Accuracy and Other Factors Affecting a Continuous Vehicle Occupancy Monitoring Program

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During the next 15 to 20 yrs, the primary methods available to manage the nation's freeways will involve increasing the average occupancy of vehicles using the freeways. Because existing vehicle occupancy measurement is typically project specific and sporadic and uses different collection procedures, it is often difficult to evaluate the effectiveness of programs intended to increase the average vehicle occupancy (AVO). The research discussed in this paper was designed to address the lack of consistent and ongoing AVO measurement in the Seattle area. Because a literature search revealed that little had been published concerning the methodology of collecting vehicle occupancies, the research attempted to determine what factors lead to inaccurate or unusable data and how much data are necessary for accurate counts. A number of observation sites, including six freeway sites, were selected. Three people counted occupancies in the same lane at the same time for 111 15-min periods. Portable computers were used for data collection. The observations were time stamped to match the counters' observations on a vehicle-by-vehicle basis. By examining the agreement or disagreement among the counters, researchers determined the error levels and related them to a variety of factors, including weather, time-of-day, light levels, speed, observation location, counter comfort, vehicle weaving, and length of time counting. Significant relationships between error rates and these factors were used to identify elements that influence the accuracy of a counting program. The research used the error rates to estimate the statistical accuracy of an AVO sampling procedure. The study then examined the cost and administrative feasibility of implementing a continuous automobile vehicle occupancy counting program.

During the next 15 to 20 yrs the primary methods available to manage the nation's freeways will involve increasing the average occupancy of vehicles using the freeways. Current demand is taxing the capacity of the freeways, and undoubtedly that demand will increase during the next decades. Because in many areas major investments in new freeway construction and rail systems are not anticipated, the challenge is to make the existing freeways more efficient.

To evaluate the effectiveness of programs intended to increase the average vehicle occupancy (AVO) on freeways and arterials, a method must be developed to measure AVO on a consistent and continual basis. Measurements generally have been conducted on a sporadic and project-specific basis. This frequently means that no consistent data base is available for program evaluation.

In addition, different research designs and field collection methods have often been used to measure AVO. As a result, historical AVO data cannot be used to evaluate past programs and trends. For example, the relationship between AVO and economic factors such as employment and the price of gasoline is not well understood.

The research project discussed in this paper was designed to address the lack of consistent and ongoing AVO measurements in the Seattle metropolitan area. The collection of reliable AVO information can be expensive, especially when information is needed on a geographically disaggregated basis. However, because a great deal of money and energy are being invested in programs to increase the AVO, and because many agencies are interested in having such data, implementing such a data collection effort is important.

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OVERVIEW OF THE STUDY

The research was carried out during the first half of 1987. The first step was to review existing methodologies for automobile occupancy monitoring. Very little literature was uncovered that dealt with the methodology of automobile occupancy monitoring. Many studies exist that use AVO data, but little has been written to investigate the best ways to collect the data.

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, 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 a suggested program for counting AVO that accounted for 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

A computer-based search of the literature concerning automobile occupancy counting methodology was conducted.

Although the search resulted in 79 references using automobile 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 to develop a methodology of automobile occupancy counting.

Four of the references related to an effort funded by FHWA around 1980. Ferlis conducted the original research (*1*, *2*). Ferlis recommended a sampling approach to measuring automobile occupancy and laid out procedures for determining sample size and for drawing the samples. By employing accepted survey techniques of stratification and sampling, reliable automobile occupancy data can be collected at a lower cost than the traditional approaches.

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 automobile occupancy data collected in a parking study to account for the fact that passengers are sometimes dropped off in other locations (*5*).

The other two studies reviewed for this project discussed variations in automobile occupancy collected at different times. A study conducted in the Minneapolis area concluded that there were significant differences in automobile 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 because the study was conducted during the 1974 oil shortage, other factors made the results difficult to interpret.

Another study of factors influencing automobile occupancy, which was 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 last two studies had some contradictory results. However, both studies may have suffered from a lack of data over a long period of time, and other influences on automobile 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 automobile occupancy counts. No study dealt with human performance issues such as weather conditions, speed of traffic, fatigue, light levels, or the like. Variations in automobile 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 a 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 most common method used to conduct automobile 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 measures 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 of using 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 the occupancy 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 above 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 make this approach infeasible. Furthermore, 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.

Automobile 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 for more than a few days before they are asked. To collect automobile occupancy data over a geographically dispersed area, thousands of surveys would have to be conducted to obtain accurate information. Because 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 (a) what motivates attentiveness in observations, (b) what conditions are important to obtaining good data, and (c) 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.

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 study, the use of portable computers to collect data was a focus of the research. 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.
- Some aspects of the supervision of observers can be conducted by checking recording times and the like.

In this research, the use of computers was essential, because the methodology required knowing the exact time that an observation was recorded.

The portable computer used for this research was programmable using the BASIC language. A program was written that allowed the observer to simply press 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 so at least three hours of observations could be stored in a computer with 32 kilobytes of random access memory (RAM). Another 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 the following:

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 observation.

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

In the Seattle area, good data on the number of vehicles passing most points were already available. On most freeways, the peak hour volumes approach the maximum lane capacity possible, on the order of 1,800–2,000 vehicles per lane per hour. On high occupancy vehicle (HOV) lanes, the volumes are lower. Because good data already existed, this research effort was not designed to collect new data on this subject.

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 single occupancy vehicles (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.

Variations by time of day, day of the week, and season can contribute substantially to the standard deviation. However, peak hour variations 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 (*2*).

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.

This research study design emphasized the objective of increasing the knowledge of the fourth factor influencing standard deviation. Variations due to observer error should be taken into account. An estimate of this influence can be made by analyzing 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: (a) determine the factors that influence errors and (b) 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 Washington State Department of Transportation (WSDOT) vehicle occupancy studies. The following nine categories were employed:

1. SOV—any four-wheeled, personal vehicle (including automobiles, pick-up 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,
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.

Types of Locations

Three types of locations were represented in this research: employment sites, arterials, and freeways. Figure 1 shows the locations. The research emphasis was on the freeway sites, with the employment and arterial sites used for observer training and machine testing. Six freeway sites were studied. Two were on either side of state Route 520 at the east end of the Evergreen Point Bridge connecting the Seattle urban area with the city of Bellevue and other smaller cities. The other four were on either side of Interstate 5 approximately 2 and 5 mi north of Seattle's downtown core.

The six freeway sites were not meant to represent all freeway sites in the region, but they do represent a cross-section of types of sites. Some of the differences 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.

Each location was selected for the following reasons:

- It had a shoulder or bank of the proper height to easily see the traffic lane (10–20 ft above the road's surface),
- It was close enough to the roadway to see into the vehicles (20–50 ft),
- It had a clear line of sight,
- It was safe for the observers while walking to the counting location and while counting,
- It was located so the observers were not a distraction to drivers, and
- It 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. To study this, observation periods were varied from

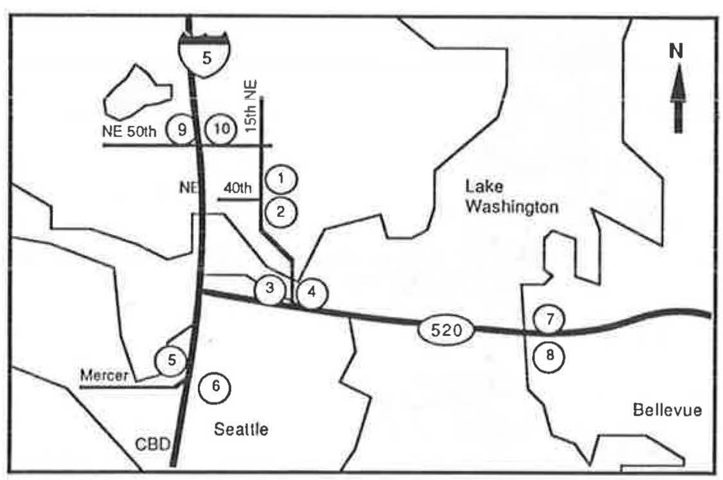

FIGURE 1 Location of observations.

session to session. The basic unit for observation was a 15-min period. Error rates were determined for each period using a process described in the next section.

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 15 min. In some sessions, two 15-min periods of observations were conducted without breaks between them, but the pairs were separated by 15-min rest breaks. In two of the sessions, no rest breaks at all were taken between 15-min 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; the others required subjective judgment by the researchers.

Because 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-min observation period. The measure used for this factor in later analysis was a subjective judgment of the most common weather in a 15-min 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-min 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 mph.

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 occurred more often than 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-min periods during which AVO data were collected. In all, there were 111 15-min 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 was in the lane.

Use of Computers

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.

In general, the computers 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 equipment 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 3-hour period to machine readable form and conducting preliminary analyses to check for reasonability took less than 10 min. 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 computers 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.

However, 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. 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

TABLE 2 MATRIX OF ACTUAL VS. OBSERVED CATEGORIES

	Actual									
Observed	0 no vehicle	1 SOV	2 2 pers. carpool	3 3 pers. carpool	4 4 pers. carpool	5 vanpool	6 bus	7 motor cycle	8 2 axle truck	9 3+ axle truck
					missed vehicle (.8%)					
0	---	529	66	9	4	0	10	6	0	6
1	340	61881	346	22	4	0	4	50	3	4
				undercount (.7%)				misclassification		
2	65	337	13522	127	17	1	0	13	0	0
3	14	19	175	1490	57	1	0	1	0	0
		overcount (.7%)								
4	4	4	11	43	649	0	0	0	0	1
	extra vehicle (.5%)				correct (97.1%)					
5	0	3	0	0	1	46	0	0	0	0
6	2	6	2	0	0	0	497	1	0	0
7	3	45	20	4	0	0	0	681	13	0
8	5	3	2	0	0	0	2	10	964	0
					misclassification (.2%)					
9	6	2	1	0	0	0	0	0	1	403
Total	439	62829	14145	1695	732	48	513	762	981	414
%	.5	76.1	17.1	2.1	.9	.1	.6	.9	1.2	.5

Interpretation of Errors

The primary variable of interest in this research was the error rate. 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. 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 right and the other two wrong, the former interpretation was probably the correct one in the vast majority of the cases.

The following 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,
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.

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

1. Total error—all the above types of 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 observed category and actual category. Different types of errors are indicated on the matrix.

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 following analysis. Furthermore, location 9 had a much higher error rate than the others. This was due primarily to significant weaving movements. Therefore, that location is also not used in the analysis described here. Excluding locations 1 through 4 and 9 leaves 11 locations remaining, with a total of 74 15-min time periods, or 222 separate observations. The overall observer error rate for these sessions was about 3.0 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, and
- 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 could be explained by location alone (13 percent of the counting error and 6 percent of the existence error). For this reason, the regression analysis used the three variables that were thought important in the distinction among locations.

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 aspect of the analysis. The higher the coefficient,

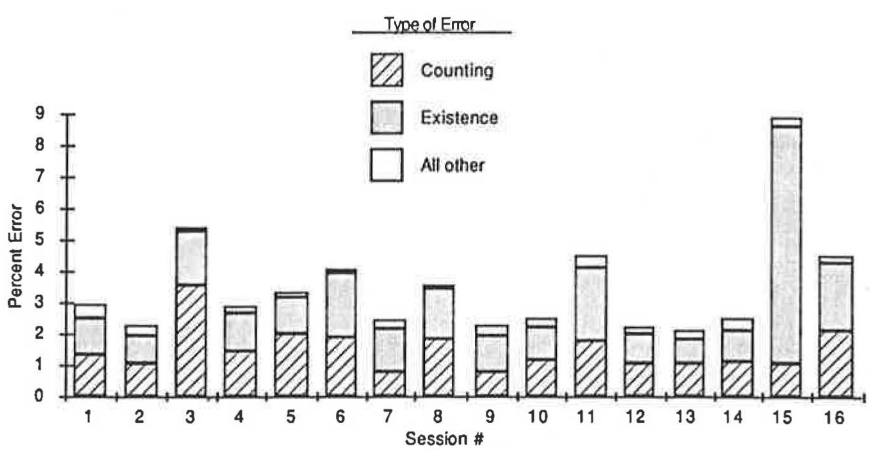

FIGURE 2 Error rates by session.

TABLE 3 REGRESSION ANALYSIS RESULTS

Variable	Type	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	
Number of obs.		222	222	
F-statistic		8.38	11.26	

* Significant at .05 level

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 are insignificant, however, except for the effect of rainy conditions on counting errors. Because 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 any significant effect on any of the errors (at the 95-percent confidence level). However, the coefficient for existence errors approached significance (two-tailed significance = .16). Negative coefficients imply that the fewest errors were made when the conditions were most uncomfortable. Because 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, which were judged to be influential at three of the locations, did not have a significant effect on any of the error rates. However, positive coefficients support the hypothesis that weaving movements have the effect of increasing the error rates. Also, remember that one location was left out of this final analysis because the weaving effects apparently had very significant effects on error rates. 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 did not 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 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-min 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.

TABLE 4 COMPARISON OF TWO CONSECUTIVE COUNTING PERIODS ($N = 36$)

Type of Error	Error Rate (%) 1st Period	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

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-min periods that observers counted without a rest.

There were twelve pairs of counting periods which 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 pair-wise 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 30 min. 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, the sunrise is so late and the sunset so early that it is not possible to accurately count vehicle occupancy during parts of the peak hours. 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 6:00 p.m. and 9:00 p.m. The sunset during this time was at about 8:30 p.m. 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 to the sunset up to 9:00 p.m. On the overcast evening, however, the last counting period, occurring between 8:45 p.m. and 9:00 p.m., resulted in a

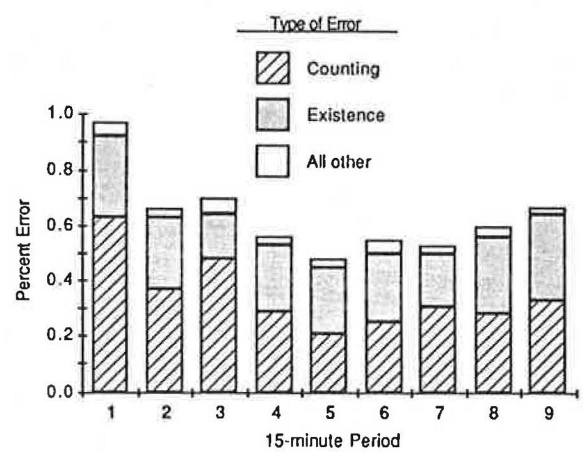

FIGURE 3 Errors in session 13 (nine consecutive counts without a break).

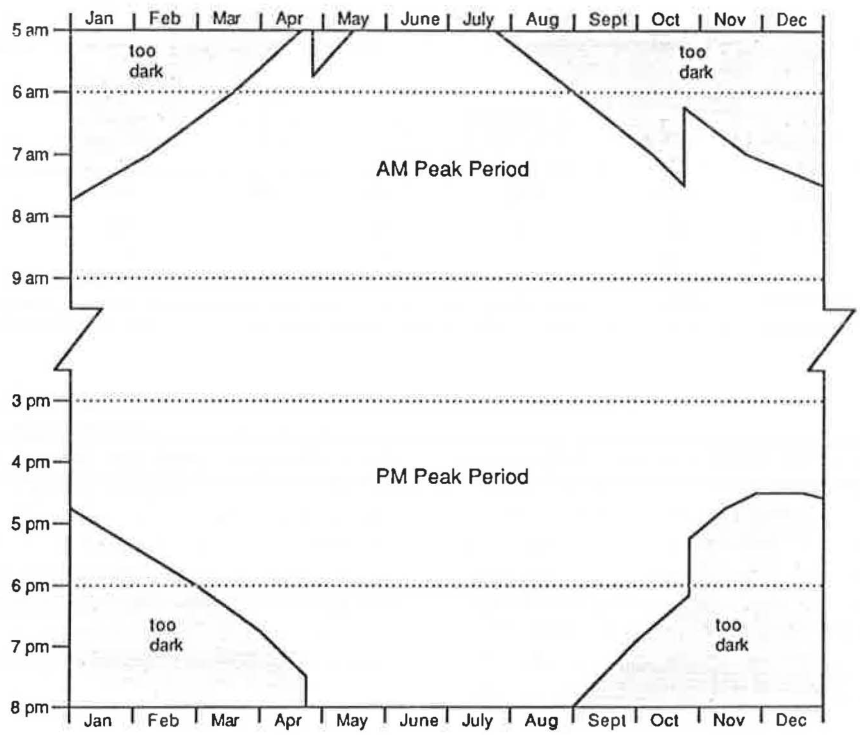

FIGURE 4 Analysis of light level sufficiency.

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 to still allow relatively accurate counts.

Graphs based on these results were constructed (Figure 4) and can be used to determine the hours when occupancy can be counted in the Seattle area 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 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 to August and evening peak three hours from March to September. In the other months, varying proportions of the peak period can be counted, with a minimum of 1½ 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 automobile 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.

TABLE 5 SOURCES OF VARIATION FOR 30-MIN COUNTING PERIODS

Source	Ferlis Recommendation	Research Finding	Value Used to Analyse 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

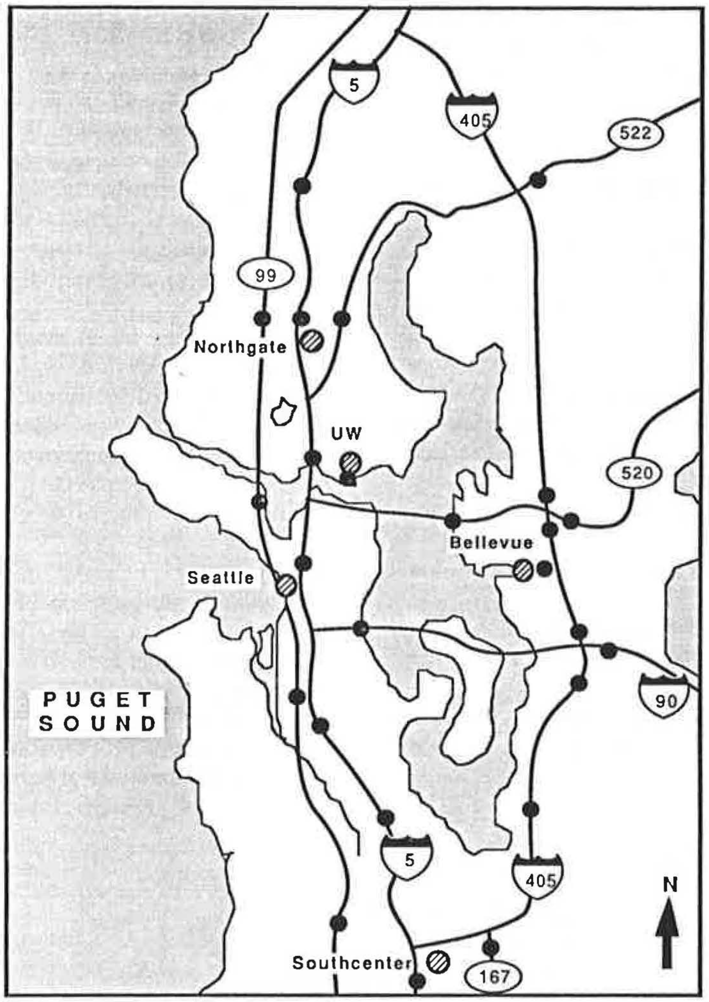

FIGURE 5 Recommended data collection locations.

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. Because 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 automobile occupancy. If one were to count 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 to this source can be estimated. Using a Monte Carlo approach, the standard deviation of AVO for 800 vehicles (the approximate number passing in one lane during one-half hour) is slightly higher than Ferlis's recommended value.

Observer error contributes to variation. It was not treated in the Ferlis study. However, from this research, the level can be estimated. Using a Monte Carlo simulation and the error data from Table 2, the variation due to this source was estimated.

Ferlis also did not deal with variation due to time of day. Based on 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 (a) day of the week, (b) seasonal, and (c) 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 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.

DEVELOPMENT OF AN AVO COUNTING PROGRAM

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

- data for the elevation of the typical long-term AVO programs as opposed to previous counting programs that have been typically 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 a clerical or secretarial position (including benefits and overhead).

The cost estimate is based on several assumptions:

- The sample will consist of ten 30-min counts conducted at each site during each peak hour.
- Twenty-five 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 30-min counts during each 3-hr peak period by working for 3.5 hrs (including travel time).
- The average travel requirement during each peak period for each counter will be 30 mi.
- 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.
- One-fifth of a full-time equivalent (FTE) researcher (early grade) will be required to administer and supervise the program.

Figure 6 shows the resulting cost calculations.

Several jurisdictions could share in the costs of a regional AVO counting 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 the 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

Counters		
Wage (25 sites x 10 counts/site/quarter/peak x 4 quarters x 2 peaks x (3.5/3) hours/count x $7.00/hour)	$16,333	
Benefits (8%)	1,307	
Total Counters		$17,640
Supervision/Administration		
Wage (12 months x 20% x $2000/month)	4,800	
Benefits (34%)	1,632	
Total Supervision/Administration		6,432
Transportation		
Total Transportation (2000 counts x 10 miles/count x $.205/mile)		4,100
Miscellaneous		
Computer Depreciation (3 computers x $500/computer ÷ 5 years)	300	
Batteries and Other Supplies	1,000	
Other Computer Costs	200	
Report Writing	500	
Total Miscellaneous		2,000
Totals		
Direct	30,172	
Overhead (60%)	18,103	
Total Cost		$48,275

FIGURE 6 Typical cost calculation.

results of the data collection can be used as an educational tool for policy makers in the jurisdictions paying for the data. The awareness of occupancy data should promote interest in programs that are designed to increase AVO.

If multiple jurisdictions are involved in supporting the data collection effort, the data collection locations should be chosen to provide information specifically useful to the jurisdictions involved. Additional locations for special studies could easily be added to the data collection program. However, a consistent set of data collection is necessary to provide the continuity necessary to conduct data analysis.

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