MAG 2012 VEHICLE OCCUPANCY STUDY

Final Report

Prepared By:

MARICOPA ASSOCIATION of GOVERNMENTS

In Association With:

the CK Group, Inc.

TRA

February 2013

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EXECUTIVE SUMMARY

I. Introduction

As the Phoenix region metropolitan planning organization, the Maricopa Association of Governments (MAG), monitors travel behaviors and traffic patterns on area freeways, high occupancy vehicle (HOV) lanes, and select arterial facilities. Monitoring the usage of HOV lanes on the freeway system in the MAG region is important. The number of shared ride trips and single occupant trips in the HOV and general purpose lanes by time of day are used to calibrate the MAG regional transportation model. In addition, understanding truck travel is important to calibrate the MAG truck travel model and is also used in air quality modeling, pavement design, and noise studies. Since the last MAG Vehicle Occupancy Study, completed in 2008, HOV lane coverage has expanded in the region from approximately 180 directional miles to more than 350 directional miles presently, and new HOV-to-HOV interchange ramps have been constructed.

The purpose of this Vehicle Occupancy Study (VOS) is to collect vehicle occupancy, vehicle classification and commercial vehicle data to assist transportation planning and modeling. The Study objectives are to determine vehicle occupancy rates and classification in the HOV and general purpose lanes. The following are the goals for this study in providing MAG with this data on existing traffic conditions.

1. The main goals of the 2012 MAG Vehicle Occupancy Study is to update the occupancy profile of the regional transportation system for travel demand forecasting modeling and transportation system analysis purposes. Occupancy data for this purpose is separated based on two main parameters; facility type and time of day.

2. Analysis of the vehicle occupancy rate trends and patterns in the region. Since 1973, several MAG occupancy studies have been performed and a significant amount of data has been compiled, with the most recent study prior to this conducted from 2006 to 2008. This study allows for continued comparison of the occupancy rates over the passage of time.

3. Evaluation of the HOV lanes in the region. Data and analysis will aid MAG in their continued monitoring of HOV lane usage and managed lane planning. This includes investigations into HOV usage, the violations occurring with single occupant vehicles in HOV lanes, and the efficiency of HOV lanes in carrying person and vehicle throughputs during all times of the day, including the AM and PM peak hours during congestion (defined as an average travel speed on a facility of 35 mph or below).

4. Vehicle classification (by vehicle size and vehicle type) is another important focus of this study. The distribution of vehicle types traveling around and through the Phoenix Metropolitan area will assist in the validation and calibration of the MAG truck travel model, as well as other uses.

II. Study Design and Data Collection Procedures

MAG 2012 VOS data has been collected in spring and fall of 2012, when there was adequate light to collect occupancy data during the HOV/peak traffic hours from 6:00 AM to 9:00 AM and from 3:00 PM to 7:00 PM. The earliest and latest dates for data collection were established as March 20th and September 21st, respectively. Data has been collected on Tuesdays, Wednesdays and Thursdays only, but not on holidays. The data collection period also matches the typical traffic peak in the region. Summer months from May 11th to August 19th, when most schools are out of session and traffic volumes are light, were excluded as ineligible data collection days. CK Group, Inc. (CK) is the prime consultant on the project and performed all carousel method data collection. Traffic Research and Analysis, Inc. (TRA) performed the Windshield method data collection with the assistance from CK.

Based on literature reviewed and the required scope for the MAG 2012 VOS, a hybrid approach was designed using Windshield and Carousel methods for vehicle occupancy data collection. The Windshield method consists of observers safely stationed on the side of the road collecting vehicle occupancy information by looking into windshields of approaching vehicles. This method was used during peak periods (6:00-9:00 AM and 3:00-7:00 PM). The Carousel method consists of the observer traveling inside the survey vehicle at 45 mph, or approximately 15 mph slower than the prevailing uncongested speed, and recording occupancy data on a GPS enabled touch-pad device. This method was used during off-peak periods (8:00 AM – 4:00 PM). Overlap of both methods being used in the last hour of the morning peak and first hour of the afternoon peak took place in order to improve the quality of the data and allow for comparison between the two methods. The data collection plan also included simultaneous supplemental traffic count and speed data collection for comparison and validation and analysis purposes. This supplemental traffic data was obtained from the Arizona Department of Transportation (ADOT) Freeway Management System (FMS) database and, where FMS data was not available, from temporary data collection sites using radar. These data collection efforts are explained in subsequent sections.

MAG identified the vehicle occupancy and classification data to be collected in the following 13 categories for both the Windshield and Carousel methods:

1. One person auto (Passenger Vehicle)
2. Two person auto (Passenger Vehicle)
3. Three person auto (Passenger Vehicle)
4. Four and four plus person auto (Passenger Vehicle)
5. Unknown occupancy auto (Passenger Vehicle)
6. Unknown 2+ occupancy auto (Passenger Vehicle)
7. Motorcycles (Motorcycle)
8. Marked autos and light trucks (business related) (Delivery Vehicle)
9. Medium trucks (single-unit trucks) (Delivery Vehicle)
10. Heavy trucks (multi-unit trucks) (Heavy Vehicle)
11. Commercial passenger vans (Other)
12. Recreational vehicles (RV) (Other)
13. Buses (Bus)

Enhanced Windshield Method

The Windshield method was considered as the most applicable approach for the VOS because it provides comprehensive temporal and spatial coverage on the freeway system. In addition, data obtained through the Windshield method could be compared to historical data for trend analysis. To further improve the accuracy of the Windshield method, the following actions were taken:

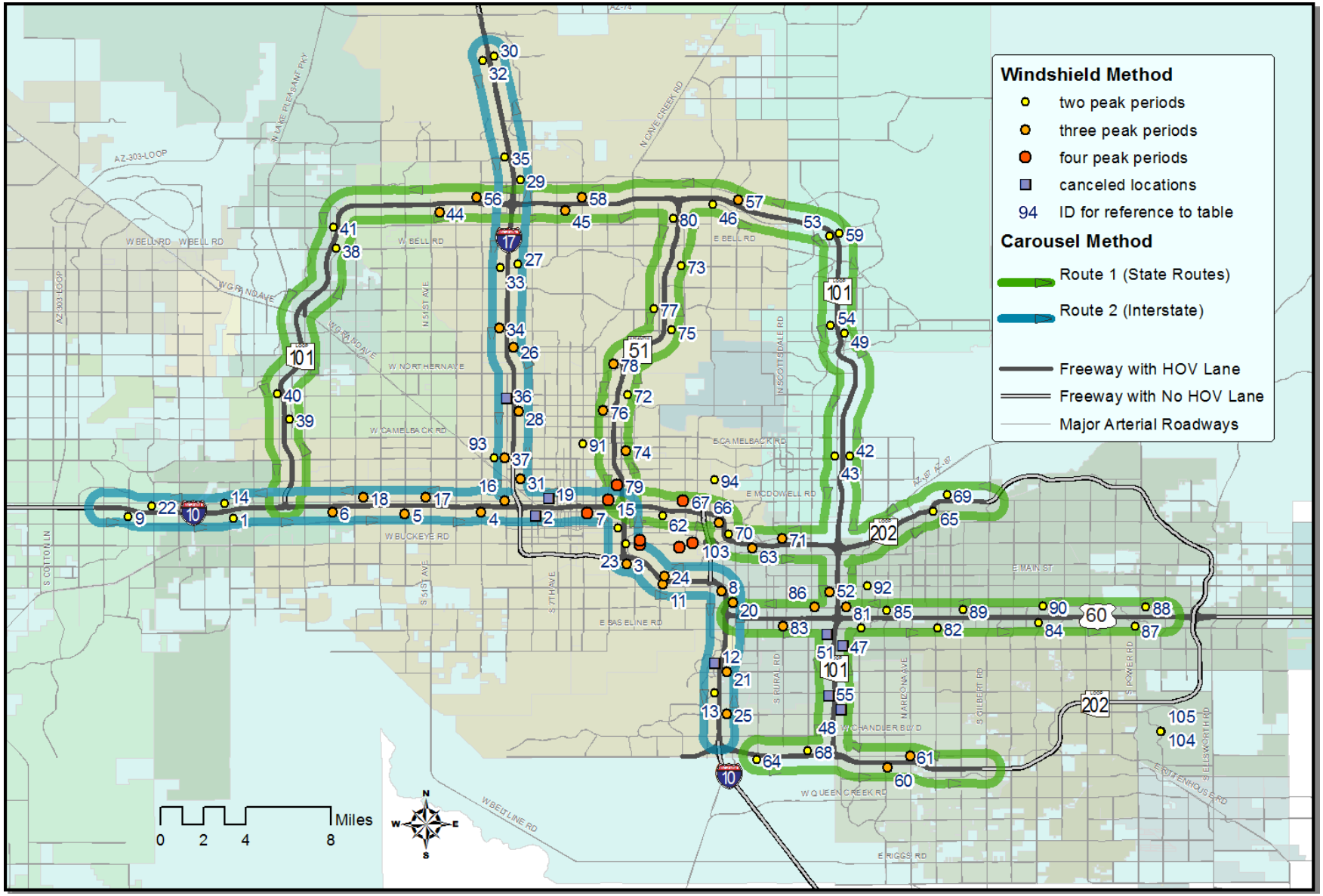
1. Site Location – Each site was reviewed using Google Map or physically visited if necessary to identify a precise spot for conducting Windshield data collection safely and accurately.
2. Pilot Study – A pilot study was performed and enhanced counting method developed based on the lessons learned through the pilot study.
3. Staff Training – All field technicians and supervisors were required to participate in a mandatory staff training in which comprehensive instructions of collecting vehicle occupancy data were provided. In addition, each technician was provided a data collection guideline document as a field reference.
4. Role of Site Supervisor – A supervisor was responsible to lead data collection assignment at each location. The supervisors were assigned to collect occupancy data for the HOV lane as the most important task among the field staff.
5. Safety – Based on training feedback and ADOT review comments, a field safety checklist was prepared and provided to field staff. MAG staff patrolled the data collection sites on a daily basis to assure and reassure the compliance with safety requirements. No data collection was performed at sites which were regarded as unsafe by ADOT.
6. Data Collection Equipment – An ergonomically designed counter board was used to collect and record the data. Using this device streamlines the data recording process and reduces human errors during the data recording.
7. Human Fatigue – At each location, multiple technicians were deployed along with one field supervisor. Each technician was assigned no more than two general purpose lanes, while the field supervisor was responsible for the HOV lane only. Technicians and field supervisors were restricted to work no more than 4 hours for each peak period. This minimized fatigue and reduced potential for human error.
8. Device Management and Data Download – Field equipment were routinely checked prior to commencement of the data collection at each site. Backup equipment was provided for each site and data was downloaded on a weekly basis for expedited data processing.

A total of 100 locations were identified by MAG for the Windshield method – 90 along freeway segments, four along arterial roadways as the historical locations, and six at the Phoenix Sky Harbor International and Phoenix-Mesa Gateway airports as required by the concurrent MAG airport study. All locations were identified for at least one day, and some important locations were planned for an additional day of data collection for AM or PM HOV hours or both. Data collection locations are shown in **Figure ES-1**.

Innovative Carousel Method

The Carousel vehicle occupancy data collection method delivers highly accurate occupancy data because of the increased observation time and the proximity to vehicles in adjacent lanes allowing for a very clear view. This method works specifically well in the case of observing large passenger vehicles and vehicles with tinted windows. It does not, however, work well in highly congested traffic condition where speeds in all lanes are significantly reduced. The

Figure ES-1 Data Collection Locations and Routes



Carousel method in this study was used as a supplement to the Windshield method. This method was designated for use on both freeway general purpose and HOV lanes during only the mid-day off-peak period from 9:00 AM to 3:00 PM. Additional occupancy and classification data for the HOV lane only were collected from 8:00 AM to 9:00 AM and from 3:00 PM to 4:00 PM, which could be compared to the Windshield method results. The GPS enabled touch-pad device records vehicle occupancy and classification data with accurate coordinate points. Two routes were designed for the Carousel method. Route 1 covers 233 miles of regional freeway while Route 2 covers 112 miles of interstate freeway. The two routes for Carousel method are shown previously in **Figure ES-1**. A total of 10 days data collection were conducted between 8:00 AM and 4:00 PM on the two routes.

The following actions were taken to improve accuracy and quality of the Carousel method data collection:

1. Route Design – The lengths of the two Carousel routes were designed such that they could be completely traversed during the time allocated to avoid partial runs in an individual data collection day.
2. Pilot Study – A pilot study was performed in advance of the scheduled collection dates and enhanced counting methods were developed and practiced based on the lessons learned through the pilot study.
3. Staff Training – Field technicians and vehicle drivers were required to participate in a mandatory staff training in which comprehensive instructions in collecting vehicle occupancy and classification data were provided. In addition, each technician was provided a data collection guideline document as a quick reference to seek guidance in the field.
4. Role of Driver and Technician – To ensure safety, roles of the driver and technician were strictly separated. The driver was assigned only for driving the vehicle along the designated route with no input towards the data collection. The count technician likewise maintained focused on his responsibility in the data collection only.
5. Safety – Based on training feedbacks, a field safety checklist was prepared and provided to field staff.
6. Data Collection Equipment – A GPS enabled touch-pad was used for the Carousel method data collection. This device recorded accurate coordinates for each vehicle occupancy and classification data point.
7. Human Fatigue – Driver and field technician were restricted to work no more than 4 hours at a time.
8. Device Management and Data Download – Field equipment were routinely checked prior to commencement of data collection runs. Backup equipment was provided in the vehicle site in case the assigned equipment malfunctions. The data collected was downloaded and processed the next day after data collection.

The Quality Assurance/Quality Control (QA/QC) plan for this study was developed to ensure the highest possible quality of data collected. The QA/QC plan has the following two components. Field data QA refers to the measures, such as training and monitoring, taken prior and during data collection to ensure that field collection is performed as accurately as possible to minimize potential for errors. Data processing QC refers to the internal checks after the actual data collection during post processing to verify data outputs are correct and accurate.

III. Challenges and Lessons

The Windshield method was the primary focus of the MAG 2012 VOS. The Windshield data was collected at 100 observation sites on one or two days. In addition, there were 21 recount locations. While strict QA and QC procedures were implemented during data collection and post data processing, there were certain occurrences throughout the project that impeded the progress. The Carousel method in this study was used as a supplement to the Windshield method. The GPS enabled touch-pad device allowed recording of vehicle occupancy and classification data with accurate coordinate points. Pros and cons for two methods are summarized in the Chapter 3 of the report.

IV. Summary of Results

Auto Occupancy

Figure ES-2 presents freeway auto occupancy by time for the day by incorporating results obtained from both the Windshield method (for AM and PM peak periods) and Carousel method (for midday time periods). The results show that the average auto occupancy rates are higher in the midday than in the peak periods. This may be due to higher proportion of non-commute travel trips which tend to have higher occupancy rates. It is also worth noting that Carousel method is expected to yield more reliable occupancy counts than the Windshield method which could partially account for higher occupancy rates during the midday.

Figure ES-2 Freeway Auto Occupancy by Time of Day

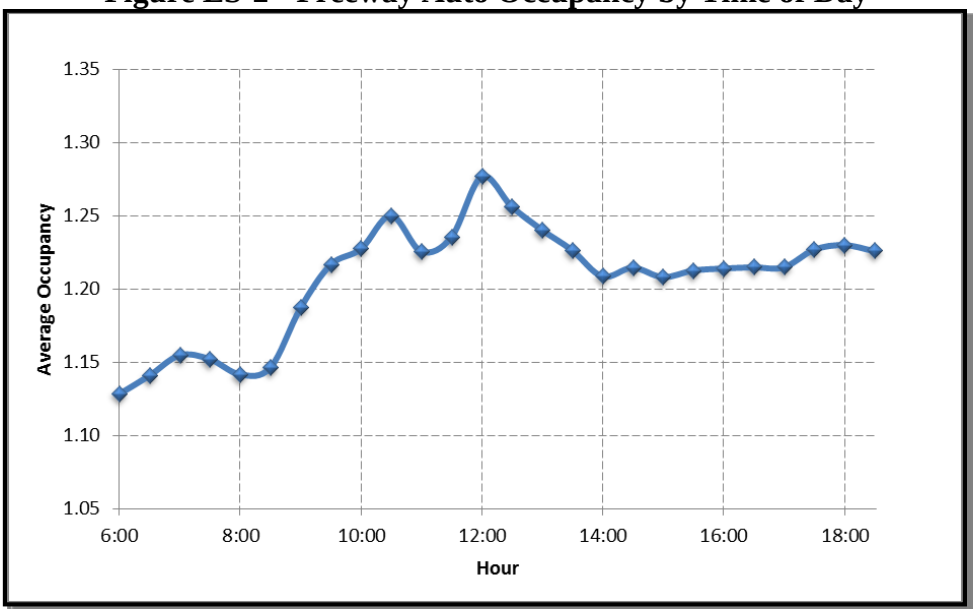
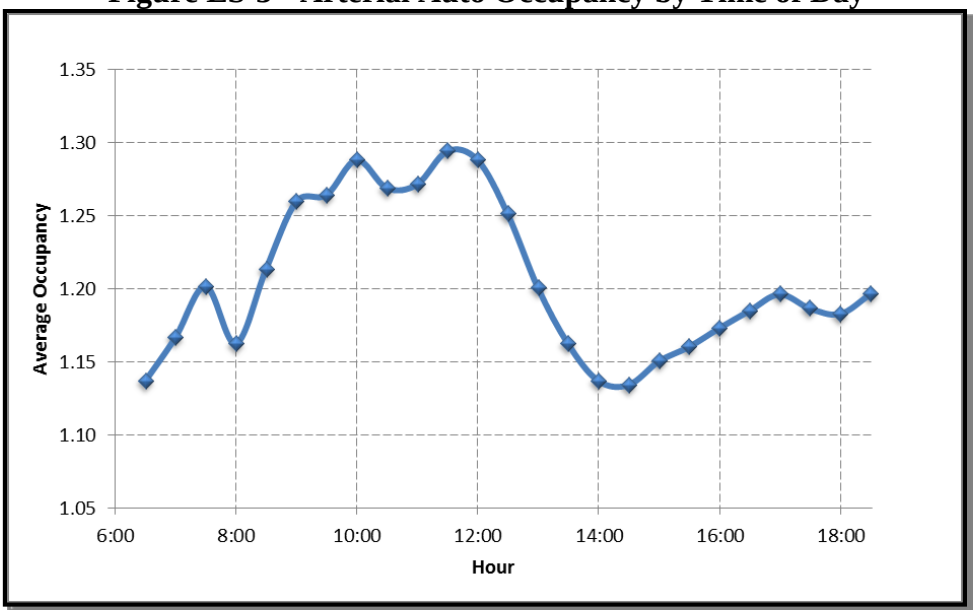


Figure ES-3 presents arterial auto occupancy by time of day from four select arterial locations where occupancy data have been collected historically. Occupancy rates are again highest near the middle of the day.

Figure ES-3 Arterial Auto Occupancy by Time of Day



Vehicle Classification

Table ES-1 presents freeway vehicle classification by 30-min interval. In this study, vehicle classification data in the AM and PM peak periods were collected by the Windshield method and mid-day classifications were collected by the Carousel approach. It is shown that passenger cars take up a large percentage of the total vehicle traveled in the valley (88.3%), followed by trucks (9.8%). Recreational vehicles, buses, commercial vans and motorcycles remain a small portion of the overall traffic distribution.

HOV Lane Evaluation

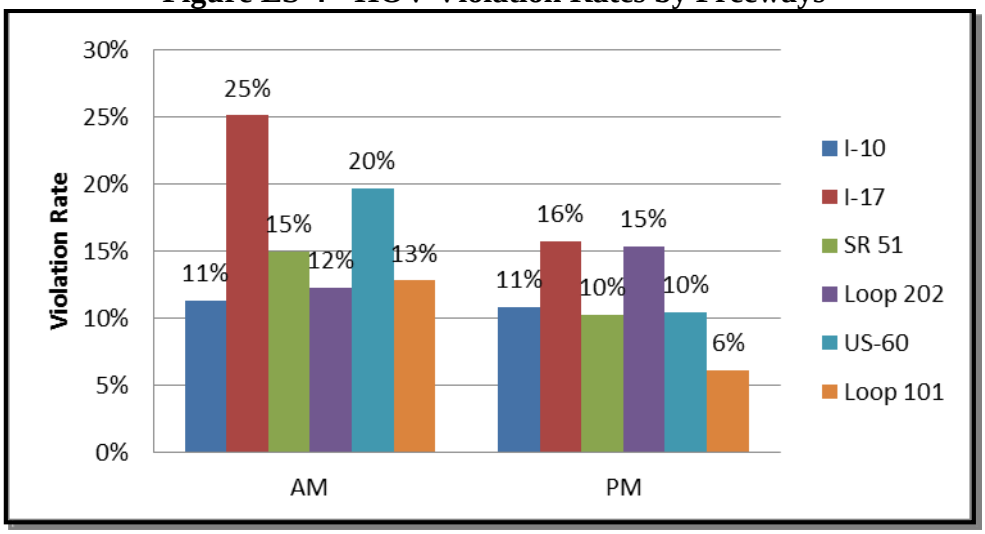
One important evaluation of the efficiency of HOV lanes is to compare the person throughput relative to the general purpose lanes. The corresponding HOV lane and average general purpose lane percentages of the total travelers and vehicles of these two lanes are investigated in the Chapter 4.

Figure ES-4 shows the comparison of HOV violation rate by freeway. The violation rate is computed as the number of single occupancy vehicles, excluding those with "Blue Sky" plates, out of total vehicles. In Phoenix region, there are no HOV violations during the off-peak hours where use of the HOV lane is unrestricted. Overall, I-17 has the highest rate of violation for both AM and PM periods. Similar conclusion can be seen from 2006 MAG vehicle occupancy report.

Table ES-1 Freeway Vehicle Classification						
Time	**Motor-cycles**	**Buses**	**Passenger Vehicles**	**Trucks**	**Commercial Vans**	**RV**
6:00	1.2%	0.3%	83.8%	13.9%	0.7%	0.0%
6:30	1.1%	0.3%	86.4%	11.6%	0.6%	0.0%
7:00	1.0%	0.3%	87.7%	10.4%	0.6%	0.0%
7:30	1.0%	0.3%	88.0%	10.1%	0.5%	0.0%
8:00	0.8%	0.3%	86.4%	11.9%	0.6%	0.1%
8:30	0.8%	0.3%	85.1%	13.1%	0.6%	0.1%
AM	1.0%	0.3%	86.3%	11.7%	0.6%	0.1%
9:00	0.8%	0.3%	88.8%	9.5%	0.5%	0.2%
9:30	0.7%	0.1%	88.1%	10.2%	0.6%	0.2%
10:00	0.5%	0.1%	88.9%	9.4%	0.9%	0.3%
10:30	0.4%	0.2%	88.0%	10.6%	0.6%	0.2%
11:00	0.8%	0.2%	86.9%	11.1%	0.8%	0.1%
11:30	0.8%	0.2%	88.0%	10.3%	0.6%	0.1%
12:00	0.9%	0.1%	87.8%	10.0%	1.0%	0.3%
12:30	1.5%	0.2%	89.0%	8.6%	0.5%	0.1%
13:00	0.9%	0.1%	87.6%	10.3%	0.9%	0.2%
13:30	1.0%	0.1%	88.5%	9.7%	0.7%	0.1%
14:00	0.6%	0.1%	89.2%	9.4%	0.6%	0.0%
14:30	1.0%	0.2%	89.7%	8.3%	0.6%	0.1%
MD	0.8%	0.2%	88.4%	9.8%	0.7%	0.1%
15:00	0.9%	0.2%	86.7%	11.4%	0.7%	0.1%
15:30	0.9%	0.2%	87.9%	10.2%	0.7%	0.1%
16:00	1.0%	0.3%	89.0%	9.0%	0.6%	0.1%
16:30	1.1%	0.3%	89.9%	8.0%	0.6%	0.1%
17:00	1.1%	0.3%	91.2%	6.9%	0.5%	0.0%
17:30	1.0%	0.2%	91.5%	6.7%	0.5%	0.1%
18:00	1.0%	0.2%	91.4%	6.8%	0.5%	0.0%
18:30	1.0%	0.2%	90.8%	7.4%	0.6%	0.1%
PM	1.0%	0.2%	89.7%	8.3%	0.6%	0.1%

Source: MAG January, 2013

Figure ES-4 HOV Violation Rates by Freeways



V. Conclusion

MAG 2012 VOS was successfully completed. All four study goals i.e., update region's vehicle occupancy profile, investigate vehicle occupancy rate trends and patterns, evaluation of the HOV lanes and vehicular classification in the region were accomplished. Safety concerns were thoroughly addressed that resulted in a safe survey execution without any safety related accidents.

➢ ***Data Collection Methods***

Two primary methods for collecting vehicle occupancy data were used: the traditional roadside Windshield method and innovative Carousel method. While the Windshield method has been used in prior studies, MAG used the Carousel method for the first time. The overwhelming majority of vehicle occupancy data was collected by the Windshield method. The data collection plan also included simultaneous supplemental radar traffic count and speed data collection for comparison and validation and analysis purposes. Video data were also recorded at select Windshield data collection sites as a validation and audit tool. A comprehensive Quality Assurance/Quality Control (QA/QC) plan was implemented to ensure the highest possible quality of data collected for the study.

➢ ***Data Validation***

The findings of the general purpose and HOV lane occupancy, Blue Sky License Plate percentages, HOV violation rates were consistent and validated for both the carousel and windshield methods.

➢ ***Freeway Auto Occupancy***

Freeway auto occupancy varies by time of day. Occupancy in the morning reaches a high average hourly occupancy rate of 1.15 for the 7:00 AM hour. The highest hourly occupancy rate recorded in the PM peak is 1.22 for the 4:00 PM hour. The highest occupancy rate for the entire day is 1.28 recorded in the middle of the day for the 12:00 PM hour.

➢ ***Arterial Auto Occupancy***

Auto occupancy on arterial roadways were recorded higher than the freeways with morning, mid-day, and evening hourly highs recorded at 1.2, 1.3, and 1.2, respectively.

- ***Freeway Vehicle Classification and Commercial Vehicle Distribution***

Passenger cars represent the largest percentage of the total vehicle (88.3%), followed by trucks (9.8%). Recreational vehicles, buses, commercial vans and motorcycles represent the remaining portion of the overall traffic distribution.

- ***Freeway HOV Lane Efficiency***

The efficiency for 18 high importance HOV lane locations is shown in detail for each peak period. Of the 82 overall HOV lane locations, 39 (or 48%) are shown to carry higher person throughput than the adjacent GP lane average in either the AM or PM peak. HOV lanes on the I-10 are most efficient while HOV lanes on the SR-51 and Loop 101 freeways are perhaps underutilized.

- ***HOV Lane Violation Rates***

HOV lane violation rates vary within each peak period with more overall violators in HOV lanes during the AM peak hours than during the PM. Higher violation rates can also be seen at the beginning and ending of restricted use HOV hours for both AM and PM peak periods. Overall, I-17 has the highest rate of violation for both AM and PM periods. Similar trends were seen during the 2006 MAG vehicle occupancy study.

1 INTRODUCTION

1.1 Background

As the Phoenix region metropolitan planning organization, the Maricopa Association of Governments (MAG), monitors travel behaviors and traffic patterns on area freeways, high occupancy vehicle (HOV) lanes, and select arterial facilities. Monitoring the usage of HOV lanes on the freeway system in the MAG region is important. The number of shared ride trips and single occupant trips in the HOV and general purpose lanes by time of day are used to calibrate the MAG regional transportation model. In addition, understanding truck travel is important to calibrate the MAG truck travel model and is also used in air quality modeling, pavement design, and noise studies.

Since the last MAG Vehicle Occupancy Study, completed in 2008, HOV lane coverage has expanded in the region from approximately 180 directional miles to more than 350 directional miles presently, and new HOV-to-HOV interchange ramps have been constructed. The Maricopa County region is now nearly fully served by HOV lanes on I-10, I-17, US 60, SR 51, Loop 101, and Loop 202. As part of the continued monitoring process MAG undertook this Vehicle Occupancy Study (VOS) collecting vehicle occupancy and vehicle classification data.

1.2 Study Objectives

Purpose of the VOS is to collect vehicle occupancy, vehicle classification and commercial vehicle data to assist transportation planning and modeling. The Study objectives are to determine vehicle occupancy rates and classification in the HOV and general purpose lanes. The following are the goals for this study in providing MAG with this data on existing traffic conditions.

1. The main goals of the 2012 MAG Vehicle Occupancy Study is to update the occupancy profile of the regional transportation system for travel demand forecasting modeling and transportation system analysis purposes. Occupancy data for this purpose is separated based on two main parameters; facility type and time of day.

2. Analysis of the vehicle occupancy rate trends and patterns in the region. Since 1973, several MAG occupancy studies have been performed and a significant amount of data has been compiled, with the most recent study prior to this conducted from 2006 to 2008. This study allows for continued comparison of the occupancy rates over the passage of time.

3. Evaluation of the HOV lanes in the region. Data and analysis will aid MAG in their continued monitoring of HOV lane usage and managed lane planning. This includes investigations into HOV usage, the violations occurring with single occupant vehicles in HOV lanes, and the efficiency of HOV lanes in carrying person and vehicle throughputs during all times of the day, including the AM and PM peak hours during congestion (defined as an average travel speed on a facility of 35 mph or below).

4. Vehicle classification (by vehicle size and vehicle type) is another important focus of this study. The distribution of vehicle types traveling around and through the Phoenix Metropolitan area will assist in the validation and calibration of the MAG truck travel model, as well as other uses.

1.3 Vehicle Occupancy Data Collection Methods Literature Review

Unlike counting vehicles, which can be automatically recorded using intrusive (pneumatic road tube, inductive loop, etc.) or non-intrusive (microwave/radar, acoustic, video image detection, etc.) devices, counting the number of persons in a vehicle in the field remains largely the task of human observers. There are a limited number of studies that have been found to examine and compare vehicle occupancy data collection methods and related issues.

A comprehensive study was performed by Heidtman et al. (1997) for the Federal Highway Administration (FHWA). The final report on "Improved Vehicle Occupancy Data Collection Methods" identified and evaluated five primary methods of collecting vehicle occupancy: Roadside Windshield, Carousel Observation, Photographic and Video Surveillance, Accident Data Extraction, and Mail-Out Survey.

The Windshield method is a standard method where observers are positioned on the side of the roadway and vehicle occupants are counted through the automobile windows and recorded using electronic counting boards. For safety reasons, the observers must stand in a protected area, such as behind a guardrail, or in the clear-zone. This method produces results comparable to historical data and provides high sample rates. This method is however labor intensive and is limited by the viewing distance, collection time and light conditions.

The Carousel method consists of observers positioned in a vehicle traveling in the right lane somewhat slower than the prevailing traffic while counting passing vehicle occupants in adjacent lanes. The proximity to passing vehicles provides a clearer perspective, viewing time is increased, and safety is enhanced. Data collected with this method is more accurate, but the method only works for a multi-lane corridor during relatively uncongested traffic conditions.

The photographic or video method offers a permanent record and high sample rates; but the method is high-cost, lane specific and vulnerable to potential data loss due to poor video quality, thus it is not recommended. The other two methods (accident database and mail-out survey) have limitations such as biased data, low sample sizes, low response rate or work trip concentrated. Infrared video counting method has been studied by Minnesota DOT. The conclusion from that study is that the camera is not able to produce sufficiently clear images at highway speeds.

A more recent and comprehensive study is the Vehicle Occupancy Data Collection Methods, dated February 2005 by the Florida Department of Transportation. The study examined methodologies and issues related to geographic, temporal, and vehicle coverage design of occupancy data collections, and presented study guidelines for performing occupancy data collection as well as in analyzing occupancy data. One finding of this study was that fully automated methods of vehicle occupancy data collection are still largely a distant future due to technological, cost, and institutional barriers. Methods with a lesser degree of automation that record and analyze

occupancy data electronically remain the current methods of choice. As part of this study, a set of study guidelines were developed for manual counting methods for corridor and area-wide studies. The guidelines address design issues related to time periods, sampling plan, field operation, work plan, personnel training, use of data collection tools and equipment, data collection plan, and data analysis.

While these prior studies are relatively comprehensive, much remains to be done. No formal guidelines have been developed to assist in selecting the proper methods and the associated geographic, temporal, and vehicle coverage for specific applications. The goal for the VOS is to collect highly accurate vehicle occupancy data using techniques which are safe for both observers and road users as well as least disruptive to the travelling public.

Based on prior MAG experience in conducting occupancy studies, as well as findings from the literature review, both Windshield and Carousel methods were selected and used for the MAG 2012 VOS. While the Windshield method has been used in prior studies, MAG experimented with the Carousel method for the first time. The planning process for implementing these data collection methods accounted for conditions such as traffic characteristics, environmental conditions, and human factors.

1.4 Report Organization

Following this introductory chapter, this report presents information in four additional chapters, as described below:

Chapter 2 – Study Design and Data Collection Procedures: This chapter presents study design parameters and data collection methods and procedures for completing the data collection process for the MAG 2012 VOS. It summarizes the data collection scope design, including methods for data collection, QA/QC procedures and processes, recount sites and additional data for “blue sky” plates.

Chapter 3 – This Chapter summarizes the lessons learned from the Windshield and Carousel methods. These lessons have been identified from the issues and the resolution of those issues during the pilot studies and main data collection efforts. These findings should be of value for conducting future similar studies and could result in improved efficiency.

Chapter 4 – This chapter presents some of the key findings from this VOS. Shown are the average vehicle occupancy rates by peak period and time of day, the distribution of vehicle types, and performance of HOV lanes, including HOV violation rates by freeway. The vehicle occupancy trend since 1970 is also shown for select locations.

Chapter 5- This chapter presents conclusions and summarizes the major effort and findings of this study.

2 STUDY DESIGN AND DATA COLLECTION PROCEDURES

This chapter presents study design parameters and data collection methods and procedures for completing the data collection process for the MAG 2012 VOS. It summarizes the data collection scope design including methods for data collection, QA/QC procedures and processes, recount sites and additional data for the vehicles with "blue sky" license plates.

2.1 Data Collection Scope Design

2.1.1 Data Collection Time Period

MAG 2012 VOS data were collected in spring and fall of 2012, when there was adequate light to collect occupancy data during the HOV/peak traffic hours from 6:00 AM to 9:00 AM and from 3:00 PM to 7:00 PM. The earliest and latest dates for data collection were established as March 20th and September 21st, respectively. The data were collected on Tuesdays, Wednesdays and Thursdays, but not on holidays. The data collection period also matches the typical traffic peak in the region. Summer months from May 11th to August 19th, when most schools are out of session and traffic volumes are light, were excluded as ineligible data collection days. Traffic Research and Analysis, Inc. (TRA) performed the Windshield data collection with the assistance from the CK Group, Inc. (CK).

2.1.2 Vehicle and Occupancy Classification

MAG identified the vehicle occupancy and classification data to be collected in the following 13 categories for both the Windshield and Carousel methods:

1. One person auto (Passenger Vehicle)
2. Two person auto (Passenger Vehicle)
3. Three person auto (Passenger Vehicle)
4. Four and four plus person auto (Passenger Vehicle)
5. Unknown occupancy auto (Passenger Vehicle)
6. Unknown 2+ occupancy auto (Passenger Vehicle)
7. Motorcycles (Motorcycle)
8. Marked autos and light trucks (business related) (Delivery Vehicle)
9. Medium trucks (single-unit trucks) (Delivery Vehicle)
10. Heavy trucks (multi-unit trucks) (Heavy Vehicle)
11. Commercial passenger vans (Other)
12. Recreational vehicles (RV) (Other)
13. Buses (Bus)

2.1.3 Data Collection Methods

Based on literature reviewed and the required scope for the MAG 2012 VOS, a hybrid approach was designed using Windshield and Carousel methods for vehicle occupancy data collection. The Windshield method was used during peak periods (6:00-9:00 AM and 3:00-7:00 PM) and the

Carousel method was used during off-peak periods (8:00 AM – 4:00 PM). Overlap of both methods being used in the last hour of the morning peak and first hour of the afternoon peak took place in order to improve the quality of the data and allow for comparison between the two methods. The data collection plan also included simultaneous supplemental traffic count and speed data collection for comparison and validation and analysis purposes. This supplemental traffic data was obtained from the Arizona Department of Transportation (ADOT) Freeway Management System (FMS) database and, where FMS data was not available, from temporary data collection sites using radar. These data collection efforts are explained in subsequent sections.

2.1.4 Enhanced Windshield Method

The Windshield method was considered as the most applicable approach for the VOS because it provides comprehensive temporal and spatial coverage on the freeway system. In addition, data obtained through the Windshield method could be compared to historical data for trend analysis. To further improve the accuracy of the Windshield method, the following actions were taken:

1. Site Location – Each site was reviewed using Google Map or physically visited if necessary to identify a precise spot for conducting Windshield data collection safely and accurately.
2. Pilot Study – A pilot study was performed and enhanced counting method developed based on the lessons learned through the pilot study.
3. Staff Training – All field technicians and supervisors were required to participate in a mandatory staff training in which comprehensive instructions of collecting vehicle occupancy data were provided. In addition, each technician was provided a data collection guideline document as a field reference.
4. Role of Site Supervisor – A supervisor was responsible to lead data collection assignment at each location. The supervisors were assigned to collect occupancy data for the HOV lane as the most important task among the field staff.
5. Safety – Based on training feedback and ADOT review comments, a field safety checklist was prepared and provided to field staff. MAG staff patrolled the data collection sites on a daily basis to assure and reassure compliance with safety requirements. No data collection was performed at sites which were regarded as unsafe by ADOT.
6. Data Collection Equipment – An ergonomically designed counter board was used to collect and record the data. Using this device streamlines the data recording process and reduces human errors during the data recording.
7. Human Fatigue – At each location, multiple technicians were deployed along with one field supervisor. Each technician was assigned no more than two general purpose lanes, while the field supervisor was responsible for the HOV lane only. Technicians and field supervisors were restricted to work no more than 4 hours for each peak period. This minimized fatigue and reduced potential for human error.
8. Device Management and Data Download – Field equipment were routinely checked prior to commencement of the data collection at each site. Backup equipment was provided for each site and data was downloaded on a weekly basis for expedited data processing.

<u>Locations</u>

A total of 100 locations were identified by MAG for the Windshield method – 90 along freeway segments, four along arterial roadways as the historical locations, and six at the Phoenix Sky Harbor International and Phoenix-Mesa Gateway airports as required by the concurrent MAG airport study. All locations were identified for at least one day, and some important locations are planned for an additional day of data collection for AM or PM HOV hours or both. Summarized in **Table 1** are the data collection locations, the assigned number of peak periods, the assignment of video back up and radar data collection, and count dates. Data collection locations are shown in **Figure 1**.

Table 1 Windshield Method Data Collection Sites

ID	Location	Day 1		Day 2		Video	Radar	Count Dates
		AM	PM	AM	PM			
1	I-10 EB at 115th Ave	x	x				x	03/27/2012
2	I-10 EB at 18th Ave	Site cancelled by ADOT due to safety reasons						
3*	I-10 EB at 24th St (Historical location)	x	x		x			09/11/12 & 09/12/12
4	I-10 EB at 34th Ave	x	x	x				8/21/2012 & 08/28/2012
5	I-10 EB at 58th Ave	x	x	x		x		4/24/2012 and 05/01/2012
6	I-10 EB at 81st Ave	x	x	x		x		3/27/2012 & 09/12/2012
7	I-10 EB at 9th St	x	x	x	x	x		5/8/2012 & 08/22/2012
8	I-10 EB at Broadway Rd	x	x		x			09/11/2012 & 09/12/2012
9	I-10 EB at Bullard Ave	x	x				x	03/27/2012
10	I-10 EB at Jefferson St	x	x					05/10/2012
11	I-10 EB at University Dr	x	x		x	x		5/10/2012 & 09/04/2012
12	I-10 EB at South of Guadalupe Rd	Site cancelled by ADOT due to safety reasons						
13	I-10 EB at South of Warner Rd	x	x					09/04/2012
14	I-10 WB at 115th Ave	x	x				x	03/27/2012
15	I-10 WB at 16th St	x	x	x	x	x		05/08/2012 & 08/2/2012
16	I-10 WB at 28th Ave	x	x		x			08/29/2012 & 9/6/2012
17	I-10 WB at 52nd Ave	x	x	x				04/24/2012 & 05/01/2012
18	I-10 WB at 77th Ave	x	x	x		x		03/27/2012 & 08/28/2012
19	I-10 WB at 7th Ave	Site cancelled by ADOT due to safety reasons						
20	I-10 WB at Alameda Dr	x	x	x				08/29/2012, 08/30/2012 & 09/05/2012
21	I-10 WB at Elliot Rd	x	x	x				8/29/2012, 8/30/2012 & 9/5/2012
22	I-10 WB at Litchfield Rd	x	x				x	05/01/2012
23	I-10 WB at Buckeye Rd	x	x					05/10/2012

Table 1 Windshield Method Data Collection Sites								
ID	Location	Day 1		Day 2		Video	Radar	Count Dates
		AM	PM	AM	PM			
24	I-10 WB at University Dr	x	x	x		x		05/10/2012 & 08/28/2012
25	I-10 WB at North of Ray Rd	x	x	x				08/28/2012, 08/30/2012 & 09/6/2012
26	I-17 NB at Dunlap Ave	x	x		x	x		08/21/2012
27	I-17 NB at Greenway Pkwy	x	x				x	05/03/2012
28	I-17 NB at Bethany Home Rd	x	x		x	x		5/3/2012 & 09/06/2012
29	I-17 NB at Deer Valley Rd	x	x			x	x	04/11/2012
30	I-17 NB at North of SR 303	x	x				x	04/11/2012
31*	I-17 NB at Thomas Rd (Historical location)	x	x		x			8/23/2012, 08/28/2012& 09/04/2012
32	I-17 SB at South of SR 303	x	x				x	04/11/2012
33	I-17 SB at Greenway Pkwy	x	x				x	05/02/2012
34	I-17 SB at Peoria Ave	x	x	x		x		5/2/2012 & 8/21/2012
35	I-17 SB at Pinnacle Peak Rd	x	x			x	x	05/03/2012
36	I-17 SB at Glendale Ave	Site cancelled by ADOT due to safety reasons						
37	I-17 SB at Indian School Rd	x	x	x				5/8/2012 & 08/29/2012
38	L101 (Agua Fria) NB at Bell Rd	x	x			x	x	03/20/2012
39	L101 (Agua Fria) NB at Bethany Home Rd	x	x				x	03/20/2012
40	L101 (Agua Fria) SB at Glendale Ave	x	x				x	03/20/2012
41	L101 (Agua Fria) SB at Union Hills Dr	x	x				x	03/20/2012
42	L101 (Pima) NB at Indian School Rd	x	x					04/19/2012
43	L101 (Pima) SB at Indian School Rd	x	x			x		04/19/2012
44	L101 EB at 51st Ave	x	x	x		x	x	3/20/2012 & 08/23/2012
45	L101 EB at 7th Ave	x	x	x				08/29/2012, 08/30/2012 & 09/05/2012
46	L101 EB at Tatum Blvd	x	x			x		4/17/2012 & 08/22/2012
47	L101 NB at Guadalupe Rd	Site cancelled by ADOT due to safety reasons						
48	L101 NB at Ray Rd	Site cancelled by ADOT due to safety reasons						
49	L101 NB at Shea Blvd	x	x			x		04/18/2012
50	L101 NB at Southern Ave	x	x	x				4/10/2012 & 08/22/2012
51	L101 SB at Baseline Rd	Site cancelled by ADOT due to safety reasons						
52	L101 SB at Broadway Rd	x	x		x			4/10/2012 & 08/22/2012
53	L101 SB at Princess Dr	x	x					04/18/2012

Table 1 Windshield Method Data Collection Sites								
ID	Location	Day 1		Day 2		Video	Radar	Count Dates
		AM	PM	AM	PM			
54	L101 SB at Shea Blvd	x	x			x		04/19/2012
55	L101 SB at Warner Rd	Site cancelled by ADOT due to safety reasons						
56	L101 WB at 35th Ave	x	x		x	x	x	3/20/2012 & 08/23/2012
57	L101 WB at 56th St	x	x		x			4/17/2012, 08/22/2012, 09/13/2012
58	L101 WB at 7th St	x	x		x	x		4/17/2012 & 08/22/2012
59	L101 WB at Princess Dr	x	x					04/18/2012
60	L202 EB at Alma School Rd	x	x		x		x	4/12/2012 & 08/23/2012
61	Loop 202 WB at Arizona Ave	x	x	x			x	4/12/2012 & 08/23/2012
62	Loop 202 EB at 32nd St	x	x			x		05/9/2012 & 09/04/2012
63	Loop 202 EB at Center Pkwy	x	x		x	x		05/15/2012 & 09/04/2012
64	Loop 202 EB at Kyrene Rd	x	x				x	09/11/2012 & 09/12/2012
65	Loop 202 EB at Mesa Dr	x	x			x	x	04/10/2012
66	Loop 202 EB at Sky Harbor Blvd	x	x		x			09/12/2012 & 09/13/2012
67	Loop 202 WB at 40th St	x	x	x	x	x		05/09/2012, 08/23/2012 & 08/28/2012
68	Loop 202 WB at McClintock Dr	x	x				x	04/12/2012
69	Loop 202 WB at Mesa Dr	x	x				x	04/10/2012
70	Loop 202 WB at Priest Dr	x	x					05/15/2012
71	Loop 202 WB at Scottsdale Rd	x	x	x				08/29/2012, 08/30/2012 & 09/05/2012
72	SR 51 NB at Glendale Ave	x	x					08/21/2012
73	SR 51 NB at Greenway Rd	x	x					04/17/2012
74	SR 51 NB at Indian School Rd	x	x		x	x		3/29/2012 & 08/22/2012
75	SR 51 NB at Shea Blvd	x	x			x		03/29/2012
76	SR 51 SB at Bethany Home Rd	x	x	x		x		03/21/2012
77	SR 51 SB at Cactus Rd	x	x					03/21/2012
78	SR 51 SB at Northern Ave	x	x	x		x		3/21/2012 & 08/22/2012
79	SR 51 SB at Thomas Rd	x	x	x	x	x		3/21/2012 & 08/21/2012
80	SR 51 SB at Union Hills Dr	x	x					03/21/2012
81	US-60 EB at Dobson Rd	x	x					05/16/2012
82	US-60 EB at Mesa Dr	x	x					05/17/2012
83	US-60 EB at Rural Rd	x	x		x	x		5/16/2012 & 08/21/2012
84	US-60 EB at Val Vista Dr	x	x					05/17/2012

Table 1 Windshield Method Data Collection Sites								
ID	Location	Day 1		Day 2		Video	Radar	Count Dates
		AM	PM	AM	PM			
85	US-60 WB at Alma School Rd	x	x			x		05/17/2012
86	US-60 WB at McClintock Dr	x	x	x		x		5/16/2012 & 08/21/2012
87	US-60 EB at Power Rd	x	x			x		03/28/2012
88	US-60 WB at Power Rd	x	x					03/28/2012
89	US-60 WB at Stapley Dr	x	x			x		03/28/2012
90	US-60 WB at Val Vista Dr	x	x					03/28/2012
91*	7th St SB b/w Camelback Rd and Indian School Rd (Historical location)	x	x					08/16/2012
92*	Broadway Rd EB b/w Dobson Rd and Alma School Rd (Historical location)	x	x					08/14/2012
93*	Indian School Rd WB b/w 27th Ave and 35th Ave (Historical location)	x	x					8/15/2012 & 8/16/12
94*	Thomas Rd WB b/w 52nd St and 48th St (Historical location)	x	x					08/16/2012
101EB	Sky Harbor Blvd West EB at PHX	x	x	x	x			04/05/2012
101WB	Sky Harbor Blvd West WB at PHX	x	x	x	x			04/05/2012
102	Sky Harbor Blvd East (EB) at PHX	x	x	x	x			04/05/2012
103	Sky Harbor Blvd East (WB) at PHX	x	x	x	x			04/05/2012
104	Sossaman Rd (NB) at AZA	x	x					04/27/2012
105	Sossaman Rd (SB) at AZA	x	x					04/27/2012

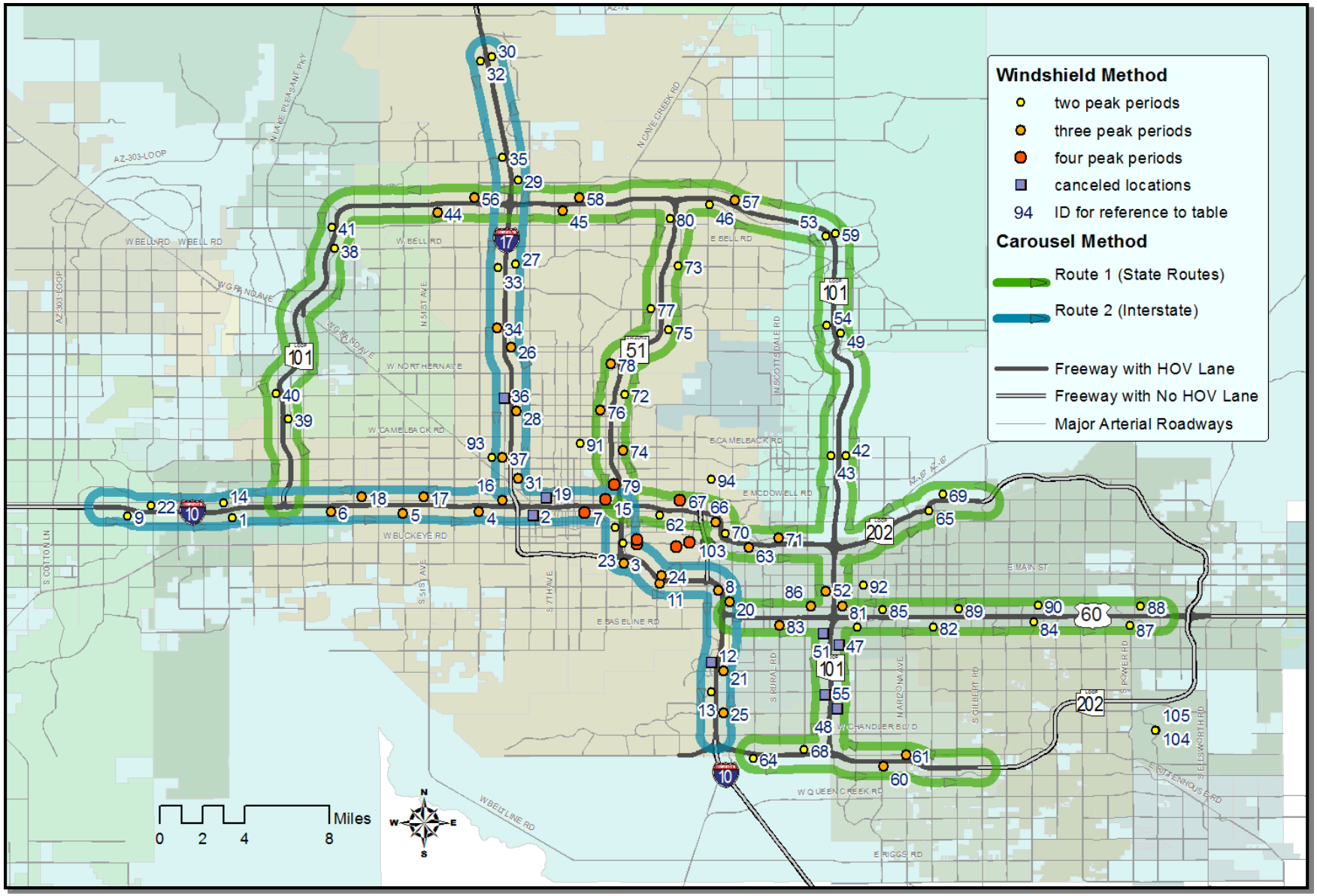
* Historic locations counted continuously from 6:00 AM to 7:00 PM
Source: MAG, CK and TRA September 2012

Two freeway and four arterial locations were selected for all day counts from 6:00 AM to 7:00 PM. MAG has historically collected vehicle occupancy data on these locations since the 1970s. Detailed data collection procedures for Carousel method are explained in Section 2.1.5.

Schedule

The data was collected on Tuesdays, Wednesdays or Thursdays only. Up to six Windshield method locations per day were deployed. Specific data collection dates for each Windshield method location are listed in **Table 1**.

Figure 1 Data Collection Locations and Routes



Equipment

Vehicle occupancy and classification data were collected using the hand-held JAMAR Technologies, Inc. electronic count boards, Model TDC8 and TDC ultra, shown in **Picture 1**. A total of 16 buttons are available for assignment. A template was created by TRA to assign one button for each of the 13 categories. The anticipated heavy volume categories were placed closer to the thumb for easy access while holding the equipment. The JAMAR board is programmed to beep every 15 minutes to signal the technician to switch lane.

Picture 1 – Jamar Board
Source: TRA, Inc.

2.1.5 Innovative Carousel Method

The Carousel vehicle occupancy data collection method delivers highly accurate occupancy data because of the increased observation time and the proximity to vehicles in adjacent lanes allowing for a very clear view. This method works specifically well in the case of observing large passenger vehicles and vehicles with tinted windows. It does not, however, work well in highly congested traffic condition where speeds in all lanes are significantly reduced. The Carousel method in this study was used as a supplement to the Windshield method. This method was designated for use on both freeway general purpose and HOV lanes during only the mid-day off-peak period from 9:00 AM to 3:00 PM. Additional occupancy and classification data for the HOV lane only were collected from 8:00 AM to 9:00 AM and from 3:00 PM to 4:00 PM, which could be compared to the Windshield method results. A GPS enabled touch-pad device was used, and this device can record vehicle occupancy with accurate coordinates of each data point.

The following actions were taken to improve accuracy and quality of the Carousel method data collection:

1. Route Design – The lengths of the two Carousel routes were designed such that they could be completely traversed during the time allocated to avoid partial runs in an individual data collection day.
2. Pilot Study – A pilot study was performed in advance of the scheduled collection dates and enhanced counting methods were developed and practiced based on the lessons learned through the pilot study.
3. Staff Training – Field technicians and vehicle drivers were required to participate in mandatory staff training in which comprehensive instructions in collecting vehicle occupancy and classification data were provided. In addition, each technician was provided a data collection guideline document as a quick reference to seek guidance in the field.
4. Role of Driver and Technician – To ensure safety, roles of the driver and technician were strictly separated. The driver was assigned only for driving the vehicle along the designated route with no input towards the data collection. The count technician likewise maintained focused on his responsibility in the data collection only.

5. Safety – Based on training feedbacks, a field safety checklist was prepared and provided to field staff.
6. Data Collection Equipment – A GPS enabled touch-pad was used for the Carousel method data collection. This device recorded accurate coordinates for each vehicle occupancy and classification data point.
7. Human Fatigue – Driver and field technician were restricted to work no more than 4 hours at a time.
8. Device Management and Data Download – Field equipment were routinely checked prior to commencement of data collection runs. Backup equipment was provided in the vehicle site in case the assigned equipment malfunctions. The data collected was downloaded and processed the next day after data collection.

Route and Schedule

Two routes were designed for the Carousel method. Route 1 covers 233 miles of regional freeway while Route 2 covers 112 miles of interstate freeway. The two routes for Carousel method are shown previously in **Figure 1**. A total of 10 days of data collection were conducted between 8:00 AM and 4:00 PM on the two routes. All data was collected on Tuesdays, Wednesdays or Thursdays when traffic volumes were likely to be highest. Summarized in **Table 2** are the dates and the number of times each route was traveled during the collection hours on each respective date.

Table 2 Carousel Method Runs

ID	Frequency		Count Dates
	Route 1	Route 2	
1	x		03/29/2012
2		x	04/04/2012
3	x		04/11/2012
4	x		04/17/2012
5		x	04/24/2012
6		x	05/03/2012
7	x		08/21/2012
8	x		08/28/2012
9	x		09/06/2012
10		x	09/11/2012

Source: CK September 2012

Equipment

CK developed a touch-pad application for the Carousel method. The touch pad is connected to a GPS unit placed on the vehicle's dashboard to log the latitude and longitude for each data point collected. In addition to the 13 categories, a "hybrid" category was introduced to account for single occupant vehicles in the HOV lane with a "Blue Sky" plate. The GPS enabled touchpad with Carousel application is shown in **Picture 2**. The data collected by the Carousel method can be easily processed to a Geo-database for in-depth analysis. A sample of Carousel method data in GIS format is shown in **Figure 2**.

2.1.6 Supplemental Traffic Data

The supplemental data included volume counts and average speeds extraction from ADOT FMS database, and collected using radar for locations where FMS data is not available. ADOT FMS detectors exist at or near 65 of the total Windshield method collection sites. Wavetronix Sidefire Radar units (SS105 and HD dual models) are set up for temporary traffic data collection at the remaining 17 sites. **Table 1** identifies the locations where radar unites where deployed. At these sites continuous 24-hour data from midnight to midnight was collected, where possible on the same date as the scheduled Windshield data collection. Traffic volume and speed data from FMS and radar were collected in 15-minute interval bins for each lane. Radar units were able to collect classification data for each lane in addition to the speed and volume data. Typical radar setup is shown in **Picture 3**.

Picture 3 - Wavetronix Sidefire Radar
Source: TRA, Inc.

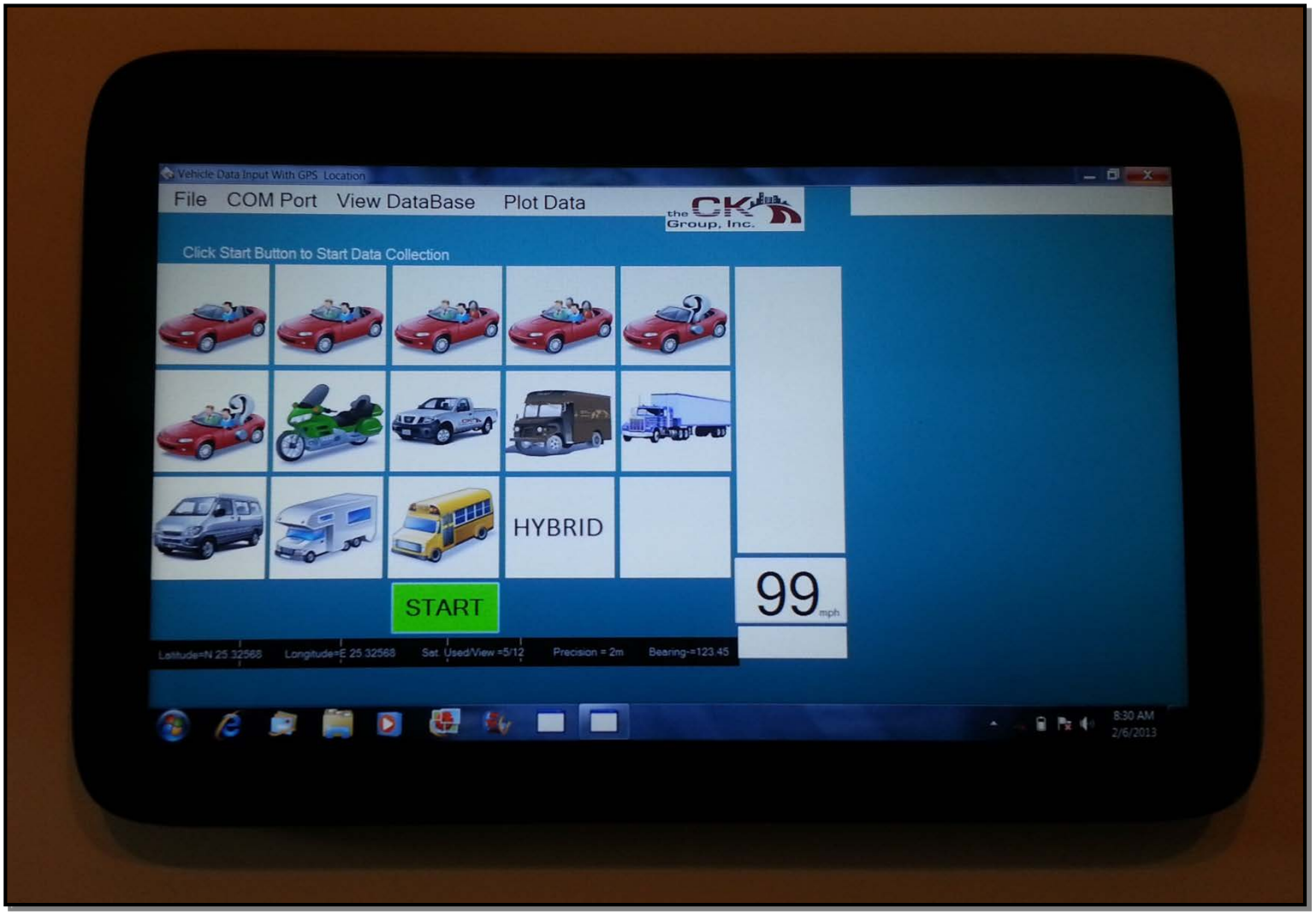
2.1.7 Site Review

Windshield data collection sites were jointly reviewed in the field by the study team and ADOT personnel to ensure that the proposed data collection sites were considered safe for data collection. Seven sites were eliminated from the study due to either safety concerns with non-adequate space for observers or poor access to observation locations. TRA and CK obtained blanket encroachment permits from ADOT to use state highway right-of-way within the Phoenix district.

2.2 Sample Rate and Confidence Interval

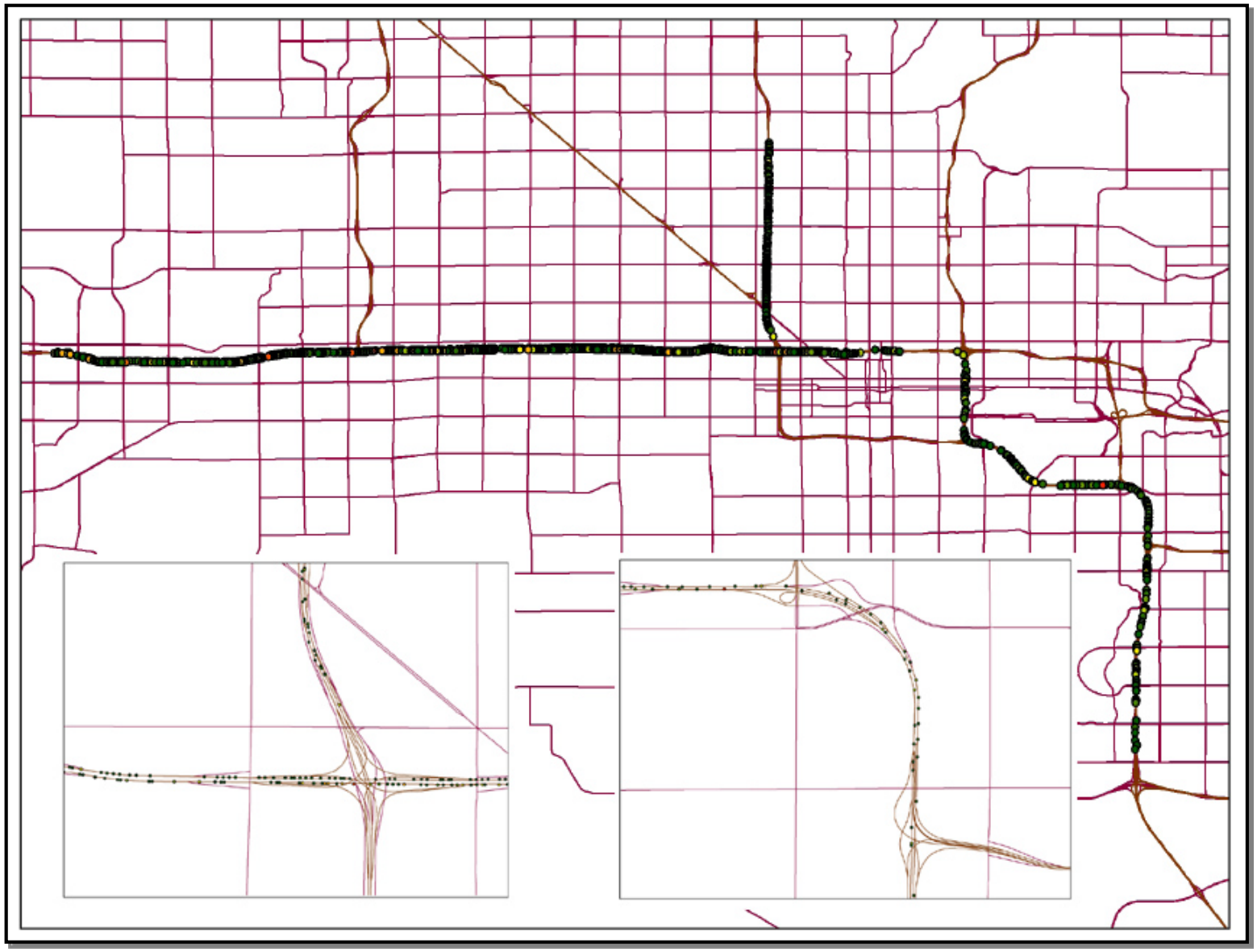
Sample size is critical to the precision of vehicle occupancy rates and other traffic parameters estimated from collected data. The desired level of precision has to be specified before the

Picture 2 GIS Enabled Touchpad with Carousel Application



Source: the CK Group, Inc.

Figure 2 Carousel Method Sample Data on GIS Map



sample size is determined. A common standard for vehicle occupancy estimation is a tolerance level of +/- 5% of the true occupancy with a 95% confidence level. The study design for this project planned to collect approximately 80% of HOV traffic and 40% of general purpose traffic. **Table 3** below identifies the target sample rates in this study for the Windshield method.

Table 3 Windshield Method Sample Rate Target

Lane Type	Estimated Sample Size	Estimated Traffic Volume	Sample Rate Target	Confidence Level	Confidence Interval (Margin of Error)
General Purpose	1,464,000	3,660,000	40%	99%	0.1%
HOV	424,000	530,000	80%	99%	0.1%
Total	1,888,000	4,190,000	45%	99%	0.1%

Source: MAG December, 2012

2.3 Quality Assurance /Quality Control Plan

The Quality Assurance/Quality Control (QA/QC) plan for this study was developed to ensure the highest possible quality of data collected. The QA/QC plan has the following two components. Field data QA refers to the measures, such as training and monitoring, taken prior and during data collection to ensure that field collection is performed as accurately as possible to minimize potential for errors. Data processing QC refers to the internal checks after the actual data collection during post processing to verify data outputs are correct and accurate.

2.3.1 Field Data Quality Assurance

Field data quality assurance was achieved through the following steps:

<u>Field Training</u>

a. MAG, CK and TRA supervisors – Pilot study/training March 13, 2012
b. TRA and CK field staff – Training either March 16, 2012 or March 19, 2012 and additional training during the study process on as needed basis

<u>Accurate Position of Observers</u>

Each observer was situated at the predetermined location behind a Jersey barrier, guard rail, and/or cement walls for safety. Each location had a count supervisor plus two or three count technicians depending on the number of lanes. Technicians and supervisors arrived 30 minutes before each count period. Each staff members wore a high-visibility vest, a hard hat and carried copies of the ADOT Phoenix Maintenance District Right-of-Way Encroachment Permit and a letter from MAG explaining the project.

Equipment Synchronization with Time of Day (TOD)

JAMAR counting boards (shown in Picture 1), video cameras, and radar units were set to automated cell phone time as directed by each field supervisor.

JAMAR Board Setup

JAMAR boards were programmed with the ID number of the count site provided on field sheets from information supplied by CK and MAG. Counting staffs were supplied with a map of the location and the times periods scheduled for data collection at each location. A template of classification bins was attached to each JAMAR board. Bin time intervals were programmed to 15-minute.

Data Collection

The HOV lane was always assigned to the supervising technician at each site. The JAMAR board dedicated to the HOV lane was clearly marked such that it could not be inadvertently mixed with the JAMAR boards used in the general purpose lanes. The remaining general purpose lanes were assigned to as much as three additional technicians depending on the number of lanes at that site. Technicians assigned to these lanes were each required to collect data from one or two general purpose lanes. Where two lanes were assigned, the technician was to shift every 15-minute from one lane to the other. During occasional technician breaks, the remaining technician(s) were required to include the additional general purpose lane(s) in the rotation every 15 minutes. At no time were individual technicians required to count more than one lane during a 15 minute interval. The time expended for a break varied due to the time it took to exit and return to the count location. If the supervisor assigned to the HOV lane required a break, one other technician took over the HOV designated JAMAR board and focused exclusively on the HOV lane until the missing technician returned. The supervisor at each site was ultimately responsible to make sure data was collected in the HOV lane at all times and that a single HOV counter board was used for HOV data only.

Backup JAMAR Units and Backup Personnel

The field supervisor had a back-up JAMAR board at each location to account for possible JAMAR board malfunctions or loss of battery power. Back-up staff were trained and made available, as needed.

Video Footage

Video data were recorded at select Windshield data collection sites as a validation and audit tool. The intent of the video data was intended to serve as a backup recording for the vehicle occupancy and classification counts. Locations where video data collection took place are shown in **Table 1**.

2.3.2 Data Processing Quality Control

The primary purpose of the data processing quality control was to identify data outliers to achieve consistency of data across equipment and observers. Field data collected by TRA during any given week was provided to CK by end of day Monday of the following week. CK processed the data required to perform the QC checks documented below and provide the charted comparisons and statistical checks to MAG by end of day Wednesday of the following week. Data processing quality control was achieved through the chartered comparisons and statistical checks as explained below:

Charted Comparisons

Charts were created for each site displaying each category of data collected in 15-minute intervals. Proportional variation in categories were compared over the data collection time period (same day) and over data collected over multiple days (at agreed upon select locations). Charts created for each site were compared with locations upstream and downstream to determine spatial variation.

Statistical Checks

For each set of processed data, summary statistics including mean, median, standard deviation, minimum/maximum, range and coefficient of variation across categories were computed for 15-minute intervals as well as hourly intervals.

2.4 Recount and Blue Sky License Plate Count

Based on the review of the draft data as part of the QC process, certain locations were identified for recount. Recount locations are identified in **Table 4**. The following were considered in defining recount scope:

1. Locations which had suspicious HOV violation rate or low sample rate;
2. Occupancy data for recount was collected only in the peak direction of travel, i.e., inbound direction during AM peak and outbound direction during PM peak;
3. Recounts were done only for HOV lanes; and
4. Recounts only covered the HOV hours i.e., 6:00 to 9:00 AM and 3:00 to 7:00 PM.

Table 4 Recount Locations			
Site	**Recount Location**	**AM Peak**	**PM Peak**
7	I-10 EB at 9th St (moved to 10th St)	x	x
15	I-10 WB at 16th St	x	
20	I-10 WB at Alameda Dr	x	
25	I-10 WB at North of Ray Rd	x	
26	I-17 NB at Dunlap Ave		x
39	Loop 101 (Agua Fria) NB at Bethany Home Rd	x	x
42	Loop 101 (Pima) NB at Indian School Rd	x	
45	Loop 101 EB at 7th Ave	x	
52	Loop 101 SB at Broadway Rd		x
57	Loop 101 WB at 56th St		x
58	Loop 101 WB at 7th St		x
60	Loop 202 (Santan) EB at Alma School Rd		x
61	Loop 202 (Santan)WB at Arizona Ave	x	
62	Loop 202 EB at 32nd St		x
74	SR 51 NB at Indian School Rd		x
75	SR 51 NB at Shea Blvd		x
76	SR 51 SB at Bethany Home Rd	x	
85	US-60 WB at Alma School Rd	x	
89	US-60 WB at Stapley Dr	x	
Source: MAG, CK			September, 2012

Arizona's "Blue Sky" program is designed to allow 10,000 hybrid or alternative fuel vehicles to use the HOV lanes during peak travel times without occupancy restrictions in Arizona. Because the observers were not in position to view the rear license plate of vehicles during the Windshield data collection, the data collected with this method on HOV lane did not reflect the actual number of "Blue Sky" license plate vehicles. To capture the actual HOV usage of "Blue Sky" vehicle during HOV hours, it was necessary to collect "Blue Sky" vehicle counts on the HOV systems. Eight representative HOV locations are selected to collect "Blue Sky" vehicle counts. Blue Sky plate count locations are identified in **Table 5**. The following were considered in defining "Blue Sky" vehicle counting locations and scope:

1. Locations needed to allow for traffic volume along with "Blue Sky" license plate vehicle needed to be counted by observing the vehicles from behind;
2. Data was collected only in the peak direction of travel, i.e., inbound direction during AM peak and outbound direction during PM peak;
3. One location per freeway corridor was selected for counts; and
4. Counts only covered the HOV hours i.e., 6:00 AM to 9:00 AM and 3:00 AM to 7:00 PM.

Table 5 Blue Sky Plate Vehicle Count Location		
Blue Sky Plate Vehicle Count Location	**AM Peak**	**PM Peak**
SR 51 SB at Bethany Home Rd	x	
I-10 EB at 43rd Ave	x	
I-10 WB at Warner Rd	x	
I-17 NB at Maryland Ave		x
SR-51 NB at Campbell Ave		x
Loop 101/Price SB at Broadway Rd		x
US 60 EB at College Ave		x
I-10 EB at 32nd St		x
Source: MAG, CK		September, 2012

3 CHALLENGES AND LESSONS

This chapter summarizes the methodological findings and pros and cons for both the Windshield and Carousel methods. These findings are based on the pilot studies, extensive field data collection, the issues arising during the data collection and the resolution of these issues. These findings should especially be of value for future vehicle occupancy studies and could result in improved efficiency in conducting similar studies.

3.1 Pilot Studies

Individual pilot studies were conducted for the Windshield and Carousel methods to identify issues with the proposed data collection procedures. Documented here are findings learned in each of the pilot studies relevant to the safe and effective collection of vehicle occupancy and classification data.

3.1.1 Windshield Method

The Windshield method pilot study was conducted by MAG, TRA, and CK staff on Tuesday, March 13th between 7:45 AM to 9:15 AM. State Route 51 (SR-51) at Northern Avenue (site ID 78 was selected for the pilot study. The site has a concrete barrier and adequate space for the pilot study team (11 members) to stand and collect the sample occupancy and classification data.

The following are the findings of the pilot study:

1. Technicians counting general purpose lane traffic should be assigned to count occupancy and classification for up to two lanes only. Technicians counting more than one lane of traffic were to rotate every 15 minutes from one lane to the next (and back) such that the technician's focus was never on more than one lane of traffic at a time. Technicians were to adhere to the 15-minute rotation as closely as possible, and were not in any case to intentionally wait to switch if, for example, they missed the transfer time (they should rotate anyway).

2. While conducting the occupancy count, the technicians should try to follow each vehicle for a time that is long enough to be certain about the number of occupants. An "unknown" count (category 5) or "unknown 2+" (category 6) should be made only after careful observation. The technicians should not purposely miss a vehicle due to the difficulty to count and should not count it as "unknown" without spending time to observe. No button (including "unknown") should be pressed until the technicians spent sufficient time to effectively observe.

3. HOV lane data collection was in many cases much more difficult due to the increased distance and interrupting lanes of traffic between the observation locations on the side of the road to the HOV lane. Under the direction of the site supervising technicians assigned to the HOV lane, technicians should in some cases be allowed to switch counter boards and assignments with general purpose lane technicians to balance the difficulty of the data collection between technicians. Actual counter boards MUST remain on the designated HOV or general purpose lanes.

4. Each counter board should be assigned to a specific lane, i.e., HOV, inner general purpose lanes, shoulder general purpose lanes, etc. Each counter board should be clearly marked and identified throughout the data collection such that counter boards are in no cases mixed. Under no circumstance should an HOV board be used on general purpose lanes or vice versa.

5. HOV lane traffic is the most important to this study and should be counted in all circumstances. The counter board assigned to the HOV lane should always be in use even in the case of a personnel disruption with the technician assigned to the HOV lane by moving a technician from one of the general purpose lanes.

6. Bathroom breaks or other personnel emergencies:
   a. The field supervisor should make a note on the comment sheet identifying what, when, and why a break was taken.
   b. Personal emergencies requiring a break should begin (where possible) after completing the current15 minute counting interval.
   c. Technicians are to resume counting as soon as possible after returning from a break at any point within a 15-minute bin.
   d. If unforeseen emergency requires counting at a location to start without all scheduled technicians, the HOV lane will be prioritized above general purpose lanes. general purpose lanes should be distributed only to technicians not needed on the HOV lane until a back-up technician arrives.

7. Under high-volume traffic conditions, visibility or other factors may make it unreasonably difficult to capture accurate occupancy rates for all vehicles. The technicians should use the following steps to collect the occupancy data:
   a. When traffic condition gets to a point that a technician cannot follow each vehicle, he/she should try to count the next available vehicle without purposely missing any difficult ones (see item 2 above).
   b. It is important that the technicians be consistent and systematic in the way vehicles are ignored or counted.
   c. In no way should the skipping of vehicles be dependent on the difficulty of seeing through windows or any other characteristic of the individual vehicle.
   d. At the end of such a 15-min interval, the technician should write down a note, e.g., impossible to count every vehicle due to traffic condition occurred.

8. Camera set up: Backup cameras should be set up to point at an angle in the direction of oncoming traffic such that the vehicle occupants are most completely visible.

9. The supervisor should log and describe in detail all traffic related incidents occurred during the data collection period as well as start/end times of incidents.

10. Should severe weather conditions occur during the counting, such as thunderstorm/sand storm/gust, or anything potentially affecting the technician's safety, the technician may withdraw/pause the data collection and resume it once the weather returns to workable conditions. The supervisor should take notes to describe the incident and the break interval.

3.1.2 Carousel Method

A pilot study for the Carousel method was conducted by MAG and CK staff on Thursday, March 15th between 2:00 PM to 4:00 PM. The GPS enabled touch-pad application was used to collect data for the pilot study. The data were collected along the following freeway segments during the pilot study:

1. I-10 westbound from 7th Avenue to Estrella Parkway;
2. I-10 eastbound from Estrella Parkway to Chandler Boulevard;
3. I-10 westbound from Chandler Boulevard to I-17;
4. I-17 northbound from I-10 to Northern Avenue; and
5. I-17 southbound from Northern Avenue to I-10.

The following are the findings of the pilot study:

1. Safety is extremely critical during this dynamic data collection method. The speed differential between the survey vehicle and the observed vehicles in the traffic stream must not trigger unsafe lane change maneuvers by the vehicles following the survey vehicle. The following steps must be taken to ensure safety:
   a. The driver must strictly obey safe driving practices and not get involved in or assist the observer with data collection.

   <u>During HOV Hours (8:00 AM - 9:00 AM and 3:00 AM - 4:00 PM)</u>

   b. The driver should drive no more than 15 miles per hour (mph) slower than the prevailing speed in the general purpose lanes. This may mean driving at speeds greater than 45 MPH on a 60 mph freeway segment.
   c. By default, the driver should not drive in the lane adjacent to the HOV lane. Under non-congested traffic conditions, drive in two lanes over from the HOV lane. The driver should drive in the lane adjacent to the HOV only when there is significant congestion in all the general purpose lanes.
   d. Double counting of vehicles in the HOV lane should be avoided. In situations where HOV travel speeds become slower or equal to that in general purpose lanes, counting the same vehicle more than once may be permissible where at least one mile of travel has taken place between counting occurrences on a single observed vehicle. This would allow individual vehicles to contribute to a representative sample of occupancy and classification characteristics both temporally and spatially.

   <u>During non-HOV hours (9:00 AM - 3:00 PM)</u>

   e. By default, the driver should drive in the right-most lane adjacent to the shoulder. If congestion occurs on all other lanes such that the survey vehicle passes other vehicles, then counting should be stopped. Double counting must be avoided at all times. Counting will be resumed outside the influence area of the local congestion.

2. While moving from one freeway to the other freeway through a system interchange (such as the stack or mini-stack), stop counting when the vehicle occupants on the mainline can no longer be identified. Do not count vehicle occupants on the multilane ramps.

3. In the case of a freeway closure due to an accident, the data collection will be discontinued. The supervisor will record the number of affected lanes and the severity of backup, and the CK Project Manager should report the incident to MAG Project Manager.

4. Motion sickness for the observer in the survey vehicle is likely to occur. The following are the ways that can help minimize potential for motion sickness.
   a. Alternate data collection between two people in the survey vehicle every hour or earlier, as needed.
   b. A mandatory 15-min break from 12:00 PM to 12:15 PM should be taken.
   c. Use of chewing gum or a light snack is known to help motion sickness.
   d. Use of over-the-counter motion sickness medicine may additionally help.

5. Additional Housekeeping items learned:
   a. The power inverter (12 volts DC to 120 volts AC) and cords must be carried in the survey vehicle to allow for uninterrupted use of the touch-pad application. A fully charged touch-pad should last for approximately three hours of data collection.
   b. The person with the touch-pad should be on the front seat looking back.
   c. If there are unforeseen breaks, a note should be made on the comment sheet identifying what, when, and why the break was taken.

6. Vehicle classifications and occupancy counts during the Carousel method should follow and be consistent with the designations defined for the Windshield method.

3.2 Pros and Cons of the Windshield and Carousel Methods

3.2.1 Windshield Method

Windshield method was the focus of the MAG 2012 VOS. The Windshield data was collected at 100 observation sites on one or two days. In addition, there were 21 recount locations. While strict QA and QC procedures were implemented during data collection and post data processing, there were certain occurrences throughout the project that impeded the progress. Pros and cons for the Windshield method are summarized below:

<u>Pros for the Windshield Method</u>

1. Complete coverage – provides a comprehensive temporal and spatial coverage on the freeway system.
2. Safety – allows identifying safe sites adequate for data collection and flushing out the unsafe sites through upfront investigative efforts.
3. Lane specific data – allows collecting occupancy data by the lane by assigning individual observers to each lane.
4. Minimum equipment requirement – no major equipment needed for data collection.
5. Observation period – Can be used during both peak and non-peak hours. More effective when traffic is at lower speeds.

<u>Cons for the Windshield Method</u>

1. Labor intensive – hiring a large number of reliable field technicians is critical to the success of data collection.
2. Extensive training – requires extensive training to staff to ensure minimum variation on observation pattern between different observers.
3. Observation time limitation – at high traffic speeds and/or high volumes there may be too little time to observe occupancy for all vehicles.
4. Excessive observation distance – observation positions off the roadway may at times be far enough that excessive distance between vehicle and observer may impede capability to accurately identify all vehicle occupants, particularly at higher speeds and in the HOV lane.
5. Conspicuous to travelling public – field staff and equipment can at times be highly visible to travelling public, may trigger inquisitive phone calls and comments on social media.
6. Weather exposure – field technicians may be directly exposed to uncomfortable weather conditions (excessive heat in the case of the MAG region) which could be fairly intrusive to human health as well as data quality.
7. Potential compliance violations – field data QA and safety procedures are difficult to enforce, require continuous patrolling to ensure compliance which could be difficult under a tight budget.
8. "Blue Sky Plate" – High speeds and excessive viewing distance makes it difficult to count vehicles with a Blue Sky Plate.

3.2.2 Carousel Method

The Carousel method in this study was used as a supplement to the Windshield method. The GPS enabled touch-pad device allowed recording of vehicle occupancy with accurate coordinates for each observation. Pros and cons for the Carousel method are summarized below:

<u>Pros for the Carousel Method</u>

1. Efficient coverage – provides efficient coverage of the study corridors, one vehicle with a driver and an observer covers up to 400 miles in a given day.
2. Safety – allows the driver and observer safely navigate the travel route inside a survey vehicle.
3. Observation position – the close proximity and position of the observer technician in the survey vehicle to passing vehicles under observation allows difficult to see passengers and children to be more easily counted.
4. Inconspicuous to travelling public – observer technician inside the survey vehicle is unrecognizable to adjacent traffic, thus does not generate attention potentially disruptive to traffic.
5. Compliance – two people in the same vehicle holds provide oversight with one another and allows easy compliance to the field data QA and safety procedures.
6. "Blue Sky" Plate Counts – the vehicles with a Blue Sky Plate in general purpose or HOV lanes can be easily identified.
7. Observation period – Can be used effectively during non-peak hours. It can also be used for data collection of HOV traffic lanes during peak hours if the HOV lanes are travelling faster compared to general purpose lanes (observed in MAG region).

Cons for the Carousel Method

1. Fewer vehicles observed – the average number of samples collected by the Carousel method is significantly lower than what the Windshield method can collect.
2. Observation period – this method cannot be used effectively during peak hours in some congested locations where the observation vehicle cannot reasonably go slower than adjacent traffic. Significant traffic congestion may lead to the same vehicles being counted multiple times.
3. Motion sickness – the observer in the survey vehicle may experience motion sickness while conducting standard Carousel data collection.

3.3 Data Collection Sites

Windshield data collection sites were jointly field reviewed by the study team and ADOT personnel to identify and approve specific observation sites that were considered safe for data collection and met the ADOT clear zone requirements. **Table 6** identifies exact locations of the 82 selected data collection sites with latitude and longitude information of where observers were positioned and the data collected. This location information is intended to be useful for future vehicle occupancy studies where specific data collection sites have been approved previously by ADOT.

Table 6 Windshield Method Data Collection Site Exact Locations

ID	Location	Actual Site Position		
		Latitude	Longitude	Description
1	I-10 EB at 115th Ave	33.459079	-112.305357	Along eastbound on-ramp at least 30' from shoulder
2	I-10 EB at 18th Ave	Site cancelled by ADOT due to safety reasons		
3	I-10 EB at 24th St	33.427761	-112.036553	Under I-17 bridge, behind jersey barrier
4	I-10 EB at 34th Ave	33.463302	-112.134053	200 yards from 35th Ave bridge along the on-ramp
5	I-10 EB at 58th Ave	33.462436	-112.185387	East of 59th Ave near the on-ramp, at least 30 feet away from shoulder, uphill
6	I-10 EB at 81st Ave	33.462675	-112.2369528	100 yards east of 83rd Ave ramp, at least 30' from shoulder
7	I-10 EB at 7th St	33.461694	-112.063862	East of 7th St, near the on-ramp, at least 30 feet away from shoulder, uphill
8	I-10 EB at Broadway Rd	33.405425	-111.969558	I-10 EB on-ramp, at least 30' from shoulder
9	I-10 EB at Bullard Ave	33.459175	-112.3729778	Along eastbound on-ramp at least 30' from shoulder
10	I-10 EB at Jefferson St	33.44685	-112.0376806	South of Jefferson St, behind metal guard rail
11	I-10 EB at University Dr	33.411328	-112.009703	South of University Dr, between on-ramp and freeway, at least 30 feet away from shoulder, uphill
12	I-10 EB at South of Guadalupe Rd	Site cancelled by ADOT due to safety reasons		
13	I-10 EB at South of Warner Rd	33.333786	-111.972680	South of Warner Rd, west side of freeway, at least 30' from shoulder

Table 6 Windshield Method Data Collection Site Exact Locations				
ID	**Location**	**Actual Site Position**		
		Latitude	**Longitude**	**Description**
14	I-10 WB at 115th Ave	33.459615	-112.306991	Westbound on-ramp from 115th Ave behind barrier
15	I-10 WB at 16th St	33.462422	-112.048678	East of 16th St, between on-ramp and freeway, at least 30 feet from the shoulder, uphill
16	I-10 WB at 27th Ave	33.462309	112.118149	Top of 27th Ave on-ramp behind steel barrier
17	I-10 WB at 51st Ave	33.463333	-112.169722	Approximately 100 feet west of 51st Ave Bridge, outside clear zone
18	I-10 WB at 75th Ave	33.46305	-112.220186	Just east of 77th St off-ramp at least 30 feet from the shoulder uphill under trees
19	I-10 WB at 7th Ave	Site cancelled by ADOT due to safety reasons		
20	I-10 WB at Alameda Dr	33.396246	-111.967034	North of I-10/US 60 merge at exit sign, at least 30 feet from shoulder behind jersey barrier
21	I-10 WB at Elliot Rd	33.349850	-111.971440	Approximately 200 feet north of Elliot Rd bridge, at least 30 feet from shoulder, uphill
22	I-10 WB at Litchfield Rd	33.4582556	-112.3596389	Approximately 400 feet west of Litchfield Road, at least 30 feet from shoulder, behind barrier
23	I-10 WB at Buckeye Rd	33.4362778	-112.0372306	Approximately 100 feet south of Buckeye Rd Bridge structure behind guardrail
24	I-10 WB at University Dr	33.412594	-112.010936	West of University Dr between on-ramp and freeway, at least 30 feet away from the shoulder
25	I-10 WB at North of Ray Rd	33.320781	-111.971853	Approximately 250 feet north side of Ray Rd bridge between on-ramp and freeway
26	I-17 NB at Dunlap Ave	33.567387	112.117222	West of frontage road on overpass behind fence
27	I-17 NB at Greenway Pkwy	33.6263111	-112.1163111	Approximately 330 feet north of Greenway Rd bridge, behind guard rail
28	I-17 NB at Bethany Home Rd	33.525503	-112.112072	Along on-ramp, 500 yards from Bethany Home Rd bridge
29	I-17 NB at Deer Valley Rd	33.68517	-112.112083	Northbound off-ramp from Greenfield Rd near barricade
30	I-17 NB at North of SR 303	33.7698278	-112.1290917	Approximately 50 feet north of NB Frontage Rd off-ramp
31	I-17 NB at Thomas Rd	33.480327	112.112751	Along Thomas Rd off-ramp at the top of incline
32	I-17 SB at South of SR 303	33.767859	-112.129696	Southbound off-ramp from SR 303 near barricade, at least 30 feet from shoulder
33	I-17 SB at Greenway Pkwy	33.624722	-112.116945	Approximately 150 feet south of Greenway Rd bridge behind guardrail
34	I-17 SB at Peoria Ave	33.5828972	-112.1167056	West of frontage road, more than 30' behind guard rail
35	I-17 SB at Pinnacle Peak Rd	33.7001861	-112.1150389	Along the freeway, approximately 130 feet from bridge behind barrier
36	I-17 SB at Glendale Ave	Site cancelled by ADOT due to safety reasons		
37	I-17 SB at Indian School Rd	33.494167	-112.113333	Approximately 225 feet south of Indian School Rd, behind chain link fence

Table 6 Windshield Method Data Collection Site Exact Locations				
ID	Location	Actual Site Position		
		Latitude	Longitude	Description
38	Loop 101 (Agua Fria) NB at Bell Rd	33.6399083	-112.2365944	Along northbound on-ramp near guardrail
39	Loop 101 (Agua Fria) NB at Bethany Home Rd	33.521536	-112.268760	Along northbound off-ramp, behind barrier
40	Loop 101 (Agua Fria) SB at Glendale Ave	33.5387306	-112.2700528	Along southbound off-ramp from Glendale Ave, behind barrier
41	Loop 101 (Agua Fria) SB at Union Hills Dr	33.6514111	-112.2326861	Along southbound off-ramp at least 30 feet from shoulder
42	Loop 101 (Pima) NB at Indian School Rd	33.496499	-111.887583	Along northbound on-ramp at least 30' from shoulder
43	Loop 101 (Pima) SB at Indian School Rd	33.4968000	-111.8881861	Along southbound off-ramp at least 30' from off-ramp, behind barrier
44	Loop 101 EB at 51st Ave	33.6691222	-112.1599056	Along frontage road approximately 240 feet east of 47th Ave, behind fence
45	Loop 101 EB at 7th Ave	33.668254	-112.081761	30 feet back on east side of 7th Ave off-ramp
46	Loop 101 EB at Tatum Blvd	33.672248	-111.970996	After on-ramp behind jersey barrier at drainage culvert
47	Loop 101 NB at Guadalupe Rd	Site cancelled by ADOT due to safety reasons		
48	Loop 101 NB at Ray Rd	Site cancelled by ADOT due to safety reasons		
49	Loop 101 NB at Shea Blvd	33.58582	-111.891086	Northbound on-ramp from Shea Blvd at least 30' from shoulder
50	Loop 101 NB at Southern Ave	33.388888	-111.890833	Approximately 650 feet south of NB Frontage Rd/Pebble Beach Dr intersection, behind concrete barrier
51	Loop 101 SB at Baseline Rd	Site cancelled by ADOT due to safety reasons		
52	Loop 101 SB at Broadway Rd	33.405543	-111.891718	On-ramp from Broadway to SR 101 SB, 70 feet from white line
53	Loop 101 SB at Princess Dr	33.647637	-111.894425	Southbound off-ramp from Princess Dr at least 30' from shoulder
54	Loop 101 SB at Shea Blvd	33.585455	-111.891882	Southbound off-ramp from Shea Blvd at least 30' from shoulder
55	Loop 101 SB at Warner Rd	Site cancelled by ADOT due to safety reasons		
56	Loop 101 WB at 35th Ave	33.668306	-111.960394	Approx. 285 feet east of 35th Ave WB on-ramp behind concrete barrier
57	Loop 101 WB at 56th St	33.669247	-112.067113	West of 56th St overpass, behind jersey barrier
58	Loop 101 WB at 7th St	33.669119	-112.069930	Approx. 704 feet east of 7th St WB on-ramp behind concrete barrier
59	Loop 101 WB at Princess Dr	33.286978	-111.856869	Approximately 240 feet north of Princess Dr underpass bridge structure
60	Loop 202 (Santan) EB at Alma School Rd	33.287562	-111.843261	On-ramp from Alma School Rd to SR202 EB top of ramp, 45' from white line
61	Loop 202 (Santan)WB at Arizona Ave	33.460187	-112.010046	On-ramp from Arizona Ave to SR 202 WB, top of hill behind cement barrier
62	Loop 202 EB at 32nd St	33.435833	-111.950372	East of 32nd St behind jersey barrier at the top of the on-ramp

Table 6 Windshield Method Data Collection Site Exact Locations				
ID	Location	Actual Site Position		
		Latitude	Longitude	Description
63	Loop 202 EB at Center Pkwy	33.291926	-111.94614	West of Center St on the on-ramp behind the jersey barrier
64	Loop 202 (Santan) EB at Kyrene Rd	33.456615	-111.836781	On hillside 75' behind white line
65	Loop 202 EB at Mesa Dr	33.450192	-111.969203	EB on-ramp east side of Country Club Dr, at least 30' from shoulder
66	Loop 202 EB at Sky Harbor Blvd	33.459503	-111.996425	West of Van Buren on-ramp to SR 202, behind jersey barrier
67	Loop 202 WB at 40th St	33.292028	-111.912038	East of 40th St behind guard rail at the top of the ramp
68	Loop 202 WB at McClintock Dr	33.466146	-111.816237	WB on-ramp from McClintock Dr, at least 30' from shoulder
69	Loop 202 WB at Mesa Dr	33.44	-111.966667	WB off-ramp east of Gilbert Rd toward Mesa Dr
70	Loop 202 WB at Priest Dr	33.436069	-111.930419	Approximately 200 feet east of Priest Dr on-ramp concrete gore behind concrete barrier
71	Loop 202 WB at Scottsdale Rd	33.539	-112.04127	Behind barrier between WB on-ramp and SR202
72	SR 51 NB at Glendale Ave	33.626944	-112.006111	Below surface street next to Glendale NB bridge, high barrier wall on on-ramp
73	SR 51 NB at Greenway Rd	33.496564	-112.043563	Approximately 150 feet north of Greenway Rd bridge outside clear zone
74	SR 51 NB at Indian School Rd	33.581487	-112.009626	Approximately 285 feet north of NB Indian School Rd on-ramp concrete gore, behind concrete barrier
75	SR 51 NB at Shea Blvd	33.52548	-112.043826	NB off-ramp from Shea Blvd at least 30 feet from shoulder
76	SR 51 SB at Bethany Home Rd	33.596001	-112.009921	Approximately 185 feet north of Bethany Home Rd SB off-ramp, behind guardrail
77	SR 51 SB at Cactus Rd	33.55922	-112.03851	SB on-ramp from Cactus Rd at least 30' from shoulder
78	SR 51 SB at Northern Ave	33.467325	-112.038435	Above surface street hillside to SR51 at Northern Ave SB at off-ramp
79	SR 51 SB at Thomas Rd	33.65713	-112.000331	Behind fencing at off-ramp SB to McDowell Rd
80	SR 51 SB at Union Hills Dr	33.385555	-111.874167	Southbound off-ramp from Union Hills Dr at least 30 feet from shoulder
81	US-60 EB at Dobson Rd	33.385833	-111.822377	Approximately 90 feet east of Dobson Rd bridge structure behind handrail
82	US-60 EB at Mesa Dr	33.385291	-111.926243	Under bridge at Mesa Dr, behind cement barrier and metal pole railing
83	US-60 EB at Rural Rd	33.386111	-111.753889	Under bridge, where Rural Rd crosses US 60, behind cement barrier and metal pole railing
84	US-60 EB at Val Vista Dr	33.386158	-111.8584	Underneath the Val Vista Dr bridge structure behind concrete barrier
85	US-60 WB at Alma School Rd	33.385978	-111.909928	West of Alma School Rd on the incline of the on ramp behind the jersey barrier

Table 6 Windshield Method Data Collection Site Exact Locations				
ID	Location	Actual Site Position		
		Latitude	Longitude	Description
86	US-60 WB at McClintock Dr	33.386352	-111.6864	West of McClintock Dr on the incline of the on ramp behind the jersey barrier
87	US-60 EB at Power Rd	33.386799	-111.683602	Eastbound off-ramp from Power Rd at least 30 feet from shoulder (barricade)
88	US-60 WB at Power Rd	33.386389	-111.807777	WB off-ramp from Power Rd, at least 30 feet from shoulder (barricade)
89	US-60 WB at Stapley Dr	33.386724	-111.756213	Approximately 335 feet east of WB Stapley Dr. on-ramp behind concrete barrier
90	US-60 WB at Val Vista Dr	33.50508	-112.06502	Westbound off-ramp from Val Vista Dr at least 30 feet from shoulder (barricade)
91	7th St SB b/w Camelback Rd and Indian School Rd	33.407447	-111.870903	1,000 feet south of Camelback Rd
92	Broadway Rd EB b/w Dobson Rd and Alma School Rd	33.49495	-112.12563	Approximately 1,100 feet' west of Dobson Rd, in a driveway on south side of Broadway Rd
93	Indian School Rd WB b/w 27th Ave and 35th Ave	33.48009	-111.97507	West of 28th Ave, at the end of the frontage road, on north side of Indian School Rd
94	Thomas Rd WB b/w 52nd St and 48th St	33.43729	-112.026111	In front of Phoenix Flower Shop.
101EB	Sky Harbor West (EB)	33.437642	-112.025754	Sky Harbor Blvd, west end
101WB	Sky Harbor West (WB)	33.436097	-111.988009	Sky Harbor Blvd, west end
102	Sky Harbor East (EB)	33.434871	-111.989849	Sky Harbor Blvd, east side
103	Sky Harbor East (WB)	33.308311	-111.669942	Sky Harbor Blvd, east side (EB) west of 44th St
104	Sossaman Rd (NB)	33.308318	-111.670312	Sossaman Rd and Texas Ave (NB), 200 feet north of intersection
105	Sossaman Rd (SB)	33.405543	-111.891718	Sossaman Rd & Texas Ave (SB), 200 feet north of intersection
Source: MAG, CK, TRA				December, 2012

4 SUMMARY OF RESULTS

This chapter presents some of the key findings from this VOS. Shown are the average vehicle occupancy rates by peak period and time of day, the distribution of vehicle types, performance of HOV lanes, including HOV violation rates, and the statistical confidence that can be had in this data. The vehicle occupancy trend since 1970 is also shown from select locations.

4.1 Auto Occupancy

4.1.1 Freeway and Arterial Auto Occupancy Rates

Auto occupancy rates measure the average number of persons per auto vehicle. This number will vary by facility type and by time of day. Occupancy rates provide a way to convert person trips to vehicle trips for regional planning. **Figure 3** represents the overall average freeway auto occupancies from 6:00 AM to 9:00 AM summarized from the 82 studied locations using roadside Windshield method (chart shows the beginning time for each 30-min designation). Traffic volume data from ADOT Freeway Management System (FMS) detectors for these studied locations are applied as weight factors to compute the average auto occupancies. As illustrated, auto occupancy rate in the morning starts from a low point and reaches to the peak at 7:00 AM.

Figure 3 Freeway AM Average Auto Occupancy

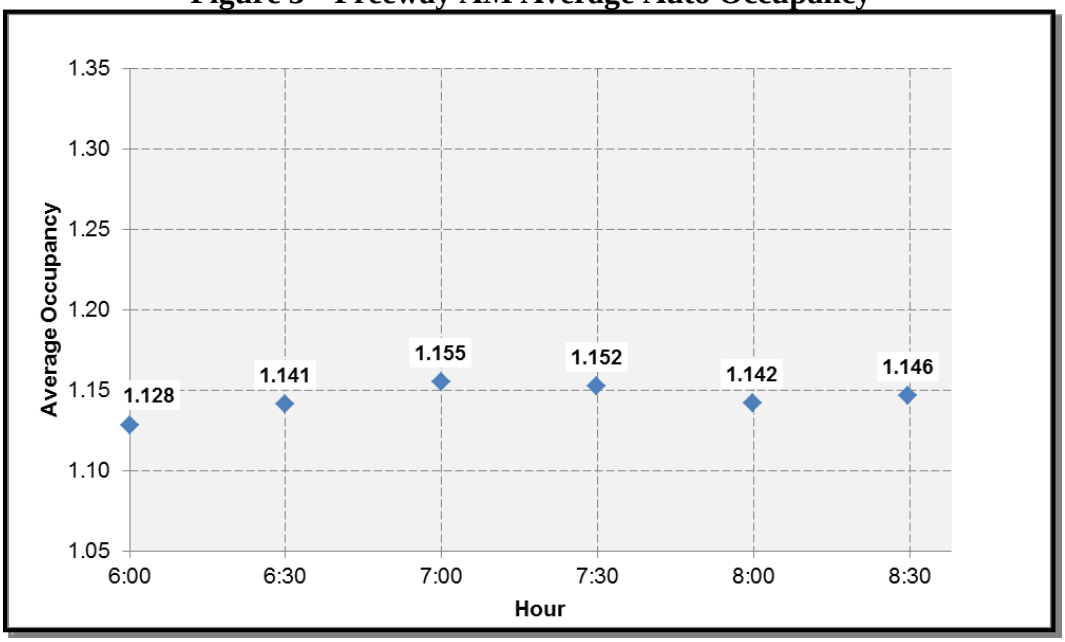


Figure 4 demonstrates higher auto occupancy rates in the PM peak period than the rates in the AM peak, because of the higher composition of non-commute trips in the traffic during PM. It is noticed that the lower occupancy rate period occurs from 4:30 PM to 5:30 PM which matches the peak of commute trip travel.

Figure 5 presents freeway auto occupancy by time for the day by incorporating results obtained from both the Windshield method (for AM and PM peak periods) and Carousel method (for

midday time periods). The results show that the average auto occupancy rates are higher in the midday than in the peak periods. This may be due to higher proportion of non-commute travel trips which tend to have higher occupancy rates. It is also worth noting that Carousel method is expected to yield more reliable occupancy counts than the Windshield method which could partially account for higher occupancy rates during the midday.

Figure 4 Freeway PM Average Auto Occupancy

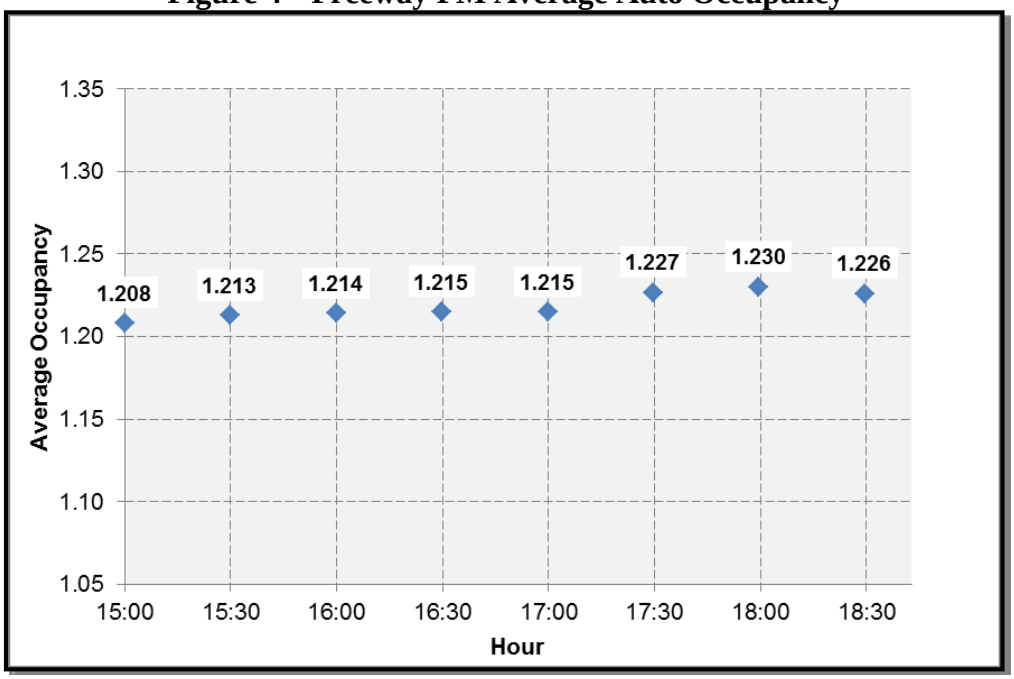


Figure 5 Freeway Auto Occupancy by Time of Day

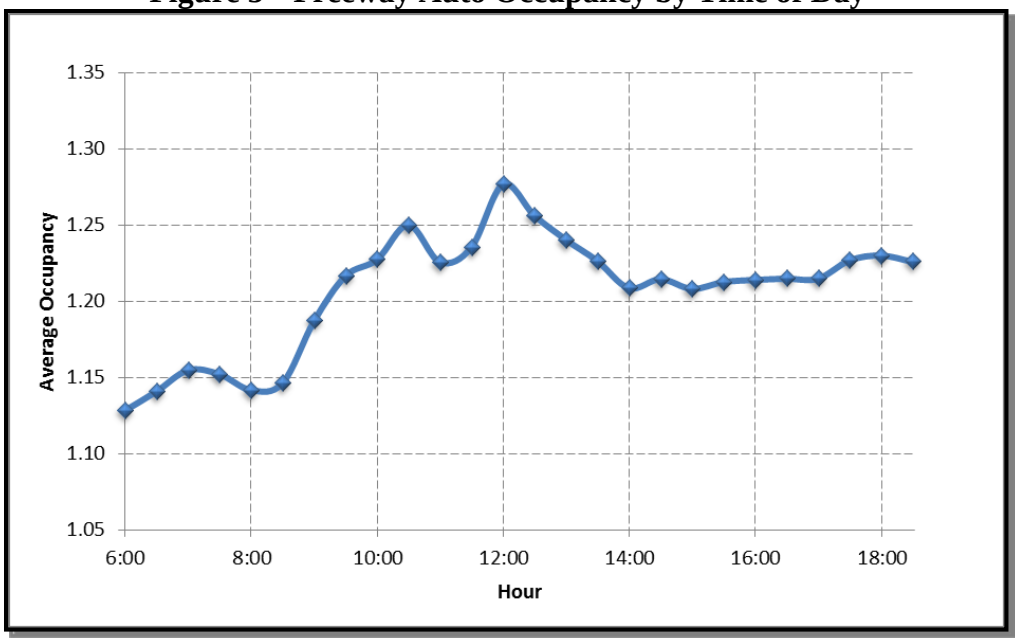


Figure 6 Arterial Auto Occupancy by Time of Day

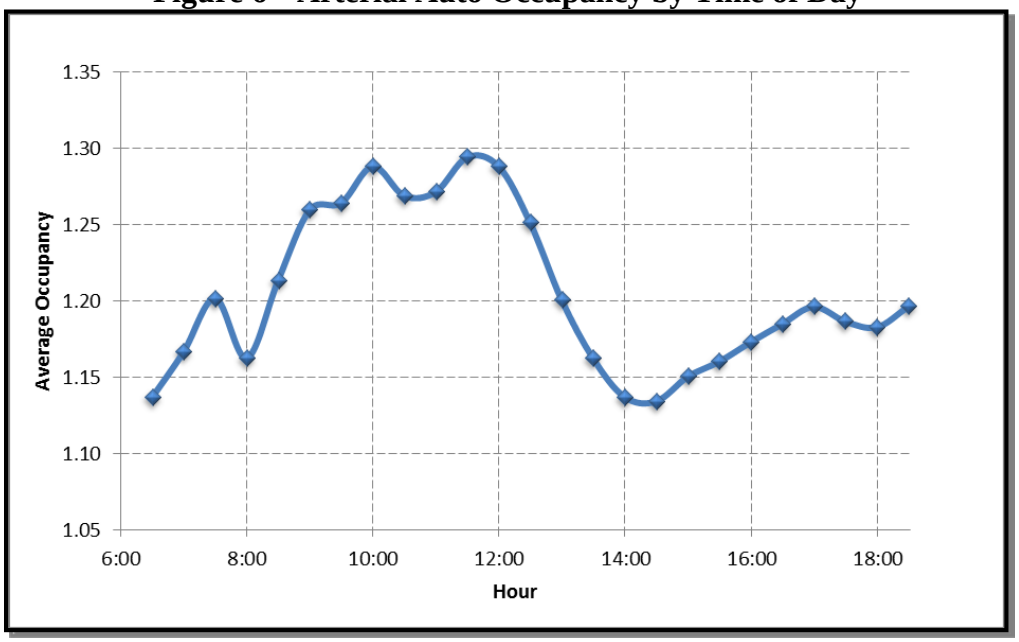


Figure 6 illustrates arterial auto occupancy rate based on data collected from four historical arterial locations using the Windshield method. Similar to freeway results, midday auto occupancy rates are found to be the highest between 10:00 AM and 12:00 PM.

4.1.2 Auto Occupancy Trend Studies

Of the 82 data collection sites for the Windshield method of this study there are six sites where occupancy data has been regularly collected by MAG since 1973, two of which are on freeways and four on local arterial roads. At these locations vehicle occupancy was surveyed continuously for a 12-hour period from 6:00 AM to 6:00 PM. **Table 7** summarizes the auto occupancy historical trend.

Table 7 Auto Occupancy Historical Trend*

Location	From	To	1973	1974	1977	1978	1979	1980	1981	1982	1988	1992	2006	2012
I-17	Thomas Rd	Indian School Rd	-	1.29	1.25	1.31	1.33	1.29	1.29	1.31	1.27	1.28	1.27	1.32
Broadway Rd	Dobson Rd	Alma School Rd	1.43	1.43	1.39	1.35	1.33	1.35	1.34	1.40	1.33	1.32	1.13	1.22
Indian School Rd	27th Ave	35th Ave	-	1.36	1.28	1.29	1.30	1.27	1.28	1.26	1.32	1.34	1.22	1.19
7th St	Camelback Rd	Indian Schol Rd	-	1.30	1.29	1.26	1.29	1.25	1.24	1.25	1.25	1.30	1.23	1.23
Thomas Rd	48th St	52nd St	-	1.31	1.28	1.27	1.32	1.29	1.27	1.31	1.27	1.28	1.22	1.23
I-10	24th St	32nd St	-	-	1.26	1.30	1.33	1.30	1.28	1.30	1.19	1.26	1.27	1.27

* 12 hours average auto occupancy
Source: MAG
January 2013

4.1.3 Percentage of Traveler and Vehicle by Auto Occupancy

Tables 8 and **9** show vehicle and traveler percentages by each occupancy number for freeways and arterials, respectively. Percentages on freeway facility are summarized from all lanes, including HOV and general purpose lanes. Single occupancy passenger vehicles are still the most frequent, ranging from 77%-88%, carrying 62%-82% of travelers. Similar results are apparent on arterial roads as well. **Figure 7** and **8** present the results by time period as well as comparison between freeway and arterial.

Figure 7 Percentage of Vehicle by Auto Occupancy on Freeway and Arterial

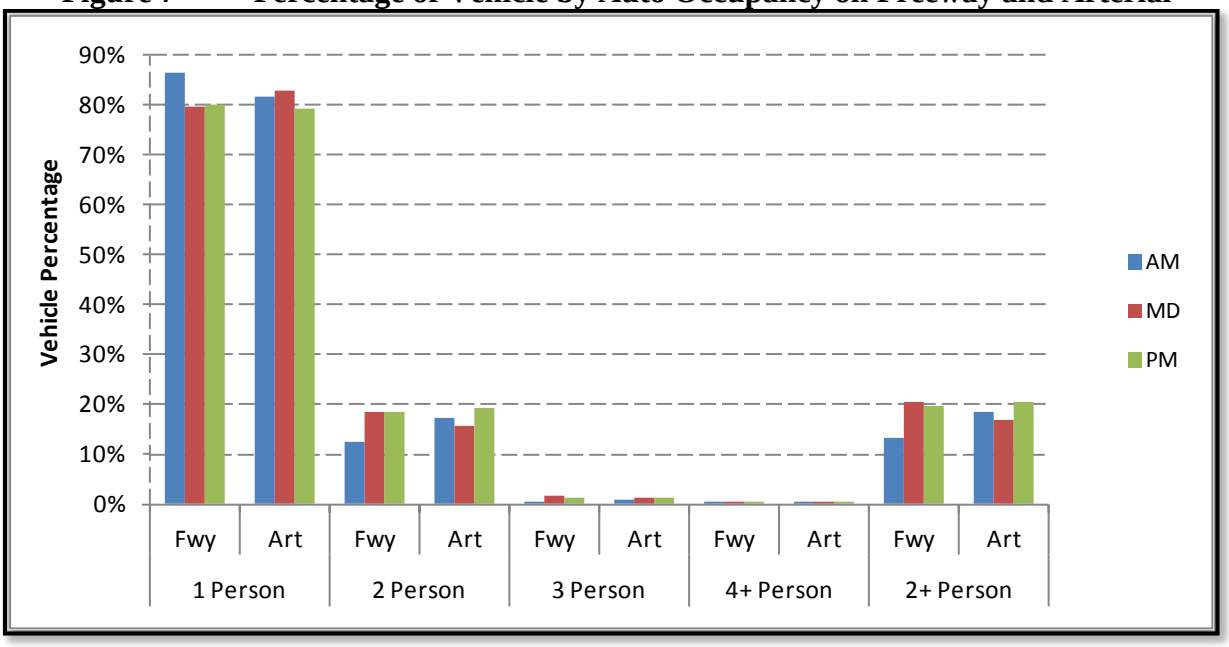


Figure 8 Percentage of Traveler by Auto Occupancy on Freeway and Arterial

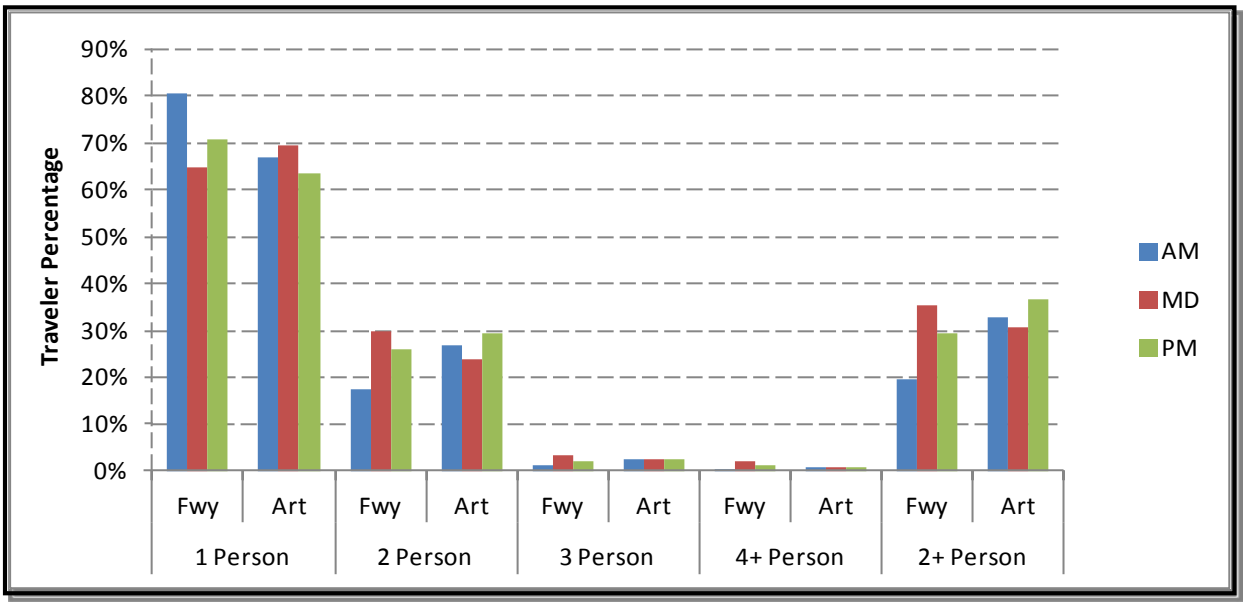


Table 8 Freeway Percentage of Vehicles and Travelers by Auto Occupancy by Time of Day										
Time	1 Person		2 Person		3 Person		4+ Person		2+ Person	
	% of Vehicles	% of Travelers	% of Vehicles	% of Travelers	% of Vehicles	% of Travelers	% of Vehicles	% of Travelers	% of Vehicles	% of Travelers
6:00	88.1%	82.3%	11.2%	16.2%	0.5%	1.1%	0.2%	0.4%	11.9%	17.7%
6:30	86.9%	81.4%	12.3%	16.9%	0.6%	1.2%	0.2%	0.5%	13.1%	18.6%
7:00	85.7%	79.8%	13.4%	18.2%	0.7%	1.4%	0.2%	0.6%	14.3%	20.2%
7:30	85.9%	80.0%	13.3%	18.2%	0.7%	1.3%	0.2%	0.5%	14.1%	20.0%
8:00	86.9%	80.9%	12.3%	17.3%	0.6%	1.3%	0.2%	0.5%	13.1%	19.1%
8:30	86.4%	79.6%	12.8%	18.5%	0.6%	1.3%	0.2%	0.6%	13.6%	20.4%
AM	86.6%	80.6%	12.6%	17.6%	0.6%	1.3%	0.2%	0.5%	13.4%	19.4%
9:00	83.6%	70.4%	14.8%	24.9%	1.2%	2.9%	0.5%	1.7%	16.4%	29.6%
9:30	80.8%	66.4%	17.5%	28.8%	1.1%	2.7%	0.6%	2.1%	19.2%	33.6%
10:00	79.8%	65.0%	18.3%	29.9%	1.4%	3.4%	0.5%	1.7%	20.2%	35.0%
10:30	77.8%	62.3%	20.0%	32.0%	1.6%	3.8%	0.5%	1.9%	22.2%	37.7%
11:00	79.7%	65.0%	18.7%	30.6%	1.1%	2.7%	0.5%	1.8%	20.3%	35.0%
11:30	79.2%	64.1%	18.7%	30.3%	1.4%	3.5%	0.6%	2.1%	20.8%	35.9%
12:00	77.0%	60.3%	19.8%	31.0%	2.0%	4.7%	1.2%	4.0%	23.0%	39.7%
12:30	77.1%	61.4%	20.6%	32.7%	2.0%	4.8%	0.3%	1.1%	22.9%	38.6%
13:00	79.0%	63.7%	18.7%	30.2%	1.5%	3.7%	0.7%	2.3%	21.0%	36.3%
13:30	79.9%	65.1%	18.2%	29.6%	1.5%	3.6%	0.5%	1.6%	20.1%	34.9%
14:00	81.3%	67.3%	17.0%	28.1%	1.4%	3.5%	0.3%	1.2%	18.7%	32.7%
14:30	80.9%	66.6%	17.3%	28.5%	1.3%	3.3%	0.5%	1.7%	19.1%	33.4%
MD	79.7%	64.8%	18.3%	29.7%	1.5%	3.5%	0.6%	1.9%	20.3%	35.2%
15:00	81.1%	71.3%	17.5%	25.6%	1.1%	2.2%	0.4%	1.0%	18.9%	28.7%
15:30	80.6%	71.2%	18.0%	25.6%	1.1%	2.2%	0.3%	1.0%	19.4%	28.8%
16:00	80.4%	71.4%	18.2%	25.5%	1.0%	2.1%	0.3%	0.9%	19.6%	28.6%
16:30	80.4%	71.7%	18.2%	25.1%	1.1%	2.1%	0.4%	1.0%	19.6%	28.3%
17:00	80.4%	71.7%	18.3%	25.2%	1.0%	2.1%	0.4%	1.0%	19.6%	28.3%
17:30	79.6%	70.4%	18.7%	25.9%	1.1%	2.3%	0.5%	1.4%	20.4%	29.6%
18:00	79.5%	69.3%	18.7%	26.6%	1.3%	2.6%	0.5%	1.5%	20.5%	30.7%
18:30	79.5%	68.7%	18.9%	27.7%	1.1%	2.3%	0.5%	1.3%	20.5%	31.3%
PM	80.2%	70.8%	18.3%	25.8%	1.1%	2.2%	0.4%	1.1%	19.8%	29.2%
Source: MAG										January, 2013

Table 9 Arterial Percentage of Vehicles and Travelers by Auto Occupancy by Time of Day										
Time	1 Person		2 Person		3 Person		4+ Person		2+ Person	
	% of Vehicles	% of Travelers	% of Vehicles	% of Travelers	% of Vehicles	% of Travelers	% of Vehicles	% of Travelers	% of Vehicles	% of Travelers
6:00	84.5%	78.4%	14.9%	25.7%	0.6%	1.7%	0.1%	0.4%	15.5%	21.6%
6:30	89.8%	79.3%	9.5%	16.3%	0.6%	1.4%	0.1%	0.5%	10.2%	20.7%
7:00	79.7%	69.3%	18.5%	32.4%	1.5%	3.3%	0.2%	0.7%	20.3%	30.7%
7:30	84.7%	70.5%	13.9%	22.1%	1.2%	2.9%	0.2%	0.6%	15.3%	29.5%
8:00	87.4%	77.1%	11.2%	18.8%	1.1%	2.9%	0.3%	1.0%	12.6%	22.9%
8:30	74.6%	51.9%	23.0%	26.4%	1.9%	2.8%	0.5%	1.1%	25.4%	48.1%
AM	81.5%	67.1%	17.2%	26.7%	1.0%	2.4%	0.3%	0.8%	18.5%	32.9%
9:00	78.0%	61.0%	20.6%	32.2%	1.1%	2.7%	0.2%	0.7%	22.0%	39.0%
9:30	72.9%	50.4%	25.3%	34.7%	1.6%	3.6%	0.2%	0.8%	27.1%	49.6%
10:00	74.1%	56.2%	23.6%	35.4%	2.2%	4.9%	0.1%	0.4%	25.9%	43.8%
10:30	76.1%	58.9%	22.8%	35.3%	1.0%	2.3%	0.2%	0.7%	23.9%	41.1%
11:00	73.7%	56.6%	24.3%	36.6%	1.4%	3.1%	0.6%	1.8%	26.3%	43.4%
11:30	72.5%	53.2%	25.5%	37.4%	1.7%	3.9%	0.3%	0.9%	27.5%	46.8%
12:00	74.1%	56.0%	24.2%	35.8%	1.5%	3.3%	0.2%	0.5%	25.9%	44.0%
12:30	79.4%	63.2%	19.1%	30.0%	1.2%	2.8%	0.3%	1.1%	20.6%	36.8%
13:00	83.7%	68.5%	15.2%	24.2%	1.0%	2.3%	0.1%	0.5%	16.3%	31.5%
13:30	85.8%	71.8%	13.7%	21.3%	0.5%	1.3%	0.1%	0.2%	14.2%	28.2%
14:00	88.9%	78.1%	10.3%	16.8%	0.2%	0.4%	0.6%	2.3%	11.1%	21.9%
14:30	86.9%	76.5%	12.0%	20.0%	0.9%	2.3%	0.1%	0.5%	13.1%	23.5%
MD	83.0%	69.5%	15.5%	23.9%	1.3%	2.7%	0.2%	0.7%	17.0%	30.5%
15:00	85.2%	73.7%	14.0%	23.4%	0.5%	1.3%	0.2%	0.7%	14.8%	26.3%
15:30	84.9%	72.5%	14.1%	23.4%	0.8%	2.0%	0.2%	0.5%	15.1%	27.5%
16:00	83.0%	69.1%	15.9%	25.1%	0.9%	2.1%	0.2%	0.6%	17.0%	30.9%
16:30	82.8%	69.6%	16.2%	25.3%	0.7%	1.5%	0.3%	0.9%	17.2%	30.4%
17:00	80.5%	66.5%	18.5%	30.2%	0.9%	2.2%	0.1%	0.4%	19.5%	33.5%
17:30	84.4%	72.4%	14.8%	24.2%	0.5%	1.1%	0.3%	1.0%	15.6%	27.6%
18:00	82.6%	68.5%	15.8%	25.1%	0.9%	2.2%	0.7%	2.2%	17.4%	31.5%
18:30	82.1%	68.4%	16.7%	26.5%	1.0%	2.2%	0.2%	0.7%	17.9%	31.6%
PM	79.4%	63.4%	19.2%	29.3%	1.1%	2.7%	0.3%	0.9%	20.6%	36.6%
Source: MAG										January, 2013

4.1.4 Carpool Characteristics

A carpool automobile is defined as any passenger vehicle with two or more travelers. This portion of the traffic improves the efficiency of freeways and arterials with regard to person throughput. **Table 10** illustrates carpool occupancies by time period. The overall carpool occupancy on freeways is higher than on arterials, except for during the AM peak period.

Table 10 Carpool Occupancy by Time Period

Time Period	Freeway	Arterial	All Region
AM 6am-9am	2.075	2.098	2.089
MD1 9am-12pm	2.137	2.089	2.108
MD2 12pm-3pm	2.123	2.086	2.101
PM 3pm-6pm	2.105	2.084	2.092
All Day	2.095	2.089	2.091

Source: MAG January, 2013

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4.2 Freeway Vehicle Classification and Commercial Vehicle Distribution

Vehicle classification data was obtained as part of the data collection process. Five separate categories of vehicle classifications were collected, including motorcycles, buses, passenger vehicles, trucks, commercial vans and recreational vehicles.

Table 11 presents freeway vehicle classification by 30-min interval. In this study, vehicle classification data in AM and PM peak periods were collected by the Windshield method and mid-day classifications were collected by the Carousel approach. It is shown that passenger cars take up a large percentage of the total vehicle traveled in the valley (88.3%), followed by trucks (9.8%). Recreational vehicles, buses, commercial vans and motorcycles remain a small portion of the overall traffic distribution.

The truck category is further broken down into light, median, and heavy trucks. These truck classifications are summarized in **Table 12**.

Table 11 Freeway Vehicle Classification						
Time	**Motor-cycles**	**Buses**	**Passenger Vehicles**	**Trucks**	**Commercial Vans**	**RV**
6:00	1.2%	0.3%	83.8%	13.9%	0.7%	0.0%
6:30	1.1%	0.3%	86.4%	11.6%	0.6%	0.0%
7:00	1.0%	0.3%	87.7%	10.4%	0.6%	0.0%
7:30	1.0%	0.3%	88.0%	10.1%	0.5%	0.0%
8:00	0.8%	0.3%	86.4%	11.9%	0.6%	0.1%
8:30	0.8%	0.3%	85.1%	13.1%	0.6%	0.1%
AM	1.0%	0.3%	86.3%	11.7%	0.6%	0.1%
9:00	0.8%	0.3%	88.8%	9.5%	0.5%	0.2%
9:30	0.7%	0.1%	88.1%	10.2%	0.6%	0.2%
10:00	0.5%	0.1%	88.9%	9.4%	0.9%	0.3%
10:30	0.4%	0.2%	88.0%	10.6%	0.6%	0.2%
11:00	0.8%	0.2%	86.9%	11.1%	0.8%	0.1%
11:30	0.8%	0.2%	88.0%	10.3%	0.6%	0.1%
12:00	0.9%	0.1%	87.8%	10.0%	1.0%	0.3%
12:30	1.5%	0.2%	89.0%	8.6%	0.5%	0.1%
13:00	0.9%	0.1%	87.6%	10.3%	0.9%	0.2%
13:30	1.0%	0.1%	88.5%	9.7%	0.7%	0.1%
14:00	0.6%	0.1%	89.2%	9.4%	0.6%	0.0%
14:30	1.0%	0.2%	89.7%	8.3%	0.6%	0.1%
MD	0.8%	0.2%	88.4%	9.8%	0.7%	0.1%
15:00	0.9%	0.2%	86.7%	11.4%	0.7%	0.1%
15:30	0.9%	0.2%	87.9%	10.2%	0.7%	0.1%
16:00	1.0%	0.3%	89.0%	9.0%	0.6%	0.1%
16:30	1.1%	0.3%	89.9%	8.0%	0.6%	0.1%
17:00	1.1%	0.3%	91.2%	6.9%	0.5%	0.0%
17:30	1.0%	0.2%	91.5%	6.7%	0.5%	0.1%
18:00	1.0%	0.2%	91.4%	6.8%	0.5%	0.0%
18:30	1.0%	0.2%	90.8%	7.4%	0.6%	0.1%
PM	1.0%	0.2%	89.7%	8.3%	0.6%	0.1%
Source: MAG						January, 2013

Table 12 Truck Traffic Distribution			
Time	**Light Truck %**	**Median Truck %**	**Heavy Truck %**
6:00	54%	20%	26%
6:30	56%	21%	23%
7:00	54%	20%	25%
7:30	52%	21%	27%
8:00	51%	20%	29%
8:30	50%	20%	29%
AM	53%	20%	27%
9:00	58%	11%	31%
9:30	61%	14%	26%
10:00	67%	9%	25%
10:30	56%	8%	36%
11:00	56%	8%	37%
11:30	58%	10%	32%
12:00	67%	12%	21%
12:30	61%	9%	30%
13:00	63%	9%	28%
13:30	59%	11%	30%
14:00	58%	12%	31%
14:30	69%	9%	23%
MD	61%	10%	29%
15:00	59%	20%	21%
15:30	60%	20%	20%
16:00	59%	21%	21%
16:30	58%	21%	21%
17:00	56%	21%	23%
17:30	55%	22%	23%
18:00	52%	21%	27%
18:30	50%	21%	29%
PM	57%	21%	23%
Source: MAG			January, 2013

4.3 HOV Lane Evaluation

4.3.1 HOV Efficiency

One of the desired goals of an HOV Lane is to move more travelers per vehicle, thereby increasing the overall efficiency of the facility. One important evaluation of the efficiency of HOV lanes is to compare the person throughput relative to the general purpose lane average. Although the actual number of vehicles per lane is usually lower in the HOV lane, the higher vehicle occupancy rates may allow travel of a higher number of people.

Of the 82 HOV lane locations, 39 (or 48%) are shown to carry higher person throughput than the adjacent GP lane average in either the AM or PM. **Figure 9** and **Figure 10** illustrate the HOV efficiency in the peak direction by freeway and by peak period. A number above 50% for HOV lanes means the HOV lane carries a higher number of persons than the average of the adjacent GP lanes. These charts show that I-10 HOV is most efficient because the per-lane throughput of people in the HOV lane is 57% and 56% (higher than GP) in AM and PM, respectively. It is also observed that HOV lanes on I-17, Loop 101 and SR 51 are under-utilized since they carry only 44% of the per lane travelers as compared to the average GP lane. HOV lane efficiency is only slightly better in the AM peak than the PM peak.

Figure 9 HOV Efficiency by Freeway for AM Peak

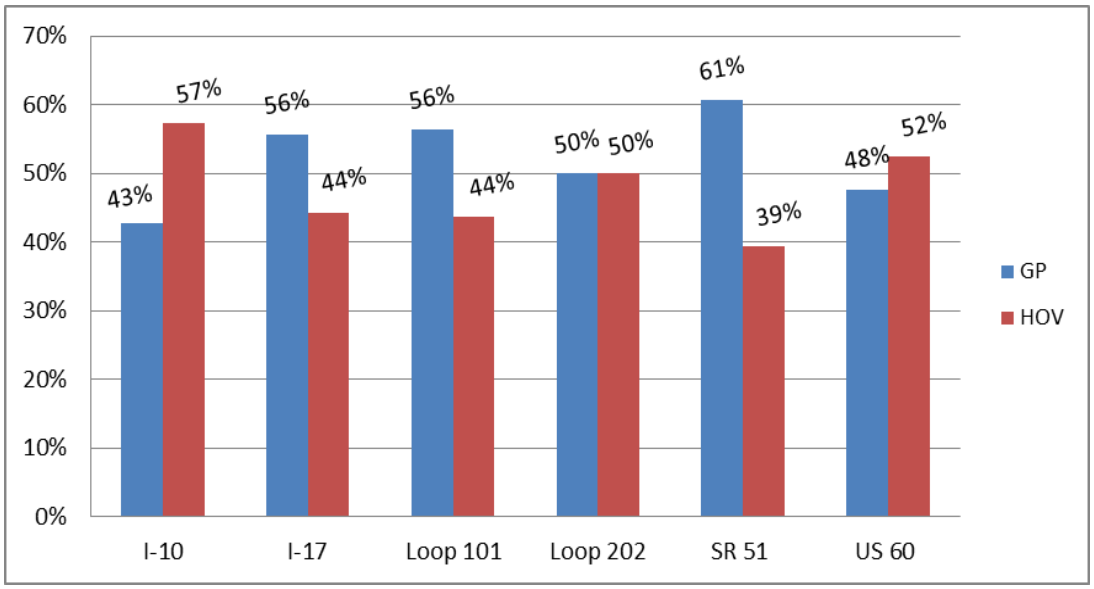
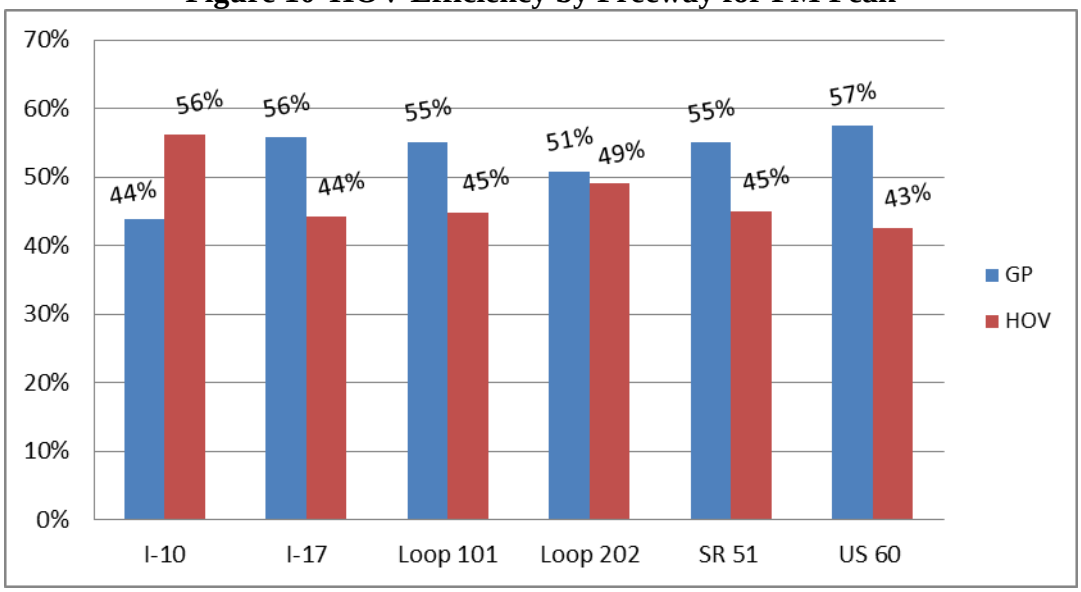


Figure 10 HOV Efficiency by Freeway for PM Peak



In **Figures 11** and **12** the HOV efficiency information for individual locations is graphically depicted for a selection of specific sites on each of the aforementioned study freeways. The corresponding HOV lane and average general purpose lane percentages of the per-lane travelers and vehicles of these two lanes are illustrated. A number above 50% for HOV lanes means a higher efficiency for person throughput or vehicle throughput comparing to a GP lane, respectively.

4.3.2 HOV Violation Rate

The HOV lane violation rates in 15-min interval during HOV hours (6:00AM - 9:00AM and 3:00PM - 7:00PM) can be seen in **Figure 13 and Figure 14**. The violation rate is computed as the number of single occupancy vehicles, excluding those with "Blue Sky" plates, out of total vehicles. In Phoenix region, there are no HOV violations during the off-peak hours where use of the HOV lane is unrestricted.

Violation rates also vary within each peak period. In comparing **Figure 13** and **Figure 14**, it's apparent that there are more violators in HOV lane during the AM peak hours than the PM. This is probably due to a higher value of time in the morning as commuters travel to work. Higher violation rate can also be seen at the beginning and ending of HOV hours for both AM and PM peak periods.

Figure 15 shows the comparison of HOV violation rate by freeway. Overall, I-17 has the highest rate of violation for both AM and PM periods. Similar conclusion can be seen from 2006 MAG vehicle occupancy report.

Figure 11 HOV Efficiency at Selected Inbound Locations during AM Peak

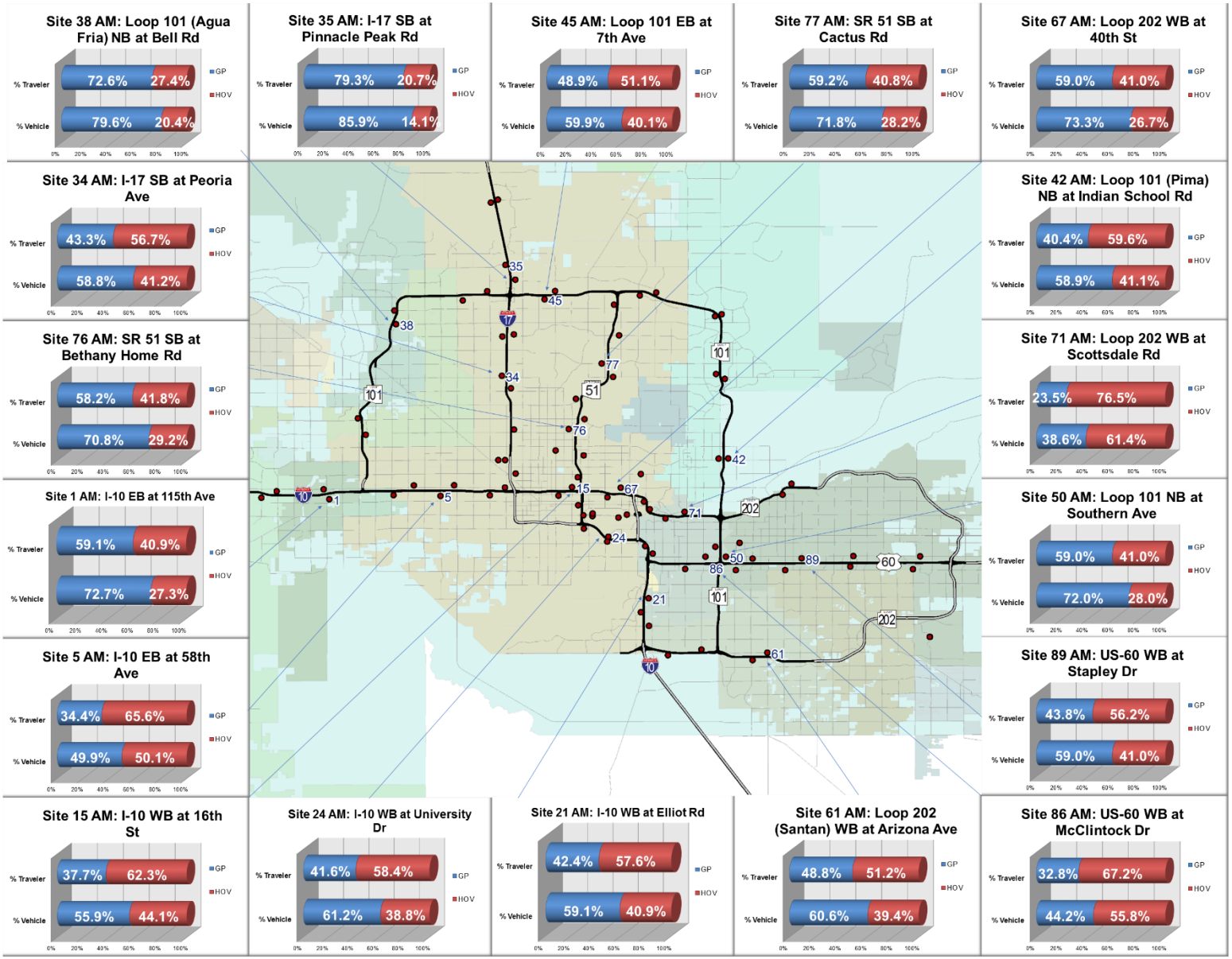


Figure 12 HOV Efficiency at Selected Outbound Locations during PM Peak

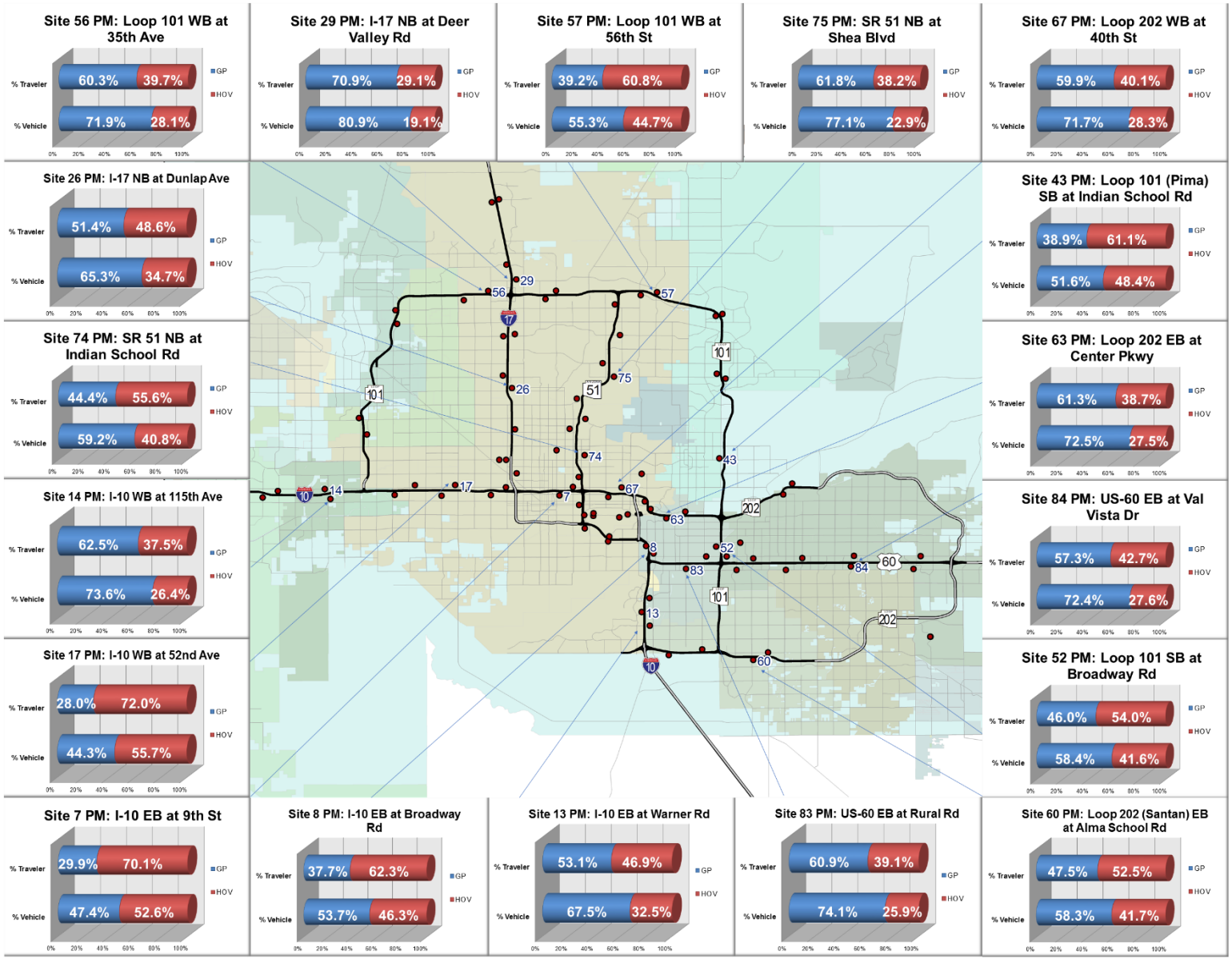


Figure 13 AM Peak HOV Violation Rate

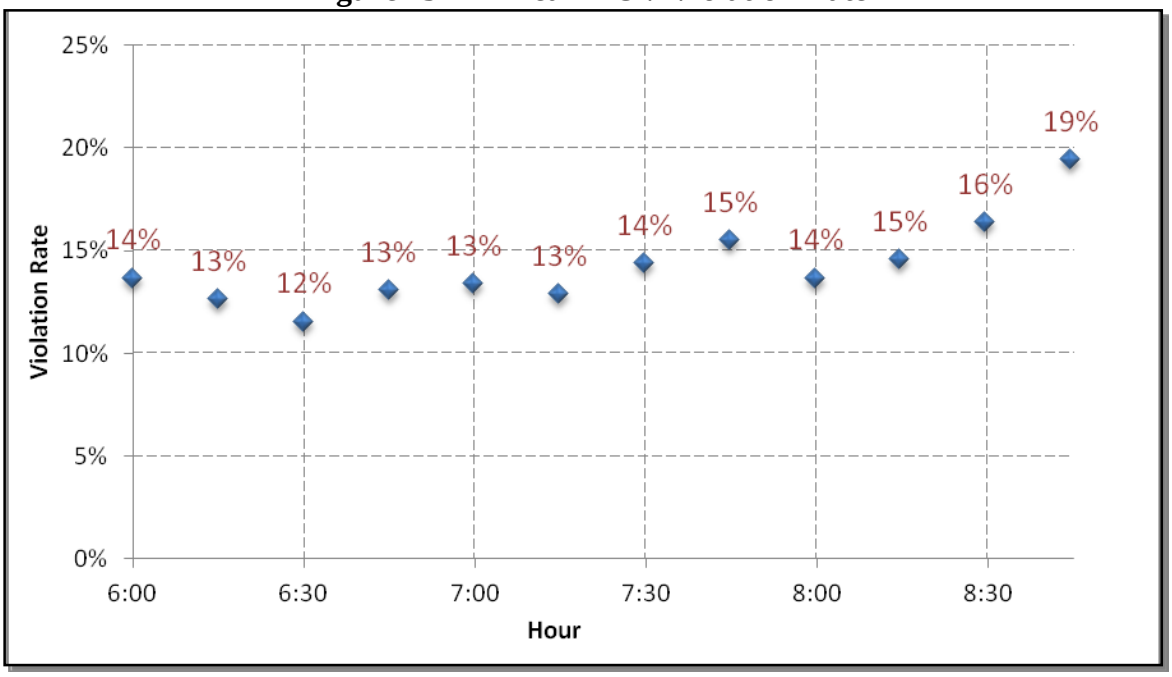


Figure 14 PM Peak HOV Violation Rate

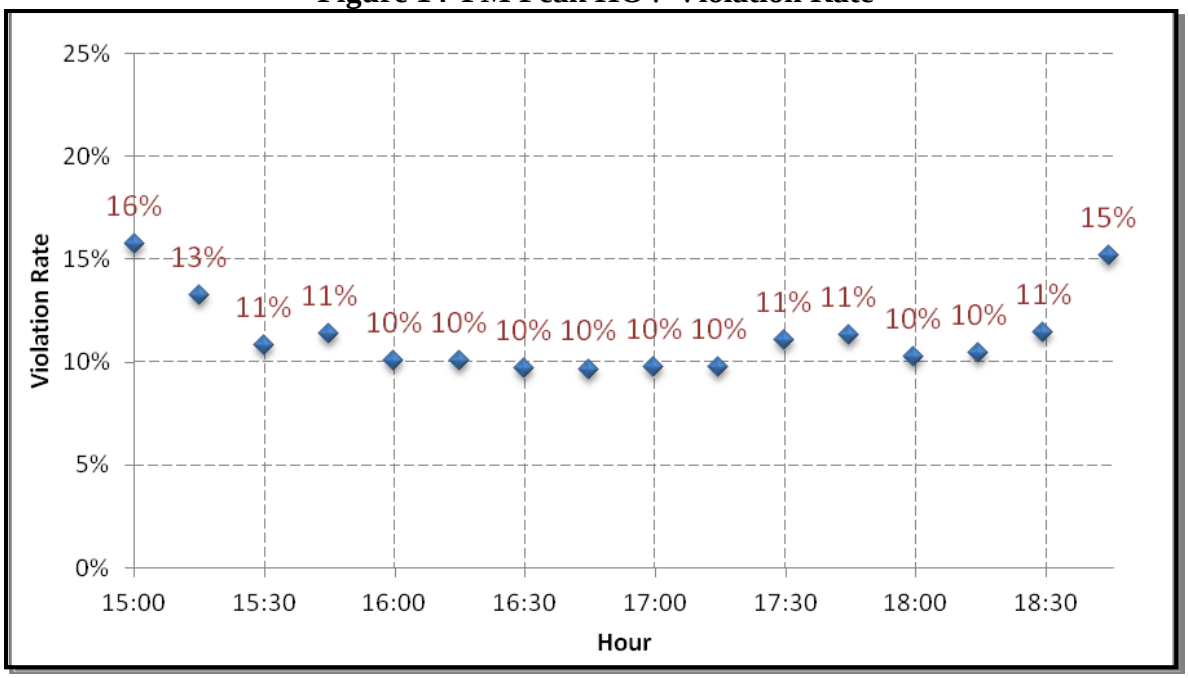
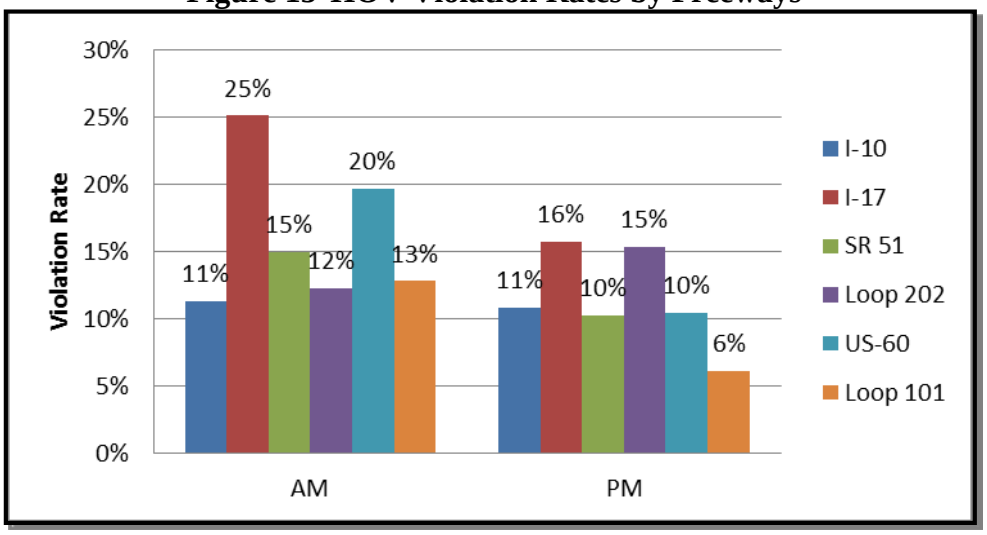


Figure 15 HOV Violation Rates by Freeways



4.4 Sample Rate and Confidence Level

The sample rates for the vehicle occupancy data and the level of confidence and confidence interval for occupancy estimates were investigated. With the Windshield method a single sample is defined as a vehicle observed on a particular location at a specified time period. Overall population of traffic was obtained from simultaneous FMS database or radar counts.

Table 13 shows the sample rate, confidence level and confidence interval for general-purpose lanes, the HOV lane, and all lanes together for the overall freeway system in the valley. Occupancy estimates from the Windshield method have 99% confidence level with 0.1% margin of error.

Table 13 Windshield Method Confidence Interval by Lane Group

Lane Type	Sample Size	Traffic Volume	Sample Rate	Confidence Level	Confidence Interval (Margin of Error)
General Purpose	1,791,159	3,248,921	55%	99%	0.1%
HOV	350,424	420,558	83%	99%	0.1%
Total	2,141,583	3,669,479	58%	99%	0.1%

Source: MAG December, 2012

Table 14 further summarizes these statistics by freeway corridor. All studied freeway corridors meet the 99% confidence level with sample rate higher than 50%. The confidence interval for occupancy estimates on I-10, I-17 and L101 are within 0.1% margin of error, and within 0.2% on L202, SR51 and US-60.

Table 14 Windshield Method Confidence Interval by Freeway						
Freeway	**No. of Sites**	**Sample Size**	**Traffic Volume**	**Sample Rate**	**Confidence Level**	**Confidence Interval (Margin of Error)**
I-10	22	626,253	1,183,970	53%	99%	0.1%
I-17	11	284,331	391,336	73%	99%	0.1%
Loop 101	18	432,930	754,420	57%	99%	0.1%
Loop 202	12	307,878	564,939	54%	99%	0.2%
SR 51	9	226,783	339,887	67%	99%	0.2%
US-60	10	263,782	459,055	57%	99%	0.2%
Source: MAG						December, 2012

The Carousel method was used to collect occupancy data for the first time in the MAG study. Unlike the Windshield method with a fixed number of data collection locations, the Carousel method survey vehicle moves continuously along a pre-designed route. The sample rate here is being defined as the average number of vehicles observed by the technician in a one-mile long freeway segment. The sample requirement is checked for every survey day to see whether the average samples meet the minimal size. **Table 15** shows that a minimal sample size is achieved for all survey days on all six freeways with 95% confidence level and a 7.5% confidence interval.

Table 15 Carousel Method Confidence Interval by Freeway						
Freeway	**Total VMT**	**Mileage**	**VMT/Mile**	**Min. Sample Size with 95% CL, ±7.5% CI**	**Days of Data Collection**	**Days to Meet Min. Sample size**
US 60	924,058	34	27,146	170	6	6
SR 51	491,780	30	16,349	169	6	6
Loop 202	793,841	50	15,801	169	6	6
Loop 101	2,002,792	118	16,938	169	6	6
I-17	820,723	46	18,006	169	4	4
I-10	1,779,266	71	25,110	170	4	4
* Minimum size of sample that is recommended to meet the 7.5% margin of error with a confidence level of 95% Source: MAG						December, 2012

The confidence level of the Carousel method is relatively low compared to the windshield method. Previous research shows that the lower sample rate may be compensated by better data quality obtained as the carousel method provides the observer with better opportunity to collect accurate occupancy data through window.

5 CONCLUSION

The MAG 2012 VOS was successfully completed. All four study goals i.e., update region's vehicle occupancy profile, investigate vehicle occupancy rate trends and patterns, evaluation of the HOV lanes, and vehicular classification in the region were accomplished. Safety concerns were thoroughly addressed and resulted in a safely execution project without any safety related accidents.

- ***Data Collection Methods***

Two primary methods for collecting vehicle occupancy data were used: the traditional roadside Windshield method and innovative Carousel method. While the Windshield method has been used in prior studies, MAG used the Carousel method for the first time. The overwhelming majority of vehicle occupancy data was collected by the Windshield method. The data collection plan also included simultaneous supplemental radar traffic count and speed data collection for comparison and validation and analysis purposes. Video data were also recorded at select Windshield data collection sites as a validation and audit tool. A comprehensive Quality Assurance/Quality Control (QA/QC) plan was implemented to ensure the highest possible quality of data collected for the study.

- ***Data Validation***

The findings of the general purpose and HOV lane occupancy, Blue Sky License Plate percentages, HOV violation rates were consistent and validated for both the carousel and windshield methods.

- ***Freeway Auto Occupancy***

Freeway auto occupancy varies by time of day. Occupancy in the morning reaches a high average hourly occupancy rate of 1.15 for the 7:00 AM hour. The highest hourly occupancy rate recorded in the PM peak is 1.22 for the 4:00 PM hour. The highest occupancy rate for the entire day is 1.28 recorded in the middle of the day for the 12:00 PM hour.

- ***Arterial Auto Occupancy***

Auto occupancy on arterial roadways were recorded higher than the freeways with morning, mid-day, and evening hourly highs recorded at 1.2, 1.3, and 1.2, respectively.

- ***Freeway Vehicle Classification and Commercial Vehicle Distribution***

Passenger cars represent the largest percentage of the total vehicle (88.3%), followed by trucks (9.8%). Recreational vehicles, buses, commercial vans and motorcycles represent the remaining portion of the overall traffic distribution.

- ***Freeway HOV Lane Efficiency***

The efficiency for 18 high importance HOV lane locations is shown in detail for each peak period. Of the 82 overall HOV lane locations, 39 (or 48%) are shown to carry higher person throughput than the adjacent GP lane average in either the AM or PM peak. HOV lanes on the I-10 are most efficient while HOV lanes on the I-17, SR-51 and Loop 101 freeways are perhaps underutilized.

- ***HOV Lane Violation Rates***

HOV lane violation rates vary within each peak period with more overall violators in HOV lanes during the AM peak hours than during the PM. Higher violation rates can also be seen at the beginning and ending of restricted use HOV hours for both AM and PM peak periods. Overall, I-17 has the highest rate of violation for both AM and PM periods. Similar trends were seen during the 2006 MAG vehicle occupancy study.