1992 Study of Occupancy and Vehicle Classification in the Metropolitan Phoenix Area

prepared for:
Maricopa Association of Governments
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Phoenix, AZ. 85007

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EXECUTIVE SUMMARY

Introduction

There is a growing need to increase auto occupancy as part of an effort to reduce fuel consumption, traffic congestion and air pollution. Auto occupancy rates are used to validate the transportation planning models and to monitor general trends in travel characteristics. These rates may also be used to evaluate the effectiveness of such programs as carpooling, park and ride facilities, and high occupancy vehicle (HOV) lanes.

As part of an on-going process to collect traffic data and monitor travel characteristics, the Maricopa Association of Governments Transportation Planning Office (MAGTPO) conducted annual surveys of auto occupancy from 1977 through 1982. Auto occupancy information is useful in a variety of transportation planning applications, and is important for air quality modeling activities. The last update of auto occupancy rates was done in 1988.

The air quality impact of freeway HOV lanes was modeled for consideration in the MAG air quality plans, but no formal assessment of the performance of existing HOV lanes had been conducted. HOV bypass lanes at ramp meters have also been proposed as a transportation control measure. Based on the need for additional data, the MAGTPO contracted with Lee Engineering to measure occupancy in the Phoenix metropolitan area.

This study was funded from an Air Quality Fund grant to develop improved auto occupancy data, including an assessment of high-occupancy vehicle lane use, for the Maricopa County Urban Planning Area. The purpose of this study is to:

- determine auto occupancy rates on arterials and freeways by area type and time of day, and

- assess the effectiveness of HOV lanes as a transportation control measure (TCM) for air quality improvement.

Simultaneous with obtaining auto occupancy data, the number of light and heavy duty commercial vehicles, buses, recreational vehicles and motorcycles was also counted. These data are required for air quality emission calculations as well as roadway design. Table ES-1 identifies the categories of vehicles that were collected as a part of this study.

Table ES-1. Data Collection Categories

1 Person Auto	Marked Vehicles
2 Person Auto	Medium Commercial Vehicles
3 Person Auto	Heavy Commercial Vehicles
4+Person Auto	Commercial Passenger Vans
Unknown Occupancy Auto	Recreational Vehicles
Motorcycles	Buses

Variation in Auto Occupancy by Area Type, Functional Classification and Time of Day

In order to determine how auto occupancy varies by area type, functional classification and time of day, it was necessary to establish data collection sites which were combinations of these three factors. Before examining the results, a brief discussion of how each of these factors is subdivided is given.

Description of Study Factors

Area Type MAGTPO uses a UTPS planning model for transportation planning in the metropolitan Phoenix area. In this model, the speed and capacity of roadways vary by Area Type - a function of employment density and population density. Area type, as used in this study, is defined by density, where density is total population plus two times total employment, all divided by gross area. "Core" area is where density is greater than 10,000 per square mile. "Urban" area is 5,000 to 10,000 density per square mile. "Suburban" is less than or equal to 5,000. These densities are calculated by district (aggregation of traffic analysis zone) and those areas with high densities are modeled with slower speeds than those areas with lower densities.

Functional Classification There are three levels of functional classification used in this study:

- freeways without HOV lanes
- freeways with HOV lanes
- arterial streets

Data were collected on each of these types of facilities to determine how auto occupancy and vehicle classification differed.

Time of Day MAGTPO desired the data to be collected by four times of day periods as shown below in Table ES-2.

Table ES-2. Time Periods for Auto Occupancy Determination

Time Period	Time of Day
AM peak	6-9 AM
Midday	9-12 AM 2-4 PM
PM peak	4-6 PM
Evening	6-7 PM

Even though data were aggregated to these time periods, the actual data were collected for 13 hours of the day. In this manner, the hours could be combined in any logical manner for further reporting. Figure ES-1 shows the different combinations of area type, functional classification and time of day which the data were collected.

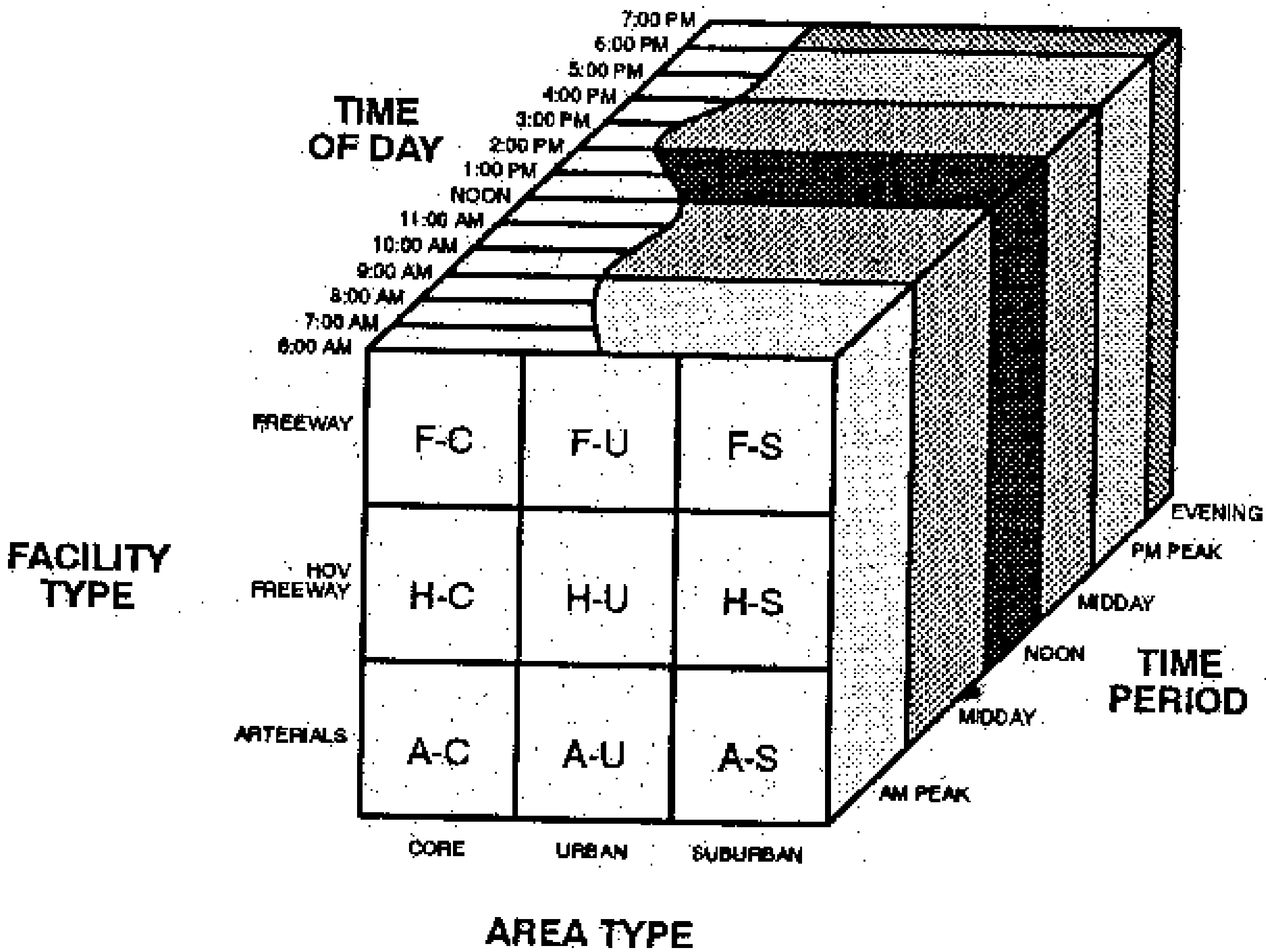

TIME OF DAY
7:00 PM
6:00 PM
5:00 PM
4:00 PM
3:00 PM
2:00 PM
1:00 PM
NOON
11:00 AM
10:00 AM
9:00 AM
8:00 AM
7:00 AM
6:00 AM
FREEWAY
HOV FREEWAY
ARTERIALS
FACILITY TYPE
F-C
F-U
F-S
H-C
H-U
H-S
A-C
A-U
A-S
CORE
URBAN
SUBURBAN
AREA TYPE
EVENING
PM PEAK
MIDDAY
NOON
MIDDAY
AM PEAK
TIME PERIOD

Figure ES-1. Data Collection Stratification

Study Locations

Using the stratifications shown in Figure ES-1, specific locations were randomly chosen for each combination. There were limited facilities for the combination of suburban area type and freeways with HOV lanes and only 4 samples were drawn. Figure ES-2 is a map depicting all the locations where data were collected.

Results

Auto occupancy and vehicle classification were collected for nearly 350,000 vehicles. In this study, auto occupancy is defined as the average occupancy of those vehicles classified as automobiles. It does not include other classifications such as RV's, motorcycles, vans, etc. Automobiles with unknown occupancies are not included in this calculation. Mean auto occupancy for 4+ vehicles was calculated to be 4.4 based upon data contained in the 1982 study. This data was not reported in the 1988 study.

The overall mean auto occupancy for the MAG area is 1.337. This value is derived by weighting the occupancy for each cell as shown in Figure ES-1 by the vehicle miles of travel (VMT) for that cell. This weighting is necessary because the data points were collected randomly from within each cell and not randomly from all facilities in the region. If the points had been randomly chosen from all facilities, then the number of samples from priority lane roadways would have been very small, as they represent a small portion of the roadways in the region.

It was found that auto occupancy differs by the three different factors that were investigated. Figure ES-3 shows how auto occupancy differs by area type. The figure shows that the highest auto occupancy is associated with the suburban area type. This makes some sense. The lowest auto occupancy is associated with the home base work trip (those trips from home to work and back). These trips are more frequent in the urban and core areas. They are less frequent in the suburban area. The suburban area is more

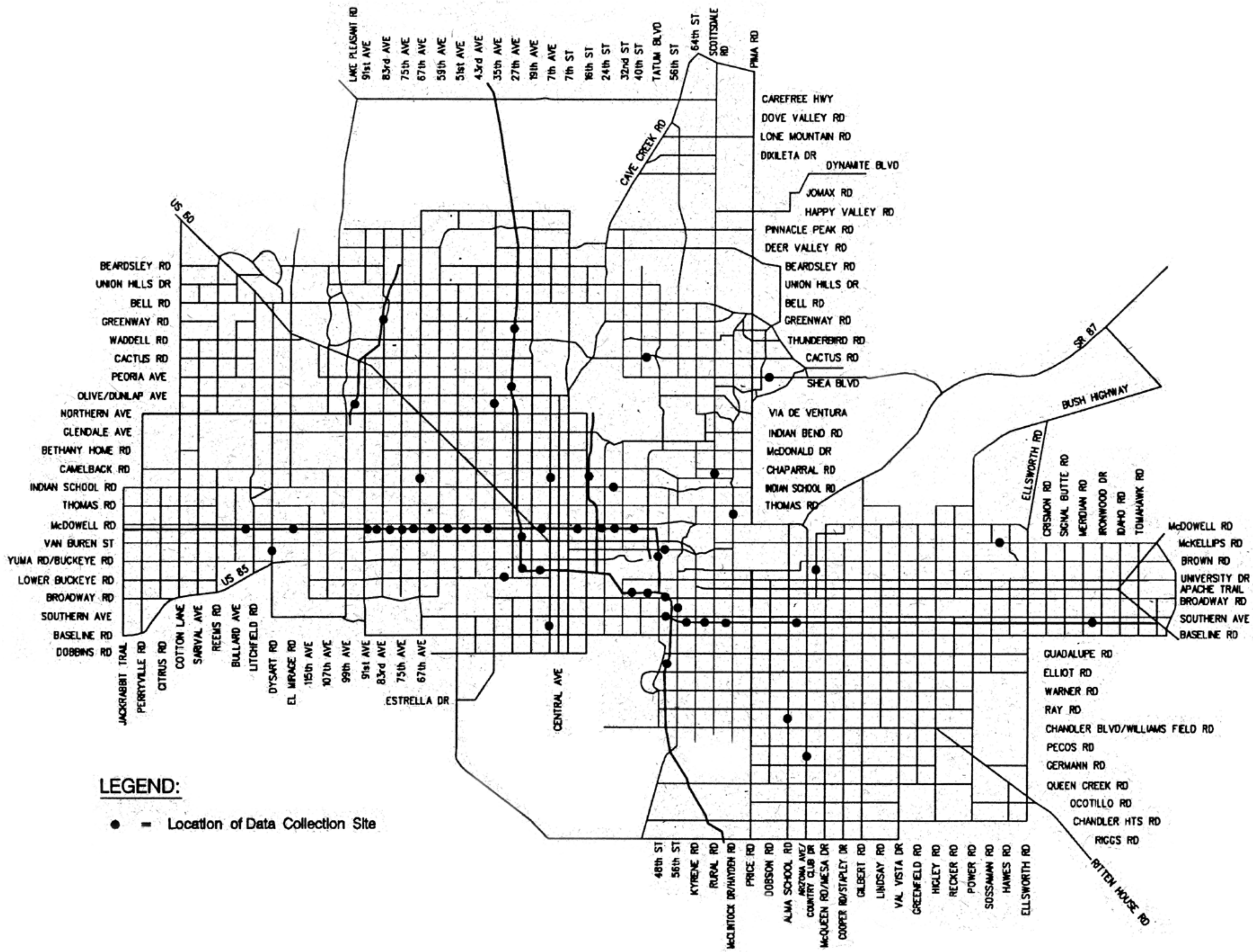
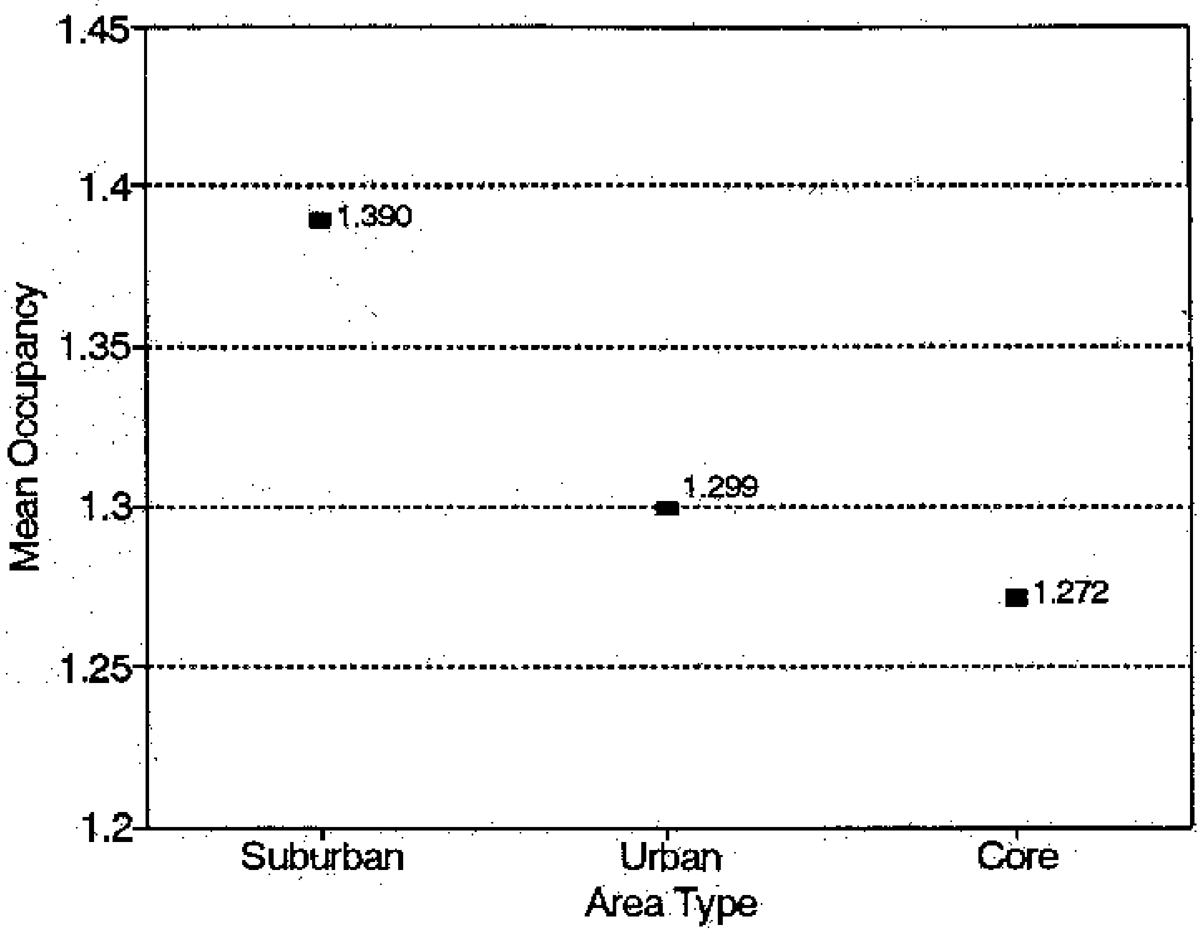

LAKE PLEASANT RD
91st AVE
83rd AVE
75th AVE
67th AVE
59th AVE
51st AVE
43rd AVE
35th AVE
27th AVE
19th AVE
7th AVE
7th ST
16th ST
24th ST
32nd ST
40th ST
TATUM BLVD
56th ST
64th ST
SCOTTSDALE RD
PIMA RD
CAREFREE HWY
DOVE VALLEY RD
LONE MOUNTAIN RD
DIXILETA DR
DYNAMITE BLVD
JOMAX RD
HAPPY VALLEY RD
PINNACLE PEAK RD
DEER VALLEY RD
BEARDSLEY RD
UNION HILLS DR
BELL RD
GREENWAY RD
THUNDERBIRD RD
CACTUS RD
SHEA BLVD
VIA DE VENTURA
INDIAN BEND RD
McDONALD DR
CHAPARRAL RD
INDIAN SCHOOL RD
THOMAS RD
CAVE CREEK RD
US 60
SR 87
BUSH HIGHWAY
ELLSWORTH RD
CRISMON RD
SIGNAL BUTTE RD
MERIDIAN RD
IRONWOOD DR
IDAHO RD
TOMAHAWK RD
McDOWELL RD
McKELLIPS RD
BROWN RD
UNIVERSITY DR
APACHE TRAIL
BROADWAY RD
SOUTHERN AVE
BASELINE RD
GUADALUPE RD
ELLIOT RD
WARNER RD
RAY RD
CHANDLER BLVD/WILLIAMS FIELD RD
PECOS RD
GERMANN RD
QUEEN CREEK RD
OCOTILLO RD
CHANDLER HTS RD
RIGGS RD
RITTEN HOUSE RD
BEARDSLEY RD
UNION HILLS DR
BELL RD
GREENWAY RD
WADDELL RD
CACTUS RD
PEORIA AVE
OLIVE/DUNLAP AVE
NORTHERN AVE
GLENDALE AVE
BETHANY HOME RD
CAMELBACK RD
INDIAN SCHOOL RD
THOMAS RD
McDOWELL RD
VAN BUREN ST
YUMA RD/BUCKEYE RD
LOWER BUCKEYE RD
BROADWAY RD
SOUTHERN AVE
BASELINE RD
DOBBINS RD
US 85
JACKRABBIT TRAIL
PERRYVILLE RD
CITRUS RD
COTTON LANE
SARIVAL AVE
REEMS RD
BULLARD AVE
LITCHFIELD RD
DYSART RD
EL MIRAGE RD
115th AVE
107th AVE
99th AVE
91st AVE
83rd AVE
75th AVE
67th AVE
ESTRELLA DR
CENTRAL AVE
48th ST
56th ST
KYRENE RD
RURAL RD
McCLINTOCK DR/HAYDEN RD
PRICE RD
DOBSON RD
ALMA SCHOOL RD
ARIZONA AVE/ COUNTRY CLUB DR
McQUEEN RD/MESA DR
COOPER RD/STAPLEY DR
GILBERT RD
LINDSAY RD
VAL VISTA DR
GREENFIELD RD
HIGLEY RD
RECKER RD
POWER RD
SOSSAMAN RD
HAWES RD
ELLSWORTH RD
LEGEND:
● = Location of Data Collection Site

Figure ES-2. Locations for Data Collection



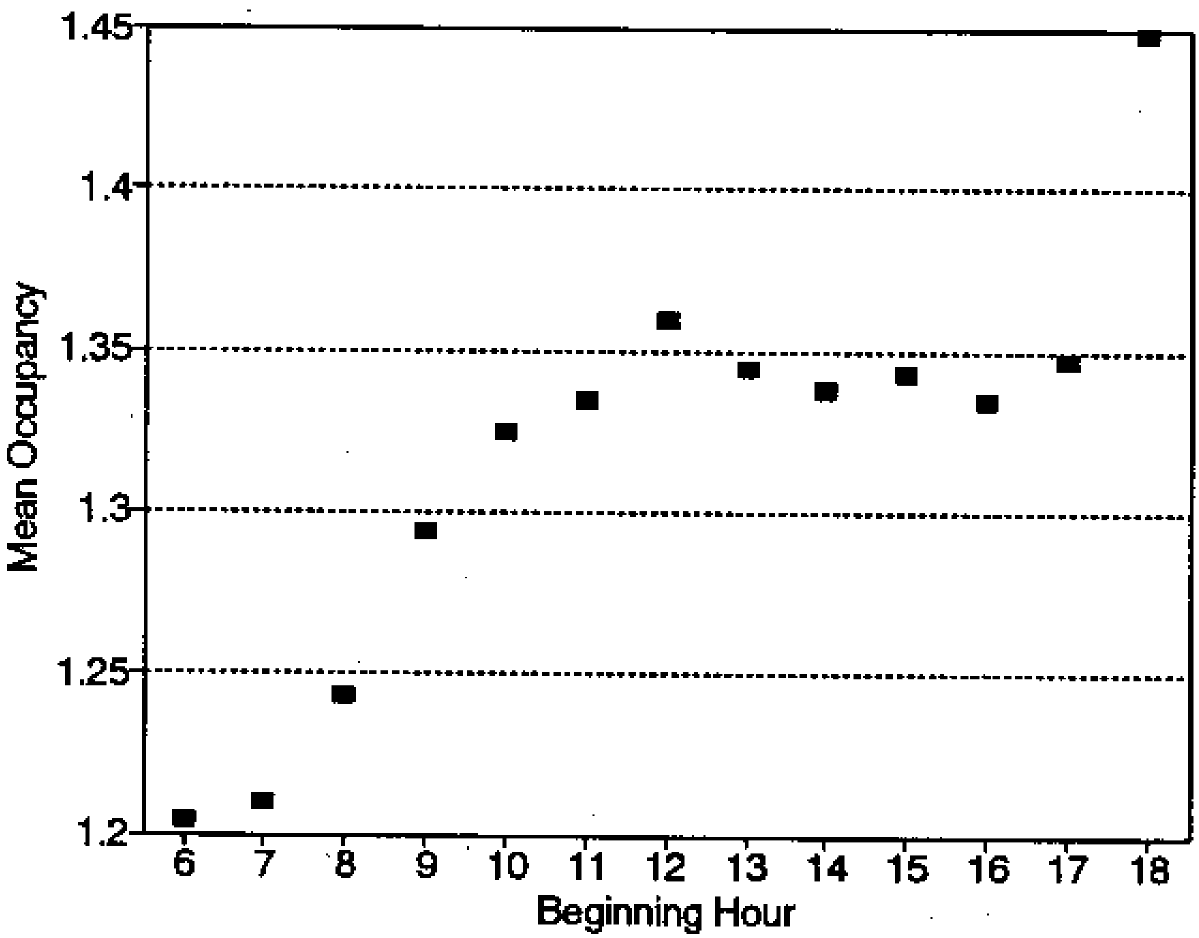
1.45
1.4
1.35
1.3
1.25
1.2
Mean Occupancy
1.390
1.299
1.272
Suburban
Urban
Core
Area Type

Figure ES-3. Mean Auto Occupancy Vs. Area Type
Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

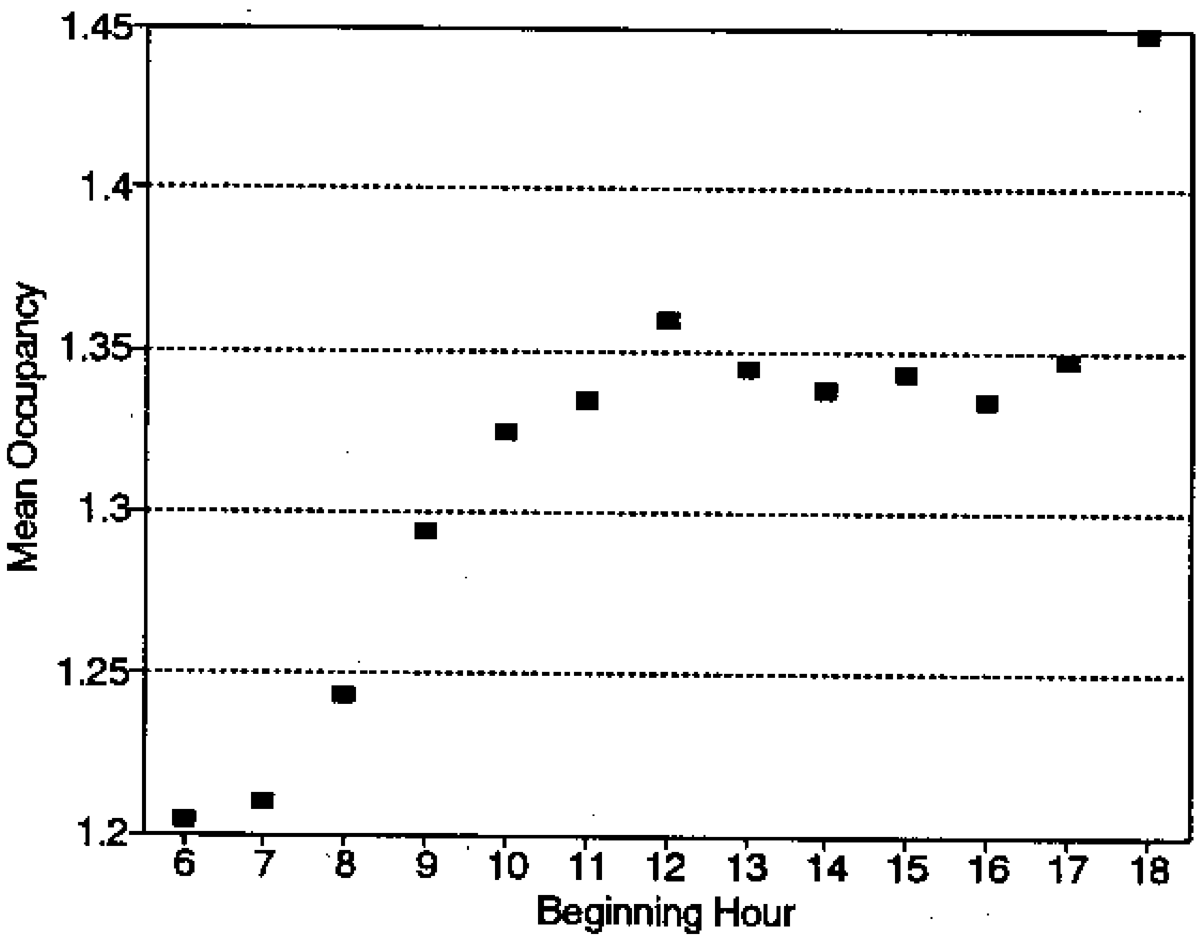
likely to have home based shopping, home based school, and other trips that are associated with high occupancy. High auto occupancy in suburban areas may also be associated with larger family size in suburban areas.

Figure ES-4 shows the plot of mean auto occupancy vs. facility type. Freeways with HOV lanes have greater auto occupancies than freeways without HOV lanes. Arterial streets, however, have the greatest mean auto occupancy.

Figure ES-5 shows the plot of mean auto occupancy versus time of day. This graph shows how auto occupancy steadily increases from a low of 1.21 from 6:00-7:00 AM to a high of 1.45 from 6:00 to 7:00 PM. There is a peak in auto occupancy from 12:00 to 1:00 which is probably explained by people carpooling for the lunch hour. As stated in previous studies for the Phoenix area, morning auto occupancies tend to be lower, and evening occupancies tend to be higher. This is because the majority of the traffic on the streets in the morning is home based work trips which is typically associated with low auto occupancies. In the evening, there are more shopping trips which is a trip associated with high auto occupancies.



1.45
1.4
1.35
1.3
1.25
1.2
Mean Occupancy
6
7
8
9
10
11
12
13
14
15
16
17
18
Beginning Hour



1.45
1.4
1.35
1.3
1.25
1.2
Mean Occupancy
6 7 8 9 10 11 12 13 14 15 16 17 18
Beginning Hour

Figure ES-4. Mean Auto Occupancy Vs. Facility Type
Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

Figure ES-5. Mean Auto Occupancy Vs. Time of Day
Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

It was also found that auto occupancy was different on facilities that had HOV lanes (depending on which area the facility was located). To better explain this, the mean values are plotted in Figure ES-6. This graphic again shows how auto occupancies are greater for the suburban area type. However, the graphic also points out a significant variation in auto occupancy for facilities in the urban area. For these facilities, freeways without HOV lanes have a substantially lower auto occupancy than arterial streets, or freeways with HOV lanes. One conclusion from this graphic is that HOV lanes are quite effective on those freeways that are located in a high density urban area.

Figure ES-6. Mean Auto Occupancy Vs. Area Type and Facility Type
Source: Counts taken by Lee Engineering on weekdays during April and May, 1992.

Variation in Auto Occupancy over Time

In addition to the sites mentioned previously, 6 sites from previous studies of auto occupancy in the MAG region were sampled. Data from these sites were compared to previous years to see how auto occupancy has changed. These sites are shown in Table ES-3.

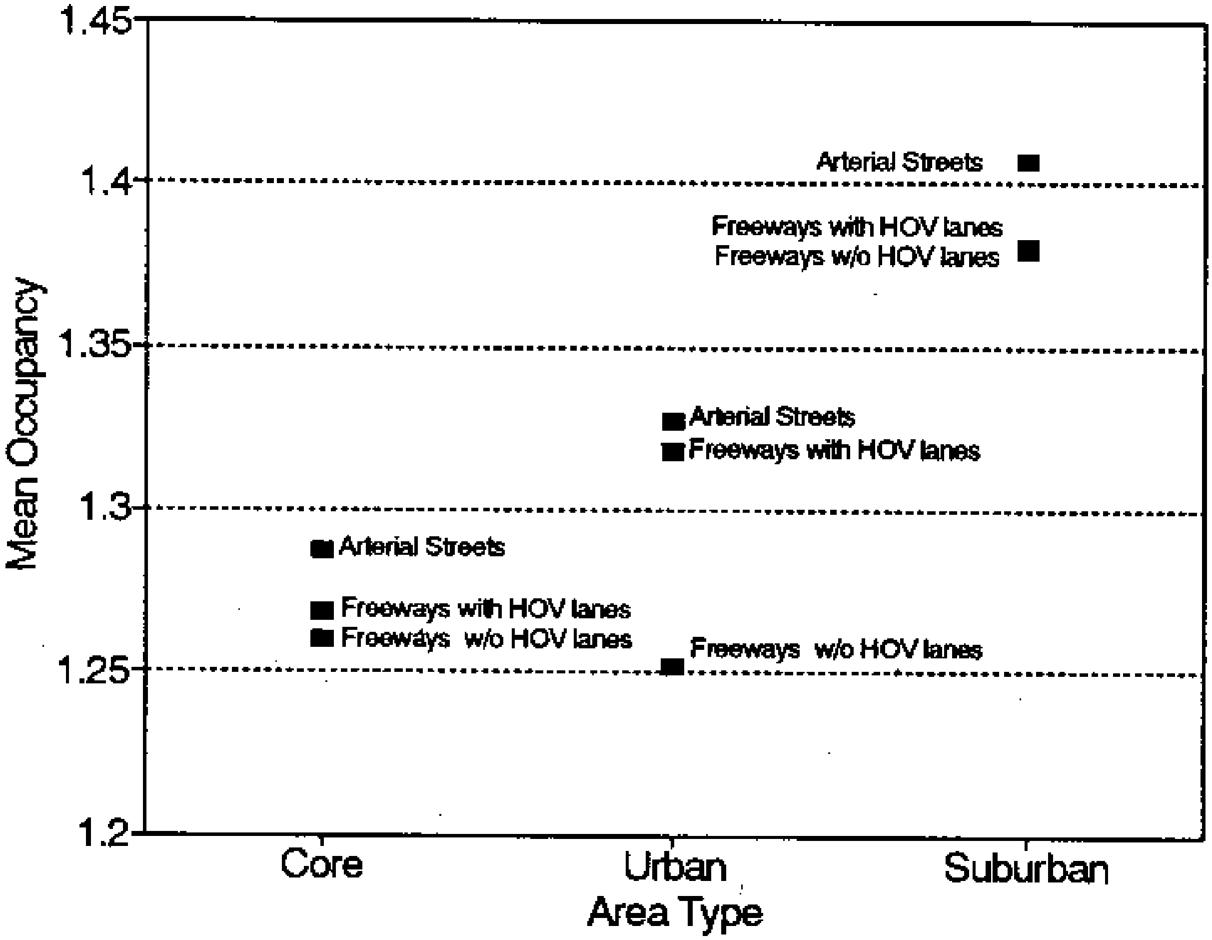

Mean Occupancy
1.45
1.4
1.35
1.3
1.25
1.2
Arterial Streets
Freeways with HOV lanes
Freeways w/o HOV lanes
Arterial Streets
Freeways with HOV lanes
Arterial Streets
Freeways with HOV lanes
Freeways w/o HOV lanes
Freeways w/o HOV lanes
Core
Urban
Suburban
Area Type

Table ES-3. Sites with Data from Previous Studies

Location	Direction
Black Canyon Fwy (I-17) North of McDowell Rd.	NB
Broadway Road East of Dobson Rd	EB
Indian School Road West of 27th Ave.	WB
7th Street North of Camelback Rd.	SB
Thomas Road West of 56th St.	WB
Maricopa Fwy. (I-10) @32nd Street	EB

In 1982, these occupancies were reported in a MAG study, *Phoenix Urban Area Vehicle Occupancy Study,* 1982. In 1988, auto occupancies were measured on a regionwide basis and these sites. To examine the trend of auto occupancy, Table ES-4 shows auto occupancy at these sites for the 9 years identified in previous studies, and the data collected at these sites as part of this study.

Table ES-4. Auto Occupancy Rates for 1973, 1974, 1977-1982, 1988, 1992

	12-Hour Average Auto Occupancy									
Location	73[1]	74[1]	77[1]	78[1]	79[1]	80[1]	81[1]	82[1]	88[2]	92[3]
I-17	-	1.29	1.25	1.31	1.33	1.29	1.29	1.31	1.27	1.28
Broadway	1.43	1.43	1.39	1.35	1.33	1.35	1.34	1.40	1.33	1.32
Indian School	-	1.36	1.28	1.29	1.30	1.27	1.28	1.26	1.32	1.34
7th St.	-	1.30	1.29	1.26	1.29	1.25	1.24	1.25	1.25	1.30
Thomas Rd.	-	1.31	1.28	1.27	1.32	1.29	1.27	1.31	1.27	1.28
Maricopa Fwy.	-	-	1.26	1.30	1.33	1.30	1.28	1.30	1.19	1.26

[1]Phoenix Urban Area Auto Occupancy Study, 1982.
[2]Vehicle Occupancy Determinators, Barton-Aschman Associates, Inc. Final Report August, 1989.
[3]Counts taken by Lee Engineering on weekdays during April and May, 1992.

The 12-hour average auto occupancy rates show very little if any change over the past 19 years. Over time, some of these locations are changing from suburban to central city locations, particularly with the rapid growth experienced in Phoenix over the past decades. Since suburban areas were found to have higher automobile occupancies, there is reason to believe that the counts at these locations would decline over time.

Auto Occupancy at Selected Ramp Locations

It was desired to collect auto occupancy at 4 ramp locations. These were collected to assess the potential demand for HOV bypass ramps. The locations and their respective daily auto occupancies are shown in Table ES-5.

Table ES-5. Mean Auto Occupancies for On-Ramps

On-Ramp	Ramp	Expected Occupancy Freeways
Interstate 17/Camelback Northbound on-ramp	1.265	1.252
Interstate 17/Camelback Southbound on-ramp	1.302	1.252
Superstition/Rural Eastbound on-ramp	1.263	1.260
Superstition/Rural Westbound on-ramp	1.313	1.260

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

The I-17 on-ramps are adjacent to freeways without HOV lanes in urban areas which, as stated previously, have a mean daily auto occupancy of 1.252. The Superstition on-ramps are adjacent to freeways without HOV lanes in core areas which have a mean daily auto occupancy of 1.260. It is interesting to note that those on-ramps that are in the PM peak direction (Superstition/Rural EB and I-17/Camelback NB) have lower auto occupancies than those ramps that are in the AM peak direction. These ramps have a higher auto occupancy than the adjacent freeway lanes.

It is reasonable that ramp auto occupancies are higher than freeway mainline occupancies. If work trips are longer than non-work trips, then a greater percentage of freeway mainline VMT will be for work purpose than ramp volumes. Each trip travels on one on-ramp, no matter how long it stays on the freeway. If non-work trips have a higher average occupancy than work trips, then ramp auto occupancies will be calculated higher than freeway mainlines.

Vehicle Classification

As part of the effort to obtain information on auto occupancy, data were also collected on eight categories of vehicle classification.

These categories included:

- private autos
- motorcycles
- recreational vehicles
- buses
- commercial passenger vans
- light commercial vehicles
- medium trucks
- large trucks

Table ES-6 shows the overall classification of automobiles for all facility types, area types, and time of day periods collected during the study. These values are weighted by vehicle miles travel (VMT).

Table E-6. Vehicle Classification in MAG Region

Vehicle Type	Percentage
Private Auto	88.7
Passenger Vans	0.3
Light Trucks	4.9
Medium Trucks	2.5
Heavy Trucks	2.3
Motorcycles	0.6
Recreational Vehicles	0.2
Buses	0.5

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

Evaluation of HOV Lanes

HOV lanes were first introduced into the MAG freeway system with the opening of the Papago Freeway (I-10) west of I-17. The system now contains approximately 27 miles of freeway with HOV lanes. Additional HOV lanes are planned with the opening of Loop 202 to the Outer Loop. This facility is currently open from I-10 to the Hohokam Freeway. This study provides the first opportunity to evaluate the operation of HOV lanes in the Phoenix metropolitan area. This section examines utilizations of HOV lanes, priority lane violation rates, and an overall analysis of the effectiveness of HOV lanes as a transportation control measure (TCM).

To evaluate priority lane effectiveness, two values have been calculated in this report, *auto occupancy and vehicle occupancy*. Auto occupancy is defined as the average occupancy when considering only the occupancy of the private auto classification. Vehicle occupancy is the average occupancy considering all vehicles on the facility. For each of the classifications where data were collected, a mean occupancy for that classification was used. Table ES-7 shows the occupancies for each classification.

Table ES-7. Mean Occupancies by Vehicle Classification

	HOV Lane		Non-HOV Lane	
Vehicle Type	Mean Occupancy	Percentage	Mean Occupancy	Percentage
Passenger Vans	10.5	0.2	5.8	0.5
Light Trucks	2.2	4.3	1.3	4.6
Medium Trucks	2.0	0.7	1.1	2.9
Heavy Trucks	2.0	0.2	1.1	5.2
Motorcycles	1.1	5.8	1.1	0.4
Recreational Vehicles	2.2	1.6	1.3	0.2
Buses	35(AM)/40(PM)	0.9	35(AM)/40(PM)	0.2

1. Average occupancy of Van Pools as provided by RPTA.
2. Average occupancy of Buses as provided by "Phoenix Metropolitan Area Quarterly Transit Ridership Report March, 1992," Phoenix Transit System.

All other values are estimated.

A tabulation of auto occupancies and vehicle occupancies for the freeway facilities was created. Auto and vehicle occupancy was tabulated for both HOV and non-HOV lanes (freeways with HOV lanes) and for all lanes (freeways without HOV lanes) and is given in Table ES-8.

Table ES-8. Auto and Vehicle Occupancy for Freeways

Facility	Lane	Mean Auto Occupancy	Mean Vehicle Occupancy
Freeways with HOV Lanes	priority	2.162	2.383
Freeways with HOV Lanes	non-priority	1.247	1.327
Freeways without HOV Lanes	all	1.288	1.357

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

As depicted in Table ES-8, the occupancies on priority lanes are considerably higher than those of the adjacent non-priority lanes.

The evaluation of HOV facilities as to their ability to reduce air and noise pollution is one goal of this study. Evaluating the impact of HOV facilities across North America has been of interest to many transportation professionals as told by a recent article by Turnbull[1], et al. which states the following:

> Evaluating the impact of HOV facilities has been a topic of interest and discussion among transportation professionals in recent years. Potential evaluation criteria, appropriate effectiveness measures, evaluation methodologies, and data collection activities have been a major focus of sessions at recent TRB Annual Meetings and National HOV Conferences, as well as numerous reports. While there appears to be general agreement among transportation professionals that HOV facilities should be evaluated, a consensus does not appear to exist regarding the most appropriate measures to use, the performance thresholds the projects should meet to be considered effective, or the data collection techniques. To date, the evaluations that have been conducted have often focused on general evaluation criteria and, given the nature of many of the facilities and limited funding for data collection, before-and-after evaluations have often been limited. In some cases, this has resulted in insufficient data to make meaningful comparisons. In addition, the lack of uniformity between approaches used in different areas has made comparisons between projects difficult.

Most evaluations of HOV lanes are in the form of before-after studies. These studies are structured to examine the same location before and after the implementation of the HOV lane. This is somewhat different than the HOV lanes constructed in the Phoenix area, as most of these were added with new freeway segments or widening of freeway segments. There does not appear to be any study which evaluates the effectiveness of HOV lanes based on the measured occupancies of freeways with and without HOV lanes.

Using the data collected for this MAG study, three different measures of effectiveness are presented to evaluate the HOV facilities

[1] Suggested Procedures for Evaluating the Effectiveness of Freeway HOV Facilities, Katherine F. Turnbull, Russell H. Henk and Dennis L. Christiansen, U.S. Department of Transportation Record DOT-T-92-01.

Effect of Congestion of HOV Usage

A review of the data indicates the facilities with traffic flowing at or below 1400 vehicles per hour per lane are in an uncongested state. As the flowrate increases over 1400, congestion begins to increase. Some facilities may exist in an uncongested state most of the day, incurring congestion only during the peak hours. A table was created showing how vehicles per lane and passengers per lane differ between those hours when the non-HOV lanes are congested and those hours when the non-HOV lane are not congested. This is presented in Table ES-9.

Table ES-9. Variation in Passengers per Lane per Hour and Vehicles per Lane per Hour by Freeway Congestion

	Vehicles/Lane/Hour		Passengers/Lane/Hour	
Facility Congestion Level	HOV	Non-HOV	HOV	Non-HOV
Congested	474	1712	1135	2147
Uncongested	140	913	343	1240
All	238	1147	575	1505

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992.

The data shown in Table ES-9 indicate that the number of passengers per lane in the HOV lane of congested facilities is much higher than the passengers per lane on uncongested facilities. The table shows that even when adjacent freeway lanes are congested, the vehicle flow rate of 474 vehicles per hour indicates that the HOV lane is operating at a very acceptable level of service. The number of vehicles on the HOV lanes is approximately one third those vehicles in adjacent congested non-HOV lanes, yet is carrying half as many passengers as the adjacent HOV lanes. If the HOV lane were opened to non-HOV traffic, the facility would be congested, as we have defined it. With the HOV lane, travelers have the option of avoiding congestion.

Mode Shift Effects

Figure ES-6 shown previously indicates that the average auto occupancies of freeways with HOV lanes is greater than the auto occupancies of freeways without HOV lanes. In the urban area type, this is a significant difference. One possible explanation for this difference in auto occupancy may be the propensity for drivers to change their driving habits due to the presence of the HOV facility. If drivers were not changing their habits, then one would expect the occupancy rates of both facilities to be similar. In fact, in the suburban area type, the occupancies are similar. However, in the suburban area, there is little advantage to using the HOV lane due to the relatively uncongested freeway operation.

This analysis shows that in the Phoenix area, there is a real mode shift of single passenger autos to higher occupancy autos on HOV facilities in urban areas.

Persons Utilizing HOV Lanes

Another evaluation of the effectiveness of HOV lanes is to tabulate the number of people being carried in the priority and non-priority lanes. Even though the raw volume of vehicles on the priority lane is typically lower than the adjacent lanes, the occupancy of these vehicles is considerably higher. If the priority lane carries more people than the adjacent lanes, then it is supposed that this is a more efficient means of automobile travel since the priority lane never incurs delay due to congestion.

Table ES-10 shows the average vehicles and passengers per lane for those facilities with HOV lanes. These values are the weighted average for the entire 13 hour data collection period. As shown in the table, priority lanes carry, on the average, less than half of the passengers carried on the non-priority lanes.

Table ES-10. Lane Passenger Volume by Area Type (Freeways with HOV Lanes)

	Vehicles/Lane		Passengers/Lane	
Area Type	HOV Lane	Non HOV Lane	HOV Lane	Non HOV Lane
Core	262	1170	609	1504
Urban	227	1172	573	1516
Suburban	81	602	208	850

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

A tabulation of the number of passengers carried on each HOV facility by time of day was performed to see if there was any instance where the HOV lane carried more passengers than the adjacent non-HOV lanes. There were six hours where this occurred and they are shown in Table ES-11.

Table ES-11. Lane Passenger Volume by Time of Day

		Passengers/Lane	
Location	Time of Day	HOV Lane	Non HOV Lane
I-10/48th St. Eastbound	4:00-5:00 PM	2064	1779
I-10/48th St. Eastbound	5:00-6:00 PM	2685	1640
I-10/Broadway Eastbound	4:00-5:00 PM	2119	2001
I-10/Broadway Eastbound	5:00-6:00 PM	1997	1597
I-10/10th St. Eastbound	5:00-6:00 PM	2106	1992
I-10/67th Ave. Eastbound	7:00-8:00 AM	1813	1483

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992.

The locations given in Table ES-11 are heavily congested during these hours. At these locations, then, it appears that the HOV lane is highly effective, allowing those people who are using it to travel at reasonable speeds. During the remainder of the day, however, the priority lanes facilities at these locations are not as effective.

Summary of effectiveness of HOV lanes

In reviewing the results of these three analysis, it would appear that HOV lanes become very effective in periods of high congestion on the adjacent freeway lanes. During periods of little congestion, the number of people on the HOV lane drops to a much smaller percentage of the total freeway traffic. Based upon the experimental design of the data collection, freeways with HOV lanes have a significantly higher auto occupancy than freeways without HOV lanes in the urban area type. It is reasoned that the cause of this increase in occupancy is due to a shift of single occupant vehicles to higher occupancy modes of travel.

If the goal of an efficient transportation system is to increase the overall person carrying capacity, then it would appear that HOV lanes are very effective in moving large volumes of people at relatively uncongested speeds. They become more effective as the adjacent freeway lanes become overloaded. It should be pointed out, however, that there is a wide range of goals by which the effectiveness of HOV lanes can be evaluated. These include:

- Creating an uncongested pathway for express buses
- Providing travel time savings and more reliable trip time to high occupancy vehicles
- Increasing overall number of people carried by the facility

High Occupancy Vehicles in Non-Priority Lanes

Sometimes high occupancy vehicles will not utilize the priority lanes. There are several reasons why this may occur. It is possible that the trip length is so short that it is not worth the driver shifting over to the priority lane. When the facility is not congested, there may not be a time savings in doing so. Also, HOV vehicles must usually enter and exit the freeway from right hand ramps, requiring travel in the non-priority lanes before reaching the HOV lanes and after leaving the HOV lanes. The lowest percentage of HOV vehicles in non-priority lanes occurs in the 6:00 to 7:00 AM and 7:00 to 8:00 AM time periods. This percentage steadily increases all day until 2:00, where it starts to decrease. This makes sense, because the freeways are starting to get more congested in this time frame and there are more work trips on the roadways which tend to be single passenger vehicles.

In the 6:00 to 7:00 PM time period, the percentage of non-priority lane vehicles which are HOV's jumps considerably. This is probably due to the fact that in this time period, there are a lot of non-work trips with higher occupancies on the road.

The average percentage of high occupancy vehicles in non-priority lanes is given below in Table ES-12.

Table ES-12. Percentage of High Occupancy Vehicles in Non Priority Lanes by Area Type

Mean	N	Area Type
22.2%	52	Suburban
18.4%	78	Urban
15.6%	78	Core

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

There is approximately 10-25% of the vehicles in non-priority lanes which are high occupancy vehicles. The lowest percentage (13%) occurs in the AM time period (6:00-9:00 AM) and the highest percentage (25%) occurs in the evening time period (6:00-7:00 PM). During the time between these two periods, the percentage is approximately 18 to 22%.

Occupancies of Priority and Non-Priority Lanes

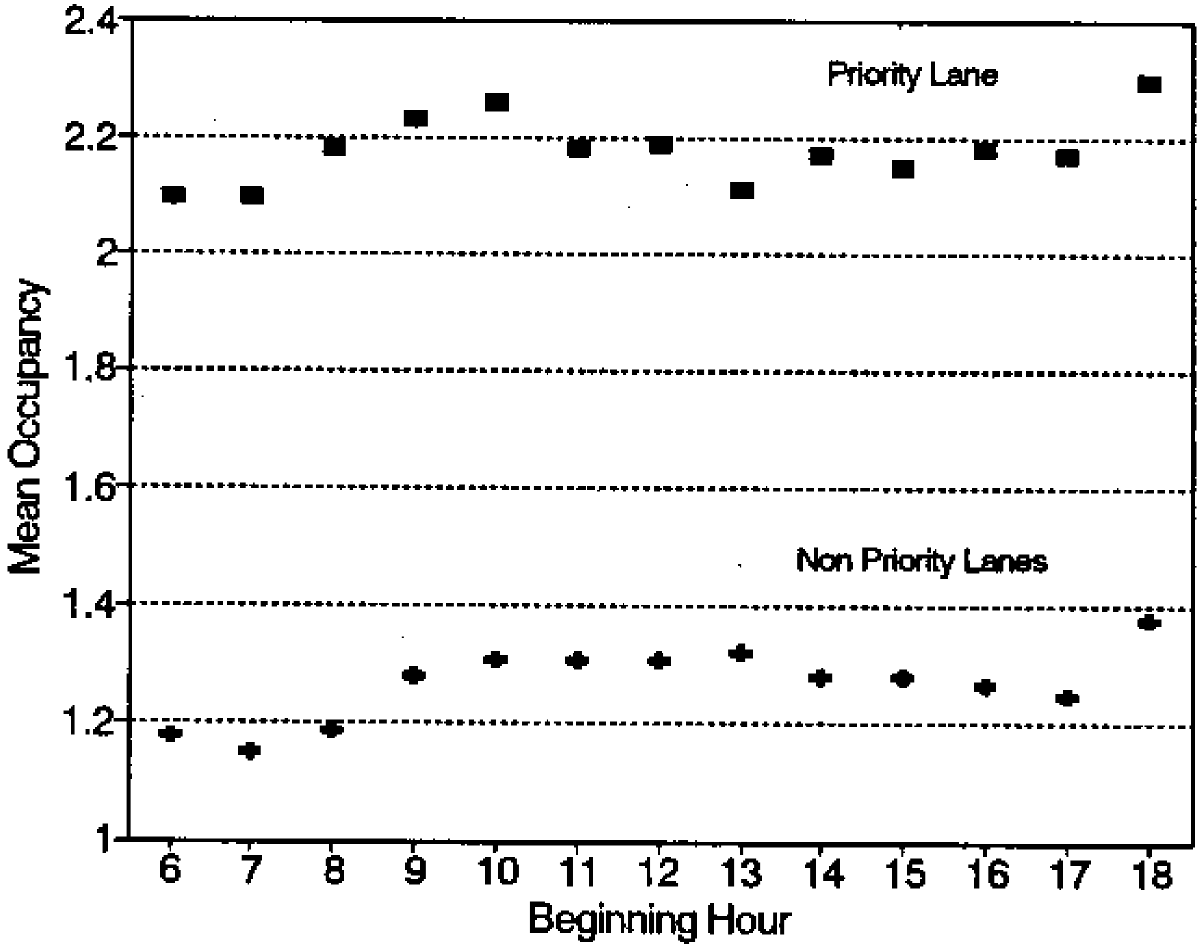
Because of the necessity to have at least two occupants in a priority lane, the average auto occupancy of priority lanes should be greater than 2.0. The lowest auto occupancy for both priority and non-priority lanes occurs during the AM peak. Area wide priority lanes have an auto occupancy of 2.10 persons per vehicle during the 6:00-7:00-8:00 AM time periods. The area wide auto occupancy of non-priority lanes during the 7:00-8:00 time period is 1.15 persons per vehicle.

The highest area-wide auto occupancy occurs during the 6:00-7:00 PM time period, with 2.30 and 1.38 for priority and non-priority lanes, respectively. The average 13-hour occupancy in priority and non-priority lanes is 2.18 and 1.27, respectively.

The mean occupancy of priority and non-priority lanes is shown in Figure ES-7. The plot shows that occupancies on the priority lanes mimic the occupancies on the non-priority lanes with the exception of the 11:00 AM to 2:00 PM time period where the priority lane occupancy dips slightly while the non-priority lane occupancy remains relatively constant.

Figure ES-7. Average Auto Occupancy of Priority and Non-Priority Lanes

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992


Priority Lane
Non Priority Lanes
Mean Occupancy
2.4
2.2
2
1.8
1.6
1.4
1.2
1
6 7 8 9 10 11 12 13 14 15 16 17 18
Beginning Hour

Priority Lane Violations

In order to determine violation rates, tabulations were developed showing the percentage of one-person automobiles driving in priority lanes. The overall violation rate, regionwide is approximately 6%. This varies somewhat depending on the location of the facility as shown in Table ES-13. This rate is generally lower than rates experienced in other cities for concurrent flow, non-separated HOV lanes.

Table ES-13. Priority Lane Violations by Area Type

Mean	N	Area
8.52%	78	Core
4.29%	78	Urban
3.08%	52	Suburban

Source: Counts taken by Lee Engineering on Weekdays during April and May, 1992

One of the more interesting findings in the data is the relatively higher violation rate in the core area. A recent article[2] on the public's attitudes toward the Seattle area HOV system notes that one factor that contributes to the public's confidence in and attitude toward HOV facilities is the violation rate. The primary purpose of the HOV lane system is to provide a travel time advantage to those people who make the extra effort to form a car pool. If people who do not make this effort are stiff afforded the same travel time benefits then the system could be in jeopardy.

The same article also notes some of the difficulties associated with enforcement of HOV facilities. However, if the Phoenix area system is to continue to succeed, rules of the system must be enforced.

As stated previously, the overall violation rate of priority lanes is approximately 6%. In the Rutherford, et al.[3] article on monitoring of HOV violations, the violation rates of various facilities within other states are reported. The type of HOV facility utilized in the MAG region is concurrent non-separated HOV lanes. According to Rutherford, Virginia has the highest violation rate of 34% for this type of facility. The violation for Colorado is the lowest at 9-31%. Therefore, the violation rate measured in Maricopa County is lower than the violation rate of similar facilities in other states.

Recommendations for Further Study

In performing the auto occupancy counts of this study, it became apparent that other issues might also be addressed in future studies. The following list is a recommendation for further work in the field of auto occupancy and HOV lane use.

---

[2]"Public Attitude Toward the Seattle Area HOV System and Effectiveness of the HERO Hotline Program" Transportation Research Record 1299, 1991.

[3]Agency Practice for Monitoring Violations of High-Occupancy-Vehicle Facilities, G. Scott Rutherford, Ruth K. Kinchen, and Leslie N. Jacobson, Transportation Research Record 1280, 1991.

Collection of travel speed There is probably a high correlation between the travel speed of adjacent lanes and the usage of priority lanes. A study which collects both these data would be beneficial in the staging of HOV construction.

Monitoring of Priority Lane Violation through Freeway Management System ADOT has created a freeway management system for the freeways throughout the MAG region. It may be possible to monitor both auto occupancy and priority lane violation with this system. Contact should be made with the developers of the management system to see if the equipment being installed could also monitor this data. While the violation rate at present is not high compared to other states, it could get higher. Increased violation rates may reduce the public's respect for the HOV system.

Opinion Survey on HOV Usage An opinion survey that questions motorist's as to their perception of the HOV system would also be a good method to evaluate system performance. As state previously, the survey would have to be structured so that little judgement would be left to the respondent. The Regional Public Transportation Authority (RPTA) has recently conducted such a survey to serve as a base for comparison of changes in attitudes and perceptions.

Continued Monitoring of Auto Occupancy Auto occupancies have been collected in the region since 1973. Prior to this study, the last measurement occurred in 1988. Continued monitoring of auto occupancy is worthwhile.

CHAPTER ONE

INTRODUCTION

There is a growing need to increase vehicle occupancy as part of an effort to reduce fuel consumption, traffic congestion and air pollution. Vehicle occupancy rates are used to validate the transportation planning models and to monitor general trends in travel characteristics. These rates may also be used to evaluate the effectiveness of such measures as carpooling programs, park and ride facilities, and high-occupancy vehicle (HOV) lanes.

As part of an on-going process to collect traffic data and monitor travel characteristics, the Maricopa Association of Governments Transportation Planning Office (MAGTPO) conducted annual surveys of vehicle occupancy from 1977 through 1982. Vehicle occupancy information is useful in a variety of transportation planning applications, and is important for air quality modeling activities. The last update of vehicle occupancy rates was done in 1988.

The air quality impact of freeway HOV lanes was modeled for consideration in the MAG air quality plans, but no formal assessment of the performance of existing HOV lanes had been conducted. HOV bypass lanes at ramp meters have also been proposed as a transportation control measure. Based on the need for additional data, the MAGTPO contracted with Lee Engineering to measure vehicle occupancy in the Phoenix Metropolitan area.

This study was funded from an Air Quality Fund grant to develop improved auto occupancy data, including an assessment of high-occupancy vehicle lane use, for the Maricopa County Urban Planning Area. The purpose of this study is to:

- determine vehicle occupancy rates on arterials and freeways by area type and time of day, and

- assess the effectiveness of HOV lanes as a transportation control measure (TCM) for air quality improvement.

Simultaneous with obtaining vehicle occupancy data, the number of light and heavy duty commercial vehicles, buses, recreational vehicles and motorcycles were also counted. These data are required for air quality emission calculations as well as roadway design.

Structure of This Report

This report is composed of six main chapters.

Chapter One contains introductory background information and describes the purpose of this study. Chapter Two describes some of the specific requirements of the study, the experimental design used to achieve those requirements and data collection methodology developed. Chapter Three presents the results of the vehicle occupancy data and a description of the factors which affect vehicle occupancy. Chapter Four provides a brief summary of findings related to vehicle classification. Chapter Five is a summary of the data which relates to the utilization and evaluation of the effectiveness of HOV lanes. Chapter Six provides conclusions from the study.

Sources of Additional Information

This report is the compilation of four separate working papers which were also prepared as part of this project.

Working Paper 1:	Data Collection Methodology and Data Collection Schedule
Working Paper 2:	Auto Occupancy
Working Paper 3:	Vehicle Classification
Working Paper 4:	Assessment of HOV Lane Performance

Computer spreadsheet files summarizing the data and original worksheets of data collected in the field were submitted to MAGTPO in a separate binder.

These additional working papers provide a complete documentation of the methodologies employed in this study.

CHAPTER TWO

STUDY DESIGN AND DATA COLLECTION PROCEDURES

This chapter defines the variables considered as part of this study and the experimental design devised to indicate the response in vehicle occupancies by these parameters. A discussion of the anticipated tolerance of the data collection and the automated data collection procedure is also presented.

Study Needs

There are several factors which were considered in the development of the design of this data collection effort. MAGTPO requested that vehicle occupancy be evaluated in terms of three factors: area type, roadway functional classification, and time of day.

Area Type

MAGTPO uses a UTPS planning model for transportation planning in the metropolitan Phoenix area. In this model, the speed and capacity of roadways vary by Area Type - a function of employment density and population density. Area type, as used in this study, is defined by density, where density is total population plus two times total employment, all divided by gross area. "Core" area is where density is greater than 10,000 per square mile. "Urban" densities are 5,000 to 10,000 per square mile. "Suburban" is less than or equal to 5,000. These densities are established on a district level and those areas with high densities are modeled with slower speeds than those areas with lower densities. The MAG planning model has 5 stratifications of area type; however, for the purposes of this study, area type is stratified into three levels:

- core (area types 1 and 2)
- urban (area type 3), and
- suburban (area types 4 and 5).

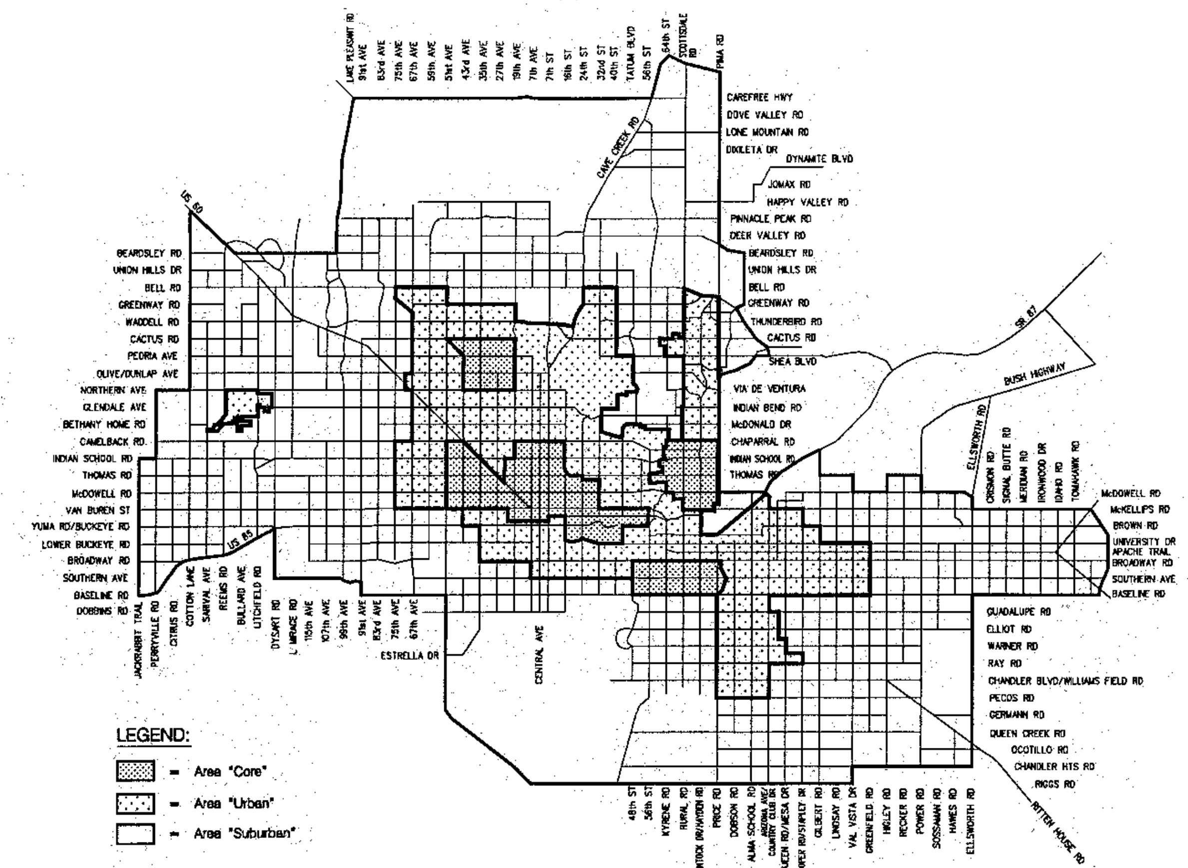
A map depicting these area types is shown in Figure 1.

Functional Classification

There are three levels of functional classification used in this study:

- freeways without priority lanes
- freeways with priority lanes
- arterial streets

One of the questions posed by this study was: "*Do freeways with HOV lanes have higher auto occupancy rates than freeways without HOV lanes*?" In order to answer this question, it was necessary to collect vehicle occupancy on both freeways with and without priority lanes. There is a substantial network of HOV facilities along some of the freeways within the region and they are shown in Figure 2.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PIMA RD
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PINNACLE PEAK RD
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BEARDSLEY RD
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CACTUS RD
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McDOWELL RD
McKELLIPS RD
BROWN RD
UNIVERSITY DR
APACHE TRAIL
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DOBBINS RD
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JACKRABBIT TRAIL
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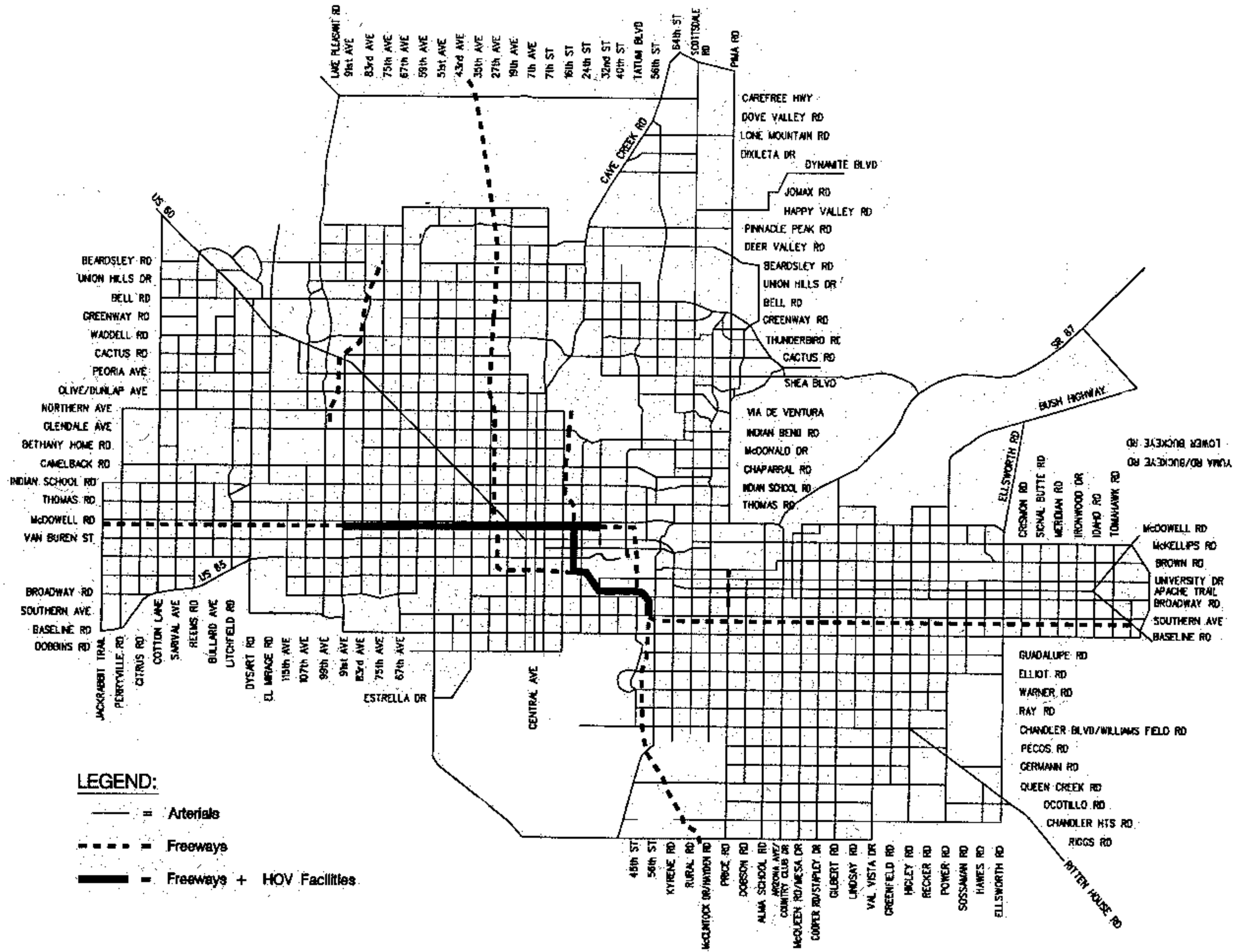
ELLIOT RD
WARNER RD
RAY RD
CHANDLER BLVD/WILLIAMS FIELD RD
PECOS RD
GERMANN RD
QUEEN CREEK RD
OCOTILLO RD
CHANDLER HTS RD
RIGGS RD
RITTEN HOUSE RD
48th ST
56th ST
KYRENE RD
RURAL RD
McCLINTOCK DR/HAYDEN RD
PRICE RD
DOBSON RD
ALMA SCHOOL RD
ARIZONA AVE/COUNTRY CLUB DR
McQUEEN RD/MESA DR
COOPER RD/STAPLEY DR
GILBERT RD
LINDSAY RD
VAL VISTA DR
GREENFIELD RD
HIGLEY RD
RECKER RD
POWER RD
SOSSAMAN RD
HAWES RD
ELLSWORTH RD
LEGEND:
= Area "Core"
= Area "Urban"
= Area "Suburban"

Figure 1. Area Types within the MAG Region



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GILBERT RD
LINDSAY RD
VAL VISTA DR
GREENFIELD RD
HIGLEY RD
RECKER RD
POWER RD
SOSSAMAN RD
HAWES RD
ELLSWORTH RD
LEGEND:
= Arterials
= Freeways
= Freeways + HOV Facilities

Figure 2. Facility Types in the MAG Region

Time of Day

Data were collected for four time of day periods and these periods are shown in Table 1.

Table 1. Time Periods for Auto Occupancy Determination

Time Period	Time of Day
AM peak	6-9 AM
Midday	9-12 AM 2-4 PM
PM peak	4-6 PM
Evening	6-7 PM

While not originally intended to be collected, early in the study design, it was felt there might be a significant change in vehicle occupancies for the time period between noon and 2:00 PM. This is a time period when there are several trips related to lunch and shopping. These trips typically have higher auto occupancies and it was felt that these time periods should be sampled also. A preliminary analysis showed that this data could be collected within the allocated data collection hours, so it was decided that these time periods should be included in the study.

Sites from Previous Studies

One of the objectives of this study was to determine how vehicle occupancy has changed in the Phoenix metropolitan area over time. To fulfill this objective, six sites which were monitored in previous years were chosen for evaluation in this study. Four of these locations were along arterial streets and two of these locations were along freeway segments.

Candidate Sites for HOV Bypass Ramps

Auto occupancy data were also collected at four freeway on-ramps to determine the potential demand for HOV bypass ramps.

Experimental Design

In order to see the change in vehicle occupancy by these factors, an experimental design approach was undertaken. This is a fixed effect 3 by 3 by 4 factorial design. These parameters are Facility Type (at 3 levels), Area Type (at 3 levels), and Time of Day (at 4 levels) as described previously.

By using these stratifications, it was determined that vehicle occupancy would be sampled every hour from 6:00 AM to 7:00 PM. In this manner, vehicle occupancy could be tabulated for each of the thirteen time of day hours, or they could be combined into the MAGTPO specified time periods blocks described in Table 1, above. This is graphically displayed in Figure 3.

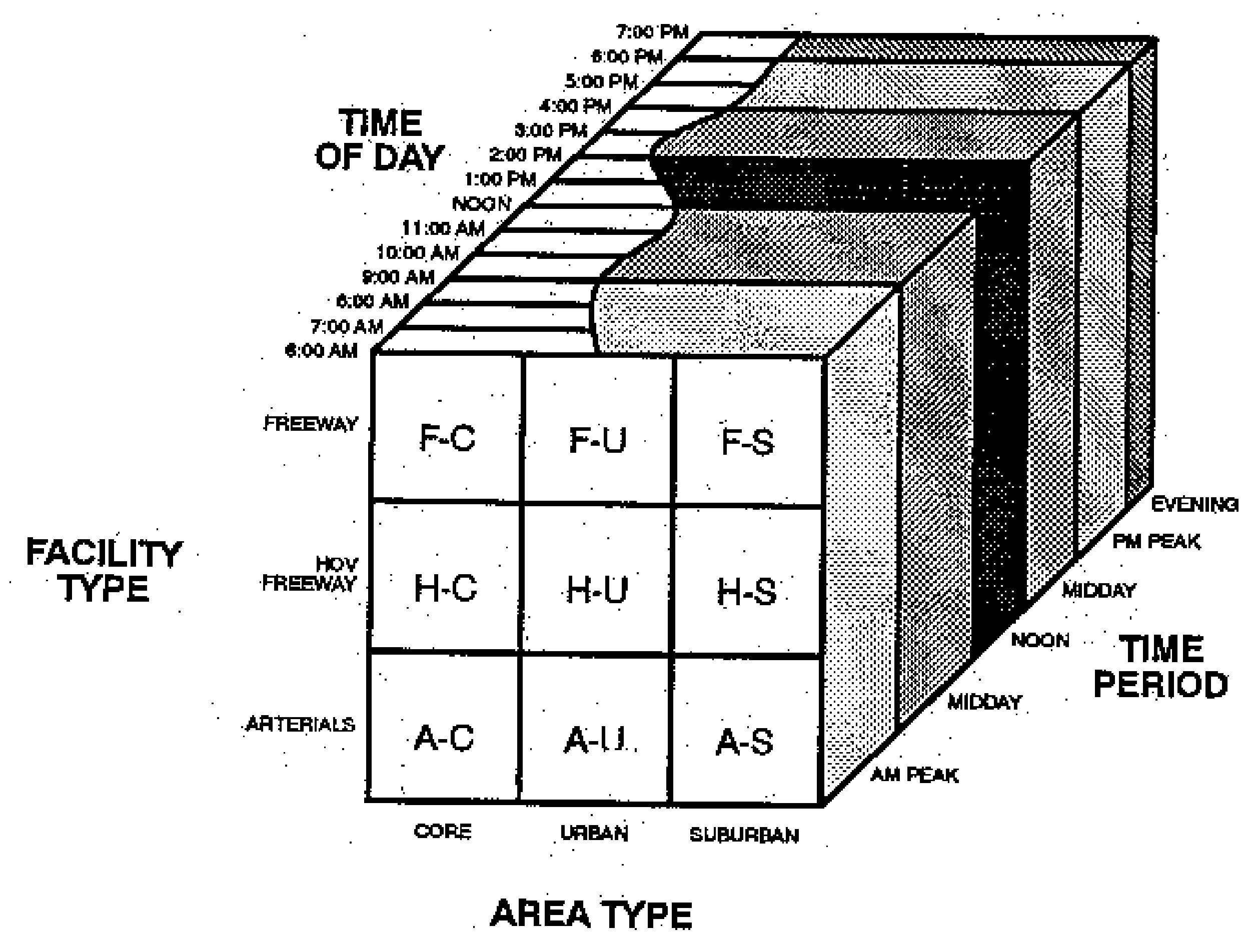

TIME OF DAY
7:00 PM
6:00 PM
5:00 PM
4:00 PM
3:00 PM
2:00 PM
1:00 PM
NOON
11:00 AM
10:00 AM
9:00 AM
8:00 AM
7:00 AM
6:00 AM
FACILITY TYPE
FREEWAY
HOV FREEWAY
ARTERIALS
F-C
F-U
F-S
H-C
H-U
H-S
A-C
A-U
A-S
CORE
URBAN
SUBURBAN
AREA TYPE
EVENING
PM PEAK
MIDDAY
NOON
MIDDAY
AM PEAK
TIME PERIOD

Figure 3. Experimental Design Used in the Study

To find the differences in vehicle occupancy based upon these parameters, samples needed to be collected from each cell. It was felt that there needed to be about 6 samples per cell to predict the response of vehicle occupancies. This decision was based on an evaluation of the minimum number of observations needed in each cell to obtain a statistically reliable estimate for the cell and, in part, on the available manhours allocated to the data collection effort.

Design of Data Collection Schedule

The goal for the study design was to estimate regional occupancy by each stratification with a .02 tolerance (E) at 95 percent confidence. (Alpha=.05) after reviewing the standard deviations in the 1988 vehicle occupancy study, Vehicle Occupancy Determinators[1], and reviewing the standard deviations in vehicle occupancy in the Guide of Estimating Urban Vehicle Classification and Occupancy[2] the number of locations was estimated as follows.

---

[1] Vehicle Occupancy Determinators, Barton-Aschman Associates, Inc. Final Report, August, 1989.

[2] Guide for Estimating Urban Vehicle Classification and Occupancy, Federal Highway Administration, Urban Planning Division, September, 1980.

Auto Occupancy Determinators, 1988

In the 1988 study, the standard deviation on vehicle occupancy ranges form .393 to .901. These standard deviations assume that every vehicle counted is an observation. Therefore, by calculating the sample size using these standard deviations, the absolute number of vehicles that needs to be collected is determined. An example calculation is shown below.

$$n = \frac{z*\text{std dev}}{E}$$

$$n = \frac{1.96 * .483}{.02}$$

$$n = 2240 \text{ vehicles}$$

Therefore, in order to obtain a .02 tolerance (E) on vehicle occupancy, a sample of 2240 vehicles must be collected. It should be noted that the standard deviation reported in the 1988 study is not from a normally distributed sample.

Guide for Estimating Urban Vehicle Classification and Occupancy

In this FHWA report, standard deviations are given for vehicle occupancy; however, these are based on link-days as the sample unit. In other words, vehicle occupancy is counted the entire day at one location and the resulting average vehicle occupancy is considered a sample, n. Using this method, a recommended standard deviation is .067 for an area wide study. For a .02 (E) tolerance, 44 locations should be collected.

There were 1200 hours allotted for data collection. Approximately 25 percent of this time was reserved for recollect, leaving 900 hours to meet the desired accuracy. Since each location was counted from 6:00 AM to 7:00 PM each day, with an hour for lunch and assuming an average hour for travel time, it was anticipated that there would be abut 70 person-link-days for data collection. These were divided up as shown in Table 2. Some facilities would require two person-link-days due to a large number of lanes.

Table 2. Locations for Data Collection

n	Purpose
52	Blocked design
6	Locations from previous studies
4	Ramps

Blocked Design Data Collection Sites

As previously discussed, it was desired to have 6 sites from within each cell shown in Figure 3. Using the stratifications within area type and facility type, specific locations were randomly chosen where occupancies would be collected. There were limited facilities located within the suburban area type which had HOV lanes. Only 4 samples were drawn from this cell. A graphic depicting these locations is shown in Figure 4 and are detailed in Table 3 on page 11.

Additional Study Sites

In addition to these sites, the 6 sites from previous studies of auto occupancy in the MAG region were sampled. Data from these sites were compared to previous years to see how vehicle occupancy has changed. These sites are shown in Table 4.

Table 4. Sites with Data from Previous Studies

Location	Direction
Black Canyon Fwy (I-17) north of McDowell Rd	NB
Broadway Rd., east of Dobson Rd	EB
Indian School Rd., west of 27th Ave.	WB
7th St., north of Camelback Rd	SB
Thomas Rd., west of 56th St	WB
Maricopa Fwy. (I-10), at 32nd St.	EB

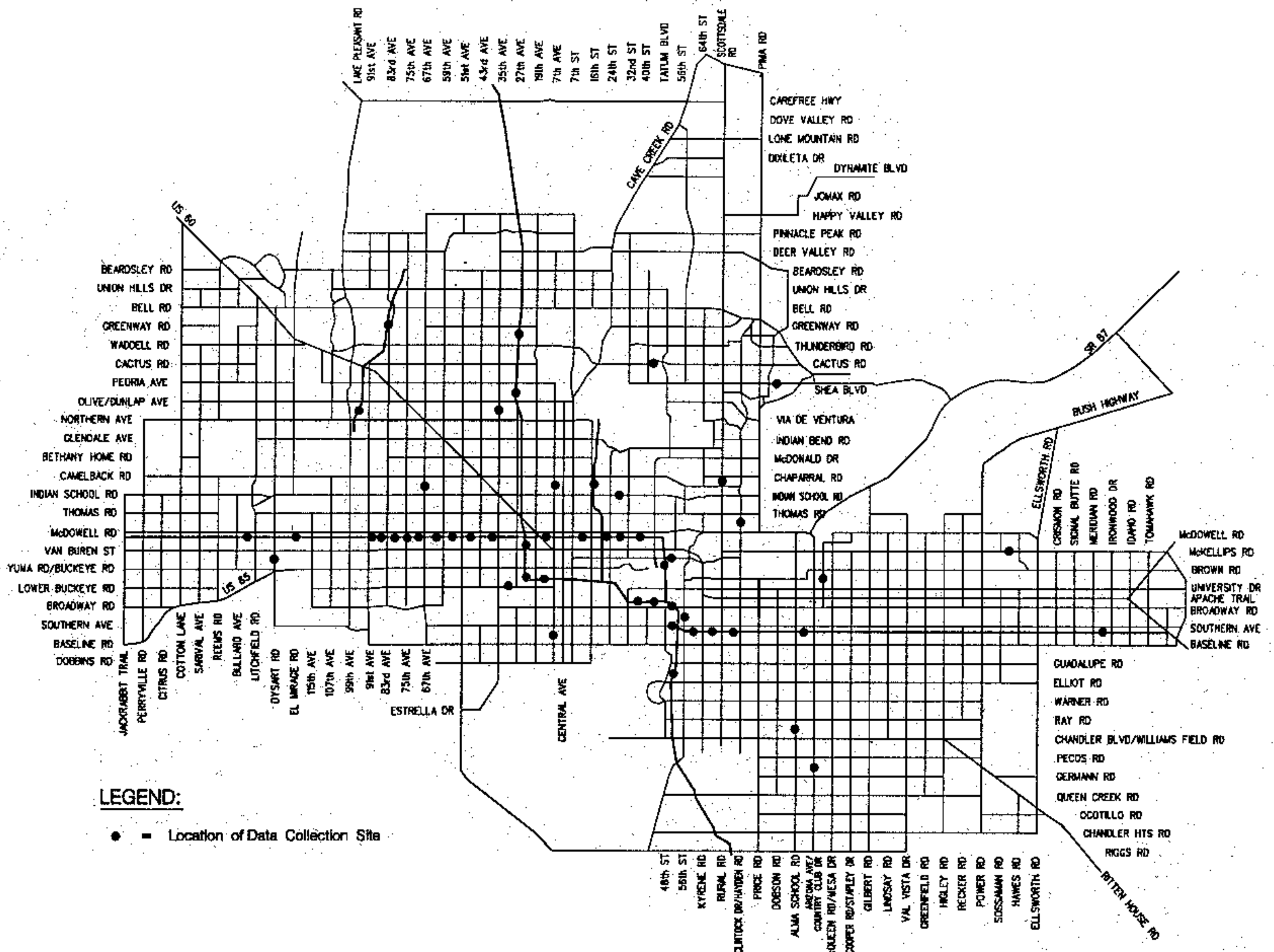
It was desired to collect vehicle occupancy at 4 ramp locations. These were collected to assess the potential demand for HOV bypass ramps. These ramps identified are shown in Table 5.

Table 5. Representative Freeway Ramps Sites

Location	Ramp
I-17 at Camelback Rd	NB & SB Entrance Ramp
Superstition Fwy. At Rural Rd.	EB & WB Entrance Ramp

Data Collection Scheduling

The method of data collection used for this study is also recommended in the FHWA report, Guide for Estimating Urban Vehicle Classification and Occupancy. Samples of vehicle occupancy were taken on each lane of a facility. Depending on the number of lanes, one or two people were assigned to a particular location at a time. Because of the thirteen hours required to count these links form 6:00 AM to 7:00 PM, a morning shift and an evening shift was created so that data collectors would only collect for approximately 6 or 7 hours per day. The first data collector sampled from approximately 6:00 AM to 12:30 PM, and the second sampled until 7:00 PM. One data collector was adequate to count up to four lanes. However, if the facility had more than four lanes, two data collectors were used. The sampling periods for each facility based on number of lanes is shown in Table 6.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WARNER RD
RAY RD
CHANDLER BLVD/WILLIAMS FIELD RD
PECOS RD
GERMANN RD
QUEEN CREEK RD
OCOTILLO RD
CHANDLER HTS RD
RIGGS RD
RITTEN HOUSE RD
48th ST
56th ST
KYRENE RD
RURAL RD
McCLINTOCK DR/HAYDEN RD
PRICE RD
DOBSON RD
ALMA SCHOOL RD
ARIZONA AVE/ COUNTRY CLUB DR
McQUEEN RD/MESA DR
COOPER RD/STAPLEY DR
GILBERT RD
LINDSAY RD
VAL VISTA DR
GREENFIELD RD
HIGLEY RD
RECKER RD
POWER RD
SOSSAMAN RD
HAWES RD
ELLSWORTH RD
LEGEND:
● = Location of Data Collection Site

Figure 4. Final Study Locations

Table 3. Selected Locations for Auto Occupancy Determination

	LOCATION	STREET	FROM	TO	DIR
HOV-AREA TYPE CORE	1	LOOP202	24^{TH} ST	32^{ND} ST	EB

	2	I-10	7^{TH} ST	16^{TH} ST	EB
	3	I-10	35^{TH} AVE	43^{RD} AVE	WB
	4	I-10	43^{RD} AVE	51^{ST} AVE	WB
	5	I-10	7^{TH} AVE	19^{TH} AVE	WB
	6	LOOP 202	24^{th} ST	I-10	EB
HOV-AREA TYPE URBAN	7	I-10	40^{th} ST	48^{TH} ST	EB
	8	I-10	59^{TH} AVE	67^{TH} AVE	WB
	9	I-10	67^{TH} AVE	75^{TH} AVE	EB
	10	I-10	51^{ST} AVE	59^{TH} AVE	EB
	11	I-10	48^{TH} ST	BROADWAY	EB
	12	I-10	32^{ND} ST	40^{TH} ST	WB
HOV-AREA TYPE SUBURBAN	13	I-10	83^{RD} AVE	91^{ST} AVE	EB
	14	I-10	83^{RD} AVE	91^{ST} AVE	WB
	15	I-10	75^{TH} AVE	83^{RD} AVE	EB
	16	I-10	75^{TH} AVE	83^{RD} AVE	WB
FREEWAY-AREA TYPE CORE	17	I-17	DUNLAP	PEORIA	SB
	18	SUPERSTITION	56TH	KYRENE	EB
	19	SUPERSTITION	RURAL	MCKLINTOCK	WB
	20	SUPERSTITION	KYRENE	RURAL	EB
	21	143	WASHINGTON	SKY HARBOR	NB
	22	I-17	I-10	VAN BUREN	NB
FREEWAY-AREA TYPE URBAN	23	I-17	7^{TH} AVE	19^{TH} AVE	SB
	24	I-17	WADDELL	GREENWAY	SB
	25	SUPERSTITION	ALMA SCHOOL	COUNTRY CLUB	EB
	26	I-17	DURANGO CURVE		WB
	27	LOOP 202	32^{ND} ST	44^{TH} ST	EB
	28	SQUAW PEAK	CAMELBACK	INDIAN SCHOOL	SB
FREEWAY-AREA TYPE SUBURBAN	29	LOOP 101	OLIVE AVE	NORTHERN AVE	NB
	30	I-10	DYSART RD	115^{TH} AVE	EB
	31	LOOP 101	WADDELL	BELL RD	NB
	32	I-10	BULLARD	LITCHFIELD RD	WB
	33	I-10	ELLIOT	GUADALUPE	EB
	34	SUPERSTITION	MERIDIAN	IRONWOOD	EB
ARTERIAL-CORE	35	7^{TH} AVE	INDIAN SCHOOL	CAMELBACK	NB
	36	SCOTTSDALE	CAMELBACK	CHAPARRELL	SB
	37	SOUTHERN	48^{TH} ST	56^{TH} ST	EB
	38	HAYDEN	THOMAS	MCDOWELL	SB
	39	56^{TH} ST	SOUTHERN	BROADWAY	SB
	40	35^{TH} AVE	NORTHERN	OLIVE	SB
ARTERIAL-URBAN	41	ALMA SCHOOL	CHANDLER	RAY RD	SB
	42	INDIAN SCHOOL	24^{TH} ST	32^{ND} ST	EB
	43	LOWER BUCKEYE	27^{TH} AVE	35^{TH} AVE	WB
	44	67^{th} AVE	INDIAN SCHOOL	CAMELBACK	SB
	45	CENTER	UNIVERSITY	BROWN	SB
	46	WASHINGTON	WEST OF PRIEST		EB
ARTERIAL-SUBURBAN	47	DYSART RD	BUCKEYE RD	VAN BUREN	NB
	48	SHEA BLVD	92^{ND} ST	96^{TH} ST	EB
	49	MCKELLIPS RD	SOSSOMAN	HAWES	EB
	50	ARIZONA AVE	GERMANN	PECOS	NB
	51	7^{TH} AVE	SOUTHERN	BASELINE	NB
	52	CACTUS	40^{TH} ST	TATUM	WB

Table 6. Sampling Time Periods

Number of Lanes	Sampling Period per Lane per Hour per Collector (Min)	Rest Time per Hour per Data Collector (Min)	Number of Collectors Needed
1	45	15	1
2	20	20	1
3	15	15	1
4	10	20	1
5	15	22	2
6	15	15	2

The time that any lane was collected during the hour was randomly chosen. In other words, from 8:00 AM to 8:15 AM the data collector may have counted lane 2, however, from 9:00 AM to 9:15 AM, the data collector may have counted lane 1. A typical schedule is shown in Table 7.

Table 7. Typical Data Collection Schedule

Time of Day	Sample Location
8:00-8:15	Lane 1
8:15-8:30	Lane 2
8:30-8:45	Lane 3
8:45-9:00	Rest
9:00-9:15	Rest
9:15-9:30	Lane 2
9:30-9:45	Lane 1
9:45-10:00	Lane 3

Data Collection Procedure

For the purposes of this study, the method of data collection was predetermined to be direct observation of actual vehicle occupancy along selected links in the metropolitan Phoenix area. An initial meeting was held with representatives of MAG and the Regional Public Transportation Authority. At the initial meeting, it was recommended that vehicle occupancy be collected for 16 distinct categories as shown in Table 8.

An initial data collection program was developed on the TANDY 102 portable computer. Because of the number of categories, it was decided that both hands would be necessary for data collection. A field test was conducted by three members of the Lee Engineering staff and it became apparent that there were two problems with this initial design. 1) The two handed approach with keys scattered across the keyboard was very cumbersome. 2) The large number of categories made remembering the classifications difficult.

Table 8. Initial Data Collection Categories

1 Person Auto	Heavy Commercial Vehicle
2 Person Auto	Medium Commercial Vehicle
3 Person Auto	Light Commercial Vehicle
4 Person Auto	1 Person Commercial Passenger Vans
5 Person Auto	2+ Person Commercial Passenger Vans
6+Person Auto	Recreational Vehicles
Unknown Occupancy Auto	Motorcycles
Bus-Non RPTA	Bus-RPTA

Another meeting was held with MAGTPO and these concerns were discussed. There is a tradeoff between collecting all 16 categories and the accuracy of the data. If all 16 categories are desired, it was felt that this could not be collected by one individual. Either two people per lane or video tape data collection would be necessary. If the categories could be narrowed, then one person would be able to collect this data, and more data could be collected. After some discussion, it was decided that the 16 categories would be narrowed to 12, and that all 12 keys would be accessible by one hand position. The 12 categories are shown in Table 9.

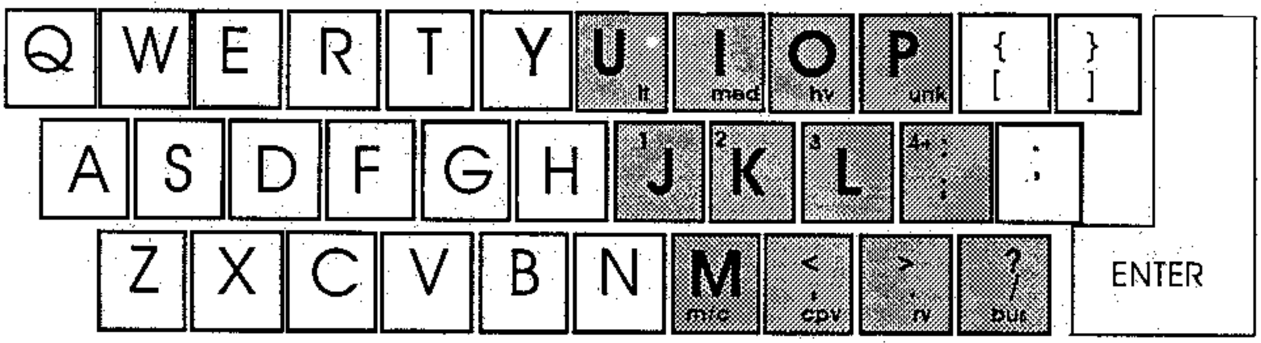
Table 9. Final Data Collection Categories

1 Person Auto	Marked Vehicles
2 Person Auto	Medium Commercial Vehicles
3 Person Auto	Heavy Commercial Vehicles
4+ Person Auto	Commercial Passenger Vans
Unknown Occupancy Auto	Recreational Vehicles
Motorcycles	Buses

These 12 categories were then reprogrammed into the TANDY 102 portable computer. Additionally, the keys were remapped so that all would be accessible from one hand position. With the right hand centered on the 'J' key, all 12 positions are easily accessed without having to look at the keyboard. This is shown in Figure 5.

This new category definition and hand positioning was then field tested and found to be manageable by Lee Engineering staff members. Data was then collected weekdays during April and May of 1992.

After the data collection, the data was downloaded from the Tandy 102s into spreadsheet files. The raw data sheets notebook and a computer disk containing spreadsheets of the data are included in a separate notebook.



lt	light truck
med	medium truck
hv	heavy truck
unk	unknown occupancy
1	1 person auto
2	2 person auto
3	3 person auto
4+	4 or more person auto
m/c	motorcycles
cpv	commerical passenger vans
rv	recreational vehicles
bus	bus

Figure 5. Tandy 102 Keyboard Layout for Vehicle Occupancy Data Collection

CHAPTER 3

AUTO OCCUPANCY

The raw data from the spreadsheet files were downloaded into an ASCII text file for processing by OS/2 SAS[R3]. The first step in the analysis of the data was to expand the vehicle and person short counts to total hour estimates. For example, the HOV lanes were counted for two 15 minute periods each hour while other lanes on the HOV facilities were counted for one 15 minute period each hour. In this case, the counts for HOV lanes were given half the weight of the counts for other lanes. Once each short count had been properly weighted, the short counts within each hour were consolidated by SAS into a mean auto occupancy for each of the sites by time of day. The mean occupancy for each of the 52 locations is included in Working Paper 3.

The final database includes 62 locations. The total number of hours of useable data is 621 hours, as shown in Table 10.

Table 10. Hours of Useable Collected Data

Source	Hours
Block Design (52 sites)	516
Previous Locations (6 sites)	66
Ramp Locations (4 sites)	39
Total	621

Mean auto occupancy for 4+ vehicles was calculated to be 4.4 based upon data contained in the 1982 study. This data was not reported in the 1988 study. In this study, auto occupancy was calculated as the average occupancy of those vehicles classified as automobiles. It does not include other classifications such as RV's, motorcycles, vans, etc. Automobiles with unknown occupancies were ignored.

Blocked Design

Full Model

Using these data, an analysis of variance was performed using PROC GLM within SAS. The initial evaluation of the data was based on the full model, including the three main effects (AREA, TYPE, and HTIME) and all interaction terms.

AREA is the area type as provided by MAG and includes Core, Urban, and Suburban. Area type, as used in this study, is defined by density, where density is total population plus two times total employment, all divided by gross area. "Core" area is where density is greater than 10,000 per square mile. "Urban" area is 5,000 to 10,000 density per square mile. "Suburban" is less than or equal to 5,000. TYPE is broken

[3]OS/2 SAS [R] is registered trade mark of the SAS Institute Inc.

into three levels, freeways with HOV lanes, freeways without HOV lanes, and arterial streets. HTIME is time of day by hour with HTIME at 13 levels, one for each hour from 6:00 AM to 7:00 PM.

The analysis of variance indicated that all three main effects, AREA, TYPE and HTIME are highly significant predictors of auto occupancy. Additionally, the AREA*TYPE interaction is significant.

A series of residual plots were examined to evaluate model adequacy. A review of the plots did not reveal any serious departures from the equality of variance assumption. A full discussion of the residual analysis may be found in Working Paper 3.

Reduced Model

Based upon the results from the full model, a new model was created which included only the main effects (AREA, HTIME, and TYPE) and the AREA*TYPE interaction. The analysis produced the following ANOVA as shown in Table 11, below. Both type I and type III sum of squares (SS) are reported here because there was not an equal number of observation in all cells resulting in an unbalanced design. Type ISS for all effects add up to the model SS. The type III SS does not have this property for an unbalanced design. Type I hypotheses are generally used for balanced ANOVA models, which type III hypotheses are considered more appropriate for the unbalanced design. For this reason, hypotheses based on the type III SS are employed. The column on the far right of Table 11 is the alpha value by which the source of variance is significant.

Table 11. ANOVA from Reduced Model

Source	DF	Type ISS	Mean Square	F Value	Pr > F
AREA	2	1.65215694	0.82607847	85.90	0.0001
TYPE	2	0.20647341	0.10323670	10.74	0.0001
HTIME	12	2.73127476	0.22760623	23.67	0.0001
AREA*TYPE	4	0.12752021	0.03188005	3.32	0.0106
Source	DF	Type III SS	Mean Square	F Value	Pr > F
AREA	2	1.58001342	0.79000671	82.15	0.0001
TYPE	2	0.20164495	0.10082248	10.48	0.0001
HTIME	12	2.73127476	0.22760623	23.67	0.0001
AREA*TYPE	4	0.12752021	0.03188005	3.32	0.0106
ERROR	655	6.29898242	0.00961677		
TOTAL	675	11.01640774			

The full output form the SAS run for the reduced model is found in Working Paper 3.

Discussion

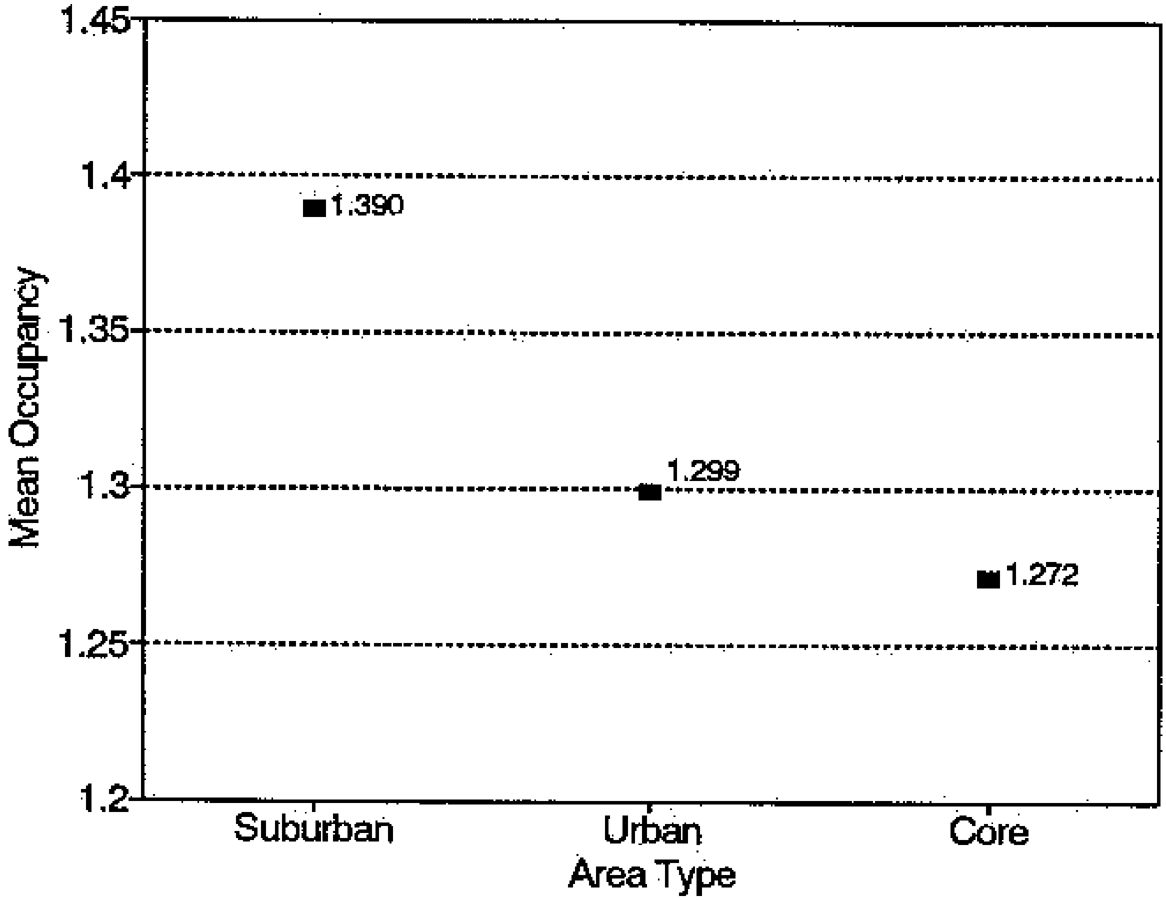
The overall mean auto occupancy as derived from the analysis of variance is 1.318. This value does not represent an overall average auto occupancy. The area-wide auto occupancy rate of 1.337 was derived by weighting cell vehicle occupancies by expected VMT for that cell. A discussion of the weighting is found in Appendix A.

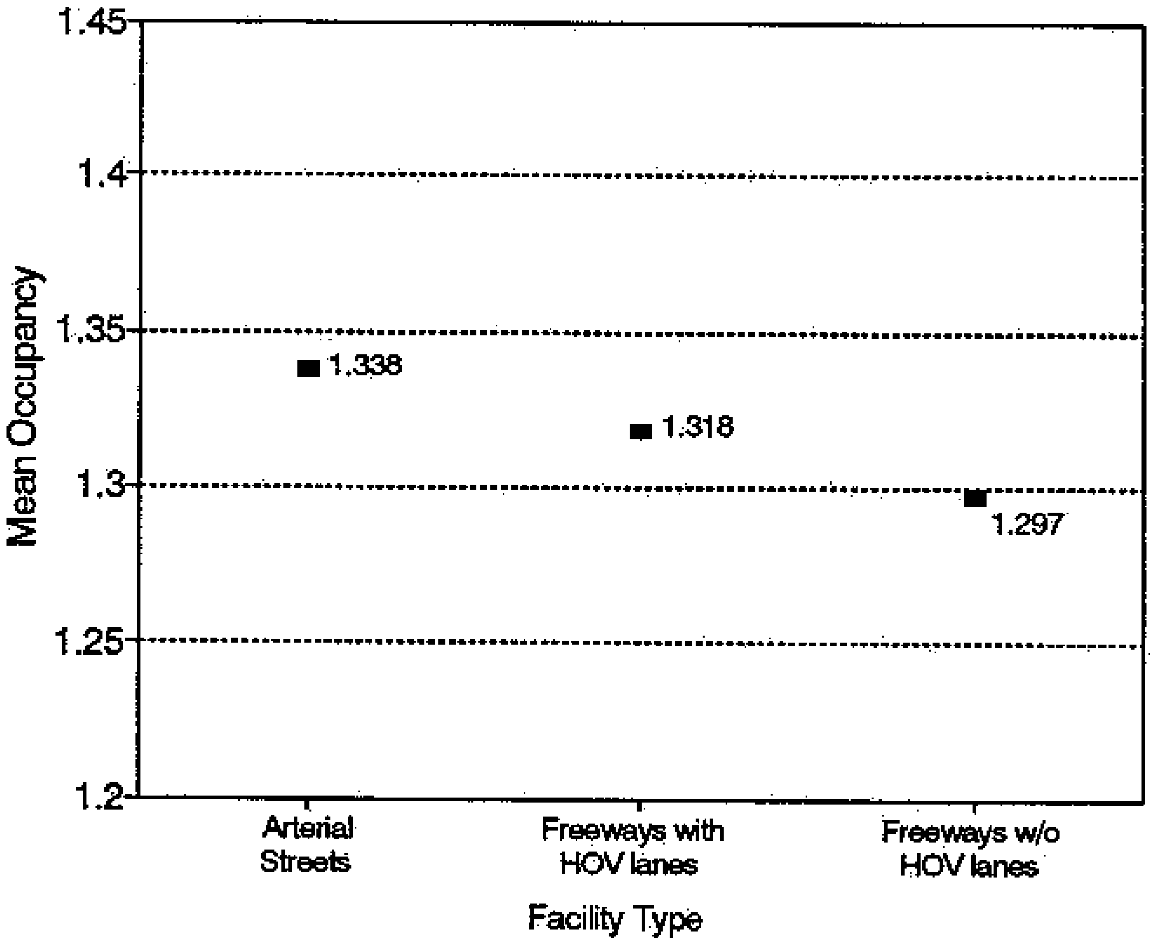
The mean square error from the ANOVA (MS_E = 0.0096) is an estimate of variance. The standard deviation is calculated as the square root of MS_E or ô = 0.0096 = 0.098 persons per vehicle. This standard deviation serves as the basis for constructing the confidence intervals and the Duncan's Multiple Range test which follow.

Auto occupancy varies by area type, facility type, and time of day. AREA (Core, Urban, Suburban) accounts for a large portion of the variability in auto occupancy. However, TYPE (Freeway, HOV, Arterial) and HTIME (time of day) account for most of the variability. The model has a R^2 of .43, which means that approximately 43% of the variability in auto occupancy can be explained by variability in the three main effects (AREA, HTIME, and TYPE) and the AREA*TYPE interaction term.

Figure 6 shows the plot of mean auto occupancy vs. area type. The 95% tolerance associated with these means is 0.013. The figure also shows that the highest auto occupancy is associated with the suburban area type. This makes some sense. The lowest auto occupancy is associated with the home based work trip (those trips from home to work and back). These trips are more frequent in the urban and core areas. They are less frequent in the suburban area. The suburban area is more likely to have home based shopping, home based school, and other trips that are associated with high occupancy. High vehicle occupancy in suburban areas may also be associated with larger family size in suburban areas. A Duncan's Multiple Range test was performed on the mean occupancies and each area type was found to have a significantly different mean occupancy. Duncan's test is a multiple comparison method to detect significant differences in various levels of a single variable. In this case the variable is area type at three levels, core urban, and suburban. A 0.05 level of significance was utilized.

Figure 7 shows the plot of mean auto occupancy vs. facility type. The 95% tolerance associated with these means is .013. A Duncan's Multiple Range test was also performed on these mean occupancies and they were found to be significantly different for each facility type. Freeways with HOV lanes have greater auto occupancies than freeways without HOV lanes. Arterial streets, however, have the greatest mean auto occupancy.

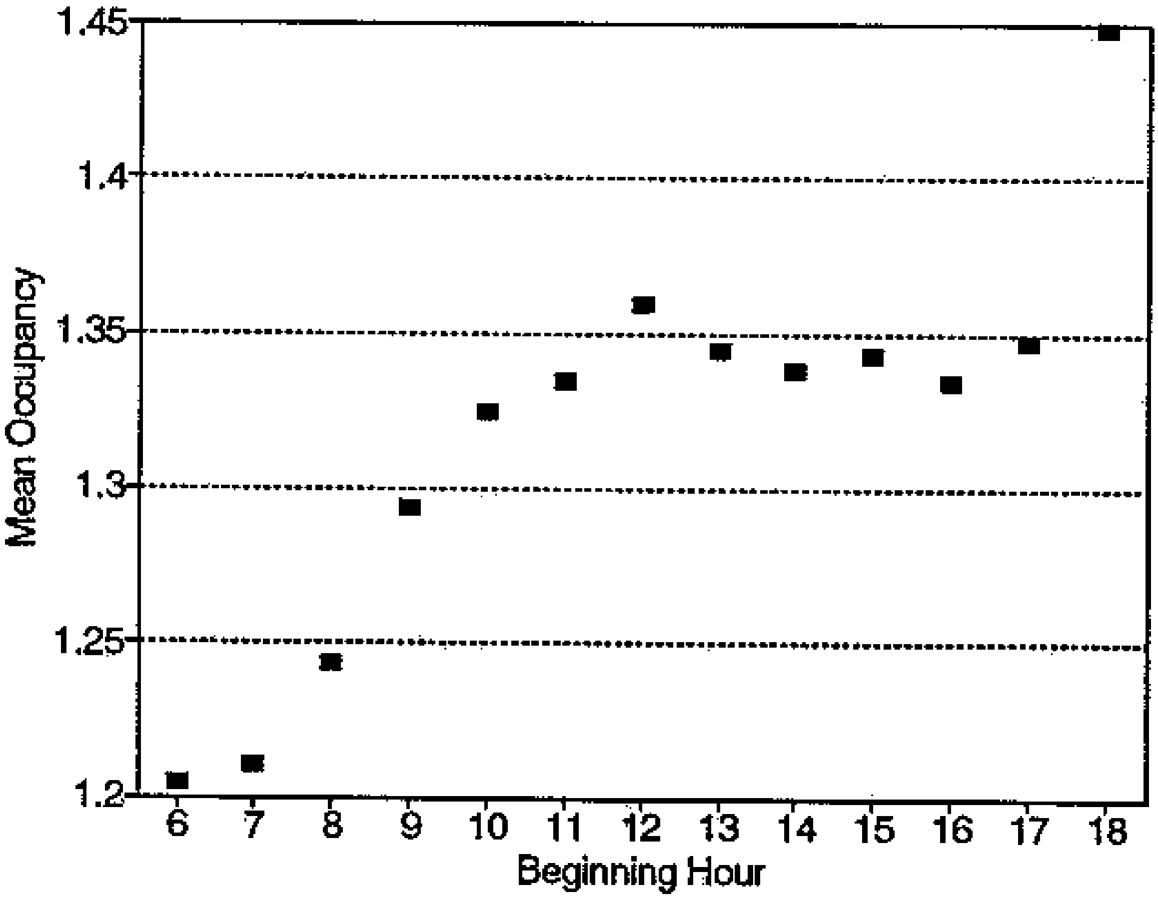

1.45
1.4
1.35
1.3
1.25
1.2
Mean Occupancy
1.390
1.299
1.272
Suburban
Urban
Core
Area Type



Mean Occupancy
1.45
1.4
1.35
1.3
1.25
1.2
1.338
1.318
1.297
Arterial Streets
Freeways with HOV lanes
Freeways w/o HOV lanes
Facility Type

Figure 6. Mean Auto Occupancy Vs. Area Type
Source: Counts taken by Lee Engineering on weekdays during April and May 1992

Figure 7. Mean Auto Occupancy Vs. Facility Type
Source: Counts taken by Lee Engineering on weekdays during April and May, 1992



1.45
1.4
1.35
1.3
1.25
1.2
Mean Occupancy
6
7
8
9
10
11
12
13
14
15
16
17
18
Beginning Hour

Figure 8 shows the plot of mean auto occupancy versus time of day. The 95% tolerance associated with these means is .026. This graph shows how auto occupancy steadily increases form a low of 1.21 from 6:00 - 7:00 AM to a high of 1.45 form 6:00 to 7:00 PM. There is a peak in auto occupancy from 12:00 to 1:00 which is probably explained by people carpooling for the lunch hour. As stated in previous studies for the Phoenix area, morning vehicle occupancies tend to be lower, and evening occupancies tend to be higher. This is because the majority of the traffic on the streets in the morning is home based work trips which is typically associated with low vehicle occupancies. In the evening, there are more shopping trips which is a trip associated with high vehicle occupancies.

Figure 8. Mean Auto Occupancy Vs. Time of Day
Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

The AREA*TYPE interaction was also found to be highly significant. To better explain the response in vehicle occupancy for the interaction, the mean values are plotted here in Figure 9. This graphic again shows how auto occupancies are greater for the suburban area type, as stated previously. However, the graphic also points out a significant variation in auto occupancy for facilities in the urban area. For these facilities, freeways without HOV lanes have a substantially lower auto occupancy than arterial streets, or freeways with HOV lanes. One conclusion from this graphic is that HOV lanes are quite effective on those freeways that are located in an urban area.

It is interesting to note that auto occupancy increases from core to suburban for all three facility types. This may be due to the following: 1) there is a large percentage of work related trips in core areas which

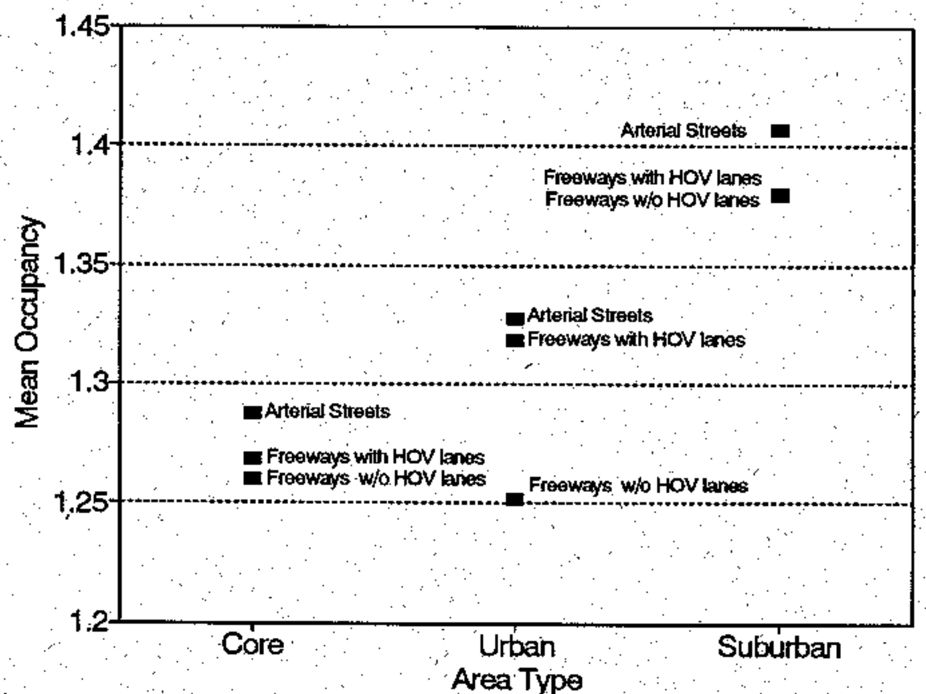


Figure 9. Mean Auto Occupancy Vs. Area Type and Facility Type
Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

Figure 9. Mean Auto Occupancy Vs. Area Type and Facility Type
Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

typically have lower occupancies, 2) there are larger family sizes in the suburban area. Since family members are the most likely source of auto passengers, this translates into higher auto occupancies.

One of the outcomes from tracking auto occupancy in a region over time is the ability to see how patterns are changing. Several studies have occurred in the Phoenix area at a small number of locations. These are described in detail later in this chapter. The 1988 study, however, provided a comprehensive analysis of auto occupancies for the region. Several tables in the 1988 study have been updated with 1992 data and are reported here. The occupancies reported are for the entire region, so a weighting factor, VMT, for each cell was used to expand the blocked design occupancies. The development of the weighting factor is given in Appendix A.

It is not clear form the 1988 study whether the values reported are also weighted values.

Table 12 shows weighted auto occupancy rates by time of day, facility class and area type. The HOV and non HOV freeway data have been combined to report occupancies by time of day. The periods shown in this table correlate to the time of day periods reported in Chapter Two.

Additionally, the 1988 study reported auto occupancies by facility type and area type. Table 12 is the 1992 data in the same format as the 1988 study for comparison.

Table 12. Weighted Auto occupancy Rates by Time of Day, Facility Class and Area Type

	AM	MID	NOON	PM	EVE	ALL DAY
All Facilities in Region	1.226	1.335	1.361	1.385	1.504	1.337
All Freeways in Region	1.204	1.308	1.332	1.297	1.396	1.291
All Arterials in Region	1.233	1.343	1.369	1.408	1.533	1.350
All Facilities in Core	1.191	1.289	1.331	1.293	1.403	1.282
Freeways in Core	1.185	1.270	1.292	1.278	1.370	1.262
Arterials in Core	1.194	1.297	1.347	1.299	1.417	1.291
All Facilities in Urban	1.195	1.315	1.324	1.361	1.494	1.312
Freeways in Urban	1.165	1.284	1.316	1.292	1.389	1.270
Arterials in Urban	1.204	1.324	1.327	1.380	1.523	1.324
All Facilities in Suburban	1.293	1.395	1.430	1.483	1.590	1.410
Freeways in Suburban	1.304	1.408	1.421	1.334	1.446	1.375
Arterials in Suburban	1.291	1.393	1.432	1.508	1.615	1.416

AM 6:00 - 9:00
MID 9:00 - 12:00, 2:00 - 4:00
NOON 12:00 - 2:00
PM 4:00 - 6:00
EVE 6:00 - 7:00
Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

Table 13, 14, and 15, show percentage of vehicles and travelers by auto occupancy by hour of day for all roadways in the region, for freeways only and arterials only.

Table 16 is a comparison of auto occupancy classifications and occupancy rates for Phoenix for 1977-1982, 1988, and 1992. For 1988 and 1993 these are data from all sites collected.

Since it is unclear whether the values reported in the 1988 study are weighted values, both weighted and unweighted auto occupancies are reported. Additionally, these values are carried out to a greater precision. This is not meant to imply this type of precision. However, the 3 person and 4+ person percentages are so low, it was felt that these numbers needed to be reported to more decimal place.

Table 17 is a tabulation of car-pool occupancies by time of day, facility class and area type. Car-pool occupancies are determined from those passenger vehicles with 2, 3, or 4+ passengers.

Table 13. (Weighted) Percentage of Vehicles and Travelers by Auto Occupancy by Hour of Day - All Roadways in Region

	ONE		TWO		THREE OR MORE	
Time	% of Vehicles	% of Travelers	% of Vehicles	% of Travelers	% of Vehicles	% of Travelers
6:00 AM	84.03	71.15	13.53	22.39	2.44	6.46
7:00 AM	82.28	68.03	14.28	22.80	3.44	9.17
8:00 AM	79.17	63.90	17.35	26.94	3.49	9.15
9:00 AM	76.06	59.85	20.57	31.29	3.37	8.86
10:00 AM	74.58	57.47	21.60	32.67	3.81	9.86
11:00 AM	72.66	54.72	22.36	33.19	4.98	12.09
12:00 PM	70.88	52.17	23.56	33.96	5.56	13.87
1:00 PM	71.45	53.55	24.13	35.60	4.42	10.85
2:00 PM	71.34	53.21	24.15	35.42	4.52	11.37
3:00 PM	72.19	53.70	21.86	31.76	5.95	14.54
4:00 PM	72.37	54.05	21.60	31.12	6.03	14.82
5:00 PM	71.28	52.47	21.31	30.19	7.42	17.34
6:00 PM	65.00	44.68	24.97	33.04	10.03	22.28

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

Table 14. Percentage of Vehicles and Travelers by Auto Occupancy by Hour of Day - Freeways in Region

	ONE		TWO		THREE OR MORE	
Time	% of Vehicles	% of Travelers	% of Vehicles	% of Travelers	% of Vehicles	% of Travelers
6:00 AM	82.96	69.18	14.19	23.21	2.85	7.61
7:00 AM	84.27	71.85	13.85	22.97	1.88	5.18
8:00 AM	81.72	67.88	15.67	24.93	2.61	7.19
9:00 AM	77.03	61.36	19.88	30.56	3.10	8.08
10:00 AM	74.36	57.44	21.83	32.75	3.81	9.82
11:00 AM	73.92	56.94	22.26	33.36	3.82	9.70
12:00 PM	73.03	55.34	22.59	33.57	4.39	11.09
1:00 PM	72.84	55.40	23.05	34.25	4.11	10.34
2:00 PM	74.81	57.52	21.02	31.82	4.16	10.66
3:00 PM	75.01	57.56	20.61	31.00	4.38	11.43
4:00 PM	76.09	59.18	19.80	30.22	4.11	10.61
5:00 PM	76.73	59.95	19.10	29.13	4.17	10.92
6:00 PM	70.61	51.66	22.86	32.28	6.53	16.06

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

Table 15. Percentage of Vehicles and Travelers by Auto Occupancy by Hour of Day - Arterials in Region

	ONE		TWO		THREE OR MORE	
Time	% of Vehicles	% of Travelers	% of Vehicles	% of Travelers	% of Vehicles	% of Travelers
6:00 AM	84.43	71.89	13.28	22.08	2.29	6.03
7:00 AM	81.74	66.99	14.39	22.75	3.87	10.25
8:00 AM	78.43	62.75	17.83	27.52	3.74	9.72
9:00 AM	75.76	59.40	20.78	31.51	3.46	9.10
10:00 AM	74.65	57.47	21.54	32.65	3.82	9.88
11:00 AM	72.33	54.14	22.39	33.15	5.28	12.71
12:00 PM	70.33	51.36	23.81	34.06	5.86	14.58
1:00 PM	71.06	53.03	24.43	35.97	4.51	11.00
2:00 PM	70.34	51.98	25.04	36.45	4.62	11.57
3:00 PM	71.40	52.61	22.21	31.97	6.39	15.42
4:00 PM	71.37	52.68	22.08	31.37	6.55	15.95
5:00 PM	69.84	50.50	21.89	30.47	8.27	19.03
6:00 PM	63.49	42.80	25.53	33.24	10.98	23.96

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

Table 16. Comparison of Auto Occupancy Classifications and Occupancy Rates for Phoenix

Time of Day	Year	Vehicles by Persons per Vehicle: 1	2 (Percent)	3	4+	Occupancy Rate
Morning Peak[1]	1992U	81.97%	15.22%	2.01%	0.80%	1.220
	1992W	81.74	15.08	2.35	0.83	1.226
	1988	84	13	2	1	1.20
	1982	84	13	2	1	1.20
	1981	84	13	2	1	1.20
	1980	82	15	2	1	1.22
	1979	83	14	2	1	1.21
	1978[6]	-	-	-	-	1.21
	1977	83	14	2	1	1.21
Morning Off-Peak[2]	1992U	73.78	22.36	2.65	1.21	1.318
	1992W	74.36	21.55	2.86	1.23	1.315
	1988	74	22	3	1	1.31
	1982	77	19	3	1	1.29
	1981	78	19	2	1	1.27
	1980	77	19	3	1	1.26
	1979	74	21	3	2	1.31
	1978[6]	-	-	-	-	1.29
	1977	82	15	2	1	1.24
Afternoon Off-Peak[3]	1992U	72.82	22.45	3.22	1.52	1.340
	1992W	71.79	22.93	3.65	1.63	1.358
	1988	74	22	3	1	1.33
	1981	76	20	3	1	1.32
	1980	75	21	3	1	1.32
	1979	74	20	4	2	1.34
	1978[6]	-	-	-	-	1.33
	1977	75	20	4	1	1.33
Afternoon Peak[4]	1992U	73.90	20.79	3.38	1.92	1.341
	1992W	71.82	21.45	4.18	2.55	1.385
	1988	76	20	3	1	1.31
	1982	76	18	4	2	1.32
	1981	76	19	3	2	1.30
	1980	77	19	3	1	1.30
	1979	71	24	3	2	1.35
	1978[6]	-	-	-	-	1.32
Daily Average[5]	1992U	74.69%	20.90%	2.96%	1.45%	1.318
	1992W	73.88	20.94	3.47	1.71	1.337
	1988	74	21	3	2	1.32
	1982	77	19	3	1	1.30
	1981	78	18	3	1	1.28
	1980	77	19	3	1	1.29
	1979	74	21	3	2	1.32
	1978[6]	-	-	-	-	1.30
	1977	78	18	3	1	1.29

[1]Defined as 6:30 to 8:00 AM for 1977-1982, and 7:00 to 9:00 AM for 1988, 6:00-9:00 for 1992.
[2]Defined as 8:00 AM to 12:00 PM for 1977-1982, and 9:00 AM to 12:00 PM for 1988, and 1992.
[3]Defined as 12:00 to 4:30 PM for 1977-1982, and 2:00 to 4:00 PM for 1988 and 1992.
[4]Defined as 4:30 to 6:30 PM for 1977-1982, and 4:00 to 6:00 PM for 1988 and 1992.
[5]Defined as between 6:30 AM to 6:30 PM for 1977-1982, 7:00 AM to 7:00 PM for 1988 and 6:00 AM to 7:00 PM for 1992.
[6]Information not available in format needed for table for vehicles/person.

Sources: For 1977 to 1988 data–Vehicle Occupancy Determinators, Barton-Aschman, August, 1989, 1992 data, vehicle occupancy counts collected by Lee Engineering, 1992.

1992 = 1992 Un-weighted vehicle occupancies
1992W=1992 Weighted vehicle occupancies

Table 17. Weighted Carpool Occupancy Rates by Time of Day, Facility Class and Area Type

	AM	MID	NOON	PM	EVE	ALL DAY
All Facilities in Region	2.234	2.245	2.249	2.331	2.407	2.272
All Freeways in Region	2.191	2.224	2.221	2.248	2.332	2.228
All Arterials in Region	2.247	2.251	2.256	2.354	2.427	2.284
All Facilities in Core	2.222	2.232	2.254	2.268	2.342	2.247
All Freeways in Core	2.185	2.217	2.193	2.229	2.330	2.214
All Arterials in Core	2.239	2.239	2.280	2.285	2.347	2.262
All Facilities in Urban	2.197	2.245	2.252	2.321	2.396	2.258
All Freeways in Urban	2.168	2.229	2.249	2.267	2.320	2.227
All Arterials in Urban	2.205	2.249	2.253	2.335	2.417	2.267
All Facilities in Suburban	2.283	2.269	2.241	2.392	2.467	2.307
All Freeways in Suburban	2.243	2.254	2.210	2.240	2.358	2.249
All Arterials in Suburban	2.290	2.272	2.246	2.418	2.486	2.318

AM 6:00 - 9:00
MID 9:00 - 12:00, 2:00 - 4:00
NOON 12:00 - 2:00
PM 4:00 - 6:00
EVE 6:00 - 7:00
Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

Previous Locations

Starting in 1977, vehicle occupancies were measured at 6 locations throughout the metropolitan Phoenix area. These six locations are as follows:

- 7th St. at Colter
- Broadway Rd. at Dobson Rd.
- Interstate 10 at 32nd St. (eastbound)
- Interstate 17 at McDowell Rd.
- Indian School Rd. at 27th Ave.
- Thomas Rd. at 56th St.

In 1982, these occupancies were reported in a MAG study, *Phoenix Urban Area Auto Occupancy Study*, 1982. In 1988, auto occupancies were measured on a regionwide basis including these 6 sites. To determine the trend of auto occupancy, Table 18 on the following page shows auto occupancy at these sites for the 9 years identified in previous studies, and the data collected at these sites as part of this study.

Overtime, some of these locations are changing from suburban to central city locations, particularly with the rapid growth experience in Phoenix over the past decades. Since suburban areas were found to have higher automobile occupancies, there is reason to believe that the counts at these locations would decline over time.

Table 18. Comparison of Occupancy Rates 1973, 1974, 1977-1982, 1988, 1992

Morning Peak

Station	73	74	77	78	79	80	81	82	88	92
1 (I-17) Black Canyon	1.20	1.20	1.18	1.22	1.22	1.26	1.22	1.20	1.18	1.17
3 Broadway	1.35	1.30	1.24	1.23	1.24	1.24	1.25	1.24	1.17	1.14
5 Indian School	-	1.25	1.22	1.21	1.18	1.19	1.18	1.15	1.18	1.21
6 7th Street	-	1.22	1.25	1.19	1.22	1.22	1.23	1.21	1.16	1.27
8 Thomas	-	1.20	1.16	1.16	1.20	1.21	1.18	1.22	1.13	1.13
11 (I-10) Maricopa Fwy	-	-	1.20	1.22	1.22	1.22	1.17	1.21	1.14	1.18
Composite	1.22	1.25	1.21	1.21	1.21	1.22	1.20	1.20	1.20	1.18

Morning Off-Peak

Station	73	74	77	78	79	80	81	82	88	92
1 (I-17) Black Canyon	1.51	1.41	1.22	1.35	1.40	1.31	1.30	1.34	1.31	1.32
3 Broadway	1.46	1.39	1.35	1.31	1.32	1.29	1.26	1.33	1.34	1.20
5 Indian School	-	1.38	1.25	1.27	1.29	1.23	1.26	1.24	1.32	1.24
6 7th Street	-	1.25	1.20	1.22	1.25	1.22	1.21	1.24	1.26	1.20
8 Thomas	-	1.22	1.20	1.26	1.29	1.23	1.25	1.26	1.28	1.21
11 (I-10) Maricopa Fwy	-	-	1.24	1.33	1.33	1.30	1.29	1.30	1.25	1.28
Composite	1.44	1.32	1.24	1.29	1.31	1.26	1.27	1.29	N/A	1.24

Afternoon Off-Peak

Station	73	74	77	78	79	80	81	82	88	92
1 (I-17) Black Canyon	-	1.32	1.28	1.33	1.33	1.30	1.32	1.33	1.31	1.26
3 Broadway	1.40	1.50	1.41	1.39	1.34	1.40	1.37	1.43	1.34	1.35
5 Indian School	-	1.36	1.30	1.31	1.33	1.31	1.30	1.27	1.32	1.43
6 7th Street	-	1.36	1.34	1.31	1.32	1.29	1.25	1.30	1.26	1.35
8 Thomas	-	1.41	1.36	1.29	1.37	1.35	1.31	1.35	1.28	1.32
11 (I-10) Maricopa Fwy	-	-	1.29	1.33	1.36	1.32	1.30	1.32	1.25	1.30
Composite	-	1.36	1.33	1.33	1.34	1.32	1.31	1.32	1.35	1.34

Afternoon Peak

Station	73	74	77	78	79	80	81	82	88	92
1 (I-17) Black Canyon	1.24	1.28	1.27	1.31	1.40	1.28	1.30	1.30	1.23	1.18
3 Broadway	1.5	1.48	1.46	1.41	1.38	1.38	1.40	1.47	1.33	1.33
5 Indian School	-	1.41	1.29	1.33	1.33	1.28	1.34	1.31	1.33	1.39
6 7th Street	-	1.31	1.34	1.26	1.33	1.25	1.25	1.22	1.32	1.36
8 Thomas	-	1.32	1.27	1.32	1.32	1.30	1.29	1.33	1.31	1.40
11 (I-10) Maricopa Fwy	-	-	1.28	1.29	1.35	1.31	1.29	1.33	1.15	1.26
Composite	1.29	1.34	1.32	1.32	1.35	1.30	1.30	1.32	1.31	1.32

12-Hour Average

Station	73	74	77	78	79	80	81	82	88	92
1 (I-17) Black Canyon	-	1.29	1.25	1.31	1.33	1.29	1.29	1.31	1.27	1.28
3 Broadway	1.43	1.43	1.39	1.35	1.33	1.35	1.34	1.40	1.33	1.32
5 Indian School	-	1.36	1.28	1.29	1.30	1.27	1.28	1.26	1.32	1.34
6 7th Street	-	1.30	1.29	1.26	1.29	1.25	1.24	1.25	1.25	1.30
8 Thomas	-	1.31	1.28	1.27	1.32	1.29	1.27	1.31	1.27	1.28
11 (I-10) Maricopa Fwy	-	-	1.26	1.30	1.33	1.30	1.28	1.30	1.19	1.26
Composite	-	1.33	1.29	1.30	1.32	1.29	1.28	1.31	1.32	1.30

1973 - 1982 Data from “Phoenix Urban Area Auto Occupancy Study 1982.
1988 Data from “Vehicle Occupancy Determinators, Barton-Aschman, Inc. Final Report, August, 1989.
1992 Data from counts taken by Lee Engineering on Weekdays during April and May, 1992.

Ramp Locations

As described previously, four on-ramp locations were evaluated for auto occupancy. The locations and their respective daily auto occupancies are shown below in Table 19.

Table 19. Mean Auto Occupancies for On-Ramps

On Ramp	Occupancy	Expected Occupancy on Freeways
Interstate 17/Camelback Rd. (northbound on-ramp)	1.265	1.252
Interstate 17/Camelback Rd. (southbound on-ramp)	1.302	1.252
Superstition Fwy./Rural Rd. (eastbound on-ramp)	1.263	1.260
Superstition Fwy./Rural Rd. (westbound on-ramp)	1.313	1.260

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

The I-17 on ramps are adjacent to freeways without HOV lanes in urban areas which, as stated previously, have a mean daily auto occupancy of 1.252. The Superstition on-ramps are adjacent to freeways without HOV lanes in Core Areas which have a mean daily auto occupancy of 1.260. It is interesting to note that those on-ramps that are in the PM peak direction (Superstition/Rural EB and I-17/Camelback NB) have lower auto occupancies than those ramps that are in the AM peak direction. These ramps have a higher auto occupancy than the adjacent freeway lanes.

A tabulation of these ramps occupancies by time of day is found on Table 20.

Table 20. Auto Occupancies for On-Ramps

Time of day	Camelback Northbound On-Ramp	Camelback Southbound On-Ramp	Rural Eastbound On-Ramp	Rural Westbound On-Ramp
6:00 - 7:00 AM	1.18	1.21	1.12	1.19
7:00 - 8:00 AM	1.21	1.22	1.20	1.16
8:00 - 9:00 AM	1.24	1.19	1.15	1.16
9:00 - 10:00 AM	1.28	1.31	1.21	1.27
10:00 - 11:00 AM	1.28	1.26	1.26	1.29
11:00 - 12:00 AM	1.31	1.32	1.30	1.27
12:00 - 1:00 PM	1.29	1.30	1.31	1.35
1:00 - 2:00 PM	1.29	1.38	1.31	1.31
2:00 - 3:00 PM	1.30	1.30	1.36	1.32
3:00 - 4:00 PM	1.24	1.34	1.32	1.39
4:00 - 5:00 PM	1.27	1.30	1.30	1.35
5:00 - 6:00 PM	1.23	1.34	1.22	1.39
6:00 - 7: 00 PM	1.33	1.45	1.34	1.60
ALL	1.27	1.30	1.26	1.31

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

CHAPTER FOUR

VEHICLE CLASSIFICATION

As part of the effort to obtain information on occupancy, data were also collected on eight categories of vehicle classification.

These categories included:

- private autos
- motorcycles
- recreational vehicles
- buses
- commercial passenger vans
- light commercial vehicles
- medium trucks
- large trucks

Private autos included privately owned, non-commercial vehicles such as passenger cars, vans and pickup trucks. Commercial passenger vans were identified as commercial or public agency vans which serve primarily to transport people such as hotel shuttles, vans taxis, public transit vans and privately sponsored van-pools. Recreational vehicles included pick-up trucks with over-the-cab campers and vehicles hauling camping trailers as well as the conventional recreational vehicle or RV. The bus category included all classes of buses such as school buses, church buses, tour buses and public transit buses. Light commercial vehicles were identified as all automobiles, vans, and pick-up trucks which could be positively identified as commercial or public agency vehicles by means of distinguishing markings such as logos. Medium trucks were defined as any vehicle which had six wheels such as single two-axle trucks with dual tires or a single truck with three axles. This class included vehicles such as delivery trucks and many classes of construction vehicles. Large trucks included all tractor/semi-trailer combination vehicles.

The data were tabulated to show vehicle classification. Table 21 is a composite of all freeway locations where data were collected; this includes freeways with and without HOV priority lanes. The percentage of vehicles within each category is presented for each area type. Each area type is also broken down into five periods to provide an indication of how vehicle mix varies throughout the day. Table 22 provides the same information for those arterial streets which were sampled. Table 23 is a composite of all sites, regardless of area type or facility type. This table provides an area wide hour by hour break down of vehicle mix.

Table 21. Vehicle Classification by Area Type and Time Period-Freeways

Area Type	Time Periods	Private Auto %	Vans %	Light Trucks %	Medium Trucks %	Heavy Trucks %	Motor-cycles %	RV's %	Buses %
Core	6:00 - 9:00 AM	87.41	0.25	4.89	3.00	3.32	0.69	0.22	0.23
	9:00 - 12:00 AM								
	2:00 - 4:00 PM	86.20	0.48	5.61	3.06	3.64	0.62	0.21	0.19
	12:00 - 2:00 PM	85.01	0.50	5.84	3.43	4.21	0.57	0.17	0.26
	4:00 - 6:00 PM	92.72	0.29	2.98	1.46	1.40	0.86	0.14	0.14
	6:00 - 7:00 PM	93.30	0.26	2.56	1.33	1.66	0.66	0.14	0.11
	ALL	87.84	0.39	4.84	2.72	3.16	0.67	0.19	0.20
Suburban	6:00 - 9:00 AM	80.29	0.93	5.65	3.00	8.09	0.59	1.22	0.23
	9:00 - 12:00 AM								
	2:00 - 4:00 PM	78.89	1.40	5.40	3.00	9.98	0.40	0.61	0.32
	12:00 - 2:00 PM	77.82	1.29	5.96	3.13	10.63	0.48	0.54	0.15
	4:00 - 6:00 PM	86.92	0.85	3.51	1.67	5.60	0.56	0.54	0.35
	6:00 - 7:00 PM	86.23	1.16	2.17	1.40	7.50	1.12	0.28	0.14
	ALL	80.85	1.17	5.00	2.69	8.78	0.53	0.70	0.27
Urban	6:00 - 9:00 AM	86.24	0.28	4.57	3.11	4.83	0.60	0.18	0.18
	9:00 - 12:00 AM								
	2:00 - 4:00 PM	83.00	0.60	5.33	3.83	6.28	0.57	0.20	0.18
	12:00 - 2:00 PM	82.41	0.61	5.55	4.23	6.16	0.75	0.10	0.18
	4:00 - 6:00 PM	90.71	0.19	3.04	1.98	3.08	0.70	0.13	0.18
	6:00 - 7:00 PM	89.96	0.42	2.25	1.71	4.37	1.00	0.11	0.17
	All	85.38	0.45	4.60	3.28	5.29	0.66	0.17	0.18

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

Table 22. Vehicle Classification by Area Type and Time Period - Arterial Streets

Area Type	Time Periods	Private Auto %	Vans %	Light Trucks %	Medium Trucks %	Heavy Trucks %	Motor-cycles %	RV's %	Buses %
Core	6:00 - 9:00 AM	91.18	0.15	4.41	1.63	0.76	0.47	0.15	1.25
	9:00 - 12:00 AM								
	2:00 - 4:00 PM	89.98	0.15	4.91	2.09	1.34	0.69	0.16	0.67
	12:00 - 2:00 PM	91.25	0.19	4.23	2.08	1.20	0.60	0.07	0.39
	4:00 - 6:00 PM	94.96	0.11	2.46	0.98	0.47	0.69	0.02	0.32
	6;00 - 7:00 PM	95.85	0.11	1.34	1.12	0.74	0.51	0.09	0.22
	ALL	91.67	0.15	4.04	1.74	1.00	0.61	0.12	0.67
Suburban	6:00 - 9:00 AM	89.52	0.36	5.41	1.84	1.32	0.65	0.13	0.77
	9:00 - 12:00								
	2:00 - 4:00 PM	89.27	0.38	5.15	2.24	1.35	0.34	0.32	0.95
	12:00 -2:00 PM	89.47	0.10	5.72	1.92	1.88	0.39	0.37	0.15
	4:00 - 6:00 PM	95.36	0.25	1.73	0.77	0.92	0.63	0.02	0.32
	6:00 - 7:00 PM	95.47	0.08	2.11	0.85	0.26	1.16	0.00	0.06
	ALL	90.77	0.29	4.54	1.77	1.28	0.53	0.21	0.62
Urban	6:00 - 9:00 AM	85.36	0.05	6.67	4.01	2.35	0.75	0.19	0.62
	9:00 - 12:00 AM								
	2:00 - 4:00 PM	84.41	0.08	7.52	4.10	2.59	0.53	0.26	0.51
	12:00 - 2:00 PM	84.68	0.26	7.16	3.92	2.79	0.64	0.20	0.35
	4:00 - 6:00 PM	92.48	0.14	3.04	1.46	1.50	0.71	0.04	0.63
	6:00 - 7:00 PM	92.08	0.00	2.47	2.19	1.92	0.91	0.10	0.33
	ALL	86.50	0.10	6.19	3.50	2.34	0.66	0.19	0.51

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

Table 23. Vehicle Classification by Time of Day - All Facilities

Time Periods	Private Auto %	Vans %	Light Trucks %	Medium Trucks %	Heavy Trucks %	Motor-cycles %	RV's %	Buses %
6:00 - 7:00 AM	86.32	0.36	4.91	2.81	3.74	0.89	0.58	0.38
7:00 - 8:00 AM	88.05	0.29	4.81	2.28	3.24	0.62	0.21	0.51
8:00 - 9:00 AM	84.61	0.42	5.78	3.45	4.62	0.36	0.30	0.45
9:00 - 10:00 AM	82.91	0.73	6.44	3.38	5.45	0.39	0.28	0.43
10:00 - 11:00 AM	83.13	0.72	6.59	3.32	5.31	0.43	0.32	0.18
11:00 - 12:00 AM	84.32	0.62	5.30	3.09	5.62	0.48	0.30	0.28
12:00 - 1:00 PM	85.00	0.56	5.47	2.93	5.06	0.62	0.16	0.21
1:00 - 2:00 PM	83.70	0.55	6.02	3.65	4.95	0.56	0.31	0.26
2:00 - 3:00 PM	85.42	0.37	5.27	3.33	4.02	0.67	0.32	0.59
3:00 - 4:00 PM	87.98	0.43	4.37	2.59	3.19	0.68	0.25	.051
4:00 - 5:00 PM	91.12	0.34	3.27	1.65	2.31	0.69	0.25	0.36
5:00 - 6:00 PM	92.42	0.30	2.50	1.31	2.45	0.72	0.09	0.21
6:00 - 7:00 PM	91.68	0.39	2.21	1.45	3.08	0.89	0.13	0.16
ALL	86.67	0.47	4.84	2.71	4.08	0.62	0.27	0.35

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992.

CHAPTER FIVE

EVALUATION OF HOV LANES

HOV lanes were first introduced into the MAG freeway system with the opening of the Papago Freeway (I-10) west of I-17. The system now contains approximately 27 miles of freeway with HOV priority lanes. Additional HOV lanes are planned with the opening of Loop 202 to the Outer Loop. This study provides the first opportunity to field evaluate the operation of HOV lanes in the Phoenix metropolitan area. This chapter examines utilizations of HOV lanes, priority lane violation rates and an overall analysis of priority lane use.

Utilization of HOV Lanes

Volume of Traffic on HOV Lanes

In order to determine how effectively priority lanes are utilized, a tabulation of the average volume by time of day was prepared for each freeway with a HOV lane. The sampled data was factored to present an approximate total hourly volume by lane for each of the facility types. The volume of traffic on priority lanes is substantially less than the volume of traffic on the non-priority lanes. The highest volume counted on a priority lane occurs on Interstate 10, at 39th Avenue in the westbound direction between 5:00 and 6:00 PM. Assuming a lane capacity of 2200 vehicles per hour, the 975 vehicles per hour sampled at this location represents a V/C ration of approximately .44.

At this low V/C ratio, there is very little speed loss due to congestion on freeway facilities. While not all HOV lanes were sampled in this study, it is safe to assume that priority lanes are operating at close to uncongested speeds. This indicates that if congestion occurs on a non-priority lane, a relief to congestion can be found by moving to the priority lane.

A statistical test was performed to see if the volume on priority lanes is a function of either area type or time of day. The following table is the analysis of variance for the total number of vehicles on the priority lane. AREA is the area type (Urban, Suburban, Core) and HTIME is the hour in which the sample was taken.

Table 24. Analysis of Variance for Total Vehicles on Priority Lanes

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AREA	2	906235.12	453117.56	20.53	0.0001
HTIME	12	1788675.94	149056.33	6.75	0.0001
AREA*HTIME	24	921133.81	38380.58	1.74	0.0233
ERROR	169	3729489.50	22067.99		
TOTAL	207	7837145.19			

This analysis of variance shows that there is a significant difference in the number of vehicles on priority lanes due to area type and time of day. The AREA*HTIME interaction is also significant to the p=.02

level. Because of the significance of the Area*Time interaction, the total volume by time of day is plotted in Figure 10. The average volume over the thirteen-hour period is shown in Table 25.

The plot shows that the volume on the urban and suburban HOV lanes follow the same shape with the exception of the 7:00 to 8:00 AM time periods. Suburban HOV lane volume stays nearly constant all day. Because there is not a great demand for HOV lane usage in the suburban area, it does not get utilized to its full advantage.

Figure 10. Average Volume on Priority Lanes by Time of Day and Area Type
Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

Table 25. Mean HOV Volume by Area Type

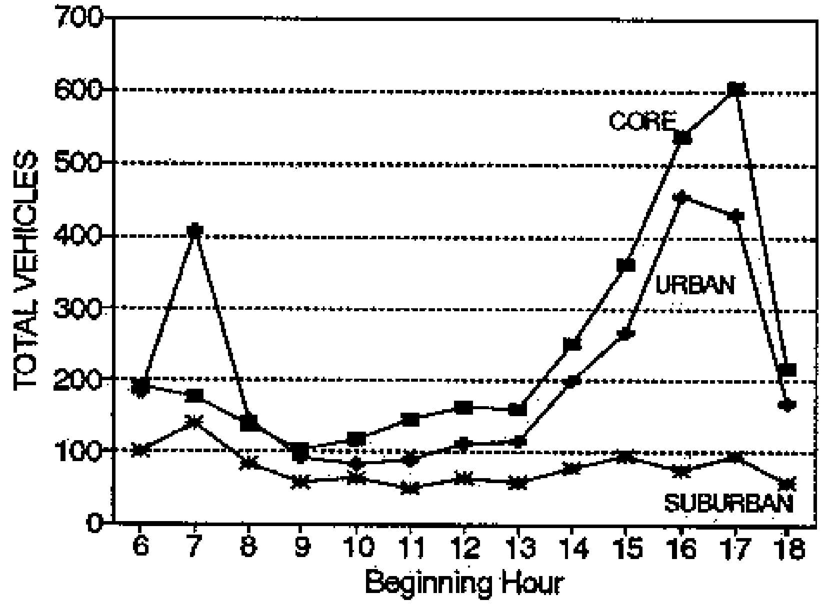
Veh/Hr.	N	Area Type
244	78	CORE
211	78	URBAN
79	52	SUBURBAN

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

It appears that priority lanes are seldom used when there is little or no congestion on the non-priority lanes. At those times, there is little need to use them. When congestion appears on the freeway, then the volumes in the priority lane increase, moving high volumes of passengers at high speeds.

High Occupancy Vehicles in Non-Priority Lanes

Sometimes high occupancy vehicles will not utilize the priority lanes. There are several reasons why


TOTAL VEHICLES
700
600
500
400
300
200
100
0
CORE
URBAN
SUBURBAN
6
7
8
9
10
11
12
13
14
15
16
17
18
Beginning Hour

this may occur. It is possible that the trip length is so short that it is not worth shifting over to the priority lane. When the facility is not congested, there may not be a time saving in doing so. Also, HOV vehicles must usually enter and exit the freeway form right hand ramps, requiring travel in the non-priority lanes before reaching the HOV lanes and after leaving the HOV lanes. The lowest percentage of HOV vehicles in non-priority lanes occurs in the 6:00 to 7:00 AM and 7:00 to 8:00 AM time periods. This percentage steadily increases all day until 2:00, where it starts to decrease. This makes sense, because the freeways are starting to get more congested in this time frame and there are more work trips on the roadways which tend to be single passenger vehicles.

In the 6:00 to 7:00 PM time period, the percentage of non-priority lane vehicles which are HOV's jumps considerably. This is probably due to the fact that in this time period, there are a lot of non-work trips with higher occupancies on the road.

A statistical analysis was performed on these data to see if the percent of high occupancy vehicles is affected by either area or time of day. The following ANOVA tests this theory.

Table 26. Analysis of Variance of High Occupancy Vehicles in Non-Priority Lanes

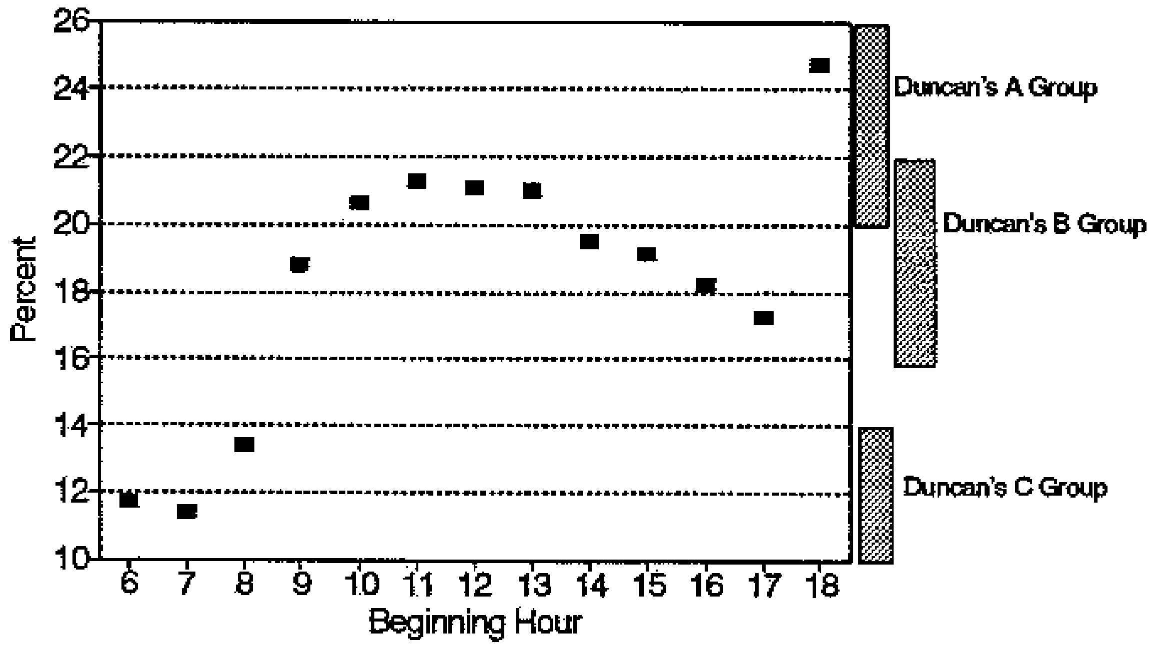
Source	DF	Type III SS	Mean Square	F Value	Pr > F
AREA	2	1323.07	661.54	22.31	0.0001
HTIME	12	3157.96	263.16	8.88	0.0001
AREA*HTIME	24	511.11	21.30	0.72	0.8283
ERROR	169	5010.78	29.65		
TOTAL	207	9885.84			

This test shows that both area type and time of day (HTIME) have an effect on the percent of high occupancy vehicles in non-priority lanes. A Duncan's test was performed on the means of these values by area type resulting in Table 27. It is interesting to note that the highest percentage of HOV vehicles in non-priority lanes occurs in the suburban area. This could be due to the fact that suburban areas have lower congestion. Also, there are left-hand ramps located in the core areas which may reduce weaving high occupancy vehicles in non-priority lanes.

Table 27. Duncan's Grouping of Mean Percentage of High Occupancy Vehicles in Non-Priority Lanes by Area Type

Duncan Grouping	Mean	N	Area Type
A	22.2%	52	Suburban
B	18.4%	78	Urban
C	15.6%	78	Core

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992



26
24
22
20
18
16
14
12
10
Percent
6
7
8
9
10
11
12
13
14
15
16
17
18
Beginning Hour
Duncan's A Group
Duncan's B Group
Duncan's C Group

Figure 11 shows ow these percentages vary by time of day. The boxes to the right show the grouping as determined by Duncan's test.

Figure 11. Percentage of High Occupancy Vehicles in Non-Priority Lanes by Time of Day
Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

Occupancies of Priority and Non-Priority Lanes

Because of the necessity to have at least two occupants in a priority lane, the average auto occupancy of priority lanes should be greater than 2.0. The tabulation of auto occupancies for priority and non-priority lanes is given on the following pages in Table 28. There are some instances where the average occupancy of a priority lane is less than 2.0. This is due to violations of the HOV system. These occupancies are calculated from 1, 2, 3, and 4+ vehicle counts only.

The lowest auto occupancy for both priority and non-priority lanes occur during the AM peak. Area-wide priority lanes have an auto occupancy of 2.10 persons per vehicle during the 6:00 - 7:00 and 7:00-8:00 AM time periods. The area wide auto occupancy of non-priority lanes during the 7:00 - 8:00 time period is 1.15 persons per vehicle.

The highest area-wide auto occupancy occurs during the 6:00 - 7:00 PM period, with 2.30 and 1.38 for priority and non-priority lanes respectively. The average 13-hour occupancy in priority and non-priority lanes is 2.18 and 1.27 respectively.

Table 28. Auto Occupancies of Priority and Non-Priority Lanes-Freeways with Priority Lanes

	I-10/10th St Eastbound		I-10/11th Ave Westbound		I-10/32nd St Westbound		I-10/39th Ave Westbound	
Time of Day	Priority Lane	Non Priority Lane	Priority Lane	Non Priority Lane	Priority Lane	Non Priority Lane	Priority Lane	Non Priority Lane
6:00 - 7:00 AM	1.89	1.12	2.22	1.19	2.10	1.08	2.24	1.18
7:00 - 8:00 AM	1.95	1.12	2.06	1.14	1.92	1.06	2.30	1.16
8:00 - 9:00 AM	2.11	1.18	2.21	1.16	1.93	1.08	2.47	1.24
9:00 - 10:00 AM	2.05	1.19	2.16	1.23	2.15	1.15	2.33	1.26
10:00 - 11:00 AM	1.96	1.22	2.07	1.26	2.22	1.21	2.43	1.27
11:00 - 12:00 AM	1.76	1.24	2.10	1.30	2.17	1.26	2.28	1.30
12:00 - 1:00 PM	1.99	1.24	1.99	1.31	2.67	1.28	2.19	1.30
1:00 - 2:00 PM	2.02	1.27	2.28	1.26	2.44	1.29	2.16	1.33
2:00 - 3:00 PM	2.03	1.27	2.09	1.22	2.52	1.29	2.21	1.25
3:00 - 4:00 PM	2.03	1.20	2.06	1.27	2.51	1.29	2.16	1.29
4:00 - 5:00 PM	2.09	1.25	2.23	1.27	2.44	1.26	2.12	1.24
5:00 - 6:00 PM	2.20	1.21	2.14	1.22	2.53	1.29	2.08	1.18
6:00 - 7:00 PM	2.07	1.25	2.18	1.45	2.54	1.39	2.42	1.36

	I-10/48th St Eastbound		I-10/51st Ave Eastbound		I-10/51st Ave Westbound		I-10/63rd Ave Westbound	
Time of Day	Priority Lane	Non Priority Lanes	Priority Lane	Non Priority Lanes	Priority Lane	Non Priority Lanes	Priority Lane	Non Priority Lanes
6:00 - 7:00 AM	2.17	1.19	2.08	1.14	2.21	1.32	1.93	1.28
7:00 - 8:00 AM	2.04	1.11	1.99	1.15	2.29	1.23	1.97	1.20
8:00 - 9:00 AM	2.23	1.20	1.91	1.23	2.26	1.28	2.50	1.27
9:00 - 10:00 AM	2.40	1.22	2.00	1.32	2.39	1.30	2.40	1.36
10:00 - 11:00 AM	1.86	1.25	2.32	1.39	2.21	1.38	2.72	1.42
11:00 - 12:00 AM	2.05	1.26	2.30	1.42	2.26	1.34	2.16	1.31
12:00 - 1:00 PM	2.18	1.33	2.57	1.32	2.41	1.33	2.32	1.31
1:00 - 2:00 PM	2.01	1.25	2.45	1.42	2.10	1.26	2.16	1.33
2:00 - 3:00 PM	2.05	1.18	2.44	1.37	2.08	1.20	2.14	1.34
3:00 - 4:00 PM	2.03	1.22	2.22	1.49	2.01	1.22	2.35	1.29
4:00 - 5:00 PM	2.00	1.12	2.59	1.51	2.00	1.20	2.28	1.25
5:00 - 6:00 PM	1.99	1.12	2.60	1.55	2.02	1.12	2.14	1.20
6:00 - 7:00 PM	1.98	1.17	2.64	1.82	2.19	1.25	2.26	1.33

	I-10/67th Ave Eastbound		I-10/79th Ave Eastbound		I-10/83rd Ave Eastbound		I-10/83rd Ave Westbound	
Time of Day	Priority Lane	Non Priority Lanes	Priority Lane	Non Priority Lanes	Priority Lane	Non Priority Lanes	Priority Lane	Non Priority Lanes
6:00 - 7:00 AM	2.24	1.16	2.24	1.10	2.20	1.10	1.82	1.20
7:00 - 8:00 AM	2.06	1.12	2.27	1.12	2.12	1.14	1.93	1.25
8:00 - 9:00 AM	2.22	1.19	2.25	1.16	2.22	1.22	2.00	1.21
9:00 - 10:00 AM	2.37	1.39	2.49	1.31	2.13	1.31	1.89	1.35
10:00 - 11:00 AM	2.39	1.41	2.65	1.44	2.08	1.34	2.05	1.30
11:00 -12:00 AM	2.53	1.35	2.38	1.42	2.17	1.28	2.02	1.38
12:00 - 1:00 PM	2.23	1.44	2.53	1.42	2.16	1.35	2.05	1.26
1:00 - 2:00 PM	2.00	1.42	2.19	1.44	2.10	1.40	2.28	1.30
2:00 - 3:00 PM	2.32	1.29	2.30	1.52	2.23	1.45	2.18	1.27
3:00 - 4:00 PM	2.47	1.39	2.39	1.47	2.05	1.30	2.14	1.36
4:00 - 5:00 PM	2.15	1.41	2.34	1.37	2.32	1.39	2.06	1.37
5:00 - 6:00 PM	2.48	1.45	2.25	1.43	2.08	1.42	2.13	1.23
6:00 - 7:00 PM	2.73	1.54	2.66	1.60	2.18	1.55	2.07	1.36

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992.

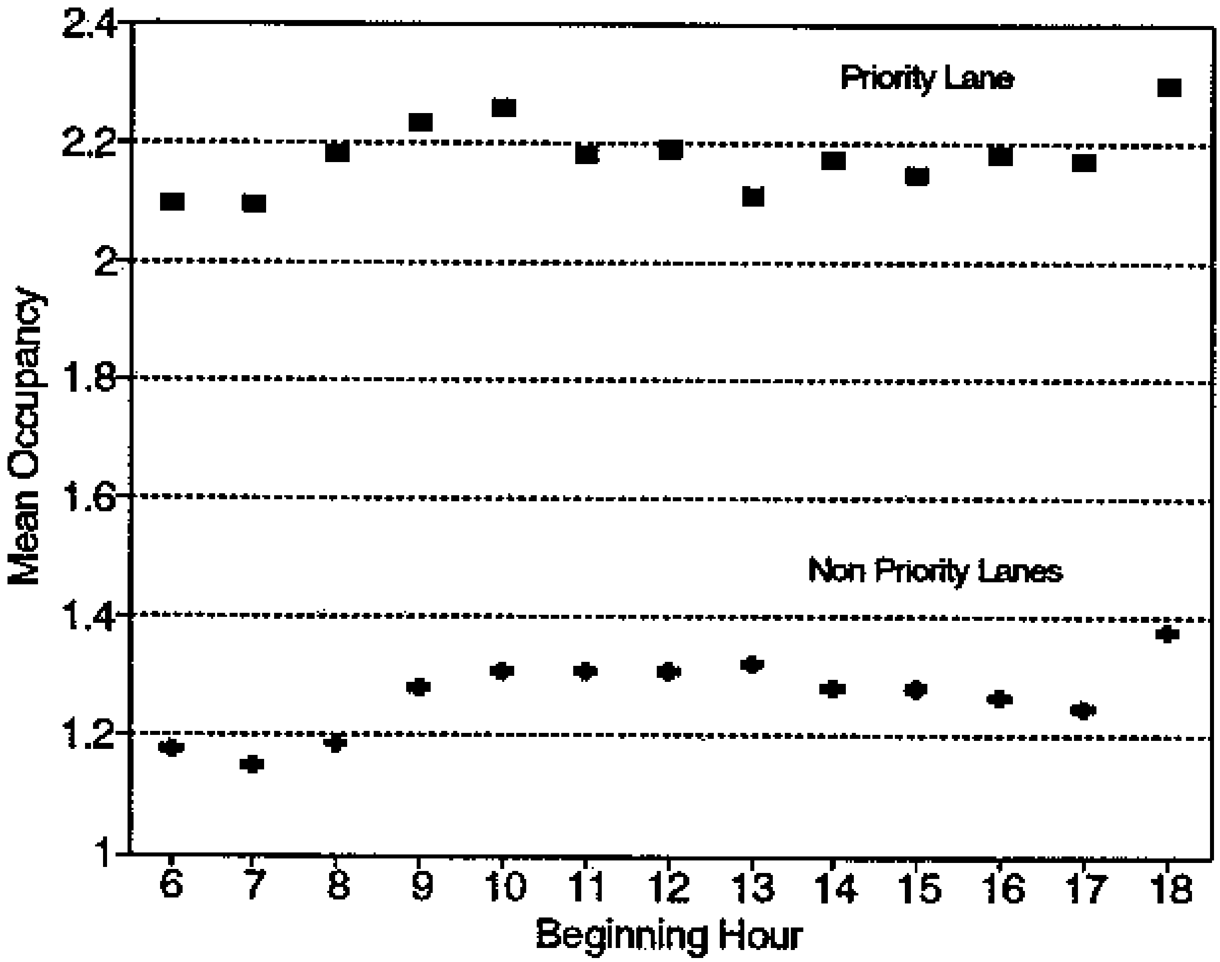
Table 28. (Continued)

Time of Day	I-10/91st Ave Westbound Priority Lane	I-10/91st Ave Westbound Non Priority Lanes	I-10/Broadway Eastbound Priority Lane	I-10/Broadway Eastbound Non Priority Lanes	Loop 202/24th St Eastbound Priority Lane	Loop 202/24th St Eastbound Non Priority Lanes	Loop 202/W. 32nd St Eastbound Priority Lane	Loop 202/W. 32nd St Eastbound Non Priority Lanes
6:00 - 7:00 AM	2.21	1.34	2.09	1.17	1.95	1.08	2.06	1.14
7:00 - 8:00 AM	2.22	1.30	2.42	1.15	1.93	1.09	2.05	1.10
8:00 - 9:00 AM	2.48	1.33	2.10	1.20	2.10	1.08	1.93	1.09
9:00 - 10:00 AM	2.56	1.52	2.30	1.21	2.11	1.16	2.00	1.14
10:00 - 11:00 AM	2.55	1.44	2.50	1.24	1.73	1.18	2.37	1.21
11:00 - 12:00 AM	2.14	1.40	2.12	1.24	2.09	1.16	2.29	1.25
12:00 - 1:00 PM	2.25	1.49	2.00	1.28	1.78	1.19	1.77	1.13
1:00 - 2:00 PM	1.88	143	2.00	1.25	1.94	1.21	1.75	1.19
2:00 - 3:00 PM	2.24	1.37	1.87	1.20	1.86	1.16	2.11	1.16
3:00 - 4:00 PM	2.31	1.31	2.01	1.15	1.75	1.15	1.91	1.14
4:00 - 5:00 PM	2.15	1.31	1.96	1.11	2.04	1.11	2.10	1.15
5:00 - 6:00 PM	2.22	1.23	1.93	1.12	1.97	1.12	1.97	1.13
6:00 - 7:00 PM	2.80	1.38	2.06	1.16	2.00	1.16	2.01	1.25

Time of Day	ALL Priority Lane	ALL Non-Priority Lanes
6:00 - 7:00 AM	2.10	1.18
7:00 - 8:00 AM	2.10	1.15
8:00 - 9:00 AM	2.18	1.19
9:00 - 10:00 AM	2.23	1.28
10:00 - 11:00 AM	2.26	1.31
11:00 -12:00 AM	2.18	1.31
12:00 - 1:00 PM	2.19	1.31
1:00 - 2:00 PM	2.11	1.32
2:00 - 3:00 PM	2.17	1.28
3:00 - 4:00 PM	2.15	1.28
4:00 - 5:00 PM	2.18	1.27
5:00 - 6:00 PM	2.17	1.25
6:00 - 7:00 PM	2.30	1.38

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

The mean auto occupancy of priority and non-priority lanes is shown below in Figure 12. The plot shows that occupancies on the priority lanes mimic the occupancies on the non-priority lanes with the exception of the 11:00 AM to 2:00 PM time period where the priority lane occupancy dips slightly while the non-priority lane occupancy remains relatively constant.



Priority Lane
Non Priority Lanes
Mean Occupancy
2.4
2.2
2
1.8
1.6
1.4
1.2
1
6
7
8
9
10
11
12
13
14
15
16
17
18
Beginning Hour

Figure 12. Average Auto Occupancy of Priority and Non-Priority Lanes
Source: Counts taken by Lee Engineering on weekdays during April And May, 1992.

Priority Lane Violations

In order to determine violation rates, tabulations were developed showing the percentage of one-person automobiles driving in priority lanes. Table 29, on the following pages, shows the number of one passenger vehicles in the priority lane, the total number of vehicles in the priority lane, and the violation rates in percent.

The overall violation rate regionwide is approximately 6%.

An analysis of variance was performed on these data to test if violation rates were different based upon area type or time of day. Table 30 shows the results of the ANOVA.

Table 29. Violation Rate of One Person Vehicles in Priority Lanes (Percent)

	I-10/10th St Eastbound			I-10/11th Ave Westbound			I-10/32nd St Westbound		
Time of Day	One Passenger Vehicles	Total Vehicles	Violation Rate (%)	One Passenger Vehicles	Total Vehicles	Violation Rate (%)	One Passenger Vehicles	Total Vehicles	Violation Rate (%)
6:00 - 7:00 AM	45	429	10	3	213	1	10	270	4
7:00 - 8:00 AM	39	438	9	9	252	4	58	468	12
8:00 - 9:00 AM	21	309	7	6	129	5	34	288	12
9:00 - 10:00 AM	30	198	15	18	129	14	14	242	6
10:00 - 11:00 AM	36	213	17	9	147	6	12	150	8
11:00 - 12:00 AM	63	255	25	27	240	11	10	174	6
12:00 - 1:00 PM	27	273	10	24	261	9	2	210	1
1:00 - 2:00 PM	36	219	16	6	219	3	0	202	0
2:00 - 3:00 PM	30	351	9	27	354	8	0	280	0
3:00 - 4:00 PM	48	507	9	24	498	5	0	392	0
4:00 - 5:00 PM	66	849	8	15	693	2	0	258	0
5:00 - 6:00 PM	21	657	3	30	915	3	0	268	0
6:00 - 7:00 PM	33	294	11	27	324	8	0	302	0

	I-10/39th Ave Westbound			I-10/48th St Eastbound			I-10/51st Ave Eastbound		
Time of Day	One Passenger Vehicles	Total Vehicles	Violation Rate (%)	One Passenger Vehicles	Total Vehicles	Violation Rate (%)	One Passenger Vehicles	Total Vehicles	Violation Rate (%)
6:00 - 7:00 AM	3	138	2	9	96	9	3	342	1
7:00 - 8:00 AM	0	69	0	6	84	7	66	867	8
8:00 - 9:00 AM	0	117	0	6	87	7	12	153	8
9:00 - 10:00 AM	0	93	0	0	39	0	3	90	3
10:00 - 11:00 AM	0	117	0	12	75	16	0	60	0
11:00 - 12:00 AM	0	102	0	0	69	0	0	81	0
12:00 - 1:00 PM	3	147	2	3	99	3	3	102	3
1:00 - 2:00 PM	21	195	11	12	120	10	0	117	0
2:00 - 3:00 PM	12	276	4	24	246	10	0	171	0
3:00 - 4:00 PM	12	495	2	48	378	13	0	204	0
4:00 - 5:00 PM	3	777	0	81	807	10	3	189	2
5:00 - 6:00 PM	27	975	3	84	900	9	0	150	0
6:00 - 7:00 PM	3	219	1	21	177	12	6	144	4

	I-10/51st Ave Westbound			I-10/63rd Ave. Westbound			I-10/67th Ave Eastbound		
Time of Day	One Passenger Vehicles	Total Vehicles	Violation Rate (%)	One Passenger Vehicles	Total Vehicles	Violation Rate (%)	One Passenger Vehicles	Total Vehicles	Violation Rate (%)
6:00 - 7:00 AM	0	84	0	6	84	7	0	201	0
7:00 - 8:00 AM	0	63	0	9	81	11	21	882	2
8:00 - 9:00 AM	6	84	7	0	72	0	6	210	3
9:00 - 10:00 AM	0	84	0	3	84	4	0	42	0
10:00 - 11:00 AM	3	90	3	9	54	17	0	90	0
11:00 - 12:00 AM	3	105	3	6	84	7	0	45	0
12:00 - 1:00 PM	0	123	0	0	87	0	0	84	0
1:00 - 2:00 PM	9	117	8	3	126	2	0	57	0
2:00 - 3:00 PM	6	231	3	3	165	2	0	135	0
3:00 - 4:00 PM	12	315	4	0	183	0	0	147	0
4:00 - 5:00 PM	12	507	2	3	414	1	3	174	2
5:00 - 6:00 PM	27	627	4	9	384	2	0	84	0
6:00 - 7:00 PM	3	177	2	0	117	0	0	102	0

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

Table 29. (Continued)

Time of Day	I-10/79th Ave Eastbound One Passenger Vehicles	Total Vehicles	Violation Rate (%)	I-10/83rd Ave Eastbound One Passenger Vehicles	Total Vehicles	Violation Rate (%)	I-10/83rd Ave. Westbound One Passenger Vehicles	Total Vehicles	Violation Rate (%)
6:00 - 7:00 AM	0	123	0	6	135	4	6	63	10
7:00 - 8:00 AM	0	252	0	9	210	4	3	60	5
8:00 - 9:00 AM	3	123	2	0	102	0	3	78	4
9:00 - 10:00 AM	0	54	0	0	57	0	6	78	8
10:00 - 11:00 AM	0	75	0	6	63	10	3	69	4
11:00 - 12:00 AM	0	57	0	0	36	0	9	87	10
12:00 - 1:00 PM	0	87	0	0	63	0	0	75	0
1:00 - 2:00 PM	0	54	0	3	75	4	0	69	0
2:00 - 3:00 PM	3	99	3	6	90	7	0	81	0
3:00 - 4:00 PM	3	135	2	6	72	8	3	114	3
4:00 - 5:00 PM	0	90	0	3	72	4	0	60	0
5:00 - 6:00 PM	3	69	4	9	66	14	0	132	0
6:00 - 7:00 PM	0	51	0	0	69	0	6	75	8

Time of Day	I-10/91st Ave Westbound One Passenger Vehicles	Total Vehicles	Violation Rate (%)	I-10/Broadway Eastbound One Passenger Vehicles	Total Vehicles	Violation Rate (%)	Loop 202/24th St Eastbound One Passenger Vehicles	Total Vehicles	Violation Rate (%)
6:00 - 7:00 AM	3	87	3	6	99	6	28	228	12
7:00 - 8:00 AM	0	48	0	0	63	0	32	196	16
8:00 - 9:00 AM	0	36	0	3	57	5	20	136	15
9:00 - 10:00 AM	0	45	0	3	60	5	12	96	13
10:00 - 11:00 AM	0	54	0	0	72	0	32	100	32
11:00 - 12:00 AM	0	24	0	6	81	7	16	144	11
12:00 - 1:00 PM	0	33	0	3	84	4	40	136	29
1:00 - 2:00 PM	6	27	22	6	63	10	40	156	26
2:00 - 3:00 PM	0	51	0	33	207	16	44	180	24
3:00 - 4:00 PM	0	60	0	27	300	9	68	236	29
4:00 - 5:00 PM	6	75	8	93	888	10	32	280	11
5:00 - 6:00 PM	9	114	8	87	804	11	32	324	10
6:00 - 7:00 PM	0	30	0	15	168	9	40	192	21

Time of Day	Loop 202/W 32nd St. Eastbound One Passenger Vehicles	Total Vehicles	Violation Rate (%)	All Vehicles One Passenger Vehicles	Total Vehicles	All Vehicles Violation Rate (%)
6:00 - 7:00 AM	3	57	5	131	2649	5
7:00 - 8:00 AM	12	57	21	264	4090	6
8:00 - 9:00 AM	3	60	5	123	2041	5
9:00 - 10:00 AM	0	27	0	89	1418	4
10:00 - 11:00 AM	0	39	0	122	1468	7
11:00 - 12:00 AM	0	30	0	140	1614	5
12:00 - 1:00 PM	9	42	21	114	1906	5
1:00 - 2:00 PM	12	60	20	154	1876	8
2:00 - 3:00 PM	9	117	8	197	3034	6
3:00 - 4:00 PM	15	120	13	266	4156	6
4:00 - 5:00 PM	12	126	10	332	6259	4
5:00 - 6:00 PM	12	120	10	350	6589	5
6:00 - 7:00 PM	12	96	13	166	2537	6

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

Table 30. Analysis of Variance for Priority Lane Violations ((Dependent Variable = Violation in Percent)

Source	DF	Type III SS	Mean Square	F Value	Pr>F
AREA	2	1131.94	565.97	13.99	0.0001
HTIME	12	222.24	18.52	0.46	0.9364
AREA*HTIME	24	564.20	23.51	0.58	0.9406
ERROR	169	6836.19	40.45		
TOTAL	207	8770.69			

Only AREA has a significant effect on the violation rate of priority lanes. This means that time of day has no significant effect on violation rates. A Duncan's test was performed on these means for AREA only with the following results:

Table 31. Duncan's Grouping for Priority Lane Violations by Area Type

Duncan Grouping	Mean	N	Area
A	8.52%	78	Core
B	4.29%	78	Urban
B	3.08%	52	Suburban

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

It is very interesting to note that the violation rate in the Core area type is almost twice as high as the violation rate in the Urban and Suburban area types. There may be any number of reasons for this phenomenon. Part of this may be due to the fact that traffic volumes tend to be higher in the core area. The non-priority lanes may be congested to the point where there is a significant travel time advantage in moving to the priority lane, and violators may be willing to accept the risk of being cited to gain this travel time advantage. The travel time advantage may not be as great in the less congested urban and suburban are types. Another possible explanation may be related to advantages associated with the location of priority ramps.

One of the more interesting findings in the data is the relatively higher violation rate in the core area. A recent article[4] on public attitudes toward the Seattle area HOV system notes that one factor that contributes to the public's confidence in and attitude toward HOV facilities is the violation rate. The primary purpose of the HOV lane system is to provide a travel time advantage to those people who make the extra effort to form a car pool. If people who do not make this effort are still afforded the same travel time benefits then the system could be in jeopardy. The same article also notes some of the difficulties associated with enforcement of HOV facilities; however, if the Phoenix area system is to continue to succeed, enforcing the rules of the system must be enforced.

[4]Public Attitude Toward the Seattle Area HOV System and Effectiveness of the HERO Hotline Program Transportation Research Record 1299.

As stated previously, the overall violation rate of priority lanes is approximately 6%. In a recent article by Rutherford, et al.[5] the violation rates of various facilities within other states is reported. Table 32 below is from the Rutherfordet al.paper.

Table 32. Reported Violation Rates on Some Facilities

State	Location	Type	Violation Rate
Virginia	I-95	Concurrent, Non-separated	34%
	I-395	Fully Separated, Reversible	2%
	I-66	HOV and airport in peak	20-30%
Texas		Exclusive Transitway	1%
Oregon	Banfield Freeway	Concurrent, Non-separated	(3+) 20% (2+) 10%
New Jersey	George Washington Bridge	Concurrent, Non-separated	30%
Colorado	South Santa Fe	Concurrent, Non-separated	9-31%
Massachusetts	I-93	Concurrent, asphalt curb Entrance monitored by state police	1%

Source: Rutherford et al.

The type of HOV facility utilized in the MAG region is concurrent non-separated HOV lanes. According to Table 32, the violation rate in Maricopa County appears to be lower than the violation rate in other states.

There are three sets of priority ramps located along Interstate 10 within the core area:

- I-10 @ 3rd Avenue,
- I-10 @ 3rd Street, and
- I-10 @ Loop 202.

Examination of those sampled links which are in the vicinity of these ramps indicate that these are high violation rate locations. Therefore, the high violation rates may not be associated with travel time advantages associated with travel on the freeway but with advantages which can be gained by traveling on alternate ramps and arterial streets.

[5] Agency Practice for Monitoring Violations of High-Occupancy-Vehicle Facilities, G. Scott Rutherford, Ruth K. Kinchen, and Leslie N. Jacobson, Transportation Research Record 1280.

Effectiveness of HOV Lanes

To evaluate priority lane effectiveness, two values have been calculated in this report, *auto occupancy and vehicle occupancy*. Auto occupancy is defined as the average occupancy when considering only the occupancy of the private auto classification. Vehicle occupancy is the average occupancy considering all vehicles on the facility. For each of the classifications where data were collected, a mean occupancy for that classification was used. Table 33 shows the occupancies for each classification.

Table 33. Mean Occupancies for each Vehicle Classification

	HOV Lane		Non-HOV Lane	
Vehicle Type	Mean Occupancy	Percentage	Mean Occupancy	Percentage
Passenger Vans	10.5	0.2	5.8	0.5
Light Trucks	2.2	4.3	1.3	4.6
Medium Trucks	2.0	0.7	1.1	2.9
Heavy Trucks	2.0	0.2	1.1	5.2
Motorcycles	1.1	5.8	1.1	0.4
Recreational Vehicles	2.2	1.6	1.3	0.2
Buses	30(AM)/40(PM)	0.9	30(AM)/40(PM)	0.2

1. Average occupancy of Van Pools as provided by RPTA.
2. Average occupancy of Buses as provided by "Phoenix Metropolitan Area Quarterly Transit Ridership Report," 1992, Phoenix Transit System.

All other values are estimated.

A tabulation of vehicle occupancies and auto occupancies for the freeway facilities was created. Auto and vehicle occupancy was tabulated for both HOV and non-HOV lanes for freeways with HOV lanes and for all lanes for freeways without HOV lanes and is given in Table 34.

Table 34. Auto and Vehicle Occupancy for Freeways

Facility	Lane	Mean Auto Occupancy	Mean Auto Occupancy
Freeways With HOV Lanes	priority	2.162	2.383
Freeways With HOV Lanes	non-priority	1.247	1.327
Freeways Without HOV Lanes	all	1.288	1.357

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

As depicted in Table 34, the occupancies on priority lanes are considerably higher than those of the adjacent non-priority lanes.

The evaluation of HOV facilities as to their ability to reduce air and noise pollution is one goal of this study. Evaluating the impact of HOV facilities across North America has been of interest to many transportation professionals as told by a recent article by Turnbull, et al.[6] which state the following:

> Evaluating the impact of HOV facilities has been a topic of interest and discussion among transportation professionals in recent years. Potential evaluation criteria, appropriate effectiveness measures, evaluation methodologies, and data collection activities have been a major focus of sessions at recent TRB Annual Meetings and National HOV Conferences, as well as numerous reports. While there appears to be general agreement among transportation professionals that HOV facilities should be evaluated, a consensus does not appear to exist regarding the most appropriate measures to use, the performance thresholds the projects should meet to be considered effective, or the data collection techniques. To date, the evaluations that have been conducted have often focused on general evaluation criteria and, given the nature of many of the facilities and limited funding for data collection, before-and-after evaluations have often been limited. In some cases, this has resulted in insufficient data to make meaningful comparisons. In addition, the lack of uniformity between approaches used in different areas has made comparisons between projects difficult.

Most evaluations of HOV lanes are in the form of before-after studies. These studies are structured to examine the same location before and after the implementation of the HOV lane. This is somewhat different than the HOV lanes constructed in the Phoenix area, as most of these were added with new freeway segments or widening of freeway segments. There does not appear to be any study which evaluates the effectiveness of HOV lanes based on the measured occupancies of freeways with and without HOV lanes.

Using the data collected for this MAG study, three different measures of effectiveness are presented to evaluate the HOV facilities.

Effect of Congestion of HOV Usage

A review of the data indicates that facilities with traffic flowing at or below 1400 vehicles per hour per lane are in an uncongested state. As the flow rate increases over 1400, congestion begins to increase. Some facilities may exist in an uncongested state most of the day, incurring congestion only during the peak hours. A table was created showing how vehicles per lane and passengers per lane differ between those hours when the non-HOV lanes are congested and those hours when the non-HOV lane are not congested. This is present in Table 35.

Table 35. Variation in Passengers per Lane per Hour and Vehicles per Lane per Hour by Freeway Congestion

	Vehicles/Lane/Hour		Passengers/Lane/Hour	
Facility Congestion Level	HOV	Non-HOV	HOV	Non-HOV
Congested	474	1712	1135	2147
Uncongested	140	913	343	1240
All	238	1147	575	1505

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

[6] Suggested Procedures for Evaluating the Effectiveness of Freeway HOV Facilities, Katherine F. Turnbull, Russell H. Henk and Dennis L. Christiansen, U.S. Department of Transportation Record DOT-T-92-01.

The data shown in Table 35 indicate that the number of passengers per lane in the HOV lane of congested facilities is much higher than the passengers per lane on uncongested facilities. The table shows that even when adjacent freeway lanes are congested, the vehicle flow rate of 474 vehicles per hour indicates that the HOV lane is operating at a very acceptable level of service. The number of vehicles on the HOV lanes is approximately one third those vehicles in adjacent congested non-HOV lanes, yet is carrying half as many passengers as the adjacent HOV lanes.

Mode Shift Effects

In Chapter 3, Figure 9 was shown indicating that the average auto occupancies of freeways with HOV lanes is greater than the auto occupancies of freeways without HOV lanes. In the urban area type, this is a significant difference. One possible explanation for this difference in auto occupancy may be the propensity for drivers to change their driving habits due to the presence of the HOV facility. If drivers were not changing their habits, then one would expect the occupancy rates of both facilities to be similar. In fact in the suburban area type, the occupancies are similar. However, in the suburban area, there is little advantage to using the HOV lane due to the relatively uncongested freeway operation.

This analysis suggests that in the Phoenix area, there is a real mode shift of single passenger autos to higher occupancy autos.

Persons Utilizing HOV Lanes

Another evaluation of the effectiveness of HOV lanes is to tabulate the number of people being carried in the priority and non-priority lanes. Even though the raw volume of vehicles on the priority lane is typically lower than the adjacent lanes, the occupancy of these vehicles is considerably higher. If the priority lane carries more people than the adjacent lanes, then it is supposed that this is a more efficient means of automobile travel since the priority lane never incurs delay due to congestion.

Table 36 shows the average vehicles and passengers per lane for those facilities with HOV lanes. These values are the weighted average for the entire 13 hour data collection period. As shown in the table, priority lanes carry, on the average, less than half of the passengers carried on the non-priority lanes.

Table 36. Lane Passenger Volume by Area Type (Freeways with HOV Lanes)

	Vehicles/Lanes		Passengers/Lane	
	HOV Lane	Non HOV Lane	HOV Lane	Non HOV Lane
Core	262	1170	609	1504
Urban	227	1172	573	1516
Suburban	81	602	208	850

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

A tabulation of the number of persons carried on all HOV facilities by time of day was performed to see if there was any instance where the HOV lane carried more persons than the adjacent non-HOV lanes. This tabulation is given in Table 37.

Table 37. Persons per Lane for Priority and Non-Priority Lanes

Area Type Core	I-10/10th St Eastbound		I-10/11th Ave Westbound		I-10/39th Ave Westbound		I-10/51st Ave. Westbound	
Time of Day	Priority Lane	Non Priority Lane	Priority Lane	Non Priority Lane	Priority Lane	Non Priority Lane	Priority Lane	Non Priority Lane
6:00 - 7:00 AM	785	2066	441	1436	389	1539	182	859
7:00 - 8:00 AM	937	2058	499	1830	151	1483	130	889
8:00 - 9:00 AM	655	1943	278	1744	361	1185	190	831
9:00 -10:00 AM	407	1579	273	1720	215	1585	296	834
10:00 - 11:00 AM	450	1651	316	1602	281	1112	189	929
11:00 - 12:00 AM	454	1525	504	1548	232	1635	233	986
12:00 - 1:00 PM	768	1497	505	2004	319	1895	400	989
1:00 - 2:00 PM	430	2079	719	1995	1406	1830	244	1205
2:00 - 3:00 PM	810	1992	836	2334	621	1930	827	1316
3:00 - 4:00 PM	1007	1907	1012	2332	1053	2165	630	1413
4:00 - 5:00 PM	2219	2311	1499	2778	1756	2648	1144	1882
5:00 - 6:00 PM	2106	1992	1944	2491	2222	2454	1360	1936
6:00 - 7:00 PM	749	1476	705	1929	569	1731	384	1151
All	970	1878	786	2022	799	1834	517	1210

Area Type Core	Loop 202/24th St Eastbound		Loop 202/W. 32nd St Eastbound		All	
Time of Day	Priority Lane	Non Priority Lane	Priority Lane	Non Priority Lane	Priority Lane	Non Priority Lane
6:00 - 7:00 AM	568	949	112	929	413	1296
7:00 - 8:00 AM	366	1159	112	1072	366	1415
8:00 - 9:00 AM	273	968	110	870	311	1257
9:00 -10:00 AM	225	706	49	1116	244	1257
10:00 - 11:00 AM	169	727	92	713	249	1122
11:00 - 12:00 AM	300	855	61	798	297	1224
12:00 - 1:00 PM	240	882	76	792	385	1343
1:00 - 2:00 PM	301	762	107	847	534	1470
2:00 - 3:00 PM	340	853	245	1029	613	1582
3:00 - 4:00 PM	560	1181	225	1232	748	1699
4:00 - 5:00 PM	560	1443	380	1358	1260	2070
5:00 - 6:00 PM	762	1432	338	1649	1455	1992
6:00 - 7:00 PM	384	987	189	1056	497	1388
All	407	1021	173	1063	609	1504

Area Type Core	I-10/79th Ave Eastbound		I-10/ 83rd Ave Eastbound		I-10/83rd Ave Westbound		I-10/91st Ave. Westbound	
Time of Day	Priority Lane	Non Priority Lane	Priority Lane	Non Priority Lane	Priority Lane	Non Priority Lane	Priority Lane	Non Priority Lane
6:00 - 7:00 AM	269	1072	294	751	224	582	191	723
7:00 - 8:00 AM	679	1630	545	1263	107	684	93	717
8:00 - 9:00 AM	273	1108	220	839	157	589	89	565
9:00 -10:00 AM	131	900	115	644	154	723	111	695
10:00 - 11:00 AM	197	760	131	600	168	557	132	652
11:00 - 12:00 AM	131	910	75	584	176	656	52	781
12:00 - 1:00 PM	213	920	136	649	152	602	74	693
1:00 - 2:00 PM	118	916	149	790	178	617	48	697
2:00 - 3:00 PM	222	1205	200	858	403	604	107	656
3:00 - 4:00 PM	537	1171	263	873	242	775	127	766
4:00 - 5:00 PM	435	1216	211	962	150	1099	159	1284
5:00 - 6:00 PM	200	998	136	905	278	1119	249	1007
6:00 - 7:00 PM	131	997	374	637	178	668	79	686
All	285	1078	224	814	201	731	121	779

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

Table 37. Continued

Area Type Suburb	All	
Time of Day	Priority Lane	Non Priority Lane
6:00 - 7:00 AM	245	782
7:00 - 8:00 AM	356	1074
8:00 - 9:00 AM	185	775
9:00 -10:00 AM	128	740
10:00 - 11:00 AM	157	642
11:00 - 12:00 AM	108	733
12:00 - 1:00 PM	144	716
1:00 - 2:00 PM	123	755
2:00 - 3:00 PM	233	831
3:00 - 4:00 PM	292	896
4:00 - 5:00 PM	239	1140
5:00 - 6:00 PM	216	1007
6:00 - 7:00 PM	191	747
All	208	850

Area Type Urban	I-10/32nd St Westbound		I-10/48th St. Eastbound		I-10/51st Ave. Eastbound		I-10/63rd Ave Westbound	
Time of Day	Priority Lane	Non Priority Lane	Priority Lane	Non Priority Lane	Priority Lane	Non Priority Lane	Priority Lane	Non Priority Lane
6:00 - 7:00 AM	732	2365	192	1303	682	1786	169	890
7:00 - 8:00 AM	1371	2937	263	1359	1813	2012	148	1052
8:00 - 9:00 AM	697	2678	194	1348	290	1552	174	707
9:00 -10:00 AM	634	1965	89	1445	673	1153	294	895
10:00 - 11:00 AM	326	1927	142	1376	135	962	147	949
11:00 - 12:00 AM	370	2014	138	1478	182	914	278	1084
12:00 - 1:00 PM	677	1944	216	1550	254	962	179	996
1:00 - 2:00 PM	486	2314	237	1851	390	1091	266	1039
2:00 - 3:00 PM	754	2411	490	1908	382	1355	338	1395
3:00 - 4:00 PM	938	2564	866	1950	901	1698	413	1438
4:00 - 5:00 PM	683	2477	2064	1779	689	1528	1042	1823
5:00 - 6:00 PM	657	2331	2685	1640	377	1184	932	1811
6:00 - 7:00 PM	829	1985	345	1703	370	1121	247	1281
All	720	2328	695	1606	573	1358	384	1217

Area Type Urban	I-10/67th Ave Eastbound		I-10/Broadway Eastbound		All	
Time of Day	Priority Lane	Non Priority Lane	Priority Lane	Non Priority Lane	Priority Lane	Non Priority Lane
6:00 - 7:00 AM	427	1145	198	1381	400	1479
7:00 - 8:00 AM	1813	1483	162	1362	928	1701
8:00 - 9:00 AM	456	1351	220	1283	338	1486
9:00 -10:00 AM	95	766	130	1378	319	1267
10:00 - 11:00 AM	211	755	180	1406	190	1229
11:00 - 12:00 AM	110	697	172	1538	208	1287
12:00 - 1:00 PM	413	776	164	1668	317	1316
1:00 - 2:00 PM	226	1022	119	1523	287	1473
2:00 - 3:00 PM	300	949	488	2134	459	1692
3:00 - 4:00 PM	699	1127	705	1852	754	1771
4:00 - 5:00 PM	477	1010	2119	2001	1179	1770
5:00 - 6:00 PM	205	747	1997	1597	1142	1552
6:00 - 7:00 PM	277	771	333	1561	400	1404
All	460	981	609	1609	573	1516

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

There were six hours where the number of people carried on the HOV lane was greater than the number of people carried on the adjacent freeway lanes. This is shown in Table 38.

Table 38. Lane Passenger Volume by Time of Day

		Passengers/Lane	
Location	Time of Day	HOV Lane	Non HOV Lane
I-10/48th St. Eastbound	4:00 - 5:00 PM	2064	1779
I-10/48th St. Eastbound	5:00 - 6:00 PM	2685	1640
I-10/Broadway Eastbound	4:00 - 5:00 PM	2119	2001
I-10/Broadway Eastbound	5:00 - 6:00 PM	1997	1597
I-10/10th St Eastbound	5:00 - 6:00 PM	2106	1992
I-10/67th Ave Eastbound	7:00 - 8:00 AM	1813	1483

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

The locations given in Table 38 are heavily congested during these hours. At these locations, then, it appears that the HOV lane is highly effective, allowing those people who are using it to travel at reasonable speeds. During the remainder of the day, however, the priority lanes facilities at these locations are not as effective.

Summary of Effectiveness of HOV Lanes

In reviewing the results of these three analysis, it would appear that HOV lanes become very effective in periods of high congestion on the adjacent freeway lanes. During periods of little congestion, the number of people on the HOV lane drops to a much smaller percentage of the total freeway traffic.

Based upon the experimental design of the data collection, freeways with HOV lanes have a much higher auto occupancy than freeways without HOV lanes. It is reasoned that the cause of this increase in occupancy is due to a shift of single occupant vehicles to higher occupancy modes of travel along HOV facilities in the urban area type.

If the goal of an efficient transportation system is to increase the overall person carrying capacity, then it would appear that HOV lanes are very effective in moving large volumes of people at relatively uncongested speeds. They become more effective as the adjacent freeway lanes become overloaded. It should be pointed out, however, that there is a wide range of goals by which the effectiveness of HOV lanes can be evaluated. These include:

- Creating an uncongested pathway for express buses
- Providing travel time savings and more reliable trip time to high occupancy vehicles.
- Increasing overall number of people carried by facility

CHAPTER SIX

CONCLUSIONS

This study documents data collected on occupancy and vehicle classification for the Metropolitan Phoenix area. Manual counts of occupancy were collected from nearly 400,000 vehicles at 62 locations on weekdays in the months of April and May, 1992. To aid in data collection and insure the quality of the collected data, occupancy measurements were directly entered into TANDY 102 portable laptop computers. The occupancy data were then directly input into SAS for analysis.

Variations of Vehicle Occupancy in the Region

Samples of vehicle occupancy were collected within stratifications of three factors. These factors are area type, facility type, and time period. A detailed discussion of these factors is provided in chapter two. The purpose of collecting data within this stratum was to determine how occupancy changes based upon these factors. Not surprising, it was found that these factors accounted for approximately 43% of the variability found in occupancy. Other factors not studied and general variance in auto occupancy would account for the remainder of the variability.

For the purposes of this study, auto occupancy is determined to be the occupancy of all passenger cars only in the traffic stream. These values, therefore do not account for occupancy of trucks, buses, recreational vehicles, motorcycles and passenger vans.

It was determined that auto occupancy varies by area type, facility type, and time of day. For area type, it was found that occupancies were greater in the suburban area than the urban or core areas. This is most likely due to the fact that there are larger household sizes in the suburban area and a smaller percentage of work trips. Work trips are those trips that people take to and from work and usually have a lower auto occupancy rate.

Occupancy was also found to vary by facility type. Three facility types were studied as a part of this study. Freeways with priority lanes, freeways without priority lanes and arterial streets. The highest occupancy rate was fund to be on the arterial streets. The next highest occupancy was found on freeways with priority lanes, and the lowest occupancy was found on the freeways without priority lanes.

The final factor studied was time of day. There is a dramatic change in auto occupancy throughout the thirteen hour period collected. The lowest occupancies occurred in the 6:00-8:00 AM time periods. This is a time of day when there is a large proportion of work trips on the network. The largest auto occupancy occurred in the 6:00 to 7:00 time period. This is a time of day when there are a number of shopping trips on the network and not as many work trips.

For the most part, auto occupancy on freeways with priority lanes was found to be the same as auto occupancies without priority lanes. In the Urban area type, however, freeways with priority lanes were found to have substantially greater occupancies than freeways without priority lanes.

Variation of vehicle occupancy over time

Table 16 in the report shows how auto occupancy rates have varied over time. It should be noted that for studies conducted in 1977 through 1982, the occupancy rates are from only 6 sites representing a very small sample. 1988 occupancies are reported for 36 sites, of which 6 are the same sites from the previous studies. The 1992 data is from 52 sites throughout the region and do not include the 6 sites from the previous studies.

Because of the small sample size associated with the 1977 through 1982 studies, they are most likely representative of overall vehicle occupancy rates; however, the variation associated with the small sample sizes make this comparison very subjective. The occupancies are most probably unweighted and should therefore be compared to the unweighted occupancies shown in the 1992 data.

A more direct comparison of auto occupancy over time is given in Table 18 of the report. In this table, only the 6 locations from the previous studies are presented. This table represents actual change in auto occupancies at these six sites and as an overall composite auto occupancy. This table shows that as a general trend, auto occupancies have not changed dramatically at these sites over time. The 12-hour average auto occupancy for the six sites has remained relatively constant at 1.28-1.33 since 1973. This is in spite of the fact that the characteristics of these sites have changed over the last twenty years.

Vehicle Classification

Concurrent with the auto occupancy counts collected in this study, vehicle classification was also collected at all sites. The following table shows the overall classification of automobiles for all facility types, area types and time of day.

Table 39. Vehicle Classification in MAG Region

Vehicle Type	Percentage
Private Auto	88.7
Passenger Vans	0.3
Light Trucks	4.9
Medium Trucks	2.5
Heavy Trucks	2.3
Motorcycles	0.6
Recreational Vehicles	0.3
Buses	0.5

Source: Counts taken by Lee Engineering on weekdays during April and May, 1992

Priority lane use

There doesn't appear to be any priority lane operating near capacity for any time period of the day. Therefore, if the adjacent lanes on the freeway are becoming congested, the HOV lane is providing a time savings. Especially during peak hours, the volumes collected for HOV lanes show that they are being utilized.

There is also approximately 10-25% of the vehicles in non-priority lanes which are high occupancy vehicles. The lowest percentage occurs in the AM time period (6:00-9:00 AM) at 13% and the highest percentage occurs in the evening time period (6:00-7:00 PM) at 25%. During the time between these two periods, the percentage is approximately 18 to 22%.

Recommendations for Further Study

In performing the occupancy counts of this study, it became apparent that other issues might also be addressed in future studies. The following list is a recommendation for further work in the field of vehicle occupancy and HOV lane use.

Collection of travel speed There is probably a high correlation between the travel speed of adjacent lanes and the usage of priority lanes. A study which collects both these data would be beneficial in the staging of HOV construction.

Monitoring of Priority Lane Violation through Freeway Management System ADOT has created a Freeway Management System for the freeways throughout MAG region. It may be possible to monitor both auto occupancy and priority lane violation with this system. Contact should be made with the developers of the management system to see if the equipment being installed could also monitor this data. While the violation rate at present is not high when compared to other states, it could get higher. Increased violation rates may reduce the public's respect for the HOV system.

Opinion Survey on HOV Usage An opinion survey which questions motorist's as to their perception of the HOV system would also be a good method to evaluate their performance. As stated previously, the survey would have to be structured so that little judgement would be left to the respondent. The Regional Public Transportation Authority (RPTA) has recently conducted such a survey to serve as a base for comparison of changes in attitudes and perceptions.

Continued Monitoring of Auto Occupancy Auto occupancies have been collected in the region since 1973. Previous to this study, the last measurement occurred in 1988. Continued monitoring of auto occupancy is worthwhile.

APPENDIX A

VEHICLE WEIGHTING

The auto occupancy measurements collected in this study were not randomly chosen throughout the metropolitan Phoenix area, but were randomly chosen within stratifications of area type and facility type. Average vehicle occupancies were determined for each of these 'cells'. In order to project the results from this study into overall results for the MAG area, a weighting must be applied to the value collected in each cell.

In the *Guide for Estimated Urban Vehicle Classification and Occupancy, FHWA, 1980,* it is recommended that Vehicle Miles of Travel (VMT) be used as a weighting factor. MAGTPO provided data showing how VMT is stratified throughout the region. Since there are 117 cells by which this study was stratified (3 area types of 3 facility types by 13 time of day periods), 117 weighting factors needed to be determined. The data provided by MAG did not specifically report these 117 factors, but provided overall guidance by which these factors could be developed. Specifically, the data provided by MAG shows the row totals for each of the stratifications. By using these percentages, all 117 weighting factors were determined.

One factor not specifically reported was the percentage of HOV to non-HOV freeways within each of the area types. To determine this percentage, a 1992 map of the MAG area showing ADT was reviewed. VMT of HOV facilities within each area type was determined and subtracted from the total freeway VMT for the stratification. These percentages were .30, .23, .06 for core, urban and suburban area types, respectively. These percentages seemed appropriate and were used to develop freeway and HOV freeway weighting.

Table A.1 shows the final VMTs associated with each cell. Table A.2 shows the breakdown of facilities within each area type provided by MAG. Table A.3 shows a breakdown by time of day for freeways and arterials within the region and was also provided by MAG. An inspection of Table A.3 reveals that 83 percent of the traffic within the region occurs between the hours of 6:00 AM and 7:00 PM. This means that the data collected in this study includes over 4/5 of all traffic on the system.

Table A.1
Vehicle Miles of Travel (VMT) for Weighting of Vehicle Occupancies

TIME OF DAY	CORE			URBAN			SUBURBAN			TIME OF DAY PERCENT	
	FRWY	HOV	ART	FRWY	HOV	ART	FRWY	HOV	ART	FRWY	ART
6:00-7:00AM(6)	116390	50721	285215	160901	49264	556310	105646	6705	467740	5.83%	4.67%
7	127770	55680	429960	176632	54080	838635	115975	7360	705115	6.40%	7.04%
8	113596	49503	358504	157037	48081	699260	103109	6544	587930	5.69%	5.87%
9	99621	43413	299262	137718	42166	583709	90424	5739	490776	4.99%	4.90%
10	99421	43326	315752	137442	42081	615873	90243	5727	517819	4.98%	5.17%
11	100819	43935	353007	139374	42673	688538	91511	5808	578916	5.05%	5.78%
12	104212	45414	370719	144066	44109	723084	94592	6003	607962	5.22%	6.07%
1	112198	48894	365833	155105	47489	713554	101840	6463	599949	5.62%	5.99%
2	125374	54636	400034	173320	53066	780264	113800	7222	656038	6.28%	6.55%
3	139349	60726	452558	192639	58981	882711	126485	8027	742174	6.98%	7.41%
4	143342	62466	487980	198159	60671	951803	130109	8257	800266	7.18%	7.99%
5	144141	62814	499584	199263	61009	974437	130834	8303	819296	7.22%	8.18%
6	109403	47676	370719	151241	46306	723084	99303	6302	607962	5.48%	6.07%
ALL DAY	1996406	870000	6107389	2759876	845000	11912429	1812102	115000	10015843		

Table A.2

1990 VMT for MAG Planning Area (1272 TAZ)
Count Data-Collector and Centroid Connector Adjusted

Facility Type	Area Type 1	Area Type 2	Area Type 3	Area Type 4	Area Type 5	Total
Freeway	316,891	2,549,515	3,604,876	1,144,229	782,873	8,398,384
Ramp	17,789	124,263	151,284	39,723	23,509	356,568
Expressway	0	114,774	282,863	224,718	486,725	1,109,080
Arterial	1,901,003	4,206,386	11,912,429	7,312,641	2,703,202	28,035,661
Six-leg	109,364	146,355	307,167	44,574	0	607,460
Collectors	511,477	436,828	1,162,627	396,251	204,948	2,712,130
Cent Conn	329,273	1,143,201	3,523,995	2,539,257	977,691	8,513,418
Total	3,185,797	8,721,322	20,945,241	11,701,392	5,178,948	**49,732,701**

These figures represent estimates form the 1990BA network HSTAT program run with 1990 count data. Collector and Centroid Connector estimates have been adjusted with the following factors making them proportional to VMT figures in the HPMS data:

Collector factor = 1.35
Centroid Connector factor = 1.688

6/12/92

Table A.3

Percent Daily Traffic by Hour

	FREEWAYS	ARTERIALS	ALL
12-12:59 AM	1.14%	0.77%	0.85%
1-1:59 AM	0.82%	0.49%	0.56%
2-2:59 AM	0.73%	0.33%	0.42%
3-3:59 AM	0.79%	0.32%	0.43%
4-4:59 AM	1.56%	0.64%	0.84%
5-5:59 AM	3.94%	2.14%	2.54%
6-6:59 AM	5.83%	4.67%	4.92%
7-7:59 AM	6.40%	7.04%	6.90%
8-8:59 AM	5.69%	5.87%	5.83%
9-9:59 AM	4.99%	4.90%	4.92%
10-10:59 AM	4.98%	5.17%	5.13%
11-11:59 AM	5.05%	5.78%	5.62%
12-12:59 PM	5.22%	6.07%	5.89%
1-1:59 PM	5.62%	5.99%	5.91%
2-2:59 PM	6.28%	6.55%	6.49%
3-3:59 PM	6.98%	7.41%	7.32%
4-4:59 PM	7.18%	7.99%	7.81%
5-5:59 PM	7.22%	8.18%	7.97%
6-6:59 PM	5.48%	6.07%	5.93%
7-7:59 PM	3.88%	4.18%	4.11%
8-8:59 PM	3.13%	3.28%	3.25%
9-9:59 PM	3.10%	2.91%	2.95%
10-10:59 PM	2.33%	2.01%	2.07%
11-11:59 PM	1.68%	1.25%	1.34%
	100.00%	100.00%	100.00%

4/24/92