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# Auto Occupancy Monitoring

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**Washington State Department of Transportation**
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in cooperation with the
United States Department of Transportation
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16. ABSTRACT

There are only limited opportunities to add significantly to the transportation infrastructure in the Puget Sound region in the next 15 to 20 years. For this reason, there is a growing interest in improving the efficiency of the existing system. One way to do this is to increase the average vehicle occupancy (AVO) on freeways and arterials. Programs to accomplish this must be capable of evaluation. Therefore, accurate and up-to-date information on AVO is required.

This research project investigated various methods to measure AVO in order to determine the feasibility and costs of a continuous, ongoing data collection program. Since it was determined that there are no promising approaches using automatic methods employing new technology, the study focused on the use of human observers. The degree of accuracy was studied using three observers counting the occupancy of the same vehicles at the same time. The results showed the observers can be highly accurate (correct 97 percent of the time) and that environmental conditions such as weather, light, traffic density, and traffic speed do not have exceptionally strong effects on accuracy (within reason). Furthermore, observers can easily count up to a half hour at a time without fatigue affecting their performance.

Taking the results of this and previous research into account, it was determined that it is possible to provide quarterly counts of AVO at 26 sites that are accurate to within about 1.5 percent for about $50,000 per year. This is about the cost of one data analyst, when benefits and overhead are taken into account.

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# AUTO OCCUPANCY MONITORING STUDY

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Final Report

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# Auto Occupancy Monitoring Study

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## EXECUTIVE SUMMARY

There are only limited opportunities to add significantly to the transportation infrastructure in the Puget Sound region in the next 15 to 20 years. For this reason, there is a growing interest in improving the efficiency of the existing system. One way to do this is to increase the average vehicle occupancy (AVO) on freeways and arterials. Programs to accomplish this must be capable of evaluation. Therefore, accurate and up-to-date information on AVO is required.

This research project investigated various methods to measure AVO in order to determine the feasibility and costs of a continuous, ongoing data collection program. Since it was determined that there are no promising approaches using automatic methods employing new technology, the study focused on the use of human observers. The degree of accuracy was studied using three observers counting the occupancy of the same vehicles at the same time. The results showed that observers can be highly accurate (correct 97 percent of the time) and that environmental conditions such as weather, light, traffic density and traffic speed do not have exceptionally strong effects on accuracy (within reason). Furthermore, observers can easily count up to a half hour at a time without fatigue affecting their performance.

Taking the results of this and previous research into account, it was determined that it is possible to provide quarterly counts of AVO at 26 sites that are accurate to within about 1.5 percent for about $50,000 per year. This is about the cost of one data analyst, when benefits and overhead are taken into account. The study team and the steering committee (consisting of representatives of the Washington State Department of Transportation (WSDOT), the Municipality of Metropolitan Seattle, the City of Seattle, the City of Bellevue, King County and the Puget Sound Council of Governments) recommended that such a data collection effort be initiated. The project should be administered by District 1 of WSDOT and funded through an interlocal agreement by a wide range of jurisdictions.

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Washington State Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

# INTRODUCTION

During the next 15 to 20 years, the primary methods available to manage the freeways in the Puget Sound area will involve increasing the average occupancy of vehicles using the freeways. Current demand is taxing the capacity of the freeways and there is no doubt that demand will increase during the next decades. Since no new freeway construction is expected and since no rail system can possibly be put into place during that time period, the challenge is to make the existing freeway more efficient.

In order to evaluate the effectiveness of programs that increase the average vehicle occupancy (AVO) on freeways and arterials, a method must be developed to measure AVO on a continuous basis. Until now, such measurements have been conducted on a sporadic and project-specific basis. This means that no consistent database is available for program evaluation. Since different research designs and field collection methods have been used to measure AVO, changes in historical data cannot be used to evaluate past programs and trends. The relationship between AVO and economic factors such as employment and gasoline price is not well-understood.

Another important reason to have good information on AVO is for long-range planning purposes. Transportation models require AVO data. The more accurate the AVO data are, the better the forecasts from transportation models can be.

This research project was designed to address the lack of consistent and on-going AVO measurements. The collection of reliable AVO information can be expensive, especially when information is needed on a geographically disaggregated basis. However, since a great deal of money and energy is being invested in programs to increase the AVO, and since many agencies are interested in having such data, implementing such a data collection effort is important. The Washington State Department of Transportation (WSDOT), the Municipality of Metropolitan Seattle (METRO), the City of Seattle, King County, the City of Bellevue and other local jurisdictions are involved in programs to encourage the use of transit, carpools, vanpools and other high occupancy vehicles (HOVs) to increase the efficiency of local highways. This research represents a joint effort of those agencies to develop a method to evaluate the success of those programs.

## OVERVIEW OF THE STUDY

The research was carried out during the first half of 1987. A steering committee composed of representatives from WSDOT, Metro, the City of Seattle, King County, the City of Bellevue and the Washington State Transportation Center (TRAC) met several times during the course of the research to provide technical guidance to the project and to establish a context for the research.

The first step was to review existing methodologies for auto occupancy monitoring. Very little literature was uncovered that dealt with the methodology of auto occupancy monitoring. Many studies exist that use AVO data, but little has been written to investigate the best ways to collect it.

The second step was to design a data collection method that would give information about a number of factors that influence the accuracy of AVO counts. These factors included weather, time-of-day, light levels, speed, observation location, speed, counter comfort, existence of weaving, length of time counting and many others.

The third step was to test the field collection methods. From early May to early June 1987 data were collected in the field using three people counting at the same locations at the same time. By examining the agreement or disagreement among the counters, researchers determined the error levels and could relate them to the factors under study.

The fourth step was to develop and recommend a proposal for counting AVO in this region that took into account the possible sources of error and minimized the cost while producing the most useful AVO data.

This report contains the results of these four steps in the next four sections.

## LITERATURE REVIEW

Staff at the WSDOT library in Olympia conducted a computer-based search of the literature concerning auto occupancy counting methodology. Although the search resulted in 79 references using auto occupancy counts, only seven were related to the methodology of counting occupancy. Exploration of the bibliographies for these articles and telephone calls to authors confirmed that very little has been done on the methodology of auto occupancy counting.

Four of the references related to an effort funded by FHWA around 1980. Robert A. Ferlis conducted the original research (1,2). Ferlis recommended a sampling approach to measuring auto occupancy and laid out procedures for determining sample size and for drawing the samples. He found that employing accepted survey techniques of stratification and sampling, reliable auto occupancy data can be collected at a lower cost than traditional approaches employing less frequent, but longer data collection periods.

The techniques presented in the Ferlis report have been employed in several places. Two of the articles discussed the application of the sampling techniques. One chronicled the experience using Ferlis' methods in Atlanta (3). Another discussed the results of the techniques used in the Detroit area (4). In both cases, the sampling technique was found useful in obtaining reliable data in a cost efficient manner.

One very short article discussed a technique for correcting auto occupancy data collected in a parking study to take into account the fact that passengers are sometimes dropped off in other locations (5).

The other two studies reviewed for this project discussed variations in auto occupancy by time of day, week or year. A study conducted in the Minneapolis area concluded that there were significant differences in auto occupancy on different days of the week, but that the differences depended on the location (6). The study found that there are probably seasonal variations as well, but since the study was conducted during the 1974 oil shortage, other factors made the results difficult to interpret.

Another study of factors influencing auto occupancy, conducted in the Seattle area, found no predictable patterns or trends in automobile occupancy by type of facility, traffic volume, level of transit service, distance to the central business district, season, day of the week, or time of day (7).

The Minnesota study found some differences in AVO not found in the Seattle study. However, both studies may have suffered from a lack of data over a long period of time and other influences on auto occupancy may have overridden the differences they were trying to detect.

The main theme emerging from the review of past studies was that little is known about the factors that influence the accuracy of auto occupancy counts. No study dealt with issues that affect human performance while counting vehicle occupancy such as weather conditions, speed of traffic, fatigue, light levels or the like. Variations in auto occupancy due to time of day, day of week, or season are not well-established and probably will not be very well understood until data are collected on a regular basis over a long period of time. The literature did show that a sampling method employing some stratification yields statistically reliable results in a cost efficient manner.

## DATA COLLECTION DESIGN

The data collection for this study was designed to answer some of the questions that have not been answered in previous research relating to recommendations for a regular data collection methodology. In order to propose a system for regular collection of AVO data, two kinds of information are necessary. First, it is necessary to understand what kinds of factors may lead to inaccurate or unusable data and to develop an administrative plan that will minimize the influence of these factors. Second, it is important to know how much data will be necessary to provide the accuracy required to use the data.

### Factors Influencing Accuracy

The primary method used to conduct auto occupancy counts has been to have observers watch vehicles and record the number of people in each one. In this study, the research focused on that method. However, other methods were considered.

**Methods Other Than Human Observations.** Several methods employing mechanical means are possible, but were not feasible to explore in depth in this study.

Photographs of vehicles may be taken automatically or manually and interpreted for occupancy later. The advantage in this method is that the observer can take as much time as necessary to make a judgment about occupancy. It is also possible to use films that can enhance the visibility of images. One disadvantage is that it would be very difficult to take pictures from the several angles that might be necessary to determine how many people are in a vehicle. A second drawback is that analyzing photographs would take as much time as counting in person. These same comments apply to videotape, as well.

Highly sensitive infrared radiation sensors are able to sense hot spots caused by people in a vehicle. However, because of the heat coming from the engine and other sources, the accuracy of this method is unlikely to be very high.

Data from photoelectric cells can be interpreted using computer-aided figure recognition techniques to determine the number of human-shaped objects visible through the windows of a car. However, the logistics of placing photoelectric cells on major highways and the cost of developing and using sophisticated computer programs probably makes this approach infeasible. Furthermore, the technology requires that vehicle occupants be silhouetted against the windows.

Sophisticated equipment for weighing vehicles in motion is under development. The weight on each of the wheels of a vehicle can be obtained and the weight distribution within the vehicle determined. By knowing the weight distribution of empty vehicles it would be possible to derive the probable location of loads in the vehicle and to infer the number of occupants. However, even if the equipment to weigh the vehicle were highly accurate (which it currently is not), the interpretation of the data would be very difficult.

Auto occupancy data can be collected through mail or telephone surveys. Trip diaries have been used in a number of research efforts to get detailed information about people's transportation choices. However, respondents are unable to give very accurate data about their trips that occurred more than a few days before they are asked. In order to collect auto occupancy data over a geographically dispersed area, thousands of surveys would have to be conducted to obtain accurate information. Since the most expensive part of a survey is contacting the respondent in the first place, the cost of this method would be prohibitive.

**Human Observers.** People can do a fairly good job of determining the number of people in a vehicle if they are motivated to do so and if the

conditions are favorable. The questions that this research addressed were 1) what motivates attentiveness in observations, 2) what conditions are important to obtaining good data and 3) what level of accuracy can be expected.

The measurement of observer motivation can be done directly only on a qualitative basis. However, accuracy can be measured under various conditions to determine when motivation might be a factor. The influence of objective conditions can be measured quantitatively. After paring down an initial list of factors influencing accuracy to take into account the time and financial limitations of this study, the following factors were deemed possible to measure:

- fatigue,
- weather conditions,
- speed of traffic,
- observer comfort,
- amount of light,
- traffic density,
- average occupancy,
- traffic weave, and
- time of day.

The research design took these into account.

**Use of Computers.** One of the known factors influencing data collection is the mechanical means used to record data. The traditional method used to count AVO employs a paper and pencil. The observer records the data on a piece of paper. Someone enters the data into a machine-readable form and the data are transferred to a computer for analysis.

In this research, the use of computers was essential, since the methodology required knowing the exact time that an observation was recorded. As a part of this study, the use of portable computers to collect data was evaluated. Several potential advantages exist for their use:

- the chance for errors in transcription of the data is decreased,
- consistency checks can be conducted while the data are being collected,
- data can be quickly transferred to a computer for analysis to detect problems early, and
- some aspects of the supervision of observers can be conducted by checking recording times and the like.

The portable computer used for this research was programmable using the BASIC language. A program (contained in Appendix A) was written that allowed the observer to simply hit one key to record a category for each vehicle. A "beep" as well as a display on the computer screen provided feedback to ensure positive contact with the key. The program automatically recorded the time of the observation. The program also allowed the observer to easily make corrections on past observations. Data were compressed in order to be able to store at least three hours of observations in a computer with 32K bytes of random access memory (RAM). A custom program was written in FORTRAN to expand the data after they were transferred to a larger personal computer.

## Factors Influencing Amount of Data Required

The size of a sample required to attain a certain level of accuracy depends on the variability in the data. In the case of AVO data, an appropriate measure is the standard deviation of the AVO. The variability in the data depends on several factors, including

1) the number of vehicles observed (determined by the density of traffic and the length of time of observation),
2) the distribution of vehicles with different occupancies,
3) the variation by time of day, day of the week and season, and
4) the error rate in counting occupants in a vehicle.

All of these factors will vary by location, but average levels can be determined to estimate requirements for a large scale data collection program.

**Number of vehicles**. In this region, good data on the number of vehicles passing most points is already available. On most freeways, the peak hour volumes approach the maximum lane capacity possible, on the order of 1800-2000 vehicles per lane per hour. On HOV lanes, the volumes are lower. Because of the existence of good data, this research

effort was not designed to collect new data on this subject.

**Distribution of vehicles** The distribution of numbers of vehicles can have an effect on the standard deviation. To illustrate with extreme examples, if all vehicles in a sample were SOVs, the AVO would be 1.00 and the standard deviation would be 0. If half of the vehicles in the sample were SOVs and the other half were 2-person carpools, the AVO would be 1.50 and the standard deviation would be .50. In actuality, the AVO and the standard deviation are usually between these two values. Distributions vary from place to place and the averages can be fairly well determined. The data from this research were used to supplement existing knowledge about these distributions.

**Time variations**. Variations by time of day, day of the week and season can contribute substantially to the standard deviation. However, variations within the peak hour tend to be rather small. Two of the studies reviewed for the literature search dealt with this topic and produced different conclusions regarding the predictability of variations. The manual written by Ferlis suggested values to use for some of the sources of variation.

If variations are predictable, their effect on the standard deviation can be obviated to some extent through stratification of the sample. Unfortunately, little new knowledge of these factors could be gleaned from the current research because of the limited number of observations and the lack of information on seasonal variations. The standard deviation from these sources can be estimated from other studies, but can be confirmed only with a large scale, regular data collection effort.

**Observer error**. This research study design emphasized the objective of increasing the knowledge of the fourth factor influencing standard deviation. Variations due to observer error are a factor to be taken into account. An estimate of this influence can be made from an analysis of the disagreements among the three observers conducting counts of the same lanes at the same times.

## Research Design

This research study was designed with two primary objectives: 1) determine the factors that influence errors and 2) determine the level of error in counting AVO. This section describes how the data collection was set up.

**Vehicle Categories.** The vehicle categories for this study were chosen to be consistent with categories used in previous WSDOT vehicle occupancy studies. Nine categories were employed, as follows:

1) SOV - any four wheeled, personal vehicle (including automobiles, pickup trucks, recreational vehicles, jeeps and vans that were not vanpools) with only one occupant

2) two-person carpool - any personal vehicle (as defined above) containing two people (including children)

3) three-person carpool - self-explanatory

4) four-plus person carpool - four or more people in a personal vehicle

5) vanpool - any van marked "vanpool" regardless of the number of people or an unmarked van with five or more people in it

6) bus - local, interstate, school and tour buses

7) motorcycle - with any number of people on it

8) two-axle truck - not including pickup trucks

9) three-plus axle truck - any truck with more than two axles or with a trailer

The categories were discussed with the observers in the training sessions before the regular observations began and clarified during practice observations.

The occupants of vans, buses, motorcycles and trucks were not counted. It is very difficult to count the occupants of vans and buses when they pass at high speeds. Vanpool programs, transit agencies and bus companies can provide much more accurate data than could be gained from observers for these categories of vehicles. Motorcycle occupancy was not counted because there are very few motorcycles in comparison with automobiles and the extra classification categories would have unnecessarily complicated the data collection process. Trucks were counted in order to provide data consistent with previous WSDOT data collection efforts and to

provide vehicle classification data that may be used for purposes other than AVO studies.

**Types of Locations**. Three types of locations were used in the research: employment sites, arterials and freeways. Figure 1 shows all of the locations. No attempt was made to represent the entire range for each kind of site, but the aim was to get a better understanding of the mechanics of data collection in a variety of places. The emphasis was on freeway sites, since that would be the major concern in a regular AVO data collection effort. The employment site was the entrance to the University of Washington at 15th Avenue NE and NE 40th Street. The site is very busy and is a difficult example of this type.

The arterial site was on the Montlake Bridge near the university. Traffic volume there is typical of arterials and the high variabilities in traffic density and speed that are found on most arterials. Data were collected in each direction.

Six freeway sites were studied. Two were on either side of State Route 520 at the east end of the Evergreen Point Bridge near the site of the old toll booth. Two were on either side of Interstate 5 just north of Northeast 50th Street. Two were on Interstate 5 just north of Mercer. The site to observe northbound traffic was at the corner of East Roy Street and Melrose Avenue East next to the freeway. The southbound site was on Boylston Avenue East, just north of its intersection with East Lynn Street.

The six freeway sites were not meant to represent all freeway sites in the region, but they are a cross-section of types of sites. Some of the differences among the sites include how close the observation points were to the traffic, whether the observers could sit down, how visible the observers were to drivers, the number of weaving movements in the traffic and the angle of the sun.

The actual location where the observers stood or sat

- had a shoulder or bank of the proper height to easily see the traffic lane (10 to 20 feet above the road's surface),
- was close enough to the roadway to see into the vehicles (20 to 50 feet),
- had a clear line of sight,

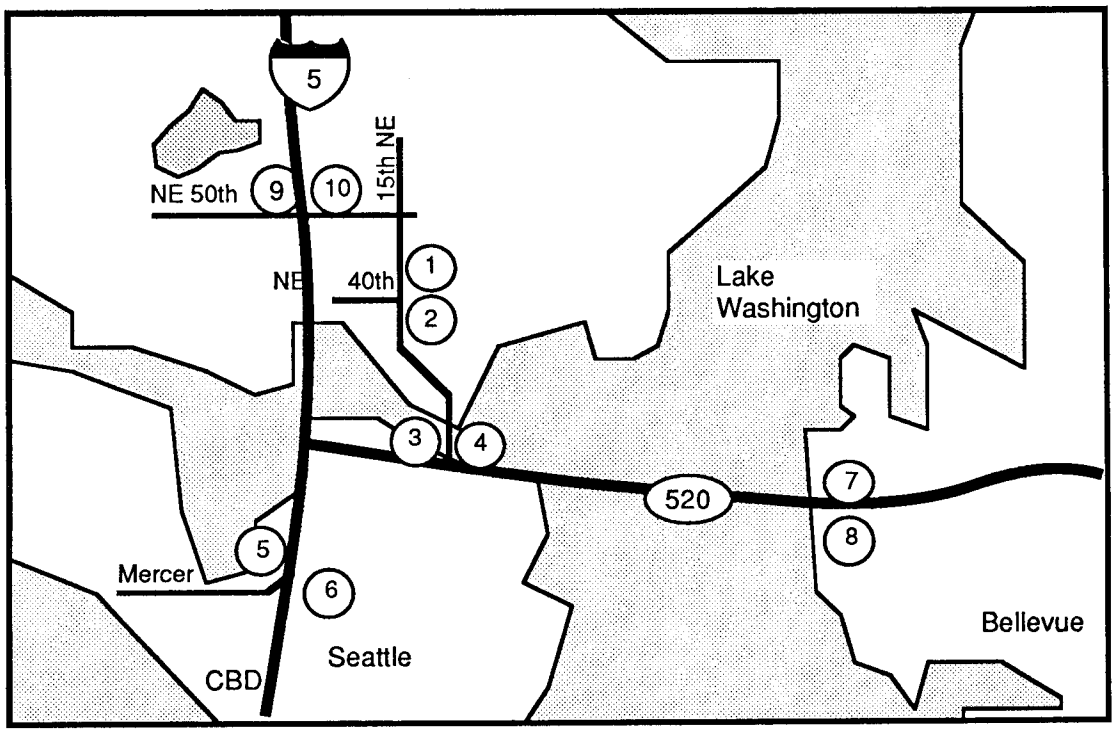



Figure 1. Location of Observations

- was safe for the observers while walking to the counting location and while counting,
- was located so the observers were not a distraction to drivers, and
- was convenient in terms of leaving a vehicle parked while counting.

**Spacing and Timing of Trials.** One of the factors of interest in this study was the influence of fatigue. In order to study this, observation periods were varied from session to session. The basic unit for observation was a 15-minute period. Error rates were determined for each 15-minute period using a process described in the next section.

In order to change the fatigue factor, different rest periods were used in each session. In some cases, each observation period was separated from the next by a 15 minute rest period. In other sessions, two fifteen minute periods of observations were conducted consecutively with a 15-minute rest break between the pairs. In two of the sessions, no rest breaks at all were taken between 15-minute observation periods.

**Measuring Environmental Conditions.** Five factors were measured during the course of this research: weather conditions, speed of traffic, observer comfort, amount of light and traffic weave. Two factors (speed of traffic and amount of light) could be measured objectively and the others required subjective judgment by the researchers.

Since the amount of time for the research was rather short, it was impossible to sample randomly from different types of weather conditions, or to test the influence of different weather conditions at each location or for each of the other factors that were under study. The researchers assumed that the range of weather conditions would be large enough to detect the effects. The researchers also recognized that it was possible that weather conditions could change within a 15-minute observation period. The measure used for this factor in later analysis was a subjective judgment of the most common weather in a 15-minute period using four categories: clear, partly cloudy, overcast and raining.

Traffic speed was measured using a portable radar gun about five times during each 15-minute period. The average among those speeds during an observation period was used to represent that factor. The averages were later allocated into five speed categories: stop and go; below 30, between 30 and 40, between 40 and 50, and over 50 miles per hour.

Observer comfort was based on a subjective assessment. Two categories were used: comfortable and uncomfortable. The major determination of comfort according to the observers was whether or not they could sit. It also happened that the observation locations that required standing were closer to the traffic and thus were noisier and contained a significant amount of dust in the air.

The amount of light was measured about five times during each observation period with a foot-candle meter. The averages of the logarithms of foot-candles for each observation period were used in later analysis.

Traffic weave was not a factor that the researchers originally intended to test in the research. However, upon retrospect, it was deemed to be an important factor in some of the freeway locations. One location was near the end of an HOV lane and the other was near an on-ramp. In both cases, weaving movements were much more common than occur in most mainline locations.

## FIELD RESEARCH AND ANALYSIS

The research design issues were incorporated into a schedule for data collection that also took into account the limitations of time and budget for this project. Table 1 shows the schedules for the 16 sessions along with locations, time of day, timing and number of 15-minute periods during which AVO data were collected. In all, there were 111 15-minute periods, or a total of 333 observation points.

Two instructions to observers were important in being able to compare observations. One was that a vehicle should be counted when it crossed a particular point in the pavement. This allowed comparison of times of observations at a later point. The second was that a vehicle that was entering or exiting the lane being counted should be recorded only if at least half of the vehicle were in the lane.

### Use of Computers

In order to match the observations of three counters on a vehicle-by-vehicle basis, computers had to be used because the observations had to be timed to the second. The use of computers in a regular AVO data collection program is not required. However, the use of computers offers several advantages which will be outlined here.

In general, the machines caused very little trouble. An effort was made to make their use as foolproof as possible by disabling all keys not used for counting. The observers had to spend some time learning the basics of using the machine and the counting program. However, the learning curve was very steep and the observers were completely competent in their use by the middle of the first recording session.

One of the major advantages of using portable computers in this data collection was the ease of data reduction and analysis. Transferring the data from the three observers for a three-hour period to machine readable form and conducting preliminary analyses to check for reasonability took less then ten minutes. Observers could get immediate feedback on the types of errors they were making. The data analysis became a continuing training tool.

A second advantage of using the machines in a regular AVO counting program is that they can act as a surrogate for a field supervisor. In this research, a field supervisor was always present. However, when AVO data can be time stamped and collected on an observation-by-observation basis, unreliable counts can be detected. Lapses in counting are obvious from the time stamps. The patterns and frequencies of each category of vehicle can be checked to see if they are reasonable.

A third advantage of using computers is that data can be transmitted over the phone lines. Observers do not have to travel to a common point each day to drop off data. Data can easily be transferred from their homes.

A few cautions about the use of computers should be noted. One is that batteries need to be replaced, or data may be lost. In most cases, batteries should be replaced on a regular schedule before they wear out rather than when the computer indicates that they are running low. Portable computers need to be protected from the weather. Some waterproof covering is necessary during rain and some method is also advisable to keep dust out of them. Software for the computer should be able to detect when an observer touches a key that should not be in use or when the observer accidentally rests a finger on a key.

In general, the use of computers was very successful. Computers with all necessary capabilities can be purchased for less than $500. The savings in data reduction costs can easily be justified. They should be considered for any regular AVO data collection program.

Table 1. Schedule and Description of Sessions

| # | Location[1] | Time of Day[2] | Timing[3] | No. of Periods | Date |
|---|---|---|---|---|---|
| 1 | 1 | AM | B | 9 | 5/12 |
| 2 | 2 | PM | C | 7 | 5/12 |
| 3 | 6 | eve | A | 6 | 5/13 |
| 4 | 3 | AM | B | 7 | 5/14 |
| 5 | 4 | PM | B | 8 | 5/14 |
| 6 | 8 | eve | A | 6 | 5/18 |
| 7 | 5 | AM | A | 6 | 5/19 |
| 8 | 10 | eve | A | 6 | 5/20 |
| 9 | 5 | AM | B | 8 | 5/21 |
| 10 | 6 | PM | A | 6 | 5/21 |
| 11 | 7 | AM | A | 6 | 5/26 |
| 12 | 6 | PM | B | 8 | 5/26 |
| 13 | 8 | PM | C | 9 | 5/28 |
| 14 | 8 | PM | B | 7[4] | 5/29 |
| 15 | 9 | AM | A | 6 | 6/2 |
| 16 | 10 | PM | A | 6 | 6/4 |

1. See Figure 1
2. AM = 6-9 a.m.; PM = 3-6 p.m.; eve = 6-9 p.m.
3. A = 15 min. periods with 15 min. breaks
   B = 30 min. periods with 15 min. breaks
   C = continuous counting
4. Data from one period lost due to machine problems

## Interpretation of Errors

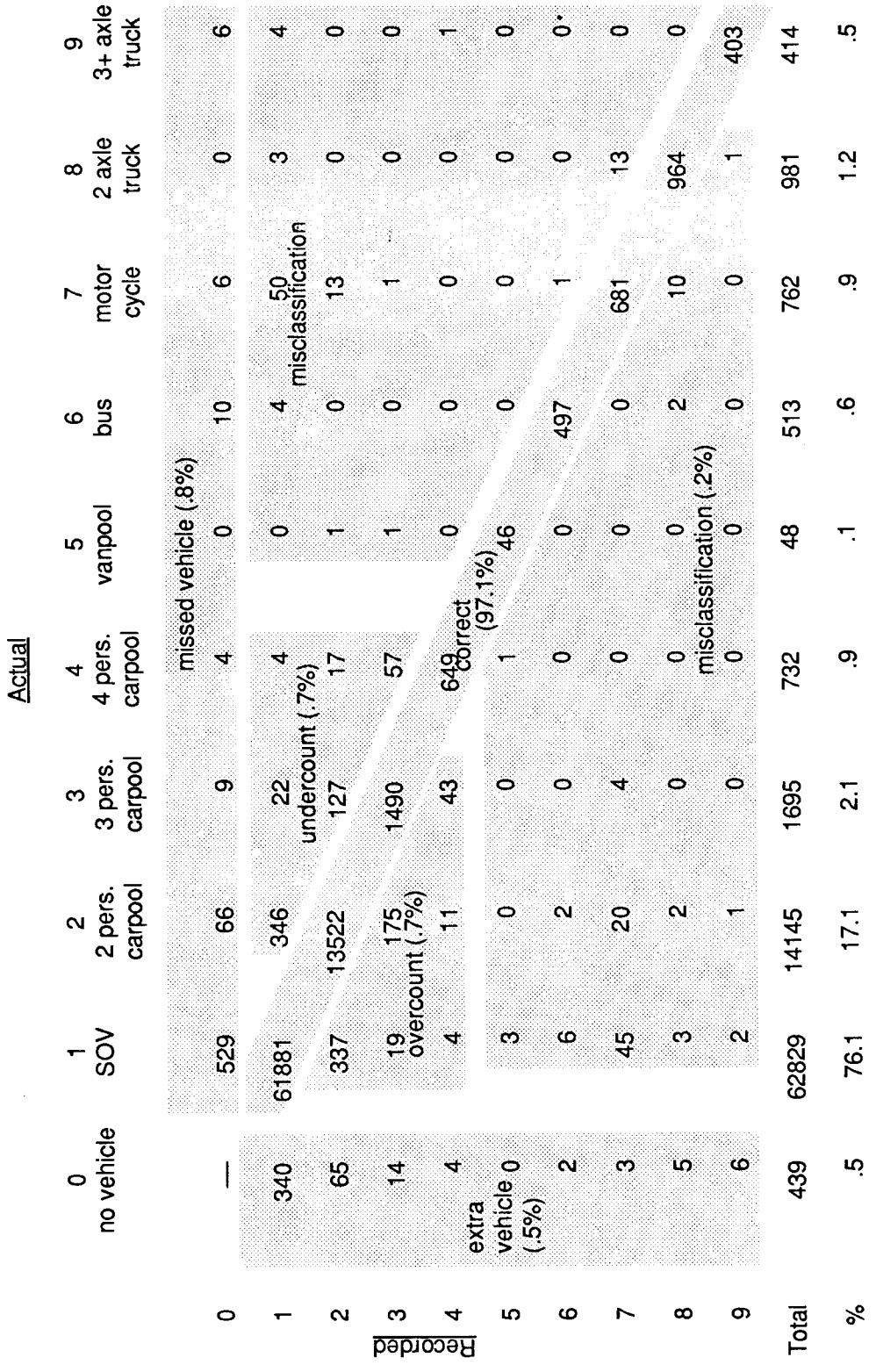
The primary variable of interest in this research was the error rate. In order to compute an error rate for each of the 333 observation periods, observations among the three observers were compared. A custom-written computer program was developed to aid in the comparison process. When at least two observers agreed on an observation, that was considered to be the "actual" category. An error was said to occur when one of the observers was the "odd man out." In other words, when two observers agreed with each other, but the third observer did not agree with him, the third observer was said to have committed an error. Although one person could have been been right and the other two wrong. the former interpretation was probably the correct one in the vast majority of the cases.

Five types of errors were recorded:

1) undercount - when an observer counted too few occupants in a personal vehicle

2) overcount - when an observer counted too many occupants in a personal vehicle

Table 2. Matrix of Actual versus Recorded Categories



3) classification - when an observer classified a vehicle wrongly (other than occupant count differences)

4) missed vehicle - when an observer failed to record a vehicle

5) extra vehicle - when an observer recorded a vehicle that was not there

Data on each of these error types can be found in Table 2. It is important to note that an undercount or overcount error was considered to be just one error, no matter how far off the count was.

These five types of errors were collapsed into three basic types for the final analysis:

1) total error - included all the above errors plus those few cases in which all three observers disagreed

2) count errors - the total of the first two types of errors defined above

3) existence errors - the total of the last two types of errors defined above

Table 2 shows a comparison of recorded category and actual category. An example will help clarify how to use the table. Under the column headed by "3 pers. carpool," is the number "127" in the row marked with a "2." Looking at the codes for the labels on the top of the table, one can see that "2" means a "2-pers. carpool." The "127" is the number of 3-person carpools that were mistakenly recorded as 2-person carpools by one of the observers.

One of the most important facts emerging from Table 2 is that observers were correct over 97 percent of the time. There were almost the same number of "overcounts" as "undercounts." the "missed vehicles" and "extra vehicles" tended to be distributed very much like the "actual" vehicles. In other words, the errors all tended to cancel each other out in the total AVO count.

## Error Analysis

Figure 2 shows the average error rates for each of the 16 observation sessions. The analysis focused on freeway counting sites, so locations 1 through 4 are not used in the remainder of the discussion. Furthermore, location fifteen had a much higher rate of error than the others. This was due

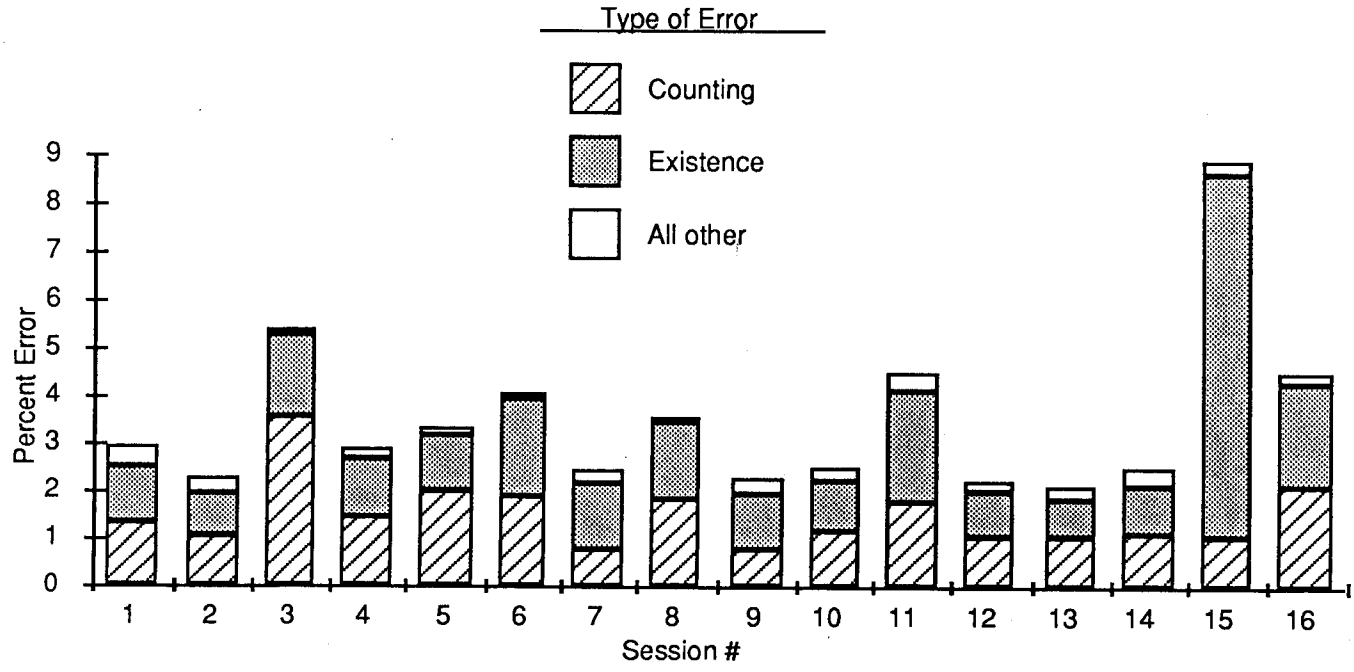



Figure 2. Error Rates by Session

primarily to significant weaving movements. Therefore, that location is also not used in the analysis described here. Disregarding those sessions left 11 remaining, with a total of 74 15-minute time periods, or 222 separate observations. The total observer error rate for these sessions was about 3 percent.

The primary method of analyzing the data was multiple regression analysis. The three major classifications of errors were the dependent variables and the following factors were the independent variables:

- weather - four dummy variables
- comfort - dummy variable
- weave - dummy variable
- time of day - dummy variable
- speed - continuous interval variable
- light - continuous interval variable
- location - dummy variable
- traffic density - continuous interval variable
- average occupancy - continuous interval variable

The variables weave, comfort and time of day (which is tied to the direction of peak hour travel) were determined entirely by the location, and were thought to be the primary distinguishing characteristics.

First, an attempt was made to relate location to error rate. Less than 10 percent of the variance in total error rate was explainable by location alone (13 percent of the counting error and 6 percent of the existence error). For this reason, the regression analysis used the variables that were thought important in the distinction among locations (comfort and weave).

Table 3 shows the results of the regressions using the three types of errors as the dependent variables and nine independent variables. The results can be interpreted by focusing on the statistically significant regression coefficients.

**Weather.** All of the weather-related dummy variables are significant. However, the differences among the coefficients are the most important aspects of the analysis. The higher the coefficient, the greater the contribution of each kind of weather condition to the error rate. Partly cloudy and overcast conditions tended to produce the fewest errors. Clear and rainy conditions produced the most errors, especially for counting errors. The differences among the types of weather are insignificant, however, except for the effect of rainy conditions on counting errors. Since it was raining during only two observation periods, other factors, not fully accounted for in the regression, may account for this difference. The observers felt that counting was not overly difficult during the rainy periods. The primary complaints were voiced when the sun was bright and the glare made seeing into the vehicles difficult.

**Comfort.** Comfort level did not have a significant effect on any of the errors (at the 95 percent confidence level). Negative coefficients imply that the fewest errors were made when the conditions were most uncomfortable. Since part of the definition of "uncomfortable" was that observers had to stand, the best interpretation of the negative coefficient is that the observers were probably able to distinguish lanes better when they had to stand. Otherwise, comfort level had little influence on accuracy.

**Weave.** Weaving movements were thought by the observers to have caused problems at three of the locations. However, the regression analysis failed to show a significant effect of weaving on any of the error rates. The positive coefficients are in the right direction to support the hypothesis that weaving movements have the effect of increasing the error rates, but they are not significant. One location was left out of this final analysis because the weaving effects apparently had very significant effects on error rates. Even though the statistical analysis didn't clearly confirm the detrimental effect of weaving on observation accuracy, weaving sections should be avoided in selecting counting sites.

**Time of day**. Time of day had a significant effect on counting error rates. The positive coefficient implies that the most accurate counts occurred in the morning. This result probably means that observers are fresher and more alert in the morning than in the afternoon.

**Speed of traffic**. The only significant effect of speeds on error rates was on the existence errors. The faster the traffic, the more likely observers were to miss vehicles or record vehicles that didn't exist. However, surprisingly, speed did not seem to affect the ability to count occupants of vehicles.

**Light**. The amount of light influences the ability to distinguish characteristics of objects. Lower light levels were expected to lead to more errors in observations. Although the coefficients are

Table 3. Regression Analysis Results

| Variable | Type | Regression Coefficients | | |
|---|---|---|---|---|
| | | Total Error | Counting Error | Existence Error |
| Clear weather | Dummy | 10.78* | 4.96* | 5.42* |
| Partly cloudy weather | Dummy | 10.12* | 4.58* | 5.20* |
| Overcast weather | Dummy | 10.46* | 4.90* | 5.21* |
| Rainy weather | Dummy | 11.82* | 7.12* | 4.39* |
| Lack of comfort | Dummy | -0.14 | .11 | -0.26 |
| Weaving | Dummy | .59 | .33 | .25 |
| Evening | Dummy | .46 | .45* | .09 |
| Speed | Interval | .06 | -0.08 | .14* |
| Light (log of foot-candles) | Interval | -0.09 | -0.05 | -0.03 |
| Traffic density (veh./min.) | Interval | -8.60* | -4.83* | -4.42* |
| AVO | Interval | -3.33 | -1.08 | -2.05 |
| $R^2$ | | .28 | .35 | .20 |
| Number of obs. | | 222 | 222 | 222 |
| F-statistic | | 8.38 | 11.26 | 5.34 |

*Significant at .05 level

in the right direction to support the hypothesis, none approach statistical significance. This may be due to the fact that counts in extremely low light conditions were attempted in only one of the 15-minute time periods. As long as there is some light, counting accuracy is not severely affected. A further discussion of the limitations that light levels impose on counting is presented in another section.

**Traffic density**. The original expectation was that higher traffic density would lead to a higher level of observation errors. The regression analysis shows just the opposite. There was a strong and significant tendency for more accurate counts to be conducted when there was more traffic. One explanation for this outcome is that when there are large spaces between vehicles, the observers' attention may wander. With low density traffic, vehicles tended to come in groups. Within those groups, the density was generally as high as it was during the higher density time periods. At least for the short time periods that were used in this research, heavy traffic conditions tended to focus the observers' attention. The counters' comments corroborated this interpretation.

**Average occupancy**. The researchers expected that error rates would tend to be higher with higher average occupancies, simply due to the fact that there is more chance for error with more multiple-occupant vehicles. The regression results indicate that there is no significant relationship between average occupancy and error rates. However, there is a slight tendency for higher occupancies to be associated with fewer errors.

**Fatigue**. Observer fatigue is an important issue in designing an AVO data collection program.

An understanding of how long observers can count occupancies before error rates significantly increase is important. This variable was studied in this research by varying the number of 15-minute periods that observers counted without a rest. Fatigue was not included as an independent variable in the regression analysis because there was a high degree of variation by location and the timing of observation sessions and rest periods was not varied randomly over all locations. The analysis of fatigue had to be controlled for by location.

There were 12 pairs of counting periods that occurred without a break and under similar conditions. Table 4 shows the average error rates for the first and second periods along with the average pairwise differences and the corresponding standard errors. For all types of errors, the second period had a higher error rate than the first. The differences are statistically significant for the overall error rate and the existence error rate. The difference for the counting errors is not statistically significant. While errors do not appear to increase drastically during the first half hour of counting, some care should be taken when continuous counting goes beyond that time period.

In retrospect, significant degradation in performance appears to occur only over a longer time period than a half hour. Had the researchers anticipated this, the research design would have included longer continuous counting periods. However, in one session, nine observation periods were conducted in a row without a break. Figure 3 shows the average error rates (among three observers) for each period in that session. Accuracy tended to improve over the first hour or so and then start to get worse. The number of observations in this session was too small to draw any definitive conclusions, however.

## Hours of Observation

In Seattle, due to the city's distance from the equator and its western location in the time zone, the sun sets and rises at relatively extreme times during the year. In the winter months, the sunrise is so late and the sunset so early that accurately counting vehicle occupancy during parts of the peak hours is not possible. Some of the results of this study can be used to determine the hours in which counting occupancies will be possible.

Two of the counting sessions occurred in the evening between 6 PM and 9 PM. The sunset during this time was at about 8:30 PM and the length of twilight was about two and one-half hours.(8) One of the evenings was clear and the other was overcast. On the clear evening, there was no noticeable impact on accuracy due the sunset up to 9 PM. On the overcast evening, however, the last counting period, occurring between 8:45 PM and 9 PM, resulted in a noticeable degradation in accuracy. However, it was not severe enough (in comparison with the earlier time periods that evening) to be unusable. The counters and the research supervisor concurred that the light level was the lowest it could be and still allow relatively accurate counts.

Graphs based on these results, were constructed (shown in Figure 4) that can be used to determine in which hours occupancy can be counted during different times of the year. The lines were constructed by adding 20 percent of the length of twilight to the sunset and subtracting 20 percent of

Table 4. Comparison of Two Consecutive Counting Periods (N = 36)

| Type of Error | Error Rate (%) 1st Period | Error Rate (%) 2nd Period | Difference | Standard Error of Difference | Probability of Difference from Zero (one-tailed) |
|---|---|---|---|---|---|
| Total | 2.16 | 2.48 | .31 | .20 | .05 |
| Counting | .96 | 1.05 | .09 | .10 | .19 |
| Existence | .92 | 1.19 | .27 | .17 | .05 |

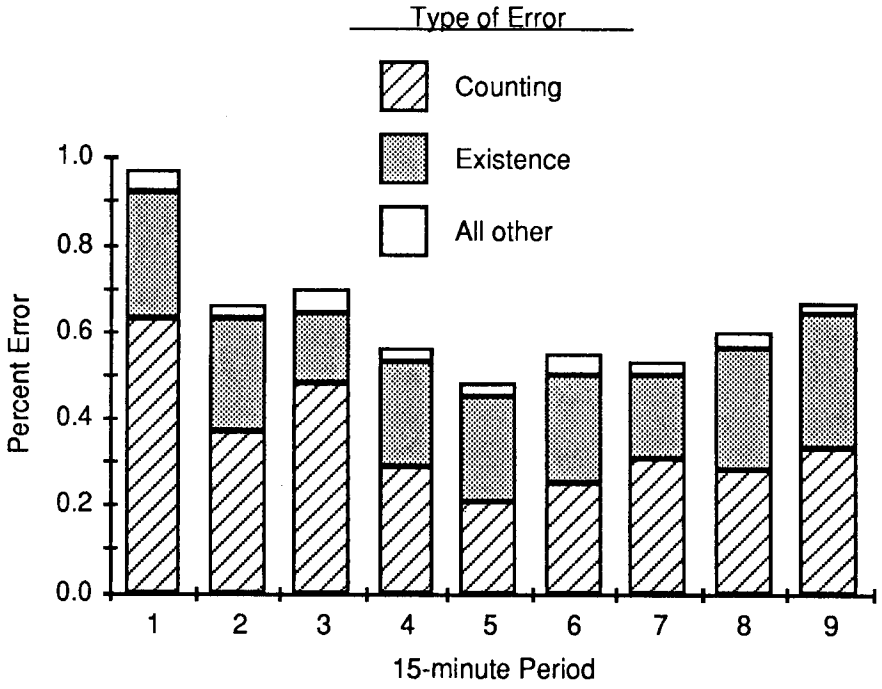



Figure 3. Errors in Session 13 (nine consecutive counts without a break)

the length of twilight from sunrise to determine the times at which occupancy can be counted, even in overcast weather. In clear weather, one could expect to expand the possible counting times.

The morning peak three hours can be counted from March through August and evening peak three hours between March and September. In the other months, varying proportions of the peak period can be counted, with a minimum of 1-1/2 at the worst times of year. Using data from each part of the peak hour from other times of the year, occupancy during the hours it was not possible to count could be estimated.

## Sample Size

Ferlis discusses fairly completely determination of sample size in conducting auto occupancy counts.(2) However, the sources of error that he discussed did not include some potential sources dealt with in this research. Specifically, he did not deal with observer counting error or variations due to time of day. In addition, one source of error (he called "short-counting") can be more precisely estimated using data from this study.

Table 5 shows five sources of error along with values from Ferlis (2), this research and the values used to estimate required sample size.

AVO tends to vary by day of the week. It tends to be higher on Mondays and decrease through the week. Research has shown, however, that the pattern varies by location. (6) A regular AVO data collection effort would probably be conducted on every day of the week and thus this source of variation should be taken into account. This research project did not involve the collection of enough data to determine the variability in the Seattle area, so the value employed here is that recommended by Ferlis.

AVO also varies across seasons and depends to some extent on location. The value Ferlis recommended is based on variation throughout the year. The recommended data collection program involves quarterly estimates. Since the variation within each quarter is likely to be smaller than that for the whole year, the estimated value for this source of variation is somewhat lower than that proposed by Ferlis.

The variation due to "short counting" takes into account the fact that there is random error in sampling auto occupancy. If one were to count

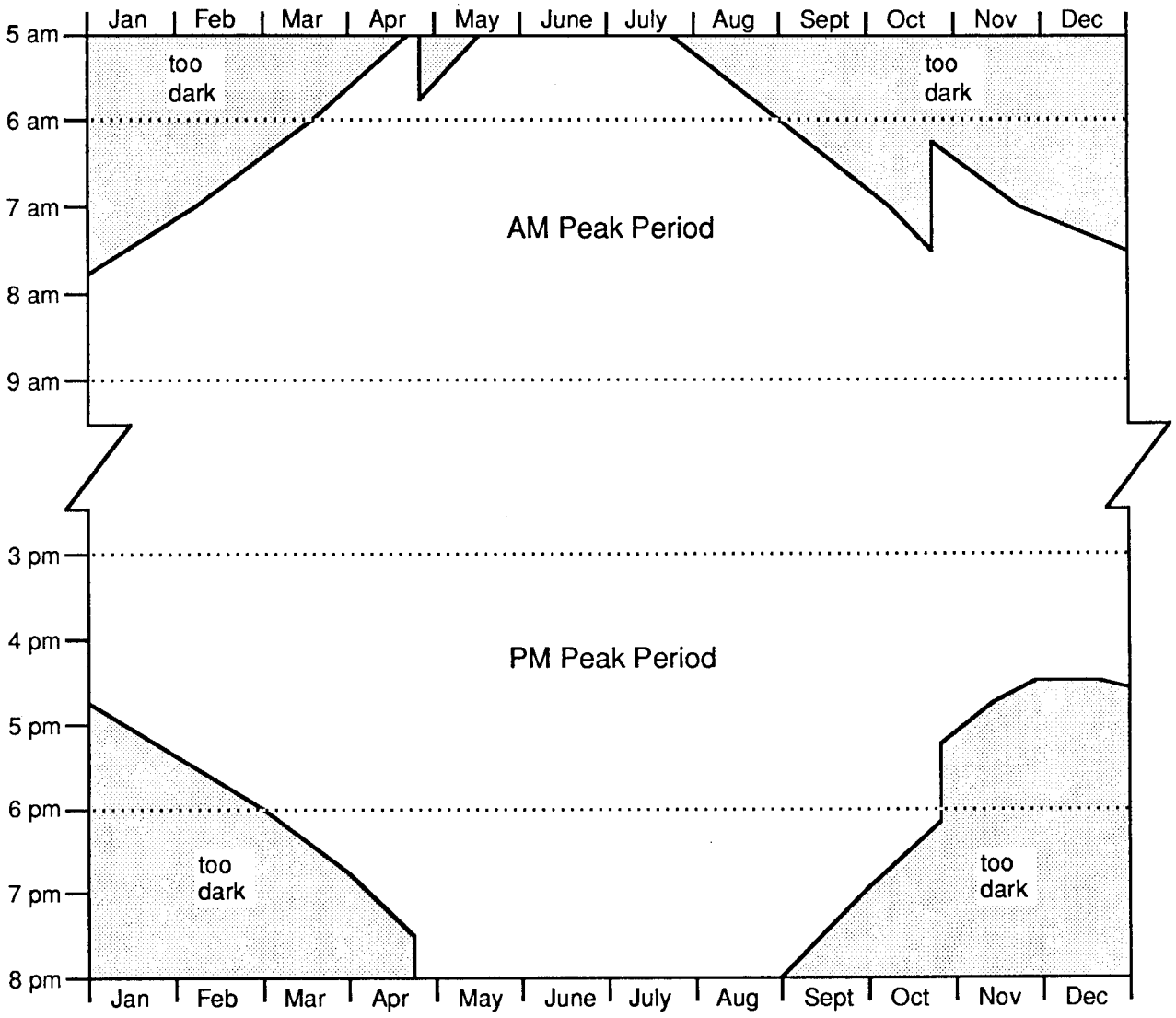



Figure 4. Analysis of Light Level Sufficiency

occupancy in the same lane, on the same day of the week, at the same time of day and at the same time of year, the occupancy would vary simply due to the fact that different vehicles passed by. While this is not a completely random sample (people tend to have regular patterns in commuting), the variation due this source can be estimated. The standard deviation of AVO depends on the distribution of vehicle occupancies and can be estimated using data from the Seattle area. The standard deviation of AVO for 800 vehicles (the approximate number passing in one lane during one half-hour) in this area is slightly higher than Ferlis' recommended value.

Observer error contributes to variation. It was not treated in the Ferlis study. However, from this research, the level can be estimated. The error data from Table 2 were used to estimate the variation due to this source.

Ferlis also did not deal with variation due to time of day. From data collected in this research the value shown in Table 5 reflects the variation within the peak hour due to this source.

The total standard deviation is the square root of the sum of the squares of each source of variation. For the values used here, that is .035. However, three of the sources of variation are predictable. They are 1) day of the week, 2) seasonal and 3) time of day. When enough data have been collected, the effects of these sources of variation can be controlled for and

essentially eliminated (with the assumption that the patterns do not change over time). The combined standard deviation for the the remaining two sources is .022.

Using these two values for the combined standard deviation, we can estimate the accuracy that can be attained in a regular AVO data collection effort. Assuming a sample size of 10 observations per quarter, the accuracy of the measured AVO will be somewhere between 1.1 percent and 1.7 percent at a 95 percent confidence level. Most programs designed to increase AVO are not expected to result in drastic changes. An increase of 2 to 5 percent would be considered a strong indication of success. It is important that the sample size be large enough that the program evaluator can rule out the possibility that the change is simply due to random error in measurement. Note that the accuracy of 1.1 to 1.7 percent is based on quarterly data. Using the same number of observations per quarter, greater accuracy could be obtained by comparing year to year data.

Table 5. Sources of Variation for One-Half Hour Counting Periods

| Source | Ferlis Recommendation | Research Finding | Value Used to Analyze Sample Size |
|---|---|---|---|
| Day of the Week | .015 | na | .015 |
| Seasonal | .015 | na | .010 |
| "Short Count" | .017 | .021 | .021 |
| Observer Error | na | .006 | .006 |
| Time of Day (w/in each peak) | na | .017 | .017 |

# RECOMMENDATIONS

One of the results of this research is the knowledge that a continuous vehicle occupancy counting program can be conducted at a reasonable cost. A continuous program has many benefits, including the following:

- data for the evaluation of the typical long-term AVO programs as opposed to previous counting programs that have been conducted on a short-term and project-specific basis,
- consistent data due to a controlled collection methodology,
- the opportunity to train and utilize a pool of professional AVO observers, and
- the ability to explore the relationship between AVO and economic factors such as employment and gas prices,

The yearly cost of a program supplying useful data would be about the same as an FTE clerical or secretarial position (including benefits and overhead).

This study's recommendation is to implement a continuous AVO program. This section discusses the costs of such a program and recommends a method to administer it.

## Costs

The cost estimate is based on several assumptions:

- the sample will consist of 10, one half-hour counts conducted on a randomly-selected lane at each site during each peak hour;
- the variation in AVO by lane will be small;
- a range of 26 to 41 sites will be selected;
- counters will be part-time hourly employees receiving $7.00 per hour, with no benefits other than half of their social security;
- counters will be able to conduct three, half-hour counts during each three hour peak period by working for 3.5 hours (including travel time);
- the average travel requirement during each peak period for each counter will be 30 miles;
- a sample of 10 counts per quarter at each site during each peak hour will give sufficient accuracy to evaluate programs to change vehicle occupancy; and
- one-fifth of a full-time equivalent (FTE) researcher (early grade) will be required to administer and supervise the program.

Table 6 shows the resulting cost calculations.

## Administration Recommendation

Several jurisdictions should share in the costs of this program. There are three reasons for this. One is simply that enough funds must be provided to sustain the project for a long period of time. Another is that involvement of people with a wide variety of interests in the results should be promoted so that the data will be useful to the maximum number of people. The third reason is that the results of the data collection can be used to stimulate interest in programs that are designed to increase AVO.

Since multiple jurisdictions will be involved in supporting the data collection effort, the data collection locations should be chosen to provide

Table 6. Typical Cost Calculation

| | Low Density | | High Density | |
|---|---|---|---|---|
| Counters | | | | |
| Wage (25 or 41 sites x 10 counts/site/quarter/peak x 4 quarters x 2 peaks x (3.5/3) hours/count x $7.00/hour) | $16,987 | | $26,787 | |
| Benefits (8%) | 1,359 | | 2,143 | |
| Total Counters | | $18,346 | | $28,930 |
| Supervision/Administration | | | | |
| Wage (12 months x 20% x $2000/month) | 4,800 | | 4,800 | |
| Benefits (34%) | 1,632 | | 1,632 | |
| Total Supervision/Administration | | 6,432 | | 6,432 |
| Transportation | | | | |
| Total Transportation (2080 or 3280 counts x 10 miles/count x $.205/mile) | | 4,264 | | 6,724 |
| Miscellaneous | | | | |
| Computer Depreciation (3 or 4 computers x $500/computer ÷ 5 years) | 300 | | 400 | |
| Batteries and Other Supplies | 1,000 | | 1,300 | |
| Other Computer Costs | 200 | | 200 | |
| Report Writing | 500 | | 500 | |
| Total Miscellaneous | | 2,000 | | 2,400 |
| Totals | | | | |
| Direct | 31,042 | | 44,486 | |
| Overhead (60%) | 18,625 | | 26,692 | |
| **Total Cost** | $49,607 | | $71,178 | |

information specifically useful to the jurisdictions involved. Figures 5 and 6 show the recommended locations for two levels of a regular data collection program. The locations are based on an analysis of the most heavily used links in the freeway and arterial system in the region. Additional locations for special studies could easily be added to the data collection program. However, it is important to have a consistent set of locations at which data are collected to provide the continuity necessary to conduct data analysis.

The program should be funded through one agency that will be responsible for conducting the counts or contracting for them. District 1 of WSDOT, King County and Metro are appropriate agencies to accept this responsibility because the ranges of their jurisdictions cover area corresponding to the recommended data collection locations. Since District 1 already has a regular AVO data effort in place, the research team recommends that it be the focus of this effort.

An interlocal agreement can be used to secure and guarantee funding. The agreement should cover multiple years (at least three) to promote continuity in the data collection.

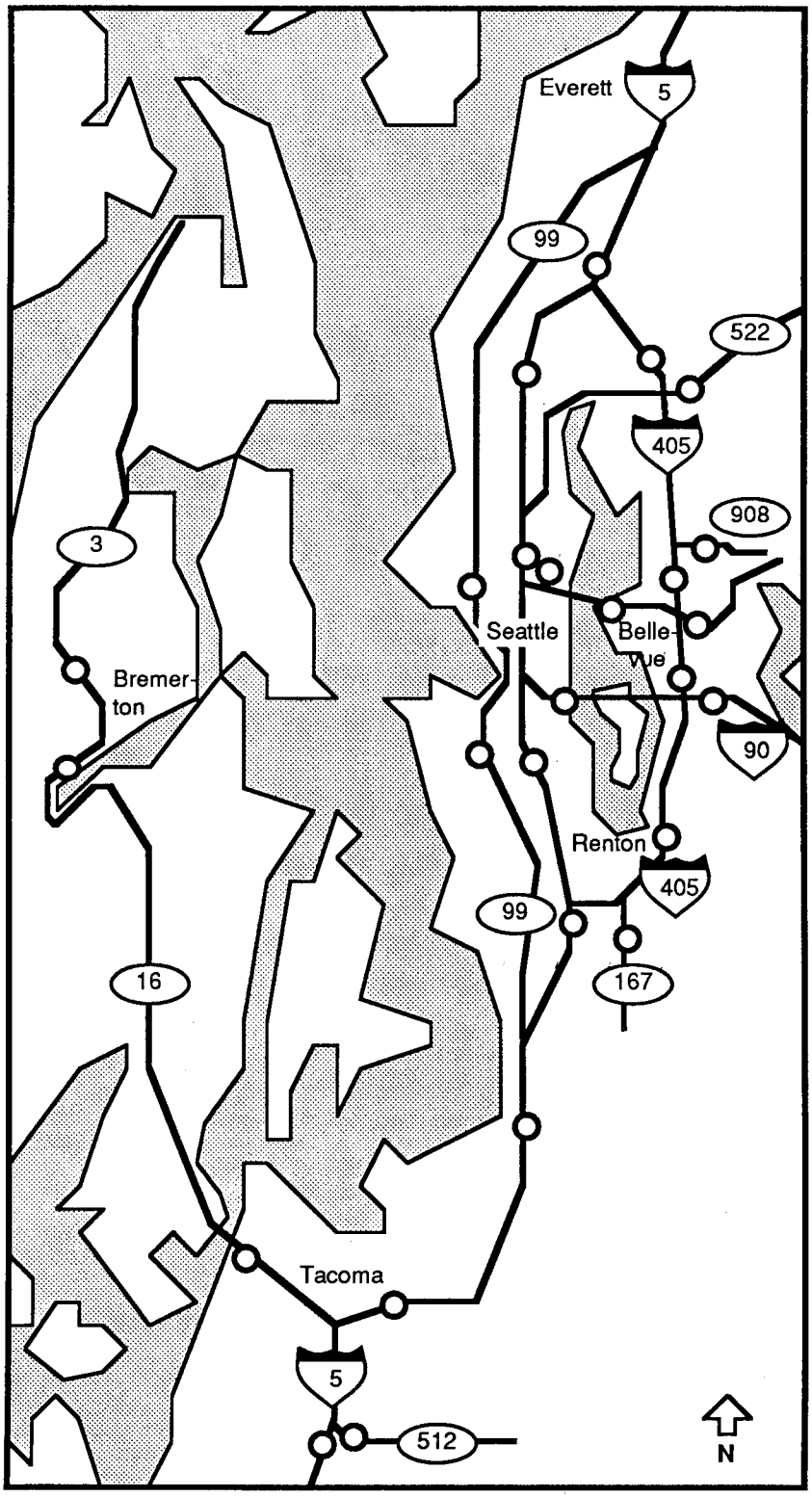



Figure 5. 26 Sites (Low Density Plan)

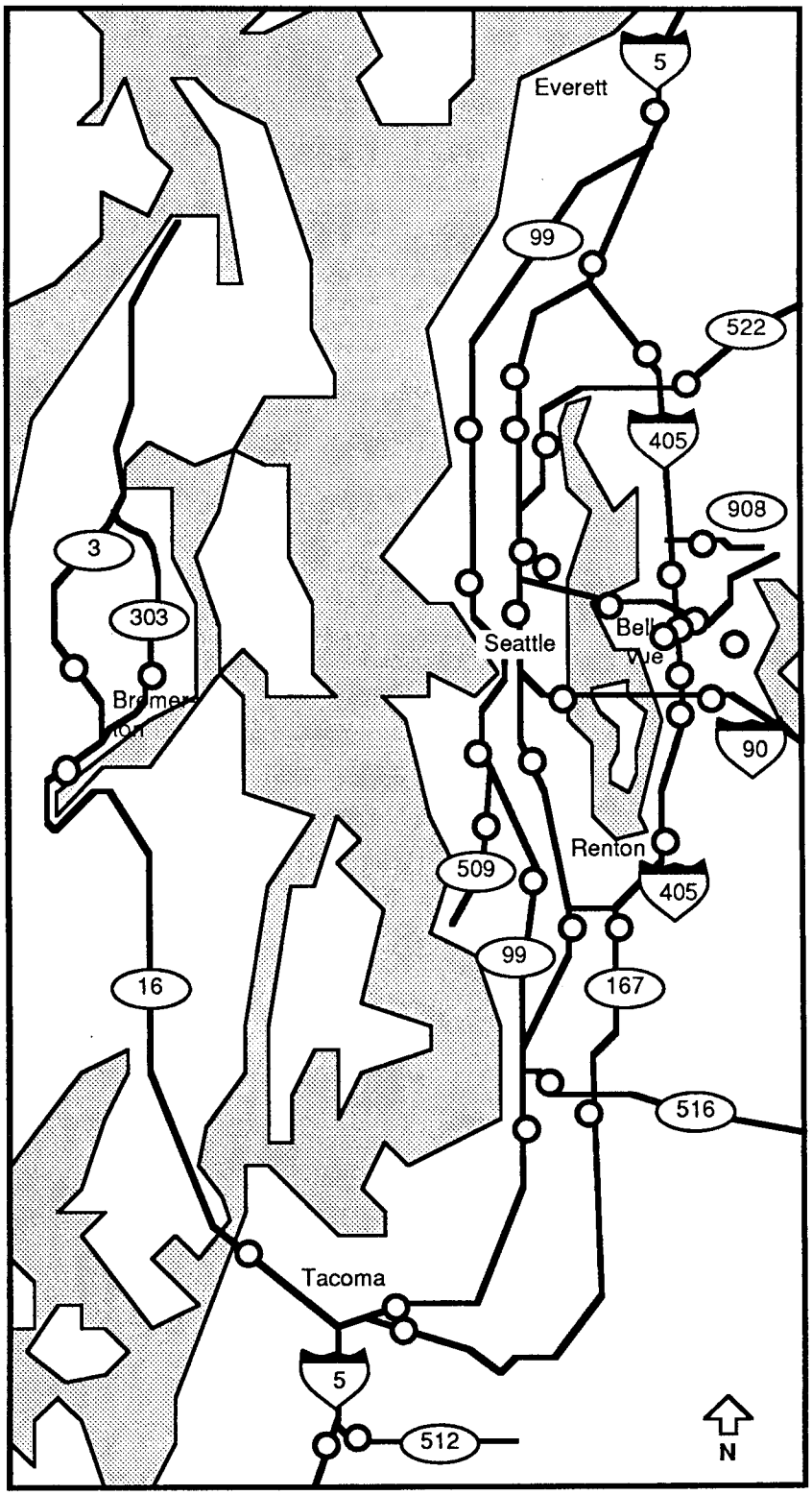



Figure 6. 41 Sites (High Density Plan)

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8. Farmer's Almanac, 1987.

# APPENDIX:
# OCCUPANCY COUNTING PROGRAM

```
10    OPEN "num" FOR INPUT AS 1
20    INPUT #1,N
30    FI$="d"+RIGHT$(STR$(N),LEN(STR$(N))-1)
40    INPUT #1,TL
50    CLOSE 1
60    CLS
70    OPEN FI$ FOR OUTPUT AS 1
80    T$=TIME$
90    T1=3600*VAL(LEFT$(T$,2))+60*VAL(MID$(T$,
      4,2))+VAL(RIGHT$(T$,2))
100   T$=TIME$
110   HR=VAL(LEFT$(T$,2))
120   MI=VAL(MID$(T$,4,2))
130   SE=VAL(RIGHT$(T$,2))
140   TT=3600*HR+60*MI+SE-T1
150   IF TT=TL THEN GOTO 360
160   A$=INKEY$
170   IF A$="" THEN GOTO 100
180   NP=VAL(A$)
190   IF A$="0" THEN NP=10
200   IF NP=0 THEN SOUND 16300,10:
      CLS:PRINT@130, "ILLEGAL KEY":GOTO 100
210   FR=3000
220   IF A$="0" THEN FR=5000
230   SOUND FR,10
240   B$=A$+" pers. carpool"
250   IF A$="1" THEN B$="SOV"
260   IF A$="5" THEN B$="vanpool"
270   IF A$="6" THEN B$="bus"
280   IF A$="7" THEN B$="2 axle truck"
290   IF A$="8" THEN B$="3+ axle truck"
300   IF A$="9" THEN B$="motorcycle"
310   IF A$="0" THEN B$="correction noted"
320   CLS
330   PRINT @120,TT;"..... ";B$
340   PRINT #1, USING "!!";A$,CHR$(TT MOD
      100+27)
350   GOTO 100
360   PRINT #1,"XXXX"
370   CLOSE 1
380   OPEN "num" FOR OUTPUT AS 1
390   N=N+1
400   PRINT #1,N
410   PRINT #1,TL
420   CLOSE 1
430   SOUND 400,20
440   MENU
```