCUPANCY DATA COLLECTED ON HOV-TO-HOT CORRIDOR

At the time of this report, three quarterly data collection field deployments have been completed on the HOT corridor (fall 2010, winter 2011, and spring 2011). The data collected from Beaver Ruin Road site (near the middle of the corridor), is displayed in the following tables with figures for all three quarters. Figure 6 displays the distribution of the records by lane for the AM peak at Beaver Ruin Road and for the PM peak in Figure 7. The existing carpool lane handles a lower traffic volume, but the vehicles are occupied by more passengers. Once the HOT lane is implemented, the number of records through the HOT lane is likely to increase, since all vehicles will have access to use the managed lane by paying a toll that varies with congestion level. The net impact of changes in vehicle use and individual vehicle occupancy on total persons served per hour will be assessed next year.



	HOV	Lane 1	Lane 2	Lane 3	Lane 4	Lane 5
Fall 2010 AM	900	1418	1448	1337	1164	1468
Winter 2011 AM	1066	1269	1164	1359	1326	1315
Spring 2011 AM	1156	1322	1327	1209	1354	1348

Figure 6: Distribution of Vehicles/Hour for Beaver Ruin Road AM Peak; Peak Hour Volumes: Fall 7735, winter 7499, spring 7716 vehicles/hour



	HOV	Lane 1	Lane 2	Lane 3	Lane 4	Lane 5
Fall 2010 PM	875	1553	1694	1227	1174	1503
Winter 2011 PM	975	1613	1530	1304	1283	1730
Spring 2011 PM	1069	1730	1627	1147	1603	1720

Figure 7: Distribution of Vehicles/Hour for Beaver Ruin Road PM Peak; Peak Hour Volumes: Fall 8026, winter 8435 spring 8896 vehicles/hour

7.1 Occupancy Data Distribution at Beaver Ruin Road

The occupancy distributions at Beaver Ruin Road for each of the three quarters are shown below in Table 3 and Table 4. Generally similar distributions are found at the Beaver Ruin Road site through each quarter of data collection. A decrease in the percentage of single occupant vehicles (SOVs) in the HOV lane is observed during the spring 2011 quarter which could be due to increased enforcement or construction activity in anticipation of the HOT conversion. However, an increased percentage of "uncertain" values were recorded by field teams that quarter. Once the HOT lane is implemented, greater percentages for 3-person or more high-occupant vehicles are anticipated, but are not definite because the HOT lane will be accessible by any vehicle willing to pay a toll that varies by congestion level. Depending upon the pricing and demand for the HOT lane, the number of carpools may rise for commuters wishing a reliable trip time through the HOT corridor and willing to form a 3-person carpool to avoid paying a toll.

Table 3: Distribution of Occupancy Records at Beaver Ruin Road for AM Peak

AM	HOV Lanes				General Purpose Lanes		
	Fall 2010	Winter 2011	Spring 2011		Fall 2010	Winter 2011	Spring 2011
1	7.3%	7.3%	0.95%		87.7%	83.8%	75.3%
1+	10.7%	3.6%	18.8%		7.9%	8.1%	20.7%
2	64.2%	54.0%	42.8%		3.55%	6.45%	2.9%
2+	12.4%	27.2%	32.95%		0.5%	1.15%	1.0%
3	2.7%	3.7%	1.7%		0.2%	0.3%	0.1%
3+	0.4%	1.4%	1.4%		0.05%	0.1%	0.0%
4+	2.3%	2.8%	1.4%		0.1%	0.1%	0.0%

Table 4: Distribution of Occupancy Records at Beaver Ruin Road for PM Peak

PM	HOV Lanes				General Purpose Lanes		
	Fall 2010	Winter 2011	Spring 2011		Fall 2010	Winter 2011	Spring 2011
1	8.7%	9.7%	5.0%		86.2%	88.6%	79.2%
1+	5.25%	17.2%	7.6%		5.9%	6.75%	11.7%
2	73.35%	41.9%	57.3%		6.8%	3.7%	6.8%
2+	5.6%	26.6%	24.0%		0.5%	0.6%	1.55%
3	4.5%	2.3%	2.5%		0.4%	0.2%	0.4%
3+	0.3%	0.4%	1.0%		0.0%	0.05%	0.15%
4+	2.3%	1.9%	2.6%		0.2%	0.1%	0.2%

There are several inconsistencies displayed in Table 3 and Table 4 between the different quarters of data collection. Because the fall 2010 quarter was the first data collection deployment, the data could be more inaccurate than the following quarters due to the learning process. As the team gained experience, there is a possibility that observers were less likely to record certain values, resulting in an increase in “uncertain” recordings. Because the winter 2011 data collection sessions began before sunrise (AM sessions) and ended after sunset (PM sessions), the ability to determine occupancy could be obstructed by the light level especially for the inside lanes furthest away from the observer. Analysis of the data collected at the other four sites is required to report more definitive results of the trends between the occupancy record values, the quarters and the lanes of traffic. Separation of the data into the first and second hours of data collection for each session did not provide any further insight into possible trends in the data.

A comparison of the AM to the PM distributions was also conducted and presented in Figure 8 and Figure 9, respectively. The percentage of SOVs for both the

AM and PM sessions at Beaver Ruin Road is almost identical, but there is a noticeable difference between the higher occupant vehicle percentages. For each quarter, the percentage of 3, 3+ and 4+ - occupant vehicles is reported as higher during the PM session than the corresponding AM period (see Table 5). This could be explained by the change in travel behaviors during the evening hours for social recreational and other multi-occupant trips.

Table 5: High-Occupant Records for Beaver Ruin Road

	Fall 2010		**Winter 2011**		**Spring 2011**	
	AM	**PM**	**AM**	**PM**	**AM**	**PM**
3, 3+, & 4+ Record Counts	406	642	259	670	428	722
% of Total Records	0.95%	1.35%	0.62%	1.42%	1.01%	1.39%

Figure 8 and Figure 9 display a percentage increase in the uncertain values (1+, 2+, 3+) recorded during the PM session as compared to the AM session, with 16.4% and 11.7% respectively. When these values are broken down into data collection quarters, in Table 6, this finding does not hold true. No significant findings within the Beaver Ruin Road data can be made about the "uncertain" values between data collection quarters or the AM vs. PM peak sessions. Further analysis of the occupancy values at other sites through each quarter may present trends that are not displayed by the Beaver Ruin Road data. During future data collection deployments on the HOT corridor, parallel observations of varying lanes at each site will allow comparison of records and confirmation of “uncertain” values and occupancy distributions.

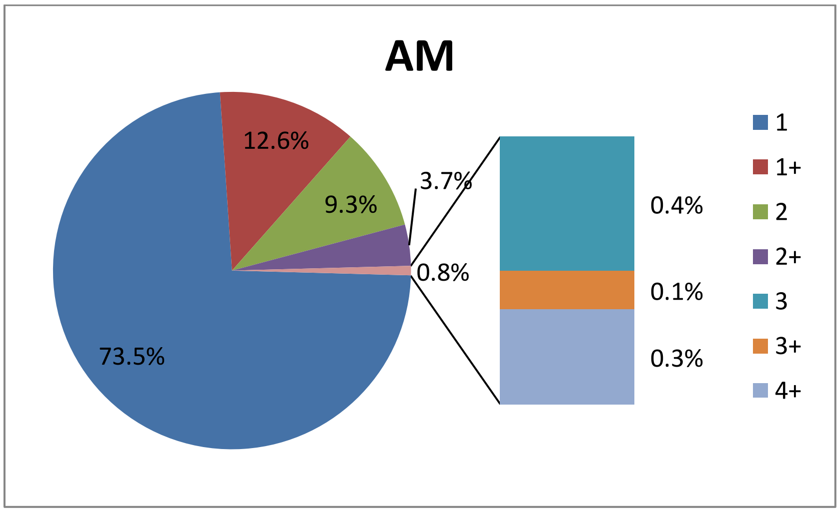


Figure 8: Occupancy Distribution for AM Data at Beaver Ruin Road, All Seasons

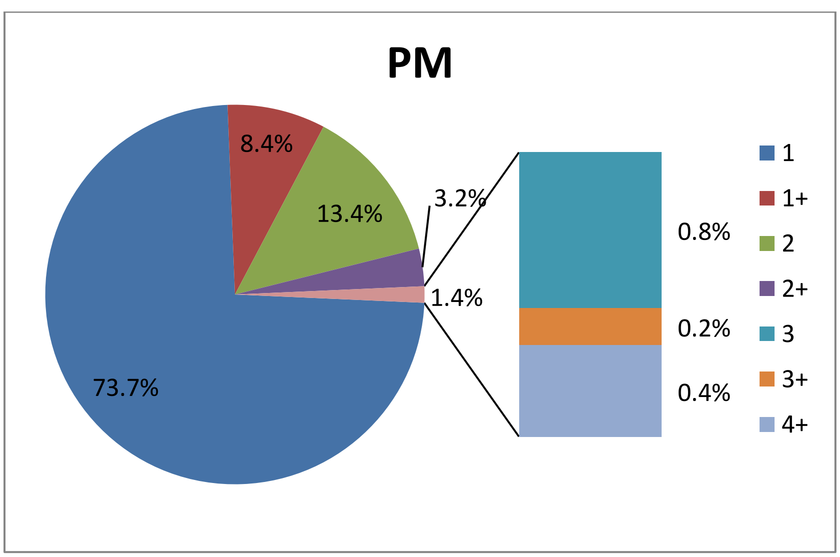


Figure 9: Occupancy Distribution for PM Data at Beaver Ruin Road, All Seasons

Table 6: Uncertain Records for Beaver Ruin Road

	Fall 2010		Winter 2011		Spring 2011	
	AM	PM	AM	PM	AM	PM
"Uncertain" Records	4413	5693	10549	3352	5647	8222
% of Total Records	10.33%	11.93%	25.05%	7.09%	13.30%	15.78%

7.2 Expectations of the Occupancy Data Collection

For the HOV-to-HOT conversion corridor project, an increase in the number of vehicles and occupants served per hour by the corridor once the HOT lane is implemented is expected. In particular, the managed lane should see significant improvements for the project to be considered a success. To monitor the effectiveness of the lane, the collection methods must be tested for consistency and accuracy. The next few chapters describe the case study on GA 400 including the deployment plan, data collection, analysis and results. The additional studies being conducted on GA 400 are designed to assess the accuracy of the methods currently being deployed, but these results were not available in time for inclusion in this thesis.

CHAPTER 8: ASSESSING THE OCCUPANCY DATA COLLECTION METHODOLOGY

After the vehicle occupancy methodology was established and implemented for the quarterly deployments, supplemental research was conducted to assess the quality of the methods. A separate deployment of the field team was conducted along GA 400 in Atlanta to test the accuracy of occupancy records, the consistency of the field team's data collection, and to quantify the distribution of the uncertain values recorded for the HOV-to-HOT conversion corridor data. The following sections report the results of the consistency analysis but the results from the accuracy study are still being developed and will be reported under a separate cover.

8.1 Data Collection Requirements and Site Selections

8.1.1 Test for Accuracy and Site Requirements

To assess the accuracy of the methodology, a comparison of likely accurate (baseline) occupancy records to records collected via the established methodology is required. The team determined that highly accurate occupancy data could be collected at existing toll booths on GA 400, where vehicles slow to a complete stop to pay a toll. An observer stationed at the toll booth has a direct view into the vehicle and the occupancy count is unobstructed by glare and window tinting; however, human error due to inattention, errors in data entry, etc, still exist. By comparing these values to upstream or downstream occupancy data collected under similar conditions to the I-85 corridor, a valid assessment of method accuracy could be conducted. The GA 400 toll plaza is located less than 10 miles from the proposed HOT corridor. The proximity of the two corridors implies some preliminary similarities in the distribution of users for the corridor in applying findings from GA400 to results on I-85.

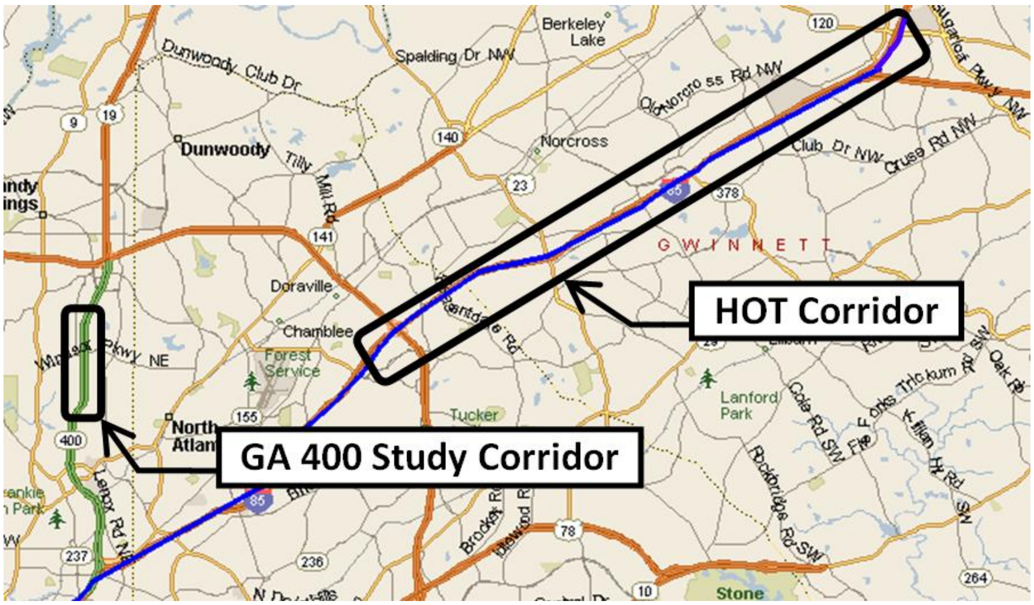


Figure 10: Map of GA 400 Study Corridors vs. HOT Corridor

8.1.1.1 Application of GA 400 Results to I-85 Data

Before the results from the case study can be applied to the data collected on the HOT corridor, it is important to confirm that the data set sampled on GA 400 is relatively similar to the data sampled on I-85. Figure 11displays the distribution of the collected occupancy along the general purpose lanes at a selected site from the HOT corridor as a comparison to the GA 400 corridor data. Because the occupancy distributions from the two corridors are similar, it may not be unreasonable to assume that occupancy mapping based upon GA 400 observations could be applied to the data collected on I-85. Based on the physical nearness of the two corridors, the same time frames for data collection and the traffic sets both exiting the center of Atlanta, it is anticipated that the data will produce similar results. On the other hand, even though the two corridors are in close proximity, the occupancy distributions will be a function of the commuter-shed demographics, jobs, and ability of the commuters on this corridor to carpool to downtown Atlanta as compared to the HOT corridor commuters who reside northeast of downtown Atlanta. Further analysis of the two data sets will be conducted to confirm the application of the GA 400 results to the HOT corridor.

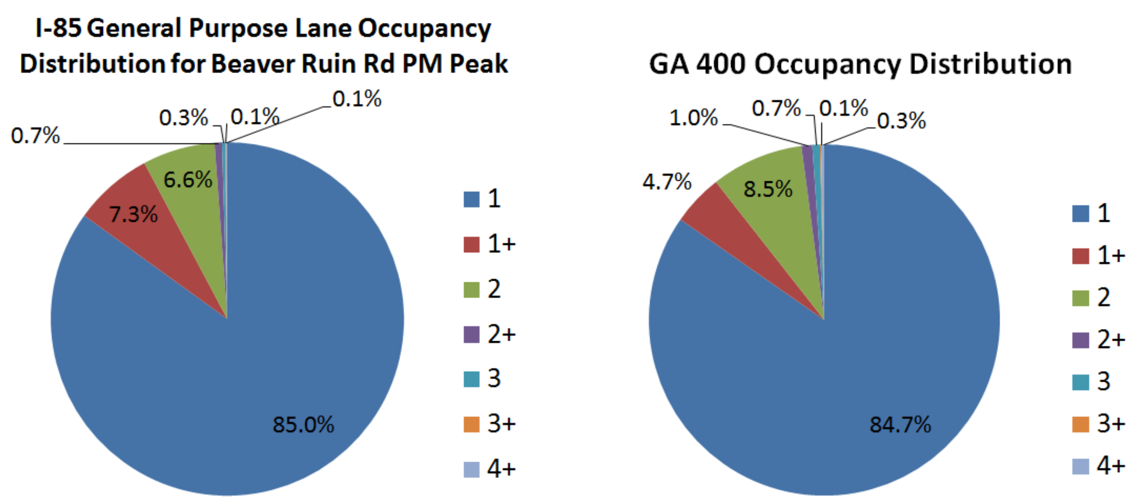


Figure 11: Distribution of Occupancy on I-85 vs. GA 400

8.1.2 Sites Selection for using HOV-to-HOT Collection Methodologies

A second site either upstream or downstream from the toll plaza had to be selected to record occupancy for the same sample set of vehicles for the accuracy comparison. Paired samples are required for this assessment, with one reading at the toll booth and a second roadside reading for the same vehicle. By comparing the recorded vehicle classifications from the occupancy files and the classifications from the license plate videos, as well as an established time difference between the two files, an occupancy value is paired to a license plate. The license plates from the toll plaza are then paired to the license plates from the downstream data and occupancy values can be compared for accuracy.

To create similar conditions to the data collection on I-85, an overpass was needed to allow the data collectors to be positioned slightly above traffic. Between the beginning of GA 400 at I-85 and the major interchange of I-285, all seven overpasses were examined for data collection compatibility. Some sites had to be eliminated from the outset, due to safety considerations defined in the safety plans (site access and/or slope). In fact, no southbound sites on GA 400 were acceptable. For the northbound traffic, the first overpass beyond the toll plaza, Windsor Parkway, was selected.

There were some differences between the Windsor Parkway overpass site and the I-85 sites. The GA 400 tollway has no exit ramps, so there are no gore areas. Instead of being located on the gore, the team collecting data at this site was positioned directly under the bridge on the concrete slope at approximately the same height and angle above the passing vehicles as that on the I-85 sites. However, the position beneath the bridge greatly eliminated the glare on the vehicles as they passed through the shadow of the overpass. Another difference is that there are only three general purpose lanes on the GA 400 corridor, unlike the 6 lanes observed on I-85 (1 HOV and 5 GP). In addition, the observers were located closer to their designated lane, with a maximum distance at about 75 feet. Alternatively, on I-85, the observers of the HOV lanes are located at a minimum of 100 ft off the lane. Given these differences, the data collectors found that making observations on GA 400 was easier and likely allowed them to collect more accurate data. Hence, accuracy analyses based upon these data are likely to be a bit optimistic in nature.

8.1.3 Test of Consistency using Parallel Observation

To analyze the consistency of individual data collectors, a parallel observation test was conducted as a part of the GA 400 deployment. At the Windsor Pkwy location, two data collectors were deployed for each lane to collect the same occupancy data. The data were collected using the same occupancy and license plate collection methodologies as on the HOT corridor. A comparison of the two files for the identical sample set is analyzed in the results section below to assess the consistency of the team members. Records are paired by comparing the patterns of the recorded vehicle classifications and confirmed with a consistent difference of the records timestamp.

8.2 Field Deployment Plan

The field deployment plan for the GA 400 corridor required an extensive coordination effort among three separate field teams in order to collect all of the necessary data. A team at the toll plaza collected accurate vehicle occupancy records for each vehicle. A second team at the Windsor Parkway location collected occupancy records using the HOV-to-HOT corridor methodology. To match the records from the toll plaza to the records from the downstream location, license plates were recorded with video cameras at the toll plaza and by a third team positioned on top of the Windsor Parkway Bridge.

The deployment was conducted for two days, a Wednesday and Thursday, during the same two hour PM-peak observed for the HOV-to-HOT data collections (4:30pm-6:30pm). In the following discussions, Day 1 refers to Wednesday April 13th 2011 and Day 2 refers to Thursday April 14th 2011.

8.2.1 Toll Plaza Deployment (Team 1)

At the toll plaza, a team of seven occupancy collectors and a supervisor were deployed to collect the accurate occupancy records for every vehicle that passed through one of the seven lanes being monitored. The GA 400 toll plaza is set up with seven "$0.50/cash" lanes and two "Fast Pass" lanes. Because of safety concerns for the observers, only the seven "$0.50/cash" lanes were monitored. A comparison of occupancy between the cash toll lanes and the fast pass lanes was not conducted but the data for the fast pass lane users was not expected to significantly impact the future assessments of accuracy or the distribution of the uncertain value records.

The observer was located in the concrete slab between each lane, to the right of the lane being observed and in front of the toll booth or change receptor, depending on the lane. This positioning gave the observer a clear view into the passenger and rear seats of the vehicles as they slow or completely stop to pay the toll. To collect the data, the same field equipment is used from the HOV-to-HOT methodology. Each observer uesed a netbook, external keypad, headphones and a drawstring backpack.

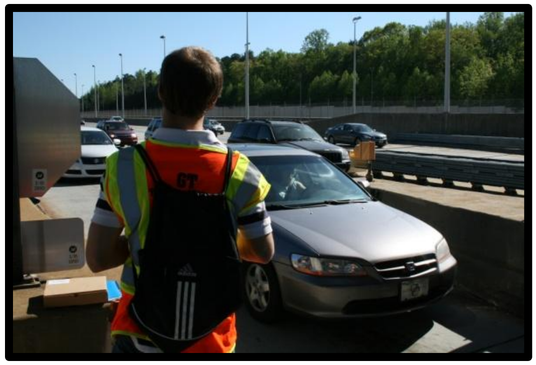


Figure 12: View of Observer at Toll Plaza

Figure 13: Picture of All Data Collectors at Toll Plaza

In case drivers questioning the presence of the collectors, each observer received a box of flyers explaining the purpose of deployment and security of the collected data (Appendix E). A total of 2000 flyers were printed for the deployment but few needed to be distributed as the number of inquiring drivers was low. All of the toll booth operators were informed of the data collection effort and received a stack of fliers to distribute from the booth. Because of the improved viewing angle and increased “accuracy” of these records, the observers were instructed not to use the uncertain (orange) buttons on the keypad while at the toll plaza. From the observation point and length of time that the vehicle was in front of the observer, it was extremely unlikely that any circumstances would warrant the uncertainty that could be observed downstream.

To record all the license plates for matching to downstream records, a camera was set up on the concrete slab behind each toll booth.

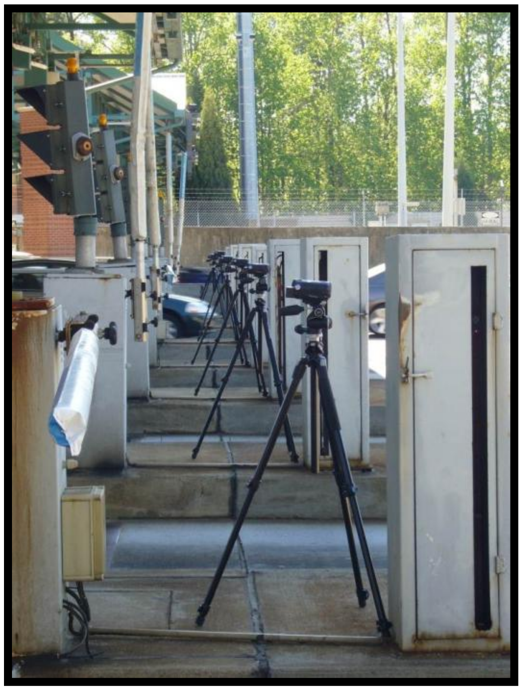


Figure 14: Picture of All Cameras Set-up at Toll Plaza

In summary, Team 1 consisted of seven occupancy collectors, a supervisor, seven netbooks, seven external keypads, and seven cameras. Extra equipment was kept with the team in case of failures.

8.2.2 Windsor Pkwy Occupancy Deployment (Team 2)

The occupancy team deployed to the downstream location at Windsor Parkway consisted of six occupancy collectors, a supervisor, and a single camera to collect a general view of what the team was observing. The team was located underneath the overpass and each observer used a netbook, external keypad, and drawstring backpack. All of these data collectors were experienced with collecting data on the HOT corridor and were instructed to collect data using the standard methodology from the HOV-to-HOT project.

In summary, team two consists of six occupancy collectors, a supervisor, six netbooks, six external keypads, and one camera. Extra equipment was deployed with the team in case of failures.

8.2.3 Windsor Parkway License Plate Deployment (Team 3)

Because the viewing angle from the Team 2 location was unacceptable for capturing license plates, a third team was deployed to the Windsor Parkway overpass to set up cameras to collect license plates. Plates from all of the vehicles using the three lanes at the downstream location during the two-hour deployment were captured to match to the occupancy records and then to the license plate from the toll plaza.

Team 3 consisted of two people (for safety consideration) to monitor the two video cameras. One camera recorded lane one and one camera recorded lanes two and three. An extra camera was deployed with this team in case of equipment failure.

8.2.4 Summary of Equipment and Manpower Required for GA 400 Deployment

For each of the two sessions for the GA 400 deployment there were a total of 17 people, 3 vehicles, 13 netbooks and keypads, and 13 cameras deployed in three separate teams.

8.2.5 Lessons Learned From GA 400 Deployment

The first full GA 400 deployment was initially scheduled for late January 2011, but the video data collected were incomplete and this deployment served as a test run. After analyzing the data that were recorded, a few changes were made to the methodology. First, the external keypads were unplugged from some netbooks, resulting in no occupancy data being recorded. To fix this, the USB plug was taped into the netbook using electrical tape to keep it from detaching. In addition, site specific training sessions were held to reduce potential confusion in data collector field assignments.

8.3 Data Collected from the GA 400 Deployment

Data were collected from 4:40pm to 6:30 pm on Wednesday April 13th, 2011 and Thursday April 14th, 2011. For each day in the field, a total of 13 occupancy files and corresponding license plate videos of the sample set were collected for processing and evaluation. The 26 occupancy files collected over the two days of data collection included a file for each of the seven toll lanes, for each day, and two files for each of the three lanes at the downstream monitoring location per day. The number of occupancy data records collected for each lane over two hours is provided in Table 7. A distribution of the vehicles through the toll plaza is displayed in Figure 15.

A total of 9032 records were created at the toll plaza over the two days and a total of 19,044 and 18,827 records were collected by parallel observers (Teams A and B, respectively) at the downstream location. From the raw data displayed in Table 7, an average of 52.3% of vehicles used the "Fast Pass" lanes at the toll plaza. Because only the cash/change lanes at the toll plaza were monitored by the data collection teams, there are occupancy records for a little less than 50% of the vehicles through the corridor to match to the records created at the downstream location.

Table 7: Raw Occupancy File Record Counts

Lane	Day 1	Day 2	Averages
TL1	632	484	
TL2	726	723	
TL3	712	616	
TL4	539	547	
TL5	789	743	
TL6	785	656	
TL7	570	510	
TL Totals	**4753**	**4279**	**4516**
L1 A	3309	3243	
L1 B	3333	3358	
L2 A	3288	3104	
L2 B	2755	3310	
L3 A	3099	3001	
L3 B	3049	3022	
Team A Total	**9696**	**9348**	**9522**
Team B Total	**9137**	**9690**	**9414**
Lane Average	**9417**	**9519**	

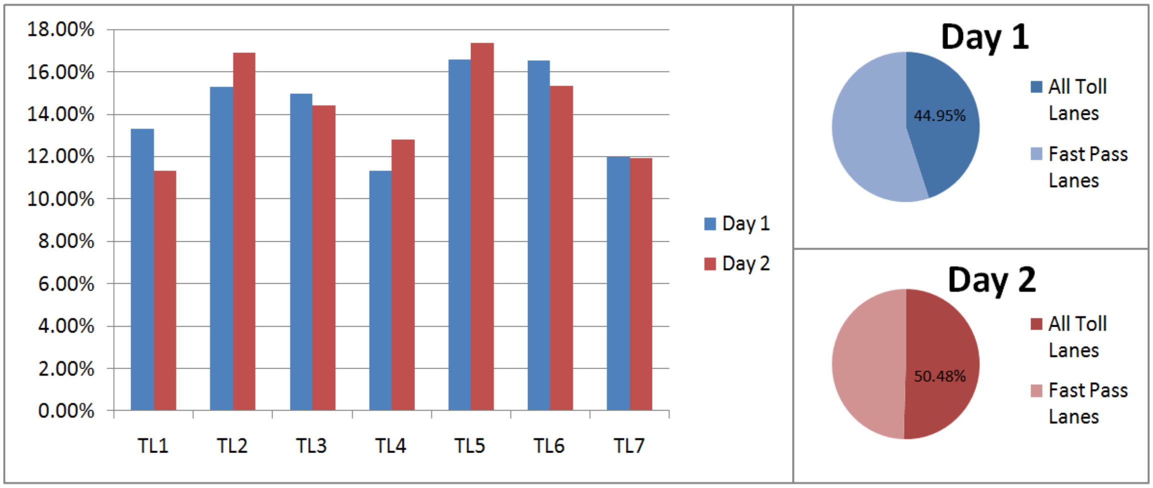


Figure 15: Distribution of Vehicle Records through Toll Plaza

A similar distribution of the records between the seven toll plaza lanes for both days which was expected with the Wednesday and Thursday data that is sampled on the GA 400 corridor. The lower percentages of throughputs observed on toll lanes 1, 4 and 7 are due to the cashier option, which requires additional time for the toll operator to make change.

The next sections describe the data processing required for the analysis of the GA400 data. It should be noted that the paired occupancy records, for the parallel observer test and for the toll booth vs. overpass data were compiled through the efforts of the two graduate research supervisors (Katherine D'Ambrosio and Katie Smith). Initial license plate video processing was conducted by undergraduate research assistants during the spring 2011, and the data were re-processed by the graduate student supervisors to improve data quality and to include extra indicators to improve the ability to pair the data.

Specifically, the three vehicle classifications defined in the occupancy collection (LDV, SUV, and HDV) were applied to the license plate data for comparison to the records in the occupancy files.

CHAPTER 9: CONSISTENCY ANALYSIS OF GA 400 DATA

The processing of the data and results from the consistency analysis are described in the following sections. Section 9.1 describes the combinations of paired occupancy values that will be considered constant vs. inconsistent for the purposes of analysis.

9.1 Consistency of Paired Vehicle Occupancy Records that Include "Uncertainty"

When including 'uncertain' occupancy values in paired observations, a matched pair of field records is consistent when: 1) one observer identically matches the second observer, 2) one observer matches a 'certain' value with a similar 'uncertain' value, or 3) both observers match similar 'uncertain' values. Table 8 provides the key used in the following analysis for consistently matched pairs of occupancy data. Table 9 displays combinations of data that are considered inconsistent for the purposes of analysis, where the two values are not similar.

As can be seen in Table 8, a 1+ recorded value is consistent with any other recording that could cause the results of the consistency analysis to be biased. To confirm the results of the consistency test, different analyses will be presented.

Table 8: Consistent Combinations of Paired Data

Record	Positive Match	Description
1	1	Only one occupant in the vehicle
1+	1	At least one occupant in the vehicle
	1+	
	2	
	2+	
	3	
	3+	
	4+	
2	2	Only two occupants in the vehicle
2+	2	At least two occupants in the vehicle
	2+	
	3	
	3+	
	4+	
3	3	Only three occupants in the vehicle
3+	3	At least three occupants in the vehicle
	3+	
	4+	
4+	4+	Four or more occupants in the vehicle

Table 9: Inconsistent Combinations of Paired Records

Record	Negative Match
1	2
	2+
	3
	3+
	4+
2	1
	3
	3+
	4+
3	1
	2
	4+

9.2 Processing of the GA 400 Data for Consistency Analysis

The consistency analysis uses the parallel observation test records collected at the downstream location on GA 400. For each of the three lanes, an “A” and “B” record was collected by separate observers. These paired data were matched for each lane using the observed vehicle classifications, the pattern of records, and an identified difference in the timestamp between the two netbooks. From the original records collected by each observer, averages of 95.3% of the records were paired to match two occupancy records for analysis. Table 10 provides the original occupancy records counts, the number of matched records, and the percentage lost by lane (i.e. across observer pairs).

Table 10: Parallel Test Matched Vehicle Occupancy to Vehicle Occupancy Records

<table>
<tr><th></th><th colspan="3">Day 1</th><th colspan="3">Day 2</th></tr>
<tr><th></th><th>Original Records</th><th>Matched Records</th><th>% Loss</th><th>Original Records</th><th>Matched Records</th><th>% Loss</th></tr>
<tr><td>L1 A</td><td>3309</td><td rowspan="2">3194</td><td>3.48%</td><td>3243</td><td rowspan="2">3185</td><td>1.79%</td></tr>
<tr><td>L1 B</td><td>3333</td><td>4.17%</td><td>3354</td><td>5.04%</td></tr>
<tr><td>L2 A</td><td>3288</td><td rowspan="2">2709</td><td>17.61%</td><td>3105</td><td rowspan="2">3007</td><td>3.16%</td></tr>
<tr><td>L2 B</td><td>2755</td><td>1.67%</td><td>3310</td><td>9.15%</td></tr>
<tr><td>L3 A</td><td>3099</td><td rowspan="2">3021</td><td>2.52%</td><td>3003</td><td rowspan="2">2900</td><td>3.43%</td></tr>
<tr><td>L3 B</td><td>3049</td><td>0.92%</td><td>3022</td><td>4.04%</td></tr>
<tr><td>Average</td><td colspan="2"></td><td>5.06%</td><td colspan="2"></td><td>4.43%</td></tr>
</table>

The un-matched records from the processing are generally because one observer created a record for a vehicle while the other did not. As can be seen in Table 10, the lesser counts of the two observers has a percent loss of less than 3.5% un-matched and the high loss percentages are driven by the greater differences between the original record counts for the same sample.

9.3 Results of Consistency Analysis for Occupancy Pairings

Because there were two days of study and three lanes each day, a consistency analysis was completed for a total of six data sets. Of these six sets, an average of 95% of the records was matched to the parallel record through the use of pattern matching of the vehicle classification and timestamp differences linked to the occupancy value. One pair of observers matched a total of 98% of their collected vehicle records. The occupancy data for the "uncertain" values of matched records were directly compared for consistency using the definition of accuracy defined in 9.1. Table 11displays the results of those comparisons vs. identically matched occupancy pairs.

Table 11: Comparison of Occupancy Values for Accuracy

	Identical Match Pairs (# / %)	Consistent Pairs (# / %)	Inconsistent Pairs (# / %)
Day 1 Lane 1	2073	3082	112
	64.90%	96.49%	3.51%
Day 1 Lane 2	2255	2553	156
	83.24%	94.24%	5.76%
Day 1 Lane 3	2771	2813	208
	91.72%	93.11%	6.89%
Day 2 Lane 1	3011	3052	133
	94.54%	95.82%	4.18%
Day 2 Lane 2	2605	2861	146
	86.63%	95.14%	4.86%
Day 2 Lane 3	2726	2762	138
	94.00%	95.24%	4.76%
Average	**85.84%**	**95.01%**	**4.99%**

With an average identical match rate of 85.84% and an average “consistent” match rate as defined in section 9.1 at 95.01%, the records collected using the proposed methodology are considered consistent among the field members. Greater variance is noted in the paired data for the identical comparison of the matched records. This variation is attributed to the fact that one of the parallel observers chose to record more “uncertain” values than the other. In fact, the percentage of “unsure” records recorded for Day 1 Lane 1 and Day 1 Lane 2 exceeded 30% and 12% respectively while the average percentage of “unsure” records is at 5.84%. The variation between the data collectors could be the result of a better eyesight, a better viewing angle, or even the under-confidence or over confidence of one observer. The test indicates that given the current level of training for the implemented methodology, the vehicle occupancy data collected will be consistent no matter which observer is assigned to the lane. Because a pairing with a 1+ record can bias the consistent pairings described in the second column of Table 11, the following section focuses on the identically matched pairings.

9.3.1 Analysis of Identically Matched Records

Further analysis of the identically matched pairings is presented in Table 12. The percentage identically matched records for Day 1_Lane 1 is lower than the results found for the other lanes and days. If the Day 1_ Lane 1 set of data is not included the average consistency value improves from 85.9% to 90.1%.

Table 12: Comparison of Identically Matched Pairings

		Day 1 L1	Day 1 L2	Day 1 L3	Day 2 L1	Day 2 L2	Day 2 L3
Total Records		3194	2709	3021	3192	3040	2909
1	**1**	1898	2095	2548	2865	2363	2444
1+	**1+**	126	8	1	0	0	0
2	**2**	14	137	214	149	260	264
2+	**2+**	35	2	0	0	1	0
3	**3**	0	8	1	1	19	21
3+	**3+**	0	0	0	0	0	1
4+	**4+**	0	5	7	1	7	4
Identical Records		2073	2255	2771	3016	2650	2734
% of Total Records		64.9%	83.2%	91.7%	94.5%	87.2%	94.0%
Consistent, Un-Identical Pairings		1009	298	42	41	256	36
% of Total Pairings		31.6%	11.0%	1.4%	1.3%	8.4%	1.2%
Inconsistent Pairings		112	156	208	135	134	139
% of Total Pairings		3.5%	5.8%	6.9%	4.2%	4.4%	4.8%

Table 12 also displays the distribution of the identically paired occupancy records, with the majority of the records matching single occupant vehicles for all days and lanes. Since the pairing of the “uncertain” values is significantly higher for the 1+ and 2+ values on Lane 1_Day 1, an external factor must have been influencing the observation of vehicle occupancy in that lane, resulting in the lower match rate. The 64.9% identically matched value is driven by the high number of observations recorded as “uncertain” by the Team A_Lane 1 data collector, at 31.6% of their total observations. As the percentage of uncertain observations increases, the percentage of identically matched records decreases (Figure 16). This result suggests that the “uncertain” recordings significantly influence the consistency of the collected data. Future analysis will determine the effects of “uncertain” recordings on the accuracy of the methodology.

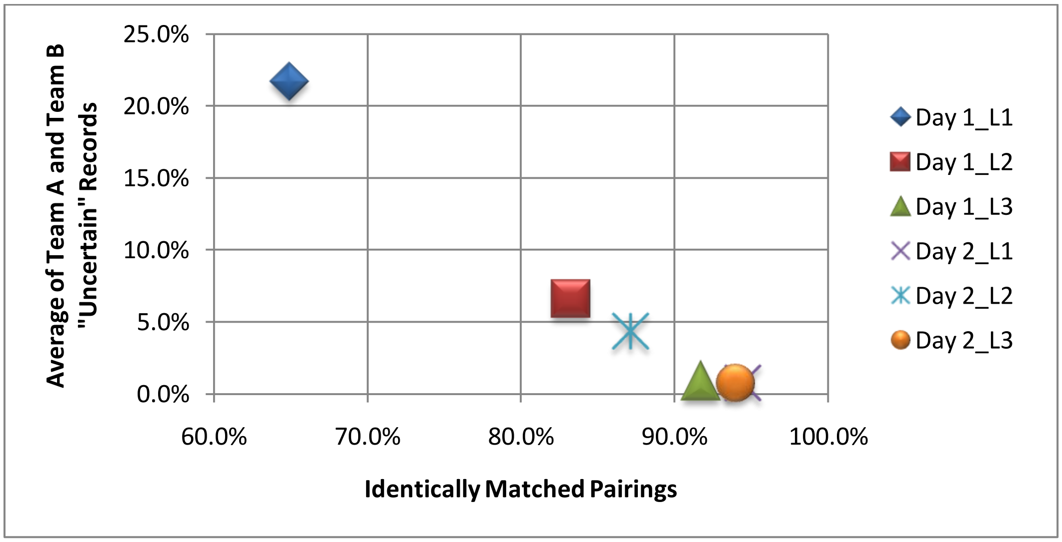


Figure 16: Identically Matched Pairings vs. Average "Uncertain" Recordings

CHAPTER 10: CONCLUSIONS

The effectiveness analysis for the High Occupancy Vehicle to High Occupancy Toll Lane conversion in Atlanta, GA requires a large scale data collection of vehicle occupancy over all travel lanes. The methodologies and field deployment plans have been developed and laid out in detail in the previous chapters.

The methodology developed to collect vehicle occupancy along the I-85 freeway is described and the results and consistency data analysis of the test deployment conducted on GA 400 are presented. From the results of the consistency analysis, an 86% identical match and a 95% "consistent" match rate were found, justifying that the methodology and training associated with the project minimize the variation of the data collection results among individual data collectors.

The plans for analyzing the accuracy assessment and for determining the distributions for the "uncertain" values were established in the previous chapters, but the results of those analyses will be published at a later date.

8.1 Recommendations

The vehicle occupancy data collection method has room for improvement in equipment, viewing angle and period of view for the methodology which uses the human eye to focus on collecting data from a high speed vehicle. Future technologies especially in video collection for vehicle occupancy and for processing the collected data could greatly increase the accuracy of the data as well as reducing the time and manpower required for the methodology established for this project. In particular, improvements for identifying a single vs. a double occupant vehicle would greatly reduce the error found in the methodology. Improvements to identify high-occupant vehicles should also be considered because of their under-representation throughout the results of this report.

Other field deployment recommendations should be focused on possible improvements in the license plate data collection and processing techniques. Future technologies should easily be able to collect and process license plates greatly reducing the time requirements for the current methods as well as improvements in identifying the possible variations in characters and determining the correct one.

8.2 Future Research

There are a several aspects of the GA 400 data still need to be analyzed and reported: the accuracy assessment and the distribution of "uncertain" values to be applied to the HOT corridor. Further research will confirm the distributions and determine the effects of the uncertain values on the data set meant to improve results from glare and window tinting.

APPENDIX A: SAFETY PLAN

HOV to HOT Evaluation Project

Field Data Collection Safety Measures

Draft for Review and Comment

September 10, 2010

Updated summer 2011

Randall Guensler, Professor

Michael Hunter, Professor

Angshuman Guin, Research Engineer

Vetri Elango, Research Engineer

Kate D'Ambrosio, Graduate Research Assistant

School of Civil and Environmental Engineering

790 Atlantic Drive

Georgia Institute of Technology

Atlanta, GA 30332-0355

HOV to HOT Data Collection Safety Measures

Beginning in September/October, 2010, the Georgia Tech Transportation Research Group will begin collecting one-week of data from each of four overpasses on the I-85 corridor between I285 and SR316. These data will support the evaluation of impacts associated with GDOT's HOV to HOT conversion project. The researchers will collect vehicle occupancy and license plate data at four locations: Jimmy Carter Boulevard, Beaver Ruin Road, Pleasant Hill Road, and Old Peachtree Road.

The field teams will be performing manual observation of vehicle occupancy (persons per vehicle) at these overpasses. Vehicle occupancy data collection requires an oblique view into the vehicle from an elevated vantage point (to see into the rear of the vehicle) and extended viewing time so that the observer can track their view into vehicle from left to right. Observers will set up in the gore areas of the intersections, facing oncoming vehicles, on the sloped landscaped triangle separating freeway traffic from offramp traffic. Detailed information for each data collection location is outlined in Appendix A-1 to A-4, along with the site access instructions to be followed by the field teams.

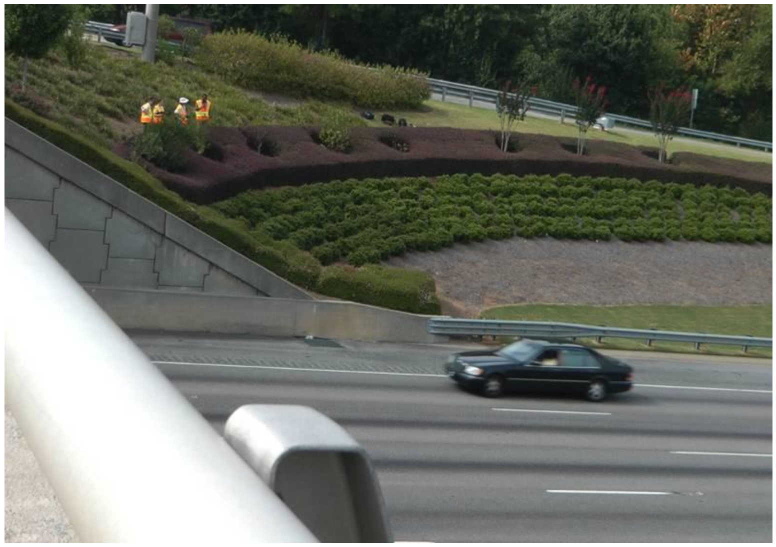


Figure 17: Vehicle Occupancy Data Collectors Beaver Ruin Road Northeast Gore Section

The safety of the data collection teams and the traveling public is of the utmost importance throughout the field data collection process. Data collectors will be working within the gore areas between the freeway and exit ramps connecting to major arterials. These traffic observers will never be working on, or walking within, the traveled way. Teams access the gore areas from the sidewalks, by stepping over the adjacent guardrail into the gore. All field personnel will wear appropriate safety vests at all times. Team members will not use umbrellas or other items that could blow onto the freeway. If used for protection from the sun, data collectors will also ensure that hats are tethered by line and safety pin to their safety vests. All field personnel will obey all traffic control devices when accessing the inspection sites.

The 2009 Edition of the FHWA's Manual on Uniform Traffic Control Devices (MUTCD) was consulted to identify any additional measures required to ensure safety of the observers. The vehicle occupancy observation stations will be located on the elevated landscaped areas of ramps, more than 15' away from the shoulder of both the freeway and the on/off-ramps. Because the distance separation between data collectors and traffic is more than 15 feet, the MUTCD does not appear to require upstream placement of warning signs or any demarcation of a construction line using temporary traffic control devices (MUTCD Section 6G.06, page 622, MUTCD Section 6H-1, page 634). If GDOT determines that the benefits of cone placement, a "Road Work Ahead" sign, or other control devices along the edge of a shoulder will provide a safety benefit outweighing the risk of the device placement, the research team will coordinate with GDOT District staff on such placement.

None of the data collection team members are currently certified in the placement of temporary traffic control (TTC) devices or preparation of official TTC plans. If TTC devices are requested by GDOT, the Georgia Tech Transportation Research Group will work with GDOT staff to ensure that a person (potentially GDOT personnel or a Georgia Tech research team member) meeting GDOT required training or certification requirement implements any TTC plans.

License plate data collection will be undertaken by video camera from the sidewalks of overpasses, with video cameras pointing down on traffic. Video cameras for license plate data collection are mounted on tripods and collect high-resolution video data from two lanes simultaneously. For sites with a safety fence, the camera and tripod assembly are Velcro-tied directly to the fence so that the lens can be placed through the diamond-shaped opening in the chain link fence. For sites without safety fence, the camera and tripod assembly are extended approximately 12" above the rail line with a clear view of traffic (see photo below). It is our understanding that data collection from the sidewalk does not require the use of any temporary traffic control devices.

Figure 18: Camera Assembly Height Camera and Tripod are Tethered to the Rail

Three of the four sites do not have safety fences on the overpass: Jimmy Carter Boulevard, Beaver Ruin Road, and Pleasant Hill Road. At these sites, the video camera, tripod head, and tripod legs are tethered and locked to the bridge rail using a wire security cable (see photo above). Data collectors will also ensure that hats are tethered by line and safety pin to their safety vests. Video data collectors will not use umbrellas or other items that could blow over the railing. Data collectors will assemble the cameras and tripod and install the battery below the rail line and tether the assembly to the railing before extending the tripod legs. Similarly, all disassembly of camera systems will occur below the rail level.

Data collection will be conducted Tuesday through Thursday at each location, during the peak periods, in the commute directions. Additional data collection may be conducted at some locations on Mondays (as a backup day in case of inclement weather or technical problems) and Fridays (to assess differences in occupancy associated with Friday travel). Field data collection will be conducted at these four sites in September/October, January/February, April, and July. Field teams are composed of graduate and undergraduate students. Each deployment is supervised by a graduate research assistant. Field teams carry with them a set of safety gear, letters explaining their activities, and telephone contact information for project managers, GDOT staff, and local police. Field teams will notify the Georgia State Patrol and the Gwinnett County Police Dispatcher each morning that data will collected before arriving at the site to collect data.

Appendix A-1
Jimmy Carter Boulevard Data Collection Locations and Access Points

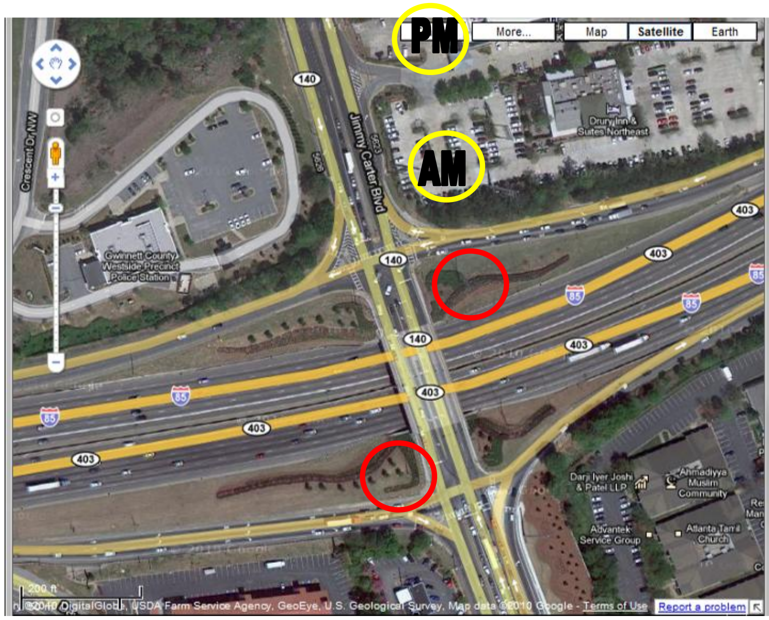


Figure 19: Jimmy Carter Boulevard Vehicle Occupancy Data Collection Stations (Red), AM Accessed from Northeast Restaurant (Papadux) Parking Lot (Yellow AM), PM Accessed from Northeast Hotel (Drury Inn) Parking Lot (Yellow PM)

Northbound occupancy sampling will be conducted from the southwest gore section, on the slope near the landscape trees. Southbound occupancy sampling will be conducted from the northeast gore section, on the slope west of the grassy landing behind the shrub line. Both the southwest and northeast sites have guard rails along the freeway. Neither the southwest and northeast sites have guard rails along the ramps. Data collectors will be located more than 15' from both the ramp and freeway traveled ways. If temporary traffic control devices are requested by GDOT the Georgia Tech Transportation Research Group will work with GDOT staff to implement their deployment.

Figure 20: Northbound Occupancy Sampling Site, Southwest Gore Sections

Figure 21: Southbound Occupancy Sampling Site Northeast Gore Section

Jimmy Carter Boulevard Access Notes:

Both data collection sites will be accessed from the Northeast. Vehicles will park at the Papadux parking lot in the morning or the Drury Inn Parking lot in the evening. The company manager has provided permission to park in the lots, provided that vehicles park in a designated location, and not in customer parking spaces. Vehicles are to park at the southern edge of the parking lot. The parking location is identified below.

Figure 22: Parking Locations for Jimmy Carter Blvd

There is no sidewalk connecting the parking lot to the intersection crosswalk; however, there is a walking trail on the grass shoulder leading directly to the crosswalk. The first crosswalk leads to a medium-sized island, from which crosswalks continue on to the west side of the overpass or cross the street to the eastern side of the road. All of these crosswalks are equipped with pedestrian signals. Crossing shall only be conducted when the walk sign is illuminated.

Figure 23: Crosswalk Approach from Parking Lot

Figure 24: Ram Turn Lane and First Crosswalk

Appendix A-2
Beaver Ruin Road Data Collection Locations and Access Points

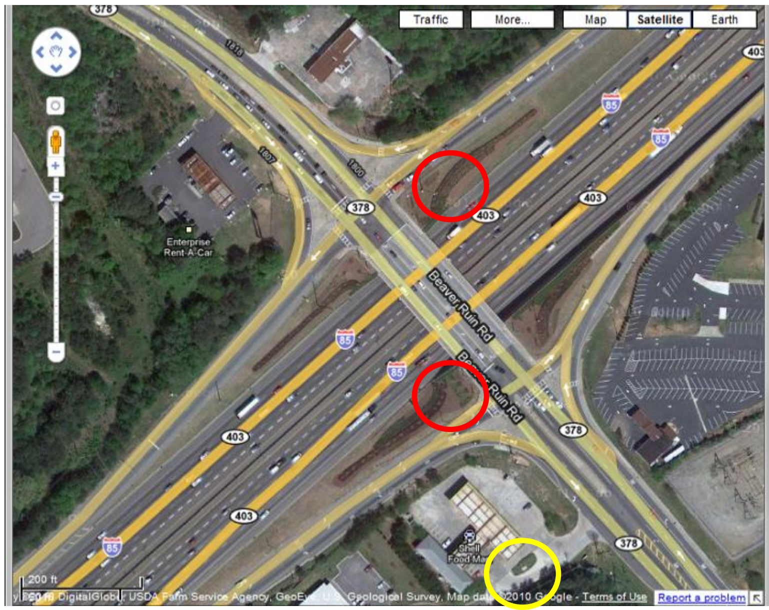


Figure 25: Beaver Ruin Road Vehicle Occupancy Data Collection Stations (Red), Accessed from Southwest Shell Gas Station (Yellow)

Northbound occupancy sampling will be conducted from the southwest gore section, on the slope near the landscape trees. Southbound occupancy sampling will be conducted from the northeast gore section, on the slope west of the grassy landing behind the shrub line. Both the southwest and northeast sites have guard rails along the freeway and along the ramps. Data collectors will be located more than 15’ from both the ramp and freeway traveled ways. If temporary traffic control devices are requested by GDOT, the Georgia Tech Transportation Research Group will work with GDOT staff to implement their deployment.

Figure 26: Northbound Occupancy Sampling Site, Southwest Gore Section

Figure 27: Southbound Occupancy Sampling Site, Northeast Gore Section

Beaver Ruin Road Access Notes:

Both the western and eastern data collection sites are accessed from the Southwest. Vehicles will park behind and to the south of the Shell gasoline station, on the right-hand side of the access road that leads to "Man's Best Friend" pet day care located behind the Shell station (see below). Staff will not park in the Shell parking lot.

Data collection teams will pass through the Shell station to the crosswalks to access both the west and east sides of the overpass.

Figure 28: Beaver Ruin Road, Parking Location

Staff will exercise caution at this location. The freeway offramp has a sweeping lane that crosses the first short crosswalk. This lane is posted with a “Yield” and a “Stop for Pedestrians” sign. However, visibility is very poor at this corner due to the presence of trees in the visibility triangle. Pedestrians will assume that these drivers WILL NOT STOP. Given the line-of-sight and speed of traffic, drivers may not see pedestrians. Data collectors will move to a position where they can see oncoming cars, and wait for the far crossing signal to light. Then, before crossing, personnel will make absolutely sure that either: 1) no cars are coming in the right turn lane, or 2) vehicles have stopped and are clearly waiting for the pedestrian to cross to the island. It is essential that personnel make eye contact with the drivers, gesture that they intend to cross, and receive a nod from the driver indicating that they expect the crossing to occur. Staff will also ensure that any vehicle rapidly approaching a stopped vehicle from behind is also going to stop. A vehicle hitting the rear of a stopped vehicle could push that vehicle into the pedestrian.

Figure 29: Beaver Ruin Road, Top View of Right-Turn Lane

Figure 30: Beaver Ruin Road, Southwest Crosswalk Line of Sight Issue

Upon arriving at the island, the walk signals apply in crossing the larger crosswalks to the west side of the overpass or the island on the eastern side of the road. A pedestrian island is provided to the southeast corner.

Appendix A-3
Pleasant Hill Road Data Collection Locations and Access Points

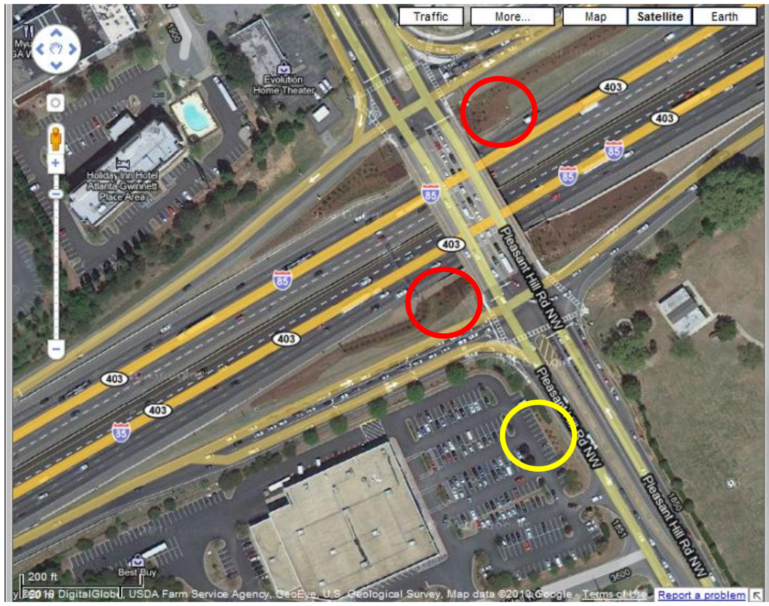


Figure 31: Pleasant Hill Road Vehicle Occupancy Data Collection Stations (Red), Accessed via Southwest Vest Buy Parking Lot (Yellow)

Northbound occupancy sampling will be conducted from the southwest gore section, on the slope east of the shrub line. Southbound occupancy sampling will be conducted from the northeast gore section, on the slope within the sparse shrub area. Both the southwest and northeast sites have guard rails along the freeway. Neither the southwest and northeast sites have guard rails along the ramps. Data collectors will be located more than 15' from both the ramp and freeway traveled ways. If temporary traffic control devices are requested by GDOT, the Georgia Tech Transportation Research Group will work with GDOT staff to implement their deployment.

Figure 32: Northbound Occupancy Sampling Site, Southwest Gore Section

Figure 33: Southbound Occupancy Sampling Site, Northeast Gore Sections

Pleasant Hill Road Access Notes:

Both the western and eastern data collection sites are accessed from the southwest corner. Vehicles will park in the back of the Best Buy parking lot in the row closest to and facing the roadway. Crosswalks are to be used to access both the west and east sides of the overpass.

Personnel will exercise caution at this location. The freeway offramp closest to Best Buy has two right-hand turn lanes separated by a small island. The sweeping lane closest to the corner crossing the short crosswalk is posted with a “Keep Moving” sign (see below). Data collectors will assume that these drivers WILL NOT STOP, even though Georgia law requires drivers to stop for pedestrians at a cross-walk. Given the line-of-sight and level of traffic, drivers may not see pedestrians. Note also that the pedestrian signal applies to the second crosswalk, not the short crosswalk. When crossing this intersection, pedestrians will wait for the far crossing signal to light and then make absolutely sure that either: 1) no cars coming in the closest right turn lane, or 2) that vehicles have stopped and are clearly waiting for the pedestrian to cross to the island. It is essential that personnel make eye contact with the drivers, nonverbally communicate the intent to cross, and receive a nod from the driver indicating that they expect the crossing. Staff will also ensure that any vehicle rapidly approaching a stopped vehicle from behind is going to stop. A vehicle hitting the rear of a stopped vehicle could push the stopped vehicle into the pedestrian. The island separating the two crosswalks is small. Pedestrians are instructed to cross in small groups and not to crowd this island. Upon arriving at the small island, the walk signals do apply to the larger crosswalks to the east side of the overpass or the western side of the road.

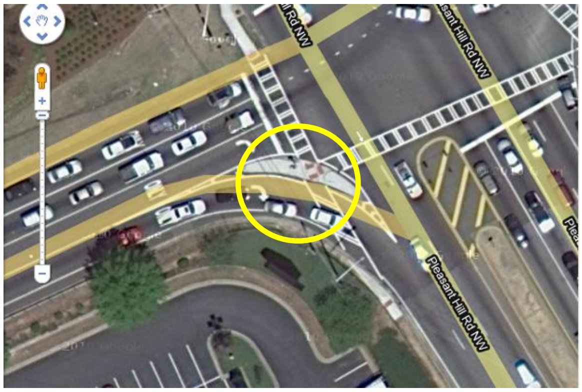


Figure 34: Pleasant Hill Road, Top View of Right-Turn Lanes

Figure 35: Pleasant Hill Road Southwest Crosswalk and Keep Moving Sign

If continuing northbound to the west side of the overpass, pedestrians must note that the inside lane at this second crosswalk is also for right turns (see top view photo above). These drivers may be looking away from the island. Pedestrians will not rely only solely on the walk signal. Staff will make eye contact with the drivers before crossing to the eastern side of the overpass.

After crossing to the west side of the roadway, care must be exercised in crossing from the southeast corner to the eastern side of the overpass. There is no pedestrian island. Vehicles will be turning directly from the inside lane onto the northbound freeway onramp. Again, after the pedestrian crossing light illuminates, personnel will make eye contact with the driver in the closest lane to ensure they will remain stopped.

Appendix A-4
Old Peachtree Road Data Collection Locations and Access Points

Due to the presence of wide access roads and the length of the overpass, vehicle occupancy data collection at Old Peachtree Road cannot be conducted from a gore section immediately adjacent to the overpass. Data will be collected from more distant sites where data collection can be conducted closer to the lanes of travel. Northbound occupancy sampling will be conducted from an access road/ramp gore section south of the overpass. Southbound occupancy sampling will also be conducted from an access road/ramp gore section south of the overpass.

Figure 36: Old Peachtree Road Vehicle Occupancy Data Collection Stations (Red), Accessed via Southwest Strip Mall Parking Low (Yellow)

The northbound occupancy sampling site will be located just past the I-85 exit ramp for Old Peachtree Road. The vehicle carrying the data collection team will slow and pull off of the freeway past the exit and will pull in behind the guard rail that parallels the freeway to ensure that the vehicle cannot be struck by oncoming vehicles that deviate from a freeway lane. The data collection team will deploy on the slope of the gore area to the north of the vehicle location, protected by guard rails both above and below the site (see photo below).

The southbound occupancy sampling site will be located along the entrance ramp from old Peachtree Road to I-85 south. The vehicle carrying the data collection team will slow and pull off to the left hand side of the entrance ramp onto the shoulder at the end of the guard rail. The vehicle will back in behind the guard rail to ensure that the vehicle cannot be struck by oncoming vehicles that deviate from the onramp lane. The data collection team will deploy on the slope of the gore area to the north of the vehicle location, protected by guard rails both above and below the site (see photo below). If temporary traffic control devices are requested by GDOT the Georgia Tech Transportation Research Group will work with GDOT staff to implement their deployment.

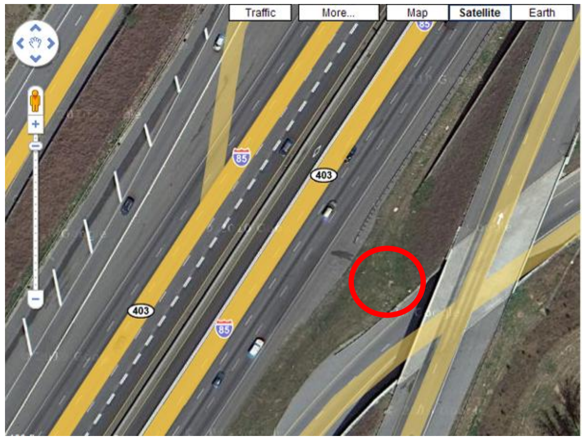


Figure 37: Northbound Occupancy Sampling Site (Red), Southwest Gore Section

Figure 38: Northbound Occupancy Sampling Site (Red), Street View and Access Point (Yellow)

Figure 39: Southbound Occupancy Sampling Site (Red), Northeast Gore Section, At Ramp Underpass

Figure 40: Southbound Occupancy Sampling Site (Red), Street View and Access Point (Yellow)

Appendix A-5
Chamblee-Tucker Road Data Collection Locations and Access Points

Figure 41: Chamblee-Tucker Road Vehicle Occupancy Data Collection Stations (Red), Accessed from the Waffle House Parking Lot (Yellow)

Northbound occupancy sampling will be conducted from the northeast gore area, on the slope. The southeast gore area is not accessible due to the presence of a channelized offramp u-turn. Under no circumstances shall field personnel enter or cross the u-turn lane. Southbound license plate sampling will not be conducted because the channelized offramp u-turn prevents effective camera placement. Northbound occupancy sampling will be conducted from the northwest gore area, on the slope. Both the northeast and northwest sites have guard rails along the freeway. Neither the northeast or northwest sites have guard rails along the ramps. Data collectors will be located more than 20’ from both the ramp and freeway traveled ways. Placement of traffic cones in conformance with Appendix B will be undertaken along the ramps if desired by GDOT.

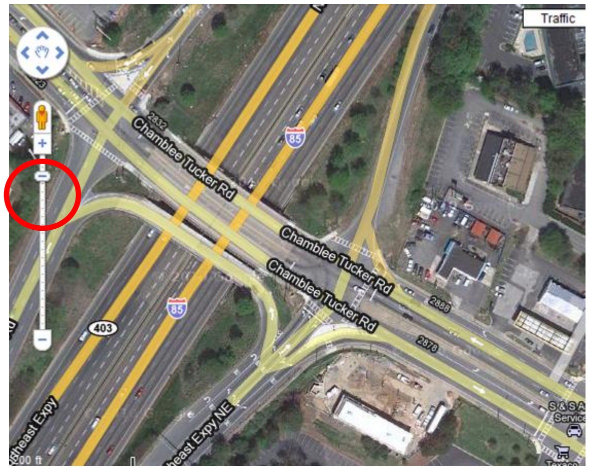


Figure 42: Northbound Occupancy Sampling Site, Northeast Gore Section

Figure 43: Northbound Occupancy Sampling Site, Northeast Gore Section

Chamblee-Tucker Road Access Notes:

Both data collection sites will be accessed from the northwest. Vehicles will park at Waffle House. The field team has permission from the manager, Joey (678-637-8179), to park in southern corner of the lot, between the rows of spaces that face southwest and southeast. The parking location is identified below.

Figure 44: Parking at Chamblee-Tucker Road

The first crosswalk leads to a large pedestrian island, from which one crosswalk continues on to the east side of the overpass and the other crosses street to the western side of the overpass. There are two right-hand offramp turn lanes to contend with on this first crossing. During the site inspection, drivers in both lanes were observed making the turn without stopping. Both of the longer crosswalks are equipped with pedestrian signals. Crossing shall only be conducted when the walk sign is illuminated. However, pedestrians shall not rely solely upon the walk signal. Pedestrians must make eye contact with drivers in both of these lanes and make sure that all vehicles are stopped before proceeding.

Figure 45: Street View of Crosswalk

Figure 46: Ramp Turn Lanes at the Northeast Approach

APPENDIX B: FIELD CONDICTIONS WORKSHEET

Daily Conditions Log for Site: ____________________ on date: _____/_____/_____ for: _____ peak

1. Current Weather at Site (www.weather.com -> Hourly -> Details)
   Type in zip code for site, record for every 30 minutes of data collection time period

Time	**Expected Temp (°F)**	**Feels Like (°F)**	**Chance Precip. (%)**	**Humidity (%)**

   Sunrise Time: ______________ Sunset Time: ______________

   Other Notes:

2. Current Road Conditions around Site (www.georgia-navigator.com)
   Record any accidents/incidents/construction around site and along the corridor of the site

3. Gas Prices around Site (http://atlantagasprices.com/GasPriceSearch.aspx)

   First Click on "Gas Prices" -> "Search Gas Prices"
   Record: Lowest Regular Gas Price in Last 24 Hours: $_______
   Highest Regular Gas Price in Last 24 Hours: $_______

   Second, Type in Zip Code for Site
   Record: Lowest Regular Gas Price in Last 24 Hours: $_______
   Highest of the Lowest Regular Gas Prices: $_______

4. Record and events which are listed on the Calendar in the Drive Lab (holidays, school events, city event, etc…)

Please keep this document in the site folder when it is complete

APPENDIX C: FIELD VISIT CHECKLIST

Prior to Leaving the Lab:

- GRA: double check that you have all of the equipment (see equipment checklists in site folder)
    - Field Kit
    - License Plate Collection Equipment
        - ***make sure that the time on the cameras is synced with standard clock***
        - Do not disconnect the batteries from the cameras once you set the time or it could cause the time and date to reset!
    - Vehicle Occupancy Collection Equipment
- Complete the "Daily Field Conditions" Worksheet
    - Blank copies are kept in the gray file box next to the equipment cabinet
    - Keep the Daily Field Conditions Sheet with you in the site folder in case other notes need to be made while you are in the field (ex – raining, accident around site…)

Carpooling to Site:

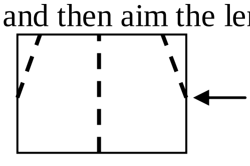
- Check out the van if possible to carry the entire team in one vehicle
- If van is unavailable, the GRA must work out who is driving to the site prior to the data session
- Drivers: directions to the site are kept in the site folders
- See Safety Plans (in site folder) for further direction on where to park vehicle and how to access the site

Walking to Site:

- Before walking to the site, put on SAFTEY VESTS
- All procedures described in the Safety Plans must be followed to ensure the safety of the team. All crossings of the roadway must be completed under the "Walk" pedestrian signal.

License Plate Collection:

- Set up the cameras along the edge of the bridge at the center lane line of the two lanes to be recorded (SB for AM and NB for PM collections). [NOTE: at Old Peachtree, because of the curve in the roadway, position the tri-pod at the inside lane line]
- Leave the legs of the tri-pods un-extended until the camera has been properly secured to the tri-pd and tethered to the bridge
- Extend the legs of the tripod, tighten and secure the tether to the camera and bridge
- Zoom in the camera as much as possible and then aim the lens so that the outer lane lines begin half way up the screen:



- Make sure you are recording the lanes identified on the camera
- ***Make sure the 1080p feature is ON***

NOTES FOR OLD PEACHTREE AND CHAMBLEE TUCKER (CHAIN LINK FENCE)

1. Get the camera as close to the fence as possible by setting up the tripod so that the front two legs are resting on the concrete ledge and then extend the back leg to rest on the ground. I even pushed the back leg in towards the concrete ledge to get the camera even closer to the fence. Just make sure that the tripod is steady because the bridge will shake some when big trucks cross it. (For Chamblee Tucker, put front two legs in front of the railing on the concrete barrier to get it closer to the fence.)
2. Make sure the camera is zoomed ALL the way in to get the furthest away view possible. Then angle the camera so that the two outside lane lines start half way up the camera view. Since Old Peachtree only has 5 lanes, camera "4/5" will only collect lane 4. Just zoom in on that one lane so that the URAs don't try to processes two lanes.
3. Zoom in and back out before you start recording to make sure the chain link fence is not in the camera view (see the video!)
4. Please attach the tethers to the larger railings in the fence, not the chain link to keep it from shaking the camera when the bridge shakes.

Occupancy Collection:

- Properly cross to the data collection zone as specified in the Safety Plans
- Set up the net-books in the grass before climbing down the slope, the floater should be near the remaining bags of equipment at all times or the bags should be returned to the bridge for safety
- Each net-book should be in a drawstring backpack on each of the occupancy collectors
- Keep a 10ft radius between any NON-WIRED keypads to prevent crosstalk
- See Occupancy Methodology for further information on the occupancy data collection

Data Collection:

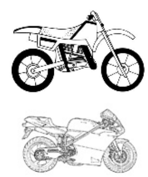
- AM Session = 7:00am – 9:00am
- PM Session = 4:30pm – 6:30pm
- ***START THE DATA COLLECTION AS CLOSE TO 7am AND 4:30pm AS POSSIBLE, AND COLLECT DATA FOR A FULL 2 HOURS!***

Returning to the Lab:

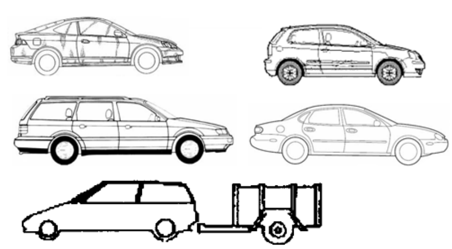
- Unpack electronic equipment into equipment cabinet for charging
- All files should be transferred to the lab computer
- Return “Daily Field Conditions” worksheet to “Completed Daily Field Conditions” file in the gray box next to the equipment cabinet
- Don’t forget to return the sun-glass holders if you used on in the field
- Return the Site folder to the gray box

APPENDIX D: VHEICLE CLASSIFICTION FLASHCARDS FOR LICENSE PLATE VIDEO PROCESSING

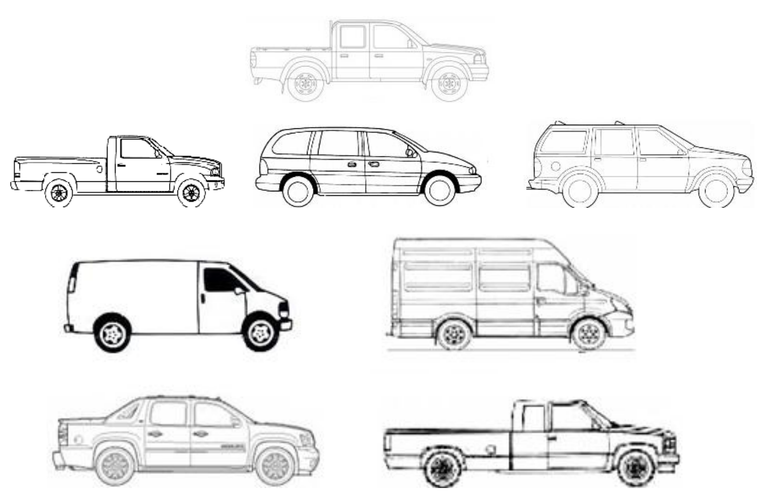
Motorcycle



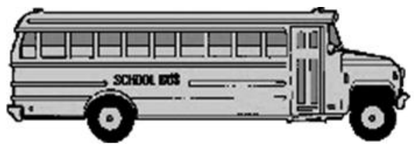
Light Utility Automobile (Passenger Car)



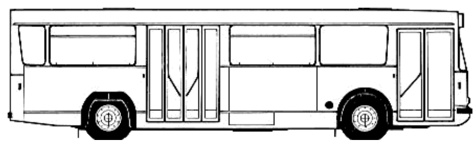
Light Utility Trucks (SUV)



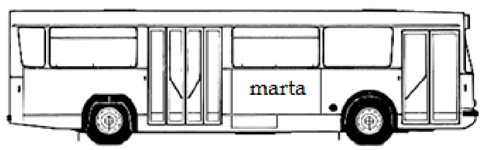
School Bus



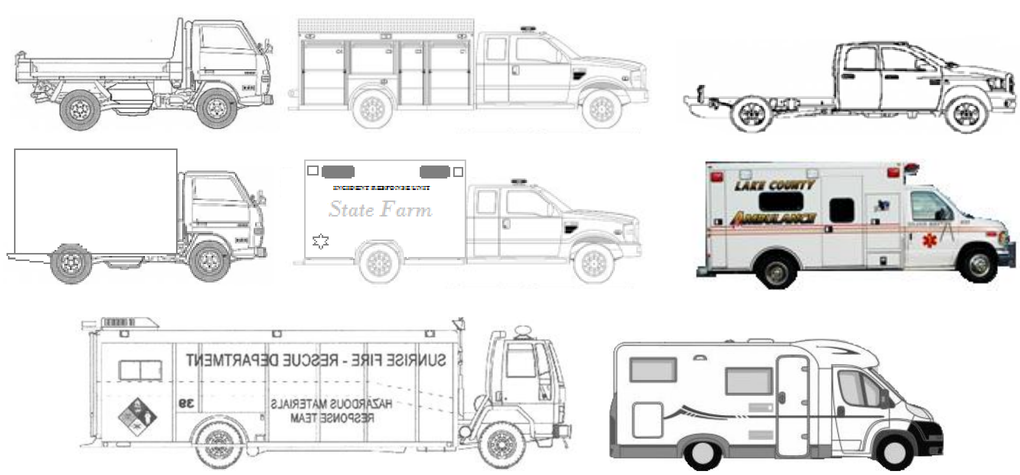
Other Buses



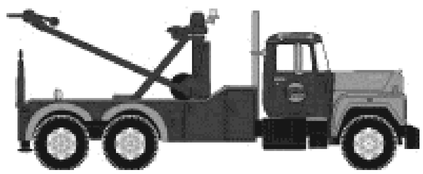
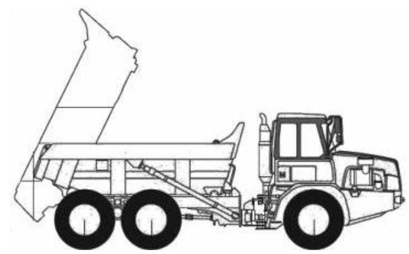
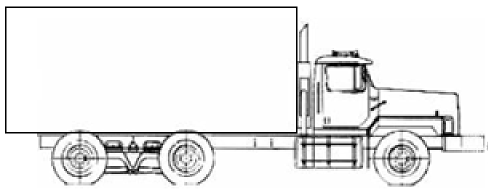
MARTA BUSES -- Bus with MARTA vehicle markings



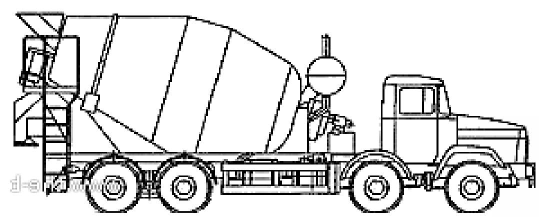
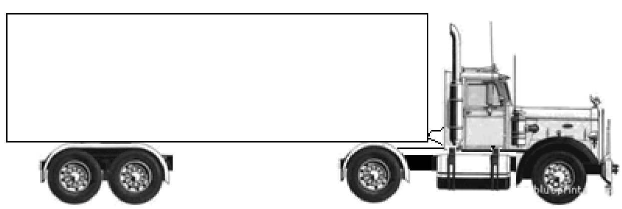
TWO AXLE, SINGLE UNIT TRUCK(s) -- All vehicles on a single frame including trucks, camping and recreational vehicles, motor homes, etc., with two axles and DUAL REAR WHEELS.



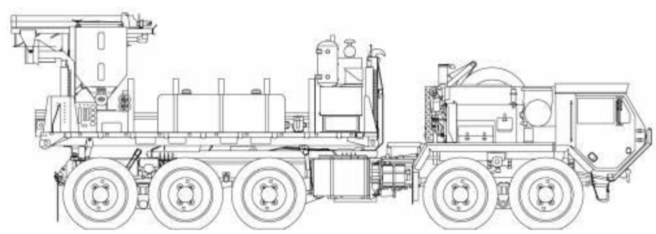
THREE AXLE SINGLE-UNIT TRUCK(s) -- All vehicles on a single frame including trucks, camping and recreational vehicles, motor homes, etc., with three axles.


THREE/ FOUR-AXLE Single Trailer Combination -- All trucks on a single frame with three or four axles & a single trailer combination.

FIVE-AXLE Single Trailer Combination -- All five-axle vehicles consisting of two units, one of which is a tractor or straight truck power unit.



APPENDIX E: GA 400 FLYER FOR INQUIRING DRIVERS

STATE ROAD & TOLLWAY AUTHORITY SRTA

Georgia Tech College of Engineering School of Civil & Environmental Engineering

GA 400 Data Collection

April 13 and 14, 2011

The data collectors at the tollbooths are part of a Georgia Institute of Technology study. Georgia Tech students and staff are counting the number of persons per vehicle along various freeways and examining changes in vehicle use over time. The video captures the rear of the vehicle and will be used anonymously for research purposes ONLY. **Georgia Tech is not recording the vehicle interior or its occupants and video images WILL NOT be associated with the driver or registered owner of the vehicle at any time.** If you have any questions, please feel free to contact Georgia Tech School of Civil and Environmental Engineering:

Randall Guensler, Professor
School of Civil and Environmental Engineering
Georgia Institute of Technology
Atlanta, GA 30332-0355
404-385-2376

REFERENCES

1. **Nelson, J. I., Li, H. and Guensler, R.** *A Geographic and Demographic Profile of Morning Rush Hour Commuters on Highways in North Metropolitan Atlanta.* Washington, DC : s.n., 2008.

2. **Nelson, J. I., et al.** *A Socio-Demographic Analysis of Northeast Atlanta I-85 Peak Period Commuters Likely to be Affected by Implementation of Value Pricing Along the Corridor.* Washington, DC : s.n., 2010.

3. **Woolsey, Matt.** Best and Worst Cities for Commuters. *Forbes.com.* [Online] 4 25, 2008. [Cited: 6 29, 2011.] http://www.forbes.com/2008/04/24/cities-commute-fule-forbeslife-cx_mx_+0424realestate.html.

4. **Heidtman, K., Skarpness, B. and Tornow, C.** *Improved Vehicle Occupancy Data Collection Methods.* s.l. : Federal Highway Administration Office of Highway Information Management, 1997.

5. **Reed, G. L., Desai, H. and Krueger, L. B.** *Determination of Vehicle Occupancy for Small and Medium Sized Areas.* Spokane, Washington : s.n., 1998.

6. **Ulber, C. and McCormack, E.** Accuracy and Other Factors Affecting a Continuous Vehicle Occupancy Monitoring Program. 1988, Vol. 1206, pp. 35-47.

7. **Gan, A., et al.** *Vehicle Occupancy Data Collection Methods: Final Report.* s.l. : Florida Dpartment of Transportation, 2005.

8. **Benuska, M., Hansen, M. and Ulberg, C.** *HOV Monitoring and Evaluation Tool.* Seattle, Washington : Washington State Department of Transportation, 1994.

9. **Levine, N. and Wachs, M.** *Factors Affecting Vehicle Occupancy Measurement.* 1998. pp. 215-229.

10. **Haase, J. J.** *2006 Vehicle Occupancy Study, City of Lincoln, Nebraska.* Lincoln, NE : The Schemmer Associates Inc, 2006.

11. **Virginia Department of Transportation.** *2007/2008 Vehicle Occupancy Study for the Richmond Area MPO.* Richmond, VA : Richmond Regional Planning District Commission, 2008.

12. **Rutherford, S. G., Kinchen, R. K. and Jacobson, L. N.** Agency Practice for Monitoring Violations of High Occupancy Vehicle Facilities. *Transportation Research Record.* 1280, 1990, pp. 141-147.

13. **Levine, N and Wachs, M.** *Factors Affecting Vehicle Occupancy Measurement.* s.l. : Transporation Research A, 1998. pp. 215-229.

14. **Georgia Department of Transportation.** www.dot.state.ga.us. *Georgia Department of Transportation Website.* [Online] 2010. http://www.dot.state.ga.us.

15. **Fisher, R. F., Williams, G. J. and Boyd, J. P.** *Atlanta Vehicle Occupancy Monitoring.* s.l. : Transportation Research Record, 1980. pp. 27-32. Vol. 779.