Comparison of Two Techniques of Aerial Photography for Application in Freeway Traffic Operations Studies

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•EACH YEAR it is becoming more apparent that many sections of urban freeways will have to be controlled during hours of peak traffic. The need for knowledge on how, when, and where to control traffic has resulted in development and installation of several types of surveillance systems to monitor traffic operations on freeways. Electronic sensing and automatic control devices provide the best solution, but equipment now available cannot accurately describe traffic operation over long sections of freeways. It is doubtful that suitable systems will be developed until a more complete criterion for the operation of a freeway system has been established. Television monitoring systems, now in operation in several locations, are providing much of the needed data, but not all study sections can, nor should be, equipped with complete television coverage. It is for such a reason that aerial surveys, which approximate the coverage provided by continuous television monitoring, were used to study traffic movement on the Gulf Freeway in Houston.

The use of aerial photography in making traffic surveys is not a recent innovation. Reports of the use of aerial photography were available as early as 1927 (1). Serious consideration has not been given to this survey method, however, because of two factors: cost of the field survey, and the difficult and time-consuming task of data reduction.

The same objections were raised when proposals to study freeway operation by motion picture film from ground locations were being considered. But the results of these film studies have provided a better understanding of the traffic movement characteristics, improved designs of entrance and exit ramps on the freeways, and improved signalization of the intersections within the interchanges.

The taking and use of motion film photography from ground locations, however, have limitations which must be considered. Numerous studies of freeway operation have documented the fact that a small disturbance at one location on the freeway, during the time when a peak number of moving vehicles is on the freeway, can create complete stoppages at some distance preceding the site of the disturbance. Therefore, a study which is limited to a small section of a freeway will reflect the change in operation without recording a cause to relate to it. The use of aerial photography permits the expansion of the study area not only along the freeway but also laterally to cover the frontage road or roads and supporting street system.

Objectives of the Survey

Aerial surveys were made of traffic on a 6-mi section of the Gulf Freeway in Houston (Fig. 1). Two types of aerial photography were investigated: (a) strip photography comprising two continuous stereoscopic photographs taken simultaneously from the beginning to the end of the traffic survey section, and (b) time-lapse photography where individual fixed-size photographs are taken at short intervals of time (Figs. 2 and 3).

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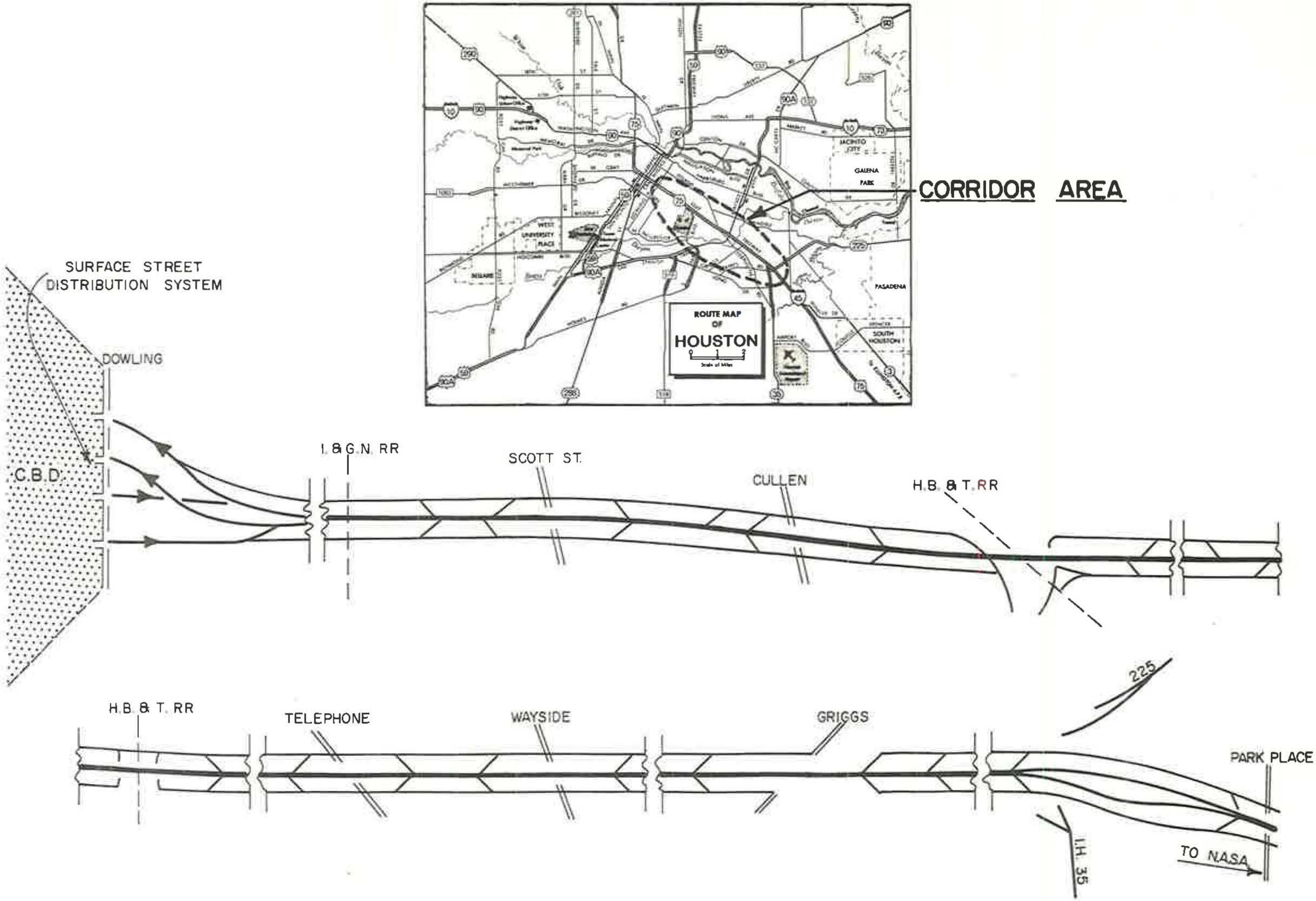


Figure 1. Study area—Gulf Freeway, Houston, Texas.

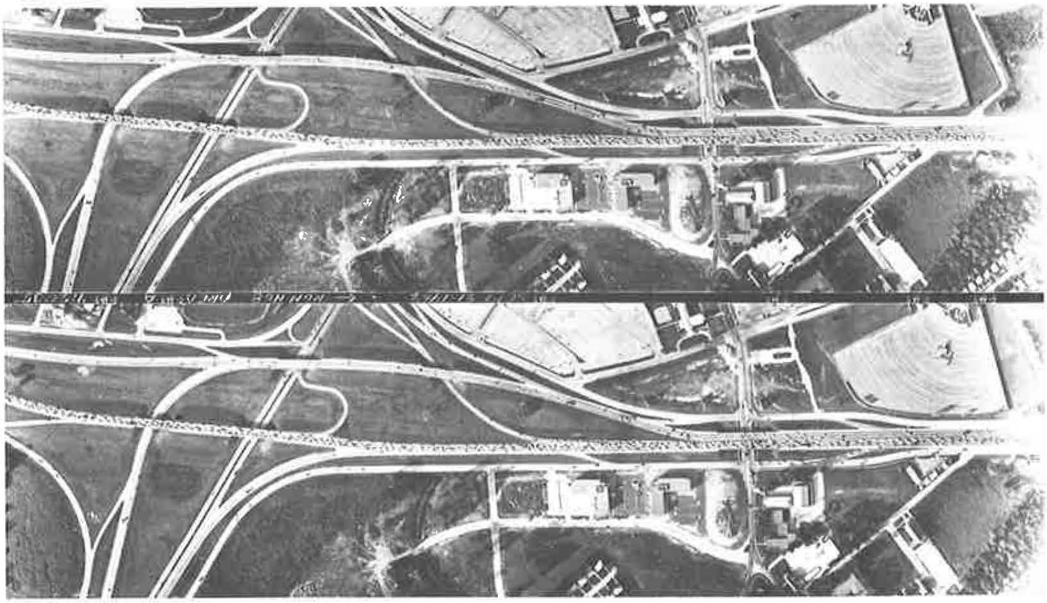


Figure 2. Continuous-strip stereoscopic photography.

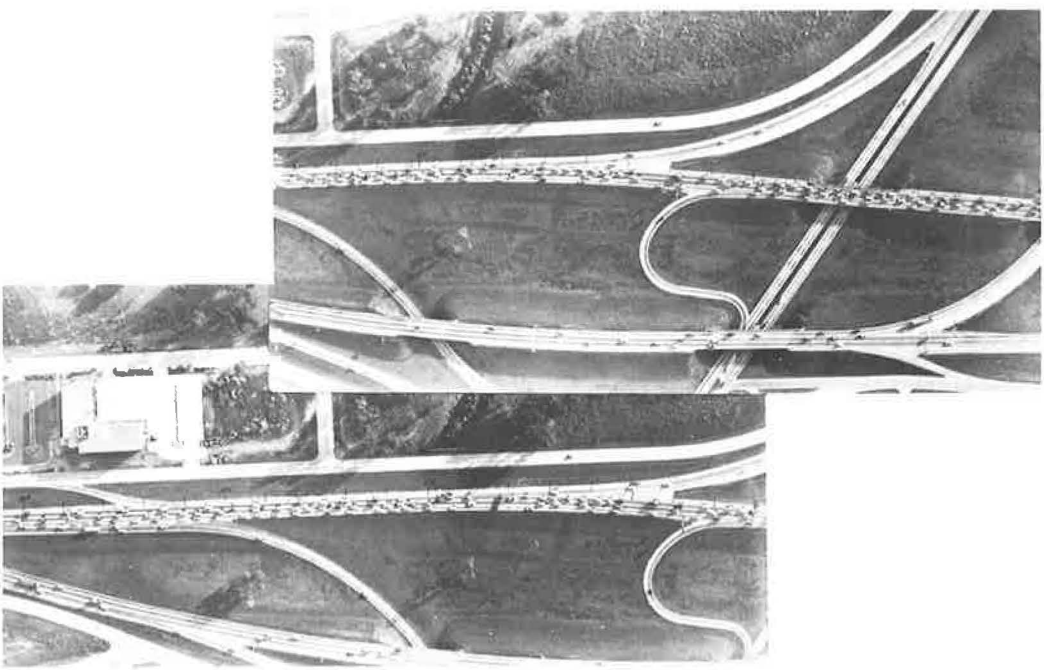


Figure 3. Time-lapse photography.

The objectives of this survey and study were (a) to determine operational characteristics of traffic on the freeway and factors which affect the level of service offered to the motorist, and (b) to evaluate two techniques of aerial photography and their applications in making traffic surveys and studying traffic movement.

The purpose of this report is to compare the two types of aerial photography used for their application to surveys for traffic study purposes. It is very difficult to evaluate the performance or applicability of these two aerial photographic techniques from this limited study because many of the disadvantages experienced in this study can be eliminated with more detailed planning and advance preparation of the test area based on the experience gained in this work. This paper reports the results of the survey made for the studies accomplished and the changes needed for making future studies of traffic operations.

Previous Work

Only in the last two years have any extensive studies of traffic operations by aerial photography been undertaken, although many experiments have been reported (2—4). Wohl (5) presented the application of strip photography for traffic studies and the relationships of speed, number of vehicles, and density as measured from the film. The fundamental principles for the continuous-strip stereoscopic photography are covered extensively in Wohl's paper and, with the exception of Figures 6 through 8 are not included in this report.

Wagner and May (6) reported the results of a density study of freeways in California using time-lapse photography. A significant development in this paper is the method of presenting density conditions on the freeway by a time-distance-density contour map.

Howes (7) reported an extensive study in the application of aerial photography to the collection and analysis of highway traffic flow data. Results from using time-lapse photography were compared to those obtained by employing conventional on-the-ground techniques. Analyses of the cost and procedure of data reduction and the accuracies of the results were made and included continuous-strip aerial photography, although no surveys were made using this technique.

There have been other reports on the application of aerial photography to studying traffic operations (8) and freeway design (9), but these studies are primarily concerned with some form of road or equipment inventory.

PROCEDURES

Description of Field Survey

The section of the Gulf Freeway in the traffic survey area extends from the Reveille Interchange at the intersection of US 75, Tex. 225, and Tex. 35, to the downtown distribution system at Dowling Street (Fig. 1). The photography flights were made in the morning peak period from 6:30 to 8 a.m. for two weekdays in September.

Two airplanes were used for obtaining film negative exposures of the aerial photography; one equipped with a 24-in. focal length camera for taking time-lapse photographs and the other equipped with a 4-in. focal length camera for taking the continuous-strip photographs (Figs. 4 and 5). Both airplanes were fixed wing Cessna 195's.

The photography flight plans required the two airplanes to be separated by at least a two-minute interval. The continuous strip photographs were taken from a flight height of 1,000 feet above the ground and the time-lapse photographs were from a flight height of 2,500 feet. Only one photographic flight was made each day in the outbound direction against the peak traffic flow. All other aerial photography flights were made in the direction of peak traffic flow. This is an important consideration in the design of photography flights for traffic survey purposes for the following reasons:

1. Time-lapse photographs will contain the images of a larger number of different vehicles, but will require fewer measurements per vehicle when photography flights are made against the flow of traffic.
2. Continuous-strip photography will have a larger number of different vehicles and the correction for density will be negative, that is, true density is less than vehicle spacing seen on the photography. This is caused by time lag, which is the length of time required to take a strip of such photography. Also, the size of the image of

Figure 4. Time-lapse camera.

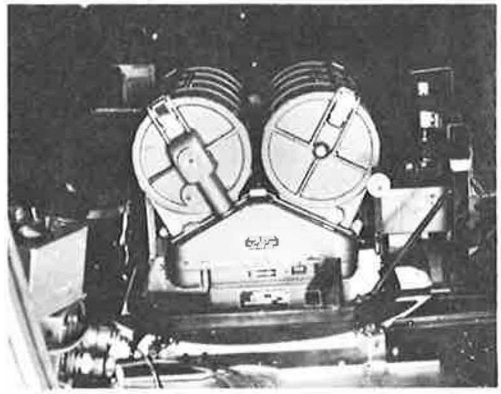


Figure 5. Continuous-strip camera.

the vehicle will be shortened. This is especially important in attempting to identify the vehicles by type or by markings.

During the photography flights by the aircraft, counts of the traffic were made by ground observers at several locations on the freeway lanes and ramps. Control vehicles with distinguishing markings on their roofs made travel time runs. Two of these vehicles were equipped with speed recording equipment for tracing speed profiles.

There was no ground-to-air communication during the time photography was being taken. A time reference was established by synchronizing watches one-half hour before the start of each photographic flight.

Analyses of Photography

The purpose of this type of traffic surveying was to determine whether or not aerial photography is practical to use for making freeway operation studies. In the design of the data reduction procedure all information which could be of any value in traffic studies was obtained by examination of the photographs. A time reference and the location of each vehicle by station number were recorded each time a vehicle was photographed. The location by lane, direction of travel, and type of vehicle were also recorded at the same time. Computer programs were developed to use these basic data and compute desired traffic movement characteristics such as speed, number of vehicles, density, headways, etc. The methods used in reducing the data from the photography and the accuracy of measurements are discussed in other sections of this report.

The important feature of the data reduction procedure was determining the location of each vehicle by roadway station numbers. These numbers were very difficult and costly to obtain, but more detailed analyses by electronic computers were then possible for specified sections of roadway, certain numbered groups of vehicles, or for each individual vehicle.

Improvement of Procedure

Many problems were encountered in this first traffic survey which can be eliminated in subsequent projects. One difficulty over which there was no control, however, was the weather. Aircraft flying at low flight heights over populated areas near the Houston International Airport required a minimum visibility of five miles which was difficult to obtain because of smoke and haze. The flights were delayed three to four days.

Communication between ground and air units is advisable. In some locations it is possible to use the control tower at a nearby airfield to provide the communication link between the airplane and the traffic survey area.

Reference points on the ground should be established at intervals which are short. Beginning and ending markers and two sets of intermediate reference points were used, and station numbers were determined from construction plans of the freeway. Each photography flight had to be numbered separately. Transferring these station numbers to the photographs is a time-consuming task subject to errors which can be eliminated by placing station markers on the pavement before the traffic survey photography is taken.

Reduction of traffic data from the aerial photography is still a time-consuming task. The work can be alleviated by obtaining photographs at scales not smaller than 200 feet to one inch, using magnifying lenses while making essential measurements, and using a recording procedure which will give working relief at specified intervals to the persons using the photographs.

The problem of traffic data reduction from the photography has been lessened by the use of electronic computer programs and a reduction procedure which records at the same time all basic information needed to make all anticipated analyses.

ANALYSIS OF THE TWO AERIAL PHOTOGRAPHIC TECHNIQUES

One of the primary objectives of this traffic survey was to develop the best procedure for obtaining traffic data from the aerial time-lapse photography and from aerial continuous-strip photography. It was further stipulated in development of the survey techniques that all traffic data available from the photography should be recorded.

The procedure adopted required basic measurements to determine vehicle location. An electronic computer program was written to calculate all traffic movement characteristics. It is only possible to compare the two photographic techniques in terms of the measurements made, resulting cost of the reduction, and accuracy of data obtained. From these traffic survey examples, it was not possible to determine which method required fewer man-hours to determine only vehicle speeds, space headways, or some other flow characteristic. A survey requiring only one or two of these parameters to be measured would probably use a different data reduction procedure.

This procedure, which records all data in a form for calculation and processing by electronic computers, permits faster and more complete analyses of the aerial photographs. This compensates to some degree for the slow process of making essential measurements by use of aerial photography.

Method of Data Reduction

Description of Methods. — To determine all traffic movement characteristics available from aerial photography, there are only two parameters to be measured: The location of each vehicle at some known time, t, and the location of each vehicle at some known time, $t + \Delta t$. This information determines the speed of the vehicles from which other traffic characteristics, such as number of vehicles, density, headways, etc., can be calculated. To obtain a complete analysis of the data available from the aerial photographs, additional information regarding lateral location of each vehicle, type of vehicle, and time of day are recorded.

Strip Photography. —There are two ways of determining vehicular speeds from continuous-strip photography. The conventional method is to measure the distance between two images of the vehicle and divide by the time lag between photographs. The other method is to measure the elongation of the image of vehicles due to the exposure time. This is a function of the vehicle speed relative to the known speed of the aircraft.

Both of these methods were investigated and the displacement method was selected. The vehicle elongation procedure required an accurate measurement of the length of the vehicle image. This required determining of the scale of the photography. Also, the true length of each vehicle measured had to be known. Because vehicle images were blurred and the photography scale was large, it was difficult to determine an exact identification for vehicle and thus apply its actual length in measuring the elongation. Figures 6 through 8 present the time-distance relationships of the continuous-

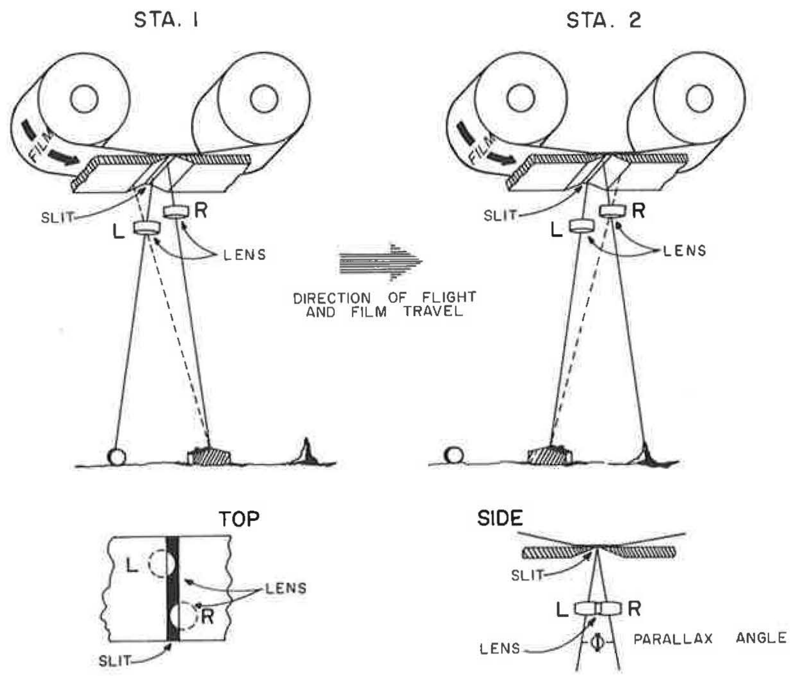


Figure 6. Plan and side views of continuous-strip aerial camera, with two stereoscopic lenses.

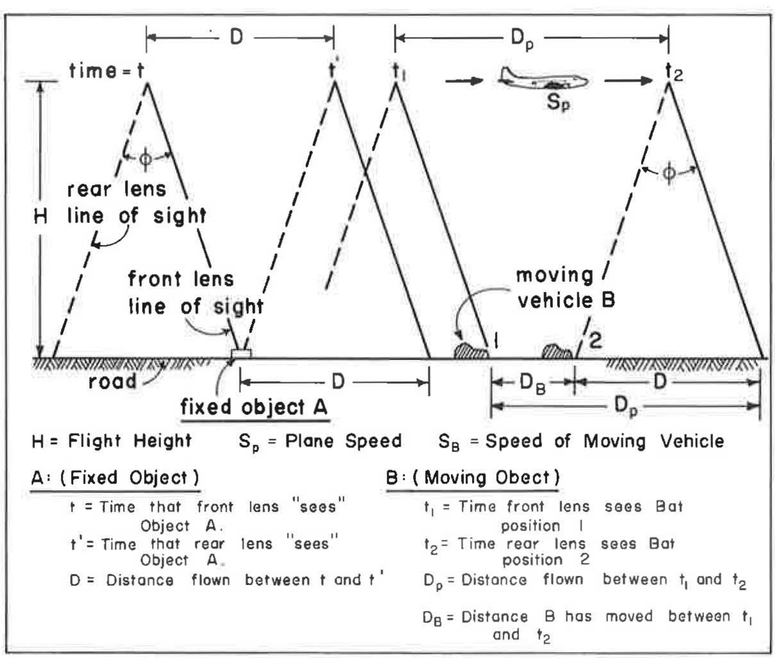


Figure 7. Time-distance relationships, continuous-strip photography.

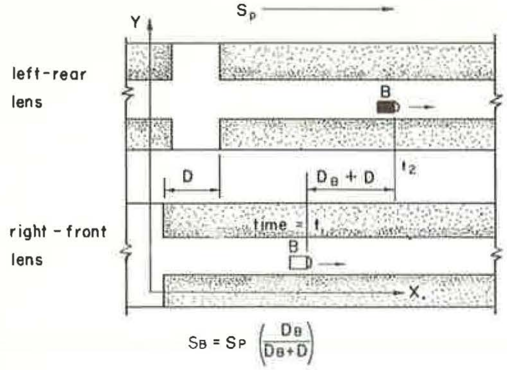
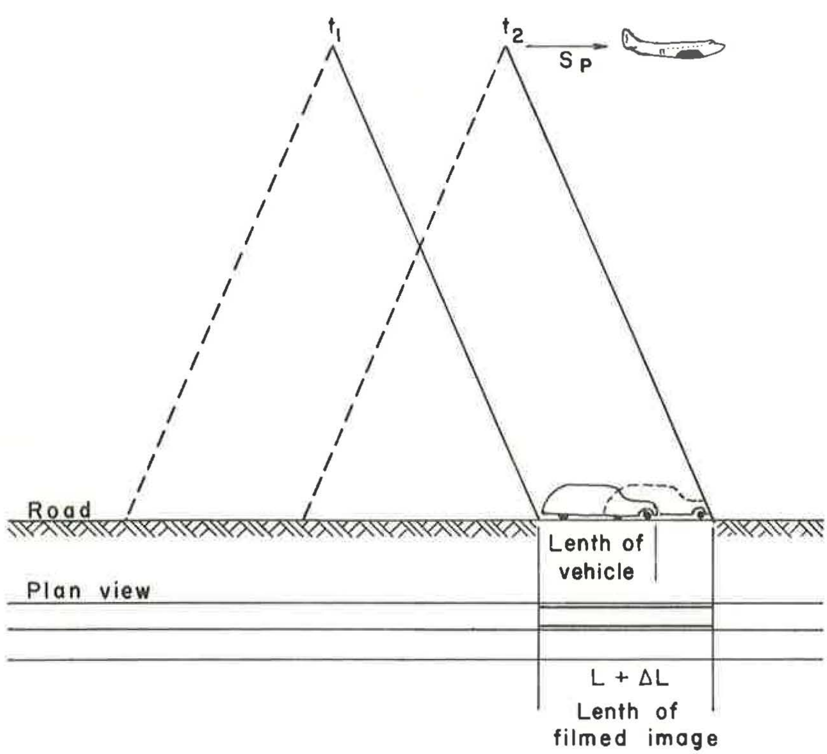


Figure 8. Time-distance relationships, continuous-strip photography.

strip photography. The precision of the speed measurements was a direct function of the precision of the displacement measurements. Therefore, several techniques were investigated for making these measurements. Figure 9 illustrates the calculation of speed using measurement of the vehicle image.

A stereoscopic viewer, capable of making displacement measurements to $\frac{1}{1,000}$ inch was considered. This equipment, which relies on stereoscopic depth perception of the user, should be used by personnel with extensive training in its operation. This method was rejected because precision of measurements could not justify cost of training instrument users and renting the equipment.



$$t_2 - t_1 = \frac{L + \Delta L}{S_P}$$

$$\Delta L = (t_2 - t_1)(S_B)$$

$$S_B = \frac{\Delta L}{L + \Delta L}(S_P)$$

S_P = Plane speed
S_B = Speed of moving vehicle
L = True lenth of vehicle
$L + \Delta L$ = Lenth of vehicle image on continuous strip film

Figure 9. Time-distance relation of strip photography.

The use of the stereoscopic view on a contractural basis was also investigated, but the cost of data reduction was too high and the information received was not as complete as needed; that is, lane usage, location with respect to stationing, and number of vehicles in the survey area, were not included in the data reduction procedure.

The displacement method, used by our staff, requires measurement of the vehicle displacement with an offset scale.

Because the scale was small, photographic enlargements were made of one strip of photographs to determine what improvements could be expected in the accuracy of measurements. Because the photography strip used was a positive transparency, contact prints made directly therefrom are negative in appearance.

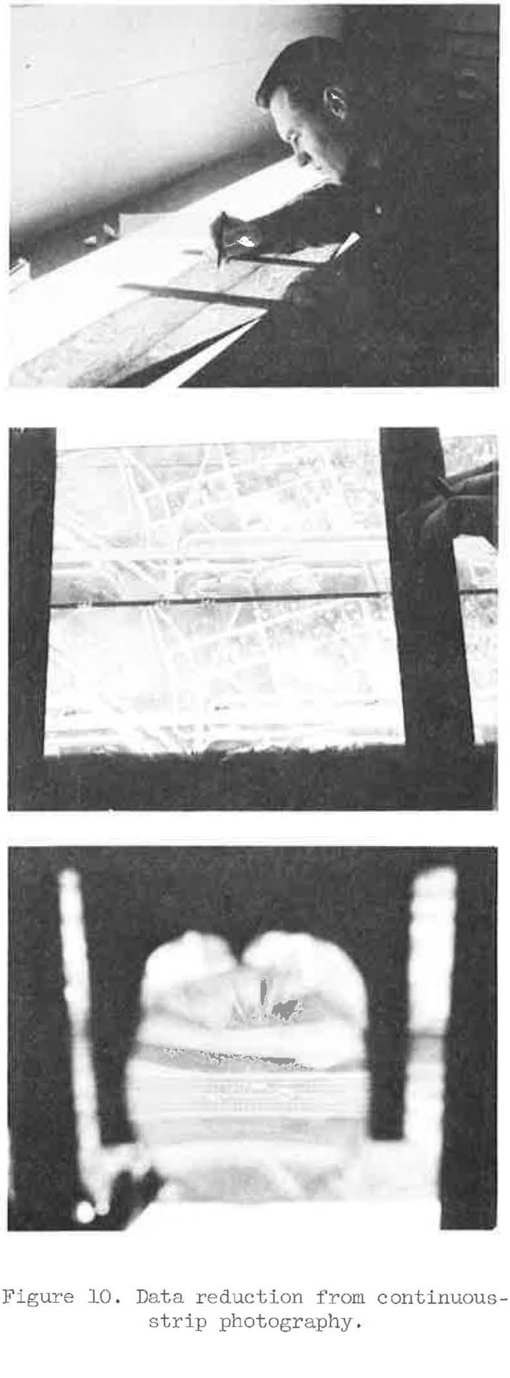


Figure 10. Data reduction from continuous-strip photography.

This is not a serious problem, but it induces some discomfort to the person who is examining the photography for long periods of time. Preparation of a film negative from which to make positive prints increases the cost of photographic enlargements by 25 percent.

The maximum photographic enlargement which could be processed by use of the equipment available is three to one. The scale would be approximately 100 feet to 1 inch. This method was rejected because the cost of making the enlargements could not justify the increase in accuracy, and there was no significant decrease in the data reduction costs.

The technique selected was measurement of data directly from the photography film transparencies. Figure 10 shows the light tables constructed for this work. A plexiglass illuminating frame was developed for making displacement measurements. The offset scale etched in the plexiglass was viewed through a magnifying glass. To make displacement measurements a reference mark on the glass was positioned over a vehicle in the lower film strip. The frame was positioned perpendicular to the film border. The displacement was measured at the location of the vehicle on the scale in the upper film strip. Measurements were made to $^{1}/_{100}$ inch.

Time-Lapse Photography. — Vehicular speeds, headways, and densities were calculated from measurement of ground displacement of the vehicles from one photograph to another photograph, exposed at known time intervals (Fig. 11). All other time-dependent parameters were obtained from these measurements. The time interval between exposures in time-lapse photography varied from one photography flight to another and had a range of from three to four seconds. Variation in the time interval within one photographic flight was ± 0.1 second.

Figure 11. Data reduction of time-lapse photography.

PRECISION OF MEASUREMENTS

Continuous-Strip Photography

Two measurements were made for each vehicle and are represented in Figure 8. Photography displacement, D, is measured on the film positive in inches. The vehicle dimension plus its photographic displacement, $D_B + D$, are dimensions measured from the film positive in inches.

Speed is calculated from the equation:

$$\text{Vehicle speed} = \text{place speed}\left[\frac{\text{vehicle displacement}}{\text{vehicle plus photographic displacement}}\right] \quad (1)$$

The accuracy of the vehicular speeds and all traffic movement characteristics dependent on speed are influenced by the precision of these measurements and by other factors subsequently explained.

Variation in Observers. —Equipment used in making measurements limited recording of displacement measurements to the nearest $\frac{1}{100}$ inch. The measurement precision depends somewhat on the instrument user's judgment. By comparing measurements made by two different recorders, it was evident that the difference between observers is negligible. The average difference and standard deviation for two observers were approximately the same as for two measurements by the one observer.

Limited Accuracy of Equipment. —Limitations of the equipment made it necessary to estimate measurements to the nearest $\frac{1}{100}$ inch. Figure 12 illustrates the error in vehicle speed resulting from errors in measurements. Low speeds of 20 miles per hour or less have considerable error, in the range of 10 to 15 percent, and can be attributed to the limited accuracy in measurements.

Variation in Scale. —As in all types of aerial photographs, there is difficulty in obtaining a uniform scale on the continuous-strip film. Variations in the scale, however, have no effect on vehicular speeds because the scale of the film does not appear in the calculations.

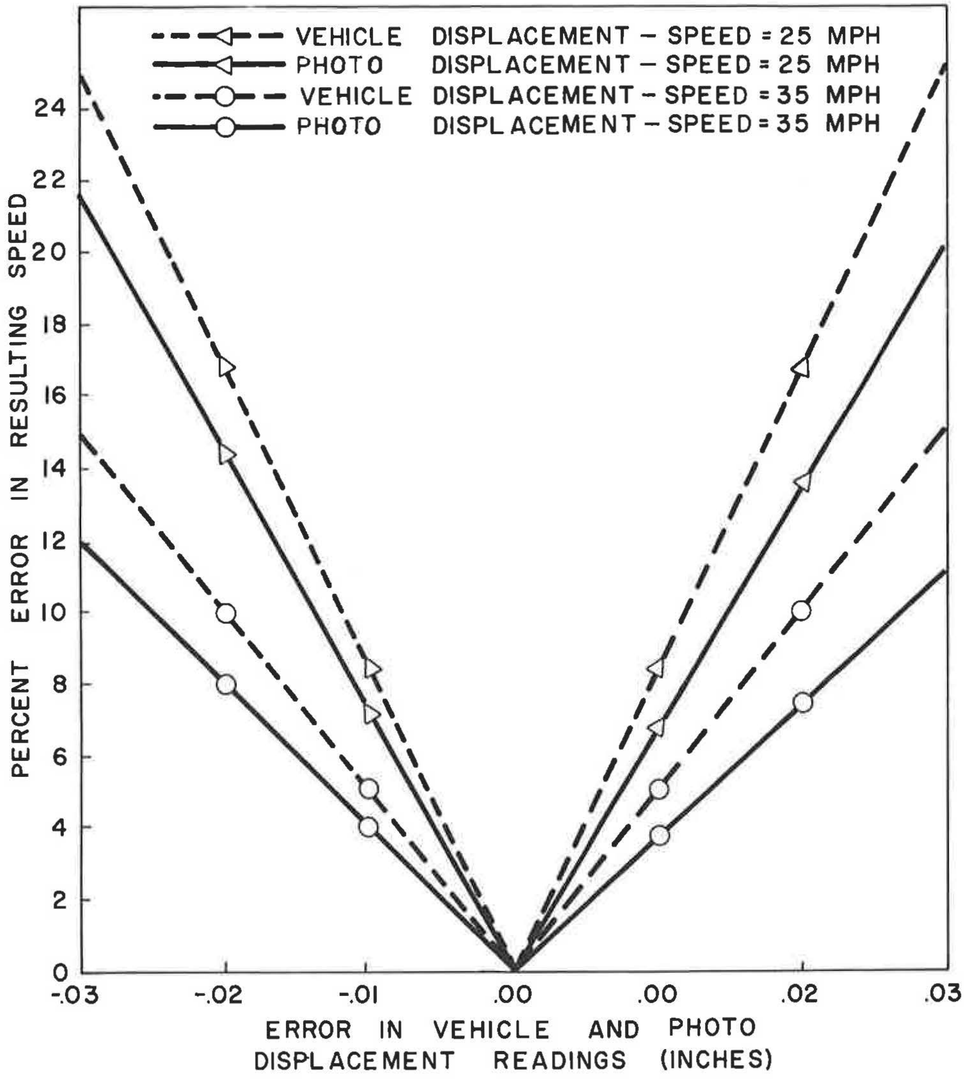


Figure 12. Errors in speeds resulting from errors in readings.

Space headways and vehicle densities cannot be measured directly because of a difference in time between the photographing of two vehicles. The correction necessary to position the vehicles in their true relative positions is small for high density conditions. The variation in scale must be considered in determining the original location of each vehicle as it appears on the photographic film positive.

Variation in Airplane Speed. —The airplane speed was calculated by dividing the length of the elapsed time during the photographic flight. This average speed was assumed to be constant throughout any one flight. This assumption is valid because the airplane speed was fast and the variations would only be a very small percentage of the true speed. The vehicle speed calculated from the continuous-strip photograph is obtained by equating the ratio of vehicle movement to airplane movement to the ratio of vehicle speed to airplane speed. Therefore, an error in airplane speed would result in the same percentage error in vehicle speed.

Variation in Flight Height. —The angle between the two camera lenses remains constant, so the only condition which would result in a change in photographic displacement of images is a change in flight height. This is one of the most difficult conditions to control and, as a result, the photographic displacement varies constantly.

It was impractical to make a photographic displacement measurement for every vehicle. Measurements were made at every 100-ft station along the roadway, and the photographic displacement for each vehicle was obtained from a straight line interpolation of the displacement measurements. Using the station numbers as reference points, the same photographic displacement was used for all three freeway lanes.

Measurements of vehicle displacement caused by its movement and photographic displacement caused by tilt were made directly on the film positive transparencies with a scale etched in a plexiglass overlay. The measurements were made to an accuracy of $1/1,000$ inch.

The accuracy of these measurements was checked by selecting 100 images of "test" vehicles at random and sending them to the contracted aerial survey company for processing with the stereoscopic viewer. Data were measured to an increment of $1/1,000$ inch. Three members of the traffic survey project staff made measurements for the same vehicle using the plexiglass overlay.

The data from the survey company were assumed to be correct and were compared to the measurements made by use of the overlay (Table 1). Figures 13 through 15 indicate results of the three test observers were consistently larger than from measurements made by the aerial company. The fact that speed differences were not distributed around a mean difference of zero indicated a bias in the measuring technique, or testing procedure.

A check of the accuracy of measurements made by the aerial survey company was obtained using a second aerial photography sample of 100 vehicles. Fifty vehicles in the sample were part of the vehicles in the original set. The measurements obtained for the fifty duplicated vehicles were different from the original (Table 2).

Because these differences occurred, there was no basis with which to determine the accuracy of the test observers' measurements. A comparison was made, however, which indicated accuracy of the test observers' measurements relative to the accuracy of the measurements supplied by the aerial survey company.

For this comparison, only the measurements of the two test observers, which were employed in the actual data reduction, were used. One of these two observers was asked to make a second set of measurements for the fifty vehicles, as this comparison was based only on the fifty vehicles for which there were duplicate measurements.

TABLE 1

SUMMARY OF DIFFERENCES BETWEEN AERIAL SURVEY COMPANY AND TEST OBSERVERS

Observer	Veh. Speed (mph)	Veh. Displacement (in.)	Photographic Displacement (in.)
		Average Difference	
1	2.7	0.006	0.040
2	1.7	0.002	0.037
3	1.7	0.001	0.036
		Standard Deviation	
1	4.4	0.020	0.021
2	7.8	0.039	0.022
3	5.0	0.025	0.020

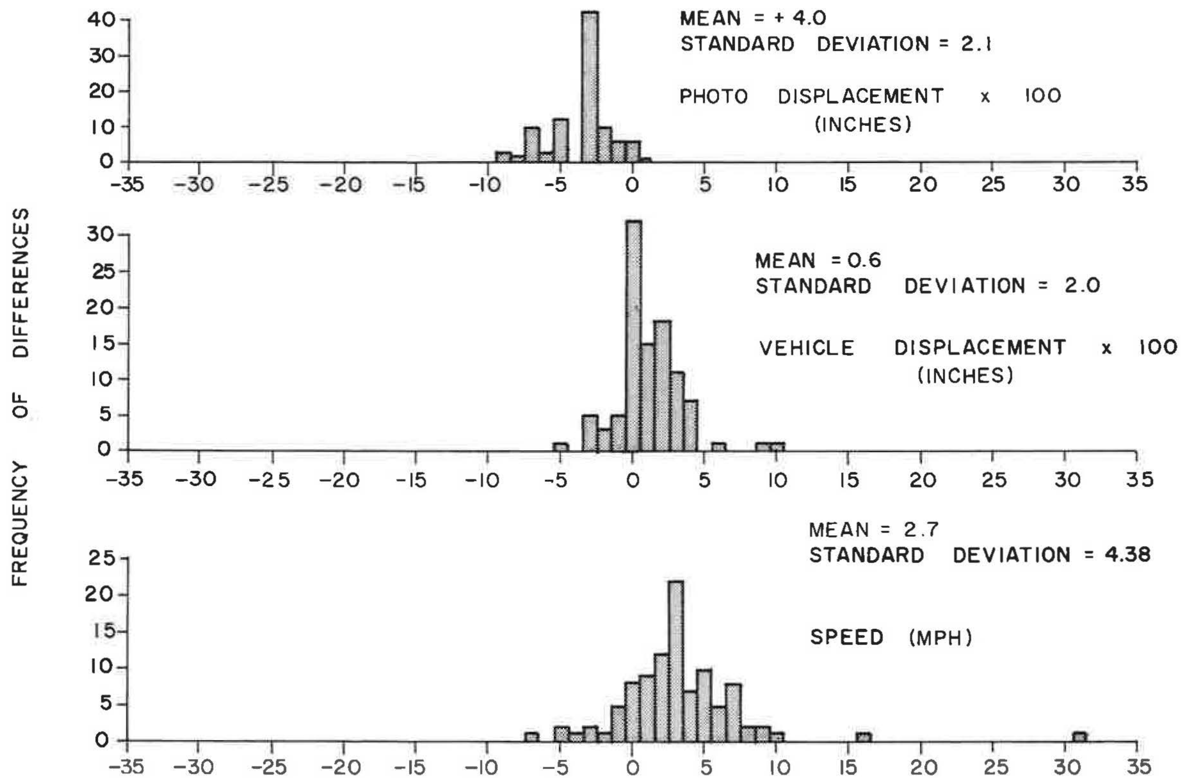


Figure 13. Distribution of differences between Test Observer 1 and aerial survey recorder.

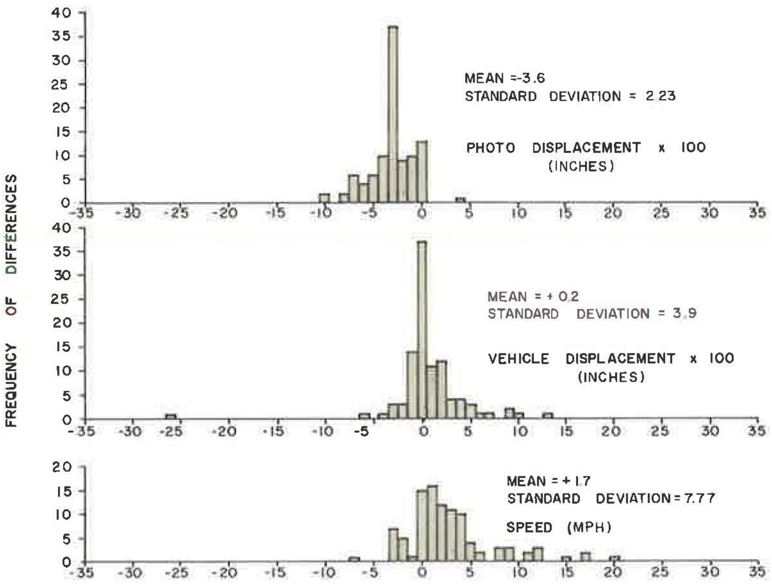


Figure 14. Distribution of differences between Test Observer 2 and aerial survey recorder.

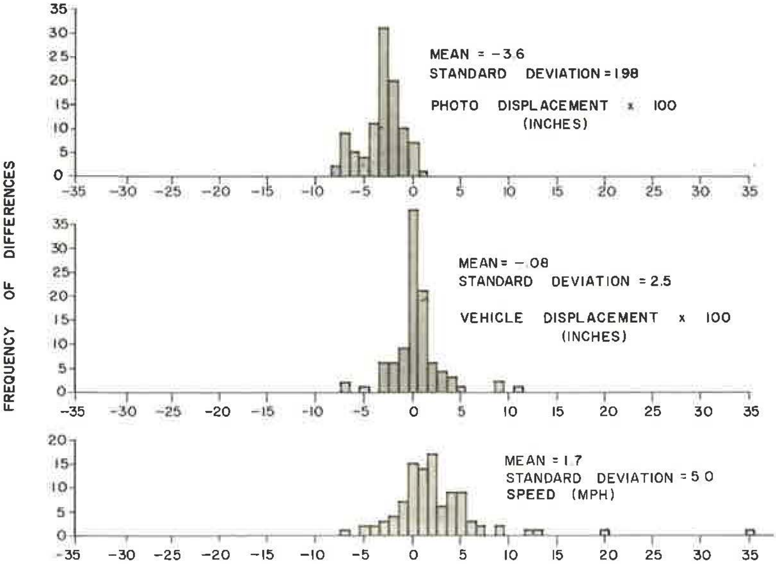


Figure 15. Distribution of differences between Test Observer 3 and aerial survey recorder.

TABLE 2

COMPARISON OF OBSERVERS

Case	Veh. Speed (mph)	Veh. Displacement (in.)	Photographic Displacement (in.)
		Mean Difference	
A[1]	-0.03	-0.002	-0.009
B[2]	0.73	0.006	0.001
C[3]	-0.85	-0.007	-0.005
		Standard Deviation	
A[1]	2.33	0.014	0.014
B[2]	4.24	0.026	0.021
C[3]	4.78	0.026	0.022

[1] Difference between two aerial survey company measurements.
[2] Difference between two test observers' measurements.
[3] Difference between two measurements of Observer 1.

The differences between the two separate measurements by the aerial survey company, the two measurements by Observer No. 1, and the measurements of Observer No. 2, were compared and are summarized in Table 2.

Table 2 gives an indication of the degree of reproducibility of the measurements. The results of the two observers are about the same as the results of two measurements by the same observer. The mean differences in speed determined from measurements by the aerial survey company are considerably less than the mean differences in speed determined from measurements by the test observers. The standard deviation of speed differences, which is the measure of scatter around the mean, was found to be in the range of four to five miles per hour for the comparisons involving test observers. The standard deviation of speed differences obtained from measurements by the stereoscopic viewer was found to be 2.3 mph.

A fundamental theorem of statistics states: If two distributions are normal, then the sums of differences of these distributions are normally distributed. Therefore, the distribution of these differences can be expected to follow a normal distribution. It could then be expected that about 70 percent of the differences will be within one standard deviation of the mean difference. The mean difference is less than 1 mph in all three comparisons.

To give an indication of the type of data used in this comparison, the speeds of the fifty test vehicles had an average of 34.7 mph, within a range of 52.6 mph, from a maximum speed of 59.7 mph to a minimum speed of 7.1 mph.

Time-Lapse Photography

The data measured from the time-lapse photographs were subject to the same factors affecting accuracy of measurements from the continuous-strip film photography. Measurements of vehicle displacement were made to the nearest $\frac{1}{100}$ inch with an engineers' scale. The time interval between photographs had an accuracy of ± 0.1 second. The maximum effect of these two measurements on the determination of vehicular speeds would be ± 3 mph at 70 mph to ± 1 mph at 15 mph.

The photographs used were ratio printed to the same scale so variations in flight height did not affect their scale.

The only major problem in the data reduction was the transfer and identification of reference points on different photographs. The movement of a vehicle was measured from one distinguishing roadway feature. If this reference point failed to appear in all photographs in which the vehicle was imaged, a new reference point was established. Frequently, the third or fourth vehicle position was located by measuring from the wrong reference marker. The electronic computer programs noted large changes in vehicle speed, which pinpointed these errors.

Measurements from these reference markers were made using an average scale for the photographs. There was image displacement at the edges of the photographs but errors in distance it caused were less than two percent.

ECONOMIC COMPARISONS

Cost of Field Survey Work

It is the general practice of aerial survey companies to negotiate contracts. Consequently, the cost of a traffic survey, such as the one accomplished for the freeway in Houston will depend on many factors. Among these are the length of the survey project and its location in relation to a base of operations, the time of the year, and the availability of equipment. The contracts for the Houston survey contained the following provisions:

> Strip Photography.—Beginning at 6:30 a.m., the airplane shall make as many photographic flights as possible until 8 a.m. This schedule is to be repeated as soon as possible. This plan resulted in 22 flights being made over the same 5-mi section of the freeway. One positive film transparency for each flight at a scale between 200 and 300 feet per inch was obtained at a total cost of $2,500.
>
> Time-Lapse Photography.—Beginning at 6:30 a.m., the airplane shall begin making the prescribed photographic flights. A total of nine flights shall be completed before 8 a.m. One set of scale ratioed photographic prints at a scale of 100 feet to one inch for each flight was provided at a cost of $2,300.

First indications were that the continuous-strip film transparencies provided much more photography coverage for the money expended. There are other factors, however, which must be considered. Table 3 contains some statistics regarding the two surveys.

On the 22 continuous photography film strips 13,774 vehicles were photographed. Only a few vehicles were imaged on two consecutive photographic flights, so most of the 13,774 measurements for speed determination pertained to different vehicles.

Nine of the continuous-strip photographs were taken at the same time the time-lapse photographs were taken. Therefore, the same number of vehicles was studied by use of photographs taken on these flights. The time-lapse photography has the added feature of tracking vehicles for several seconds. Most of the vehicles were imaged in three consecutive photographs, and a few of the vehicles traveling at fast speeds were image recorded in four or five. This represented a time interval of twelve to fifteen seconds during which speed changes could be determined.

Table 4 indicates the cost per mile for the aerial surveys. The continuous-strip photography provided the least cost, considering the length of roadway covered by the airplane. The unit cost per length of roadway, however, as measured from the pho-

TABLE 3

COMPARATIVE STATISTICS

Photography	Photographic Flights (No.)	Flight Height (ft)	Flying Time (min)	Photography Time (min)	Cost of Taking Photographs ($)	Veh. Observed (No.)	Measurements Made to Determine Veh. Speed (No.)
Time lapse	9	2,500	55	26	2,300	7,186	15,700
Continuous stereoscopic photography	22	1,000	175	50	2,500	13,774	13,774

TABLE 4

COMPARISON OF COST/MILE FOR AERIAL PHOTOGRAPHY

Photography	Overlap (%)	Scale (ft/in.)	Cost per Freeway Mile Photographed ($)	Cost per Mile Corrected for Overlap ($)
Continuous strip—Houston[1]	0	300	18.90	18.90
Time lapse—Houston[1]	60	100	41.90	16.75
Time lapse—California[2]	15	200	20.49	17.40

[1] Traffic studies.
[2] Inventory study.

tographs after correcting for the overlap, indicates the time-lapse surveys are less expensive.

Cost of Data Reduction

Continuous-Strip Photography.—The continuous-strip photography was in the form of positive film transparencies which require a light table or film examination unit for viewing. Several different approaches to the problem of data reduction of the aerial film positives are subsequently outlined. The methods which give greater accuracy are usually more time-consuming and more expensive than others.

Stereoscopic Viewer.—A stereoscopic viewer with the capability for making measurements to within 1/1,000 inch was available from the aerial survey company which took the photography for the survey. The two alternatives available were either to rent the viewer and provide a number of the project staff with instruction and training in its use or to contract the measurement work to the survey company. The estimated cost of each proposal is, as follows:

Renting Stereoscopic Viewer:

Rental Cost:	
6 Months at $120 for first month	
80 for each additional month	$ 520
Cost of training viewer operator	500
Salary for viewer operator	1,500
Total	$2,520

Contracting Data Reduction:

Cost of Data Reduction	
13,774 vehicles at $1.25 per vehicle	$17,200

Enlargements of Continuous-Strip Film Positive Photography.—Another approach to improving the accuracy of measurements taken from the continuous-strip film positive photography was to improve the scale of the film. The Texas Highway Department made available their photographic equipment which has the capacity of enlarging film strips threefold. Sample prints were made from the film for study. At a 3:1 enlargement ratio, 15 sheets were required to make prints of each film strip. The cost for enlarging the photography for the entire traffic survey would be 330 sheets at $4.50 per sheet or $1,485.

Because the film strips were positive transparencies, positive contact prints could not be obtained directly. The cost of a set of negatives would be 330 negatives at $1.50 per negative or $495.

Limited investigations regarding the cost of measuring basic data from these sheets of photographic enlargements indicate the man-hour requirements for the measuring work was not significantly different from measuring data using the original film positive strips.

Measurements from the Film Positive Strips. —The technique which was used on this traffic survey project was to make measurements directly from each film strip transparency. Cost of equipment and personnel used in this data reduction technique are, as follows:

Equipment:	
2 light tables 60 × 24 in.	$160
2 magnifying glasses	6
2 engineers' scales	10
Data Reduction:	
13,774 vehicles at $0.05 per vehicle	$690
Total	$866

The cost of data reduction was calculated from a pay rate of $1 per hour for student workers. The $0.05 per vehicle rate was determined after the data reduction procedure was well established. The rate includes cost of identifying the station numbers and measuring displacement caused by movement of each vehicle and the photographic displacement for each station number and recording the vehicle type, lane, and direction of travel. The cost of position identifying the station numbers was approximately $6 per film strip. This cost was not included in the per-vehicle rate because it is independent of the number of vehicles photographed and because this reduction task can be eliminated by placing station markers on the pavement before the traffic survey photography is taken.

Time-Lapse Photography. —Measurements of vehicle movements during the time interval between photographs were made directly from the contact prints made from the aerial film negatives by the aerial survey company. These prints had a scale of 100 feet to 1 inch, which permitted making measurements with an engineers' scale to the acceptable degree of accuracy.

The cost of traffic data reduction using the time-lapse photography was 15,700 measurements for determining vehicle speed at $0.07 per vehicle or $1,100.

The cost of data measurement and reduction was calculated using a pay rate of $1 per hour for student workers. The $0.07 per vehicle rate was determined after the data reduction procedure was well established. The rate includes the cost of measuring and calculating the station number of the vehicle, the vehicle type, lane, and direction of travel. The cost of position identifying the station numbers is approximately $25.00 per flight strip of time-lapse photography. This cost item was not included in the unit cost because it is a reduction task which can be eliminated by placing station markers on the pavement before the traffic survey photography is taken.

The cost of data reduction using time-lapse photography was higher than when using the continuous-strip positive film transparencies because of difficulty in referencing vehicles to station numbers. Electronic computer programs were prepared for computing all traffic flow data from the basic measurements made for each vehicle, which were the location of the vehicle and the time of day. Locating the position of vehicles by station number on each photograph was complicated by scale distortions at the edge of the photographs and by inaccuracies of the station numbers. Station numbers were transposed onto the aerial film positives from a set of construction plans for the freeway. Because of scale distortions, more than two reference markers should have been used, but on some photographs there were no distinguishing roadway features to establish references. This problem can be averted by placing station markers on the pavement before photography is taken for the traffic.

Because no station markers were placed for use in making this survey, a special reduction procedure was used whereby the first vehicle position was determined from the transposed station markers. Each succeeding location was calculated by measurements from a common reference marker. This process of having to repeatedly make reference to the photograph in which the vehicle first appeared resulted in loss of efficiency.

DATA OBTAINED FROM THE TWO AERIAL SURVEYS

Speed

Both photographic methods provide means of obtaining vehicle speeds. The accuracies of these measurements are different because of the time interval used to calculate speeds and the scale of the photographs.

Density

Density must be calculated using the data measured from the continuous-strip film positive photography. The data have to be corrected for the time transpiring while photography was being taken throughout the length of roadway section along which the traffic survey was being made. This correction is very small, in the order of five to ten seconds, for freeway segments one or two thousand feet long.

The time-lapse photography furnishes a true measure of traffic density within a freeway section approximately 1,800 feet long, which is included in the image of coverage of one photograph. Measurements over a longer section required use of two or more photographs for which their instant of exposure is separated by a short interval of time. In this event the same correction for the elapsed time must be made to determine density of traffic.

Space Headways

Determining the distance between two vehicles, space headways, is subject to the same conditions and corrections applying to measurements for determining traffic density.

Time Headways

The time separating two vehicles can be calculated by dividing the space headway by the speed of the trailing vehicle.

Volume

The volume, the number of vehicles comprising the traffic, can be determined from aerial photographs if continuous coverage was maintained for one hour or more. Rates of traffic movement (flow) can be calculated for each flight strip of photography from the following expression (9):

$$V_t = \frac{\bar{s}\,(n\ 1)\,S_p}{D + (S_p - S_d)}$$

in which

V_t = rate of flow of traffic in vehicles per hour for a time period of $t = D_t/S_p$;
$\bar{s}$ = average overall speed of n vehicles;
D_t = distance between end vehicles (measured on photography);
n = number of vehicles in distance, D_t;
S_p = speed of the airplane in mph; and
S = speed of last vehicle in traffic lane.

The determination of n must be done carefully to avoid counting the same vehicle more than one time.

Acceleration--Deceleration

Speed change by individual vehicles cannot be measured by use of the continuous-strip film positives. Each vehicle is photographed only twice each on each flight strip of stereoscopic photography.

The time-lapse method of aerial photography can be used to make multiple measurements for determining the speed of each vehicle. There are several factors which influence the number of times a vehicle will be photographed: (a) the percent overlap between successively adjacent photographs, (b) the difference in airplane and vehicle speeds, and (c) the direction of aircraft flight relative to the direction of the traffic movement.

In the survey made in Houston, sixty percent overlap and an airplane speed of 120-140 mph resulted in several vehicles traveling in the same direction being photographed five times. From these several measures of speed, the acceleration and deceleration of each vehicle can be calculated. These speed traces can be of value in measuring the build up to, or relief of, congested areas.

These measures of speed change can also be used in calculating traffic density. Rather than making an assumption of constant speed, the acceleration or deceleration of the vehicle can be projected for the time interval involved to get a more accurate location for density determination.

Vehicle Classification

Large commercial vehicles can be identified from both the continuous-strip film positive and time-lapse photography. Small single-unit and pickup trucks are difficult to distinguish from passenger vehicles on the strip film positive photography especially when traffic is moving fast.

Markings, which had been placed on the top of control vehicles, were easily noted in the time-lapse photography, but required very close inspection to be seen on film strip positive photography.

CONCLUSIONS

The application of aerial photography to making traffic surveys has been demonstrated and has proven to be an excellent means of gathering traffic data. Through the use of this technique, the traffic survey areas have been expanded in breadth and length, and inclusion of traffic on the street systems supporting the freeway is now possible. Traffic flow characteristics requiring measurements of distance, such as density and space headways, can be determined more accurately.

There are disadvantages which must be considered in designing a traffic survey for accomplishment by use of aerial photography. Although the traffic conditions are recorded pictorially in true relationship to the geometric design of the traffic facilities, aerial photography does not provide continuous motion data throughout a period of time as motion pictures will. This fact should be carefully considered in determining the length of freeway section to be surveyed and the frequency for making the aerial photography flights.

Data measurement and reduction from aerial photographs is still a time-consuming task. But an electronic computer program utilizing only a few basic measurements to calculate all traffic flow characteristics eliminates any necessity for using the photographs time after time.

Traffic surveys by aerial photographic techniques are limited to the hours of good lighting and flying conditions. This prevents getting aerial photography during hours of peak traffic during winter months under the worst driving conditions.

Selecting the type of aerial photography to use requires considering the information to be obtained from the photography. The following conclusions are drawn from the aerial surveys made in Houston:

1. Time-lapse photography is more suited for making measurements to determine traffic density. The aerial photography should be taken from the flight height which will provide ample coverage over the roadway segments to be included in the traffic

density calculations. The amount of photographic overlap in line of flight can be adjusted to requirements of the traffic survey.

2. Time-dependent parameters can be measured more readily by use of continuous-strips film positive photography.

3. Vehicular speed changes can be measured by use of the time-lapse photography.

4. Land distribution and vehicle classification can be obtained by use of both types of photography, but vehicle identification by examination of the continuous-strip film positive photography is more difficult because of blurred images.

5. When freeway sections less than 2,000 feet long are photographed, the effect of time lag in the continuous-strip film photography is slight. The assumption of uniform speed for the traffic gives results within an acceptable level of accuracy.

6. Continuous-strip film photography provides more coverage for the money expended, 22 flight strips of photography in three hours of true time. Time-lapse photography provided nine flight strips in one hour of true time.

7. More speed readings were obtained by use of the time-lapse photography.

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