

# TRAFFIC DATA COLLECTION THROUGH AERIAL PHOTOGRAPHY

David J. Cyra, Division of Highways, Wisconsin Department of Transportation

In April 1969, the Wisconsin Department of Transportation conducted a comprehensive traffic study on the freeway in the state with the highest volume. This input-output study consisted of manually recording volumes and speeds during peak periods over a 5½-mile freeway section. Vehicle accumulation and speed data were collected and processed. An aerial study using time-lapse photography collected similar data during the same peak period. Oblique aerial photography was used to collect vehicle accumulation data, and vertical aerial photography was used to collect vehicle speed data. Statistical analyses were made to determine the reliability of the aerial photographic collection techniques as compared to the conventional collection procedures. In addition to method reliability, actual cost comparisons were made and indicated that oblique aerial photography is a reliable and economical method for collecting vehicle accumulations and that vertical photography is a reliable method for collecting vehicle speeds and headways. The vertical method allows traffic flow evaluation based on the performance of individual vehicles in the traffic flow but is an expensive method of collection when only speed data are considered. However, when data on vehicle accelerations, headways, and platoon behavior are required, vertical photography is convenient and economical as well.

•THE comprehensive freeway study of April 1969 on the East-West Freeway in Milwaukee served two purposes: It provided a quantitative inventory of peak-hour traffic data to be used in a freeway control program, and it served as an excellent basis for comparing manual and aerial photographic methods of collecting vehicle accumulation and speed information. The purpose of this comparison was to test the reliability of the aerial photographic collection method against the conventional method of collection. In addition, the actual costs incurred with each of these collection methods were documented for the purpose of establishing a general cost guideline that can be used in future freeway studies of this sort. The purpose of this paper is not only to investigate the reliability of the aerial photographic collection technique but also to present a practical guide based on the types of traffic data needed and the cost associated with fulfilling this need.

## STUDY LOCATION

The East-West Freeway in Milwaukee carries the highest traffic volumes of any freeway in Wisconsin. The study section used in the comparison of the manual traffic data collection method and the aerial photographic collection method was from the Marquette Interchange in the east to the Zoo Interchange in the west (Fig. 1), a distance of 5.5 miles. Congestion occurs regularly on that section during the peak hours of 7:00 to 9:00 a. m. in the eastbound direction and of 3:30 to 5:30 p. m. in the westbound direction.

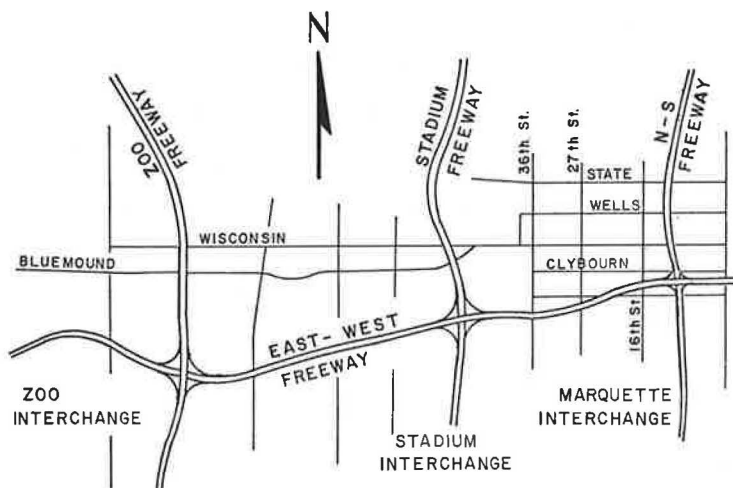


Figure 1. Study location.

### STUDY TECHNIQUE

Time-lapse photography, where pictures are taken at short intervals of time, was the aerial method of traffic data collection. For the purposes of comparison, two types of traffic data were collected through aerial photography. The first type, vehicle accumulation, which represents the number of vehicles on the freeway at some given time, was collected through the use of oblique aerial photography. The second type was vehicle speed data. The acquisition of speed data through photographic means requires a controlled collection technique. Aerial vertical photography affords the control necessary for data collection of this type, especially over the  $5\frac{1}{2}$ -mile study section. This collection represented a microscopic study that permitted an investigation of the interaction of individual vehicles and their behavior in the traffic stream. Individual vehicle speed data and also headway, or that distance between the front bumpers of the lead and following vehicles, were collected in this study.

#### Oblique Aerial Photography

The requirements of oblique photography were that some overlap be provided and that the photographs permit the identification of individual vehicles. The study technique used was similar to the technique presented by Wattleworth and McCasland (7).

For the purpose of comparison, the study section was identical to the one used in the manual input-output study. The oblique photographic equipment and procedure used to collect vehicle accumulations were as follows.

The plane was a Cessna 172 Skyhawk. Two 35-mm cameras were used—a Kodak Retinette IA with a 55 mm/F 1:2.8 lens and a Pentax (H-1-A) with a 55 mm/F 1:2 lens. The flight plan was to photograph only in the direction of traffic and make as many runs over the section as possible during the study period. The plane flew at an altitude of 1,000 ft and approximately 500 ft to the side of the freeway. The flight crew consisted of a pilot and two photographers who shared the responsibility of photographing the freeway. In this way, while one photographer was taking the pictures of the freeway the other had time to reload his camera and record the time of the beginning and ending of each flight along with any appropriate notes regarding the flight. The first exposure of each flight contained the beginning of the study section. The following overlapping exposures were taken in order to achieve a mosaic of the entire length of the study section.

After the film was exposed it was taken to a commercial photofinishing firm that had a 1-day film developing service. This firm processed the film into 3- by 4-in. prints. These prints were taken to the Wisconsin DOT office where one man assembled the prints by proper sequence and flight number. Each flight used one roll of film (about 32 prints), and these prints furnished a complete picture of the study section. The vehicle accumulations were extracted from the study section in the following manner.

1. The study section was broken into subsections, and the vehicles were counted with respect to subsections. The total accumulation of vehicles on the freeway was the sum of the vehicles in the subsections.

2. The time of day for this total vehicle accumulation was that time when the center photograph was exposed. This technique assumed that there was no change in vehicle accumulation during the entire flight, which was approximately 4 min.

### Vertical Aerial Photography

The vehicle speed data collected by vertical aerial photography were the speeds of vehicles traveling through 1,000-ft speed traps painted on the freeway at four bottlenecks. The equipment and procedure used for the vertical photography were the following.

A twin-engine Cessna Skymaster with a push-pull engine arrangement made as many passes over the study section as possible during the peak period. The camera used was a Zeiss RMK 15/23A with a 6-in. focal length and a maximum shutter speed of  $\frac{1}{1,000}$  sec and a minimum automatic cycling capability of 2 sec. The photographs were taken in the direction of the peak traffic flow. The desired scale of the photography was 1 in. equal to 600 ft. This scale dictated a flying height of about 3,600 ft. The intervalometer was set at an exposure rate of one photograph every 8 sec. These photographs were 9 by 9 in. and were taken with a 60 percent overlap to ensure workable enlargements of a consistent 1 in. equal to 100 ft scale.

Only two successive prints of each of the four bottleneck areas were enlarged to the hundred scale. Each flight required eight enlargements; a total of 10 flights were flown. Each of these 80 enlargements measured 2 by 3 ft. This size permitted vehicle identification quite readily inasmuch as a foot of ground measure was represented by 0.01 in. on the enlargement.

The next step was to identify the same vehicle on two successive enlargements. Each vehicle was given an identification number. This number consisted of four digits that represented, reading from left to right, lane, vehicle type, and placement in the queue. That is,

<u>Lane</u>	<u>Type</u>	<u>Queue Placement</u>
0	0	00

On each enlargement there were basically three primary reference points: (a) the beginning of the speed trap designated with a paint stripe on the freeway, (b) the ending of the same speed trap, and (c) the middle of the front bumper of each vehicle. These reference points were used to determine the position of the vehicle in reference to the speed trap.

To measure the distance between reference points, we used a coordinatograph to assign relative x and y coordinates to each reference point. After the coordinates of each vehicle were assigned, they were keypunched onto data processing cards. Each vehicle on each photograph had its own data card that represented flight, photograph, lane, vehicle type, and placement in the queue.

We reduced the photographic reference point data to ground coordinate data and then computed speeds and headways of the vehicles by writing a computer program for the IBM 360/50 computer. The format of the output data included flight number and time, photograph pair number, vehicle identification number, headway on photograph number one, headway on photograph number two, average headway, and average speed.

Time synchronization of personnel on the ground and in the air was a necessity for the successful completion of this study. During this study the 8-sec aerial speed sample by lane (about 20 vehicles) was compared to the 1-min speed sample by lane of a single vehicle taken on the ground. Speed data were compared by analysis of variance to indicate level of significance and by a standard error of the net difference to represent the difference between speed data collected aerially and manually.

## STATISTICAL ANALYSIS

### Vehicle Accumulation

The comparative plotting of these data, oblique aerial versus manual, is shown in Figures 2 through 7. Table 1 gives data collected for the westbound direction, and Table 2 gives data collected for the eastbound direction. Generally speaking a combined 5 percent error is associated with the eastbound and westbound directions with the aerial method usually providing the higher accumulation.

To investigate the level of significance between the means of the two collection methods, we conducted an independent t-test. This test assumes (a) a homogeneity of variance (8), (b) no difference in the vehicle accumulation collection methods due to time during the peak period and day of the week, and (c) normal vehicle accumulation distribution during the peak period.

The hypothesis statement assumes that there is no difference between the manual and aerial collection techniques. The alternative hypothesis is that the manual is not equal to the aerial. That is, the null hypothesis is  $\mu_1 = \mu_2$ , and the alternate hypothesis is  $\mu_1 \neq \mu_2$ .

TABLE 1  
INCREMENTAL VEHICLE ACCUMULATION COMPARISON FOR  
WESTBOUND DIRECTION

Date <sup>a</sup>	Time	Manual Survey	Aerial Survey	Difference
April 18, 1969	4:01	556	517	-39
	4:12	625	625	0
	4:21	544	579	+35
	4:32	600	593	-7
	4:41	860	884	+24
	4:50	830	903	+73
	4:59	790	845	+55
	5:11	860	922	+62
	5:23	820	844	+24
	5:31	<u>652</u>	<u>698</u>	<u>+46</u>
Total		7,137	7,410	+273
April 21, 1969	3:48	673	671	-4
	3:59	520	552	+32
	4:09	550	628	+78
	4:19	500	550	+50
	4:28	540	527	-13
	4:38	731	766	+35
	4:56	820	835	+15
	5:06	883	870	-13
	5:15	928	888	-40
	5:24	<u>862</u>	<u>880</u>	<u>+18</u>
Total		7,007	7,167	+158
April 22, 1969	3:37	597	623	+26
	4:00	403	416	+13
	4:22	488	497	+9
	4:32	643	631	+12
	4:43	910	997	+87
	5:06	712	735	+23
	5:26	<u>588</u>	<u>692</u>	<u>+104</u>
Total		4,341	4,591	+274

<sup>a</sup>Percent error for combined westbound direction =  $3.81 = (3\text{-day absolute difference}/3\text{-day manual sum})$  or 3.82 for April 18, 2.25 for April 21, and 6.31 for April 22.

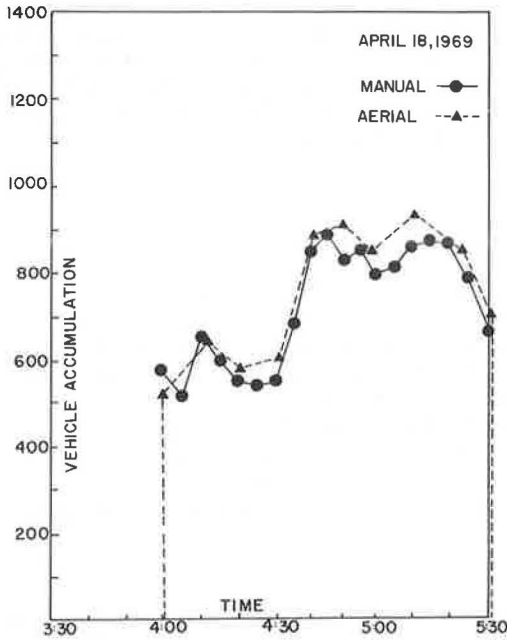


Figure 2. Vehicle accumulation in westbound direction on April 18, 1969.

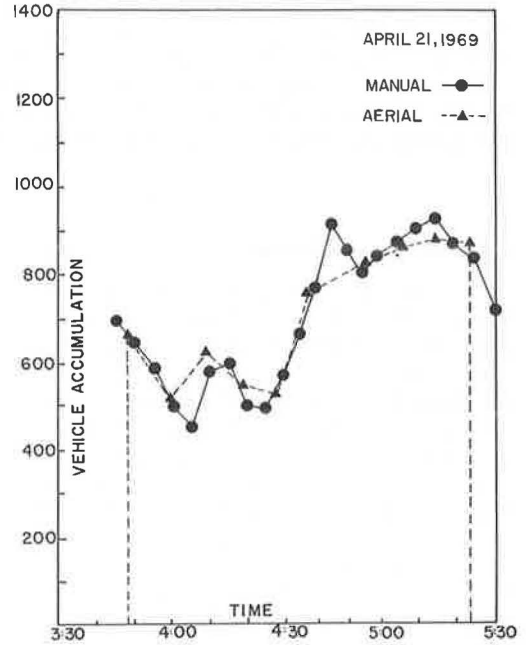


Figure 3. Vehicle accumulation in westbound direction on April 21, 1969.

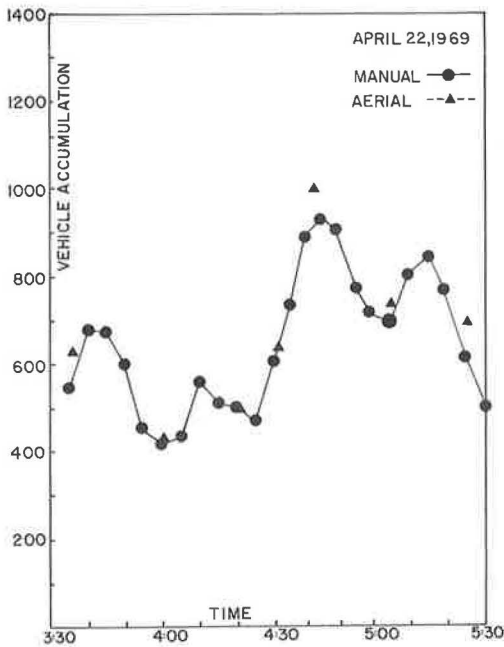


Figure 4. Vehicle accumulation in westbound direction on April 22, 1969.

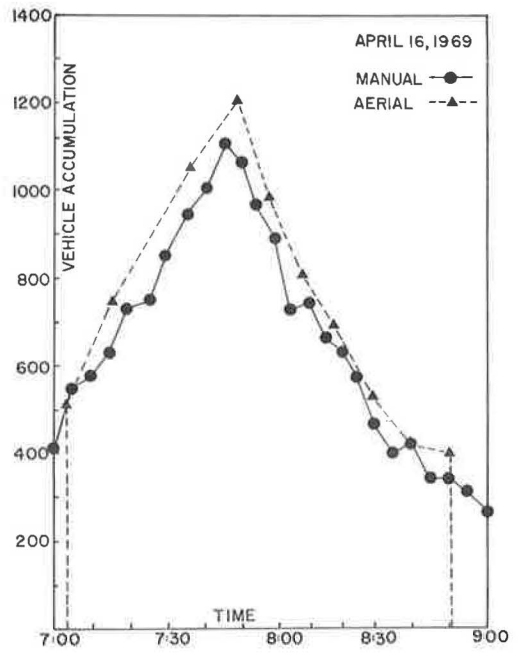


Figure 5. Vehicle accumulation in eastbound direction on April 16, 1969.

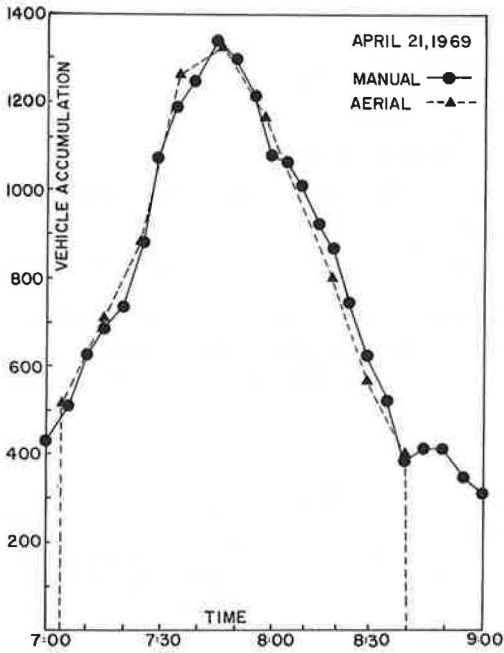


Figure 6. Vehicle accumulation in eastbound direction on April 21, 1969.

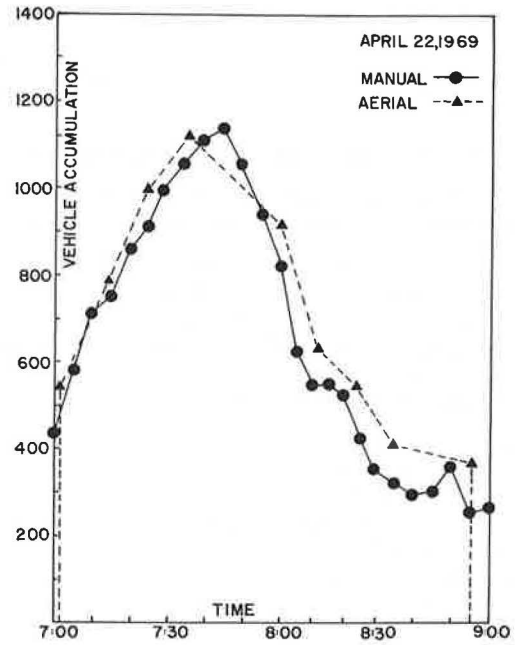


Figure 7. Vehicle accumulation in eastbound direction on April 22, 1969.

The following procedure was used in the testing:

1. Obtain the mean accumulations.

For manual,

$$\bar{X}_1 = 700.67$$

For aerial,

$$\bar{X}_2 = 735.40$$

2. Determine the variance of each technique.

$$S_1^2 = \frac{(X_1 - \bar{X}_1)^2}{n_1 - 1} \quad S_1^2 = 54,996$$

$$S_2^2 = 55,395$$

where  $n_i$  is the number of observations tested.

3. Pool the variances.

$$S_p^2 = \frac{(n_1 - 1) S_1^2 + (n_2 - 1) S_2^2}{(n_1 - 1) + (n_2 - 1)} = 55,196$$

4. Find the V-statistic.

$$V(\bar{X}_2 - \bar{X}_1) = S_p^2 \left( \frac{1}{n_1} + \frac{1}{n_2} \right) = 2,004$$

5. Compute a t-statistic.

$$t = \frac{(X_2 - X_1) - E(\text{statistic})}{V\text{-statistic}} = 0.7759$$

6. Test at a 5 percent significance level ( $\pm$  tabulated = 1.96).

By using the results of the two comparative tests—the percent error test and the analysis of variance test—we derived the following conclusions:

1. For the percent error test, the aerial method is generally 5 percent higher than the manual method of collecting vehicle accumulations.

2. With the analysis of variance test, at the 5 percent level of significance, there is no significant difference between the means of the aerial and manual methods.

3. Therefore, it is reasonable to assume that either method can be used to collect vehicle accumulation data.

### Vehicle Speeds

The speed data recorded during the study are given in Tables 3 through 6. These tables give the variability of speed at each bottleneck location dependent on time of the peak period, method of collection, and lane for which the data were taken. To analyze the relationship that exists between speed and these variables in terms of statistical significance required that an analysis of variance technique with the index F as a test

TABLE 2  
INCREMENTAL VEHICLE ACCUMULATION COMPARISON  
FOR EASTBOUND DIRECTION

Date <sup>a</sup>	Time	Manual Survey	Aerial Survey	Difference
April 16, 1969	7:04	515	515	0
	7:16	655	755	+100
	7:38	988	1,057	+69
	7:48	1,085	1,218	+133
	7:58	920	984	+64
	8:09	743	803	+60
	8:18	654	692	+38
	8:30	463	528	+65
	8:40	428	417	-11
		8:50	<u>356</u>	<u>402</u>
Total		6,807	7,371	+564
April 21, 1969	7:04	493	513	+20
	7:14	675	712	+37
	7:26	925	885	-40
	7:37	1,235	1,268	+33
	7:46	1,342	1,329	-12
	7:58	1,142	1,168	+26
	8:20	868	800	-68
	8:30	612	563	-49
		8:40	<u>387</u>	<u>402</u>
Total		7,679	7,640	-68
April 22, 1969	7:02	490	529	+39
	7:14	740	787	+47
	7:25	910	997	+87
	7:37	1,065	1,107	+42
	8:00	807	906	+99
	8:12	545	624	+79
	8:24	439	546	+107
	8:35	320	402	+82
		8:56	<u>250</u>	<u>370</u>
Total		5,566	6,268	+702

<sup>a</sup>Percent error for combined eastbound direction = 6.31 = (3-day absolute difference/3-day manual sum) or 8.28 for April 16, 0.88 for April 21, and 12.61 for April 22.

TABLE 3  
SPEED COMPARISON, 19TH STREET

Time	Median				Middle				Shoulder			
	Aerial Survey		Manual Survey Speed	Difference	Aerial Survey		Manual Survey Speed	Difference	Aerial Survey		Manual Survey Speed	Difference
	Vehicles	Average Speed			Vehicles	Average Speed			Vehicles	Average Speed		
4:00	8	54.4	62.5	-8.1	14	51.4	52.5	-1.1	6	48.3	47.5	+0.8
4:10	19	50.7	57.5	-6.8	17	52.5	42.5	+10.1	13	46.0	52.5	-6.5
4:21	14	52.1	57.5	-5.4	15	50.2	47.5	+2.7	13	41.0	52.5	-11.5
4:31	22	51.4	57.5	-6.1	19	46.4	52.5	-6.1	10	42.0	47.5	-5.5
4:41	47	22.7	12.5	+10.2	41	23.2	27.5	-4.3	33	29.2	32.5	-3.3
4:50	43	19.7	32.5	-12.8	34	29.7	22.5	+7.2	27	30.2	37.5	-7.3
4:59	21	44.6	52.5	-7.9	23	42.1	52.5	-10.4	17	37.2	47.5	-10.3
5:10	24	28.3	27.5	+0.8	26	29.4	32.5	-3.1	21	27.0	32.5	-5.5
5:22	58	10.9	12.5	-1.6	60	9.4	2.5	+6.9	60	7.9	2.5	+5.4
Total	281	37.2	41.4		279	37.1	36.9		223	34.3	34.9	
Error Percent error		10.1		-37.7		0.54		+1.8		14.15		-43.7

statistic be used. This technique is conducted as a multifactorial design. It is realized that the statistical experimental error may be appreciable in this analysis of variance because of the small manual speed sample (one) compared to approximately 20 aerial samples and because a comparison of this type is generally true only during relatively dense periods. However, this comparative analysis seems to be the most reasonable considering the method of data collection. Table 7 gives the results of the analysis of variance investigation of speed in relation to time during the peak period, method of collection, and freeway lane. The following results were obtained from the analysis of variance:

1. There is generally no significant difference between the aerial and the manual speed collection methods. However, at one bottleneck, Hawley Road, the difference was significant, which prompted a test of the difference of the means at all bottleneck locations by lane. The results of this test indicate that the shoulder lane at Hawley

TABLE 4  
SPEED COMPARISON, 29TH STREET

Time	Median				Middle				Shoulder			
	Aerial Survey		Manual Survey Speed	Difference	Aerial Survey		Manual Survey Speed	Difference	Aerial Survey		Manual Survey Speed	Difference
	Vehicles	Average Speed			Vehicles	Average Speed			Vehicles	Average Speed		
4:00	10	54.0	52.5	+1.5	11	50.7	42.5	+8.2	8	50.0	47.5	+2.5
4:10	20	47.5	52.5	-5.0	17	44.3	52.5	-8.2	17	38.1	47.5	-9.4
4:21	13	52.1	52.5	-0.4	12	47.1	42.5	+4.6	10	47.5	42.5	+5.0
4:31	13	57.5	52.5	+5.0	14	50.0	52.5	-2.5	12	45.8	42.5	+3.3
4:41	25	30.3	37.5	-7.2	25	29.3	27.5	+1.8	19	20.6	17.5	+3.1
4:50	27	29.4	32.5	-3.1	31	25.9	32.5	-6.6	28	21.4	27.5	-6.1
4:59	28	25.9	37.5	-11.6	27	25.6	22.5	+3.1	21	25.6	27.5	-1.9
5:11	22	24.3	27.5	-3.2	25	24.5	22.5	+2.0	20	20.2	17.5	+2.7
5:23	21	45.8	37.5	+8.3	16	44.1	22.5	+21.6	14	42.9	22.5	+20.4
Total	199	40.8	42.5		199	37.9	35.3		175	34.7	32.5	
Error Percent error		4.28		-15.7		7.03		+24.0		6.28		+19.6



TABLE 5  
SPEED COMPARISON, HAWLEY ROAD

Time	Median				Middle				Shoulder			
	Aerial Survey		Manual Survey Speed	Difference	Aerial Survey		Manual Survey Speed	Difference	Aerial Survey		Manual Survey Speed	Difference
	Vehi- cles	Aver- age Speed			Vehi- cles	Aver- age Speed			Vehi- cles	Aver- age Speed		
4:01	17	44.0	42.5	+1.5	15	42.8	37.5	+5.3	19	38.3	32.5	+5.8
4:11	20	51.5	47.5	+4.0	17	50.1	37.5	-12.6	10	50.0	42.5	+7.5
4:21	21	54.2	42.5	+11.7	19	51.2	42.5	+8.7	16	47.2	32.5	+14.7
4:32	19	50.1	52.5	-2.4	17	46.6	42.5	+4.1	20	44.5	37.5	+7.0
4:41	23	39.9	37.5	+2.4	23	37.7	37.5	+0.2	20	35.0	32.5	+2.5
4:51	34	29.7	27.5	+2.2	26	33.7	32.5	+1.2	24	35.0	27.5	+7.5
5:00	25	29.7	32.5	-2.8	25	27.5	32.5	-5.0	25	27.3	22.5	+4.8
5:11	36	31.3	32.5	-1.2	33	29.2	32.5	-3.3	27	35.1	27.5	+7.6
5:23	21	45.8	52.5	-6.7	16	44.1	47.5	-3.4	14	42.9	37.5	+5.4
Total	236	41.8	40.8		208	40.3	38.0		194	39.5	32.5	
Error				+8.7				+20.4				+62.8
Per- cent error		2.31				5.62				17.68		

TABLE 6  
SPEED COMPARISON, 92ND STREET

Time	Median				Middle				Shoulder			
	Aerial Survey		Manual Survey Speed	Difference	Aerial Survey		Manual Survey Speed	Difference	Aerial Survey		Manual Survey Speed	Difference
	Vehi- cles	Aver- age Speed			Vehi- cles	Aver- age Speed			Vehi- cles	Aver- age Speed		
4:01	8	55.0	47.5	+7.5	11	50.7	52.5	-1.8	12	46.7	47.5	-0.8
4:12	26	35.6	37.5	-1.9	22	34.3	37.5	-3.2	21	32.3	42.5	-10.2
4:22	10	50.0	42.5	+7.5	14	52.5	57.5	-5.0	10	46.5	47.5	-1.0
4:33	21	43.7	32.5	+11.2	11	46.6	42.5	+5.9	10	47.5	47.5	0
4:42	29	34.7	37.5	-2.8	23	36.4	37.5	-1.1	24	34.6	27.5	+7.1
4:51	16	44.7	62.5	-17.8	13	43.3	47.5	-4.2	18	40.0	42.5	-2.5
5:01	18	47.8	42.5	+5.3	18	40.6	37.5	+3.1	27	28.2	42.5	-14.3
5:12	22	41.6	42.5	-0.9	23	36.8	32.5	+4.3	24	31.0	32.5	-1.5
5:24	11	53.0	47.5	+5.5	8	50.6	52.5	-1.9	9	51.4	47.5	-3.9
Total	179	45.1	43.6		159	43.5	44.2		171	39.8	41.9	
Error				+13.6				-3.9				-19.3
Per- cent error		3.35				1.00				5.39		

TABLE 7  
ANALYSIS OF VARIANCE SUMMARY AT THE 5 PERCENT SIGNIFICANCE LEVEL

Location	Source	F (calculated)	F (0.05) (tabulated)	Results
19th Street	Time during peak period	56.47	2.59	Significant
	Aerial versus manual	4.47	4.49	Not significant
	Freeway lanes	1.34	3.63	Not significant
28th Street	Time during peak period	83.13	2.59	Significant
	Aerial versus manual	1.58	4.49	Not significant
	Freeway lanes	32.61	3.63	Significant
Hawley Road	Time during peak period	61.80	2.59	Significant
	Aerial versus manual	31.74	4.49	Significant
	Freeway lanes	26.25	3.63	Significant
92nd Street	Time during peak period	26.75	2.59	Significant
	Aerial versus manual	0.26	4.49	Not significant
	Freeway lanes	7.01	3.63	Significant

Road was the only lane of all 12 tested to have a significant difference at the 5 percent level. The reason for this difference cannot be determined.

2. Speed with respect to time during the peak period is the relationship that had the most significant results. This means that speed is most apt to change because of the change in traffic flow that occurs regularly during a time change in the peak period.

3. The fact that there is no significant difference among speeds for the three lanes of 19th Street appears to be reasonable; i.e., speed data collected in all three lanes at this bottleneck were generally about the same. Normally the speed on the freeway is distributed such that the fastest speed occurs in the median lane and the slowest occurs in the shoulder lane. At 19th Street, probably as a result of congestion caused by its proximity to the CBD and also caused by the stop-and-go driving at the gore of a high-volume entrance ramp, there was no large difference in the speed data collected by lane during the same time period.

To examine the range in the difference in speed between the aerial and manual methods of collection required that the standard error of the net difference be computed. This procedure assumes equal variances and normal distributions of the difference between the two samples. The standard error of the net difference indicates the range about the mean speed expressed as one standard deviation. One standard deviation represents approximately 68 percent of the vehicles observed traveling at some speed about the mean speed. Table 8 gives a summary that compares the speed data collected by the two methods of collection. The comparison is in terms of net difference—algebraic sum of differences between aerial speed data and manual speed data; percentage of error, which is net difference divided by total of average aerial speeds; mean speed; and one standard error and two standard errors.

Based on the data presented there is no significant difference at the 5 percent level of significance between the speed data collected manually and through aerial photography. One standard deviation of the net difference generally represents  $\pm 6$  mph around a mean speed of 39 mph. In addition, an average  $5\frac{1}{2}$  percent error represents a difference between collection methods of about 2.2 mph when an average speed of 40 mph is used. The results would indicate the general acceptability of aerial photography for the collection of speed data. That is, speed data can be collected through either manual or aerial methods.

## DATA APPLICATION

The application of aerial photography as a potential tool in traffic operations rests directly with the traffic engineer. His decision to use this collection method would

TABLE 8  
AERIAL VERSUS MANUAL SPEED DATA

Location	Lane	Net Difference (mph)	Percent Error	Mean Speed (mph)		One Standard Deviation of Net Difference (mph)	Two Standard Deviations of Net Difference (mph)
				Manual	Aerial		
19th Street	Median	-37.7	10.1	41.4	37.2	$\pm 6.6$	$\pm 13.0$
	Middle	+1.8	0.5	36.9	37.1	$\pm 6.9$	$\pm 13.5$
	Shoulder	-43.7	14.2	39.2	34.3	$\pm 5.3$	$\pm 10.5$
29th Street	Median	-15.7	4.3	42.5	40.8	$\pm 6.1$	$\pm 12.0$
	Middle	+24.0	7.0	35.3	37.9	$\pm 8.8$	$\pm 17.3$
	Shoulder	+19.6	6.3	32.5	34.7	$\pm 8.4$	$\pm 16.4$
Hawley Road	Median	+8.7	2.3	40.8	41.8	$\pm 5.2$	$\pm 10.2$
	Middle	+20.4	5.6	38.0	40.3	$\pm 5.9$	$\pm 11.6$
	Shoulder <sup>a</sup>	+62.8	17.7	32.5	39.5	$\pm 3.3$	$\pm 6.6$
92nd Street	Median	+13.6	3.3	43.6	45.1	$\pm 8.7$	$\pm 17.0$
	Middle	-3.9	1.0	44.2	43.5	$\pm 3.9$	$\pm 7.7$
	Shoulder	-19.3	5.4	41.9	39.8	$\pm 6.5$	$\pm 12.8$

<sup>a</sup>Speeds proved to be significantly different; therefore, the results are unrealistic.

TABLE 9  
COMPARISON OF DATA COLLECTION METHODS

Method	Data Collected	Advantages	Disadvantages	Cost
Manual	Freeway volumes, ramp volumes free-way spot speeds, vehicle accumulation, vehicle type	Provides continuous volume counts on main line as well as on ramps, provides continual speed observations	Requires many people (approximately 50), is difficult to coordinate, is not reliable because of large number of personnel and because of counting equipment	\$600 for 1 hour of data collection plus \$1,500 for data processing time to program, sort, and summarize data (developmental in nature)
Oblique aerial photography	Vehicle accumulations, ramp queues, shoulder use, lane density, vehicle type	Requires few people (2), requires no programming, is reliable, provides photographic record, enables density contours to be plotted quite readily	Depends on weather, requires 1-day photofinishing time, requires 4 hours to obtain vehicle counts from approximately eight flights (1 hour of flying time), requires 4 hours to obtain density contours from eight flights	\$100 for 1 hour of data collection plus \$30 to calculate and plot densities from vehicle accumulations that occur during 1 hour
Vertical aerial photography	Lane densities, vehicle speeds, headways, vehicle type, shoulder use, queues at ramps	Is reliable, is flexible in regard to the types of data collected, can provide very large samples, provides photographic record	Is expensive, requires trained personnel and special equipment, depends on weather, requires time to retrieve speed and headway data (approximately 1 month to receive printout of headways and speeds after vehicles were identified and sent to coordinator)	\$3,000 for 1 hour of speed data collection plus \$150 for acquisition of acceleration and headway data

probably be based principally on two factors, reliability and cost. The hourly costs incurred for each method are given in Table 9. A general evaluation by method follows.

1. The manual method (input-output study) requires a large number of personnel and, because of this, is inconvenient to use and becomes very expensive.
2. The oblique aerial method uses two men to gather and extract vehicle count data. The time expended in the collection and extraction of the data is less than 3 days. In addition, the photographs can be used to examine other traffic-related activities. Therefore, the oblique aerial method is very economical, about one-sixth as expensive as the input-output study, and very convenient to use, affording the flexibility of acquiring other traffic data when needed.
3. The vertical aerial method is not very economical when only vehicle speeds are collected; in fact, speed data collection is about 20 times more expensive by vertical aerial photography than by manual methods. However, vertical photography offers the greatest flexibility in traffic data collection, and, when traffic data concerning accelerations, headways, and platoon behavior are needed, this method of collection is not only convenient but also economical.

### CONCLUSION

The comparative analyses of traffic data collection methods used in this study have indicated the acceptance of aerial photography as a collection method in the following ways.

1. Oblique aerial photography can reliably collect vehicle accumulations.
2. Oblique aerial photography is a convenient, practical, and economical method of collecting traffic data.
3. Vertical aerial photography can reliably collect vehicle speed data representative of the speeds occurring on the freeway at  $\pm 30$  sec at the time the picture is taken.
4. Vertical aerial photography affords the flexibility of collecting a broad spectrum of traffic data with economic feasibility depending on the amount and types of traffic data collected.

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