Aerial Photography Applied to Traffic Studies

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INTRODUCTION

Within the next decade, more than $30 billion will be spent at the federal, state and local levels for the construction of new roadways in the United States. Additional billions will be allocated for the operation and maintenance of existing facilities. Toward what end is this huge expenditure being made? Most highway officials would agree that it is to promote the efficient flow of the nation's goods and populations. But what assurance do we have that this program will actually foster efficient transportation? A frank reply would have to be, "Very little, indeed."

Remarkably little is known about the patterns of flow of motor vehicles on the highway. Traffic data on speed, volume and headway characteristics have traditionally been gathered at a fixed location, thereby denying the investigator a complete "view" of flow patterns over an extended length of roadway. Furthermore, most studies have been concerned with but one or two traffic characteristics and, thus, fail to reveal possible inter-relationships between the many components of vehicle flow. Numerous attempts have been made in recent years to develop theories relating the various elements of traffic movement and, by means of mathematical models and computer techniques, to apply these factors to route capacity determination and to design and control criteria. These efforts, however, have been hampered by a lack of appropriate field data; i.e., data collected over "space" as opposed to the conventional "spot," or fixed location, studies.

For general data gathering techniques are presently in use. By far the most common are the various manual and automatic methods. These, however, are applicable principally to "spot" studies of speed, volume, and headways and are of limited value in the study of vehicle flow. Moving test vehicle procedures, while affording spacial data, are quite limited in the accuracy and variety of information obtainable.

Photography has often been suggested as a valuable tool in the collection of spacial traffic data. As early as 1927, the speed, volume, and headway components of vehicle flow were being studied with the aid of aerial photography (8). By 1933 Bruce Greenshields had developed a terrestrial time-lapse motion picture technique which yielded accurate speeds and headways (4). Greenshields noted in 1947 the potential uses of aerial photography in traffic research (6). In recent years, Chicago Aerial Survey has pioneered the application of stereo continuous strip photography to the study of traffic flow (11, 9).

PURPOSE AND SCOPE

It was the purpose of this research to study, in terms of applicability, accuracy, and efficiency, the time-lapse vertical aerial photography method of collecting traffic flow data. The technique was investigated relative to its ability to detect and record volume, speed, vehicle spacing, and lane use information. Consideration was also given its use in gathering density, acceleration, vehicle placement, minimum passing distance, and other pertinent flow data.

DESCRIPTION OF THE METHOD

The vertical view of all points on a horizontal plane surface yields an object image of unchanging scale provided a single height of observation above the surface is maintained. The aerial photography technique permits a recording, with certain inherent distortions, of this image on a photographic film. The scale of the photographic image is a function of the lens focal length (f) and the above ground elevation (H) of the camera (aircraft) as equated by

$$\text{Scale} = s = \frac{H(\text{feet})}{f(\text{inches})}$$

Through a partial overlapping in the fields of view of two vertical photos taken at slightly different, but known, points in time and space, the motion of ground objects, such as motor vehicles, can be measured and recorded in terms of distance per unit time. In addition, measurements of headways between moving objects and their positions relative to fixed points may be obtained directly from the aerial photographs.

Procedure—Data Gathering

The Indiana State Highway Commission, Bureau of Photogrammetric and Electronic Processes, secured and processed the aerial photography used in this research. Employing a K-17C aerial camera adapted for a high speed recycling of two seconds or better and mounted in a state-owned Piper Apache aircraft, nine inch by nine inch photography was obtained at five level and tangent highway locations in Hammond and Indianapolis, Indiana. By virtue of a 12-inch focal length lens and an 1800 foot flight elevation, a photo scale of approximately 150 feet per inch was maintained.

As estimated by the following relationship, a 72 per cent overlap was considered sufficient to assure the appearance of nearly all vehicles in at least two photographs when a time interval of three seconds between exposures was used.

$$Q = \frac{\frac{1}{2}\,ls + S'_v\,(t)}{ls}\,(100)$$

where Q = per cent overlap
l = the photograph's dimension, in inches, parallel to the flight line
s = scale of photography in feet per inch
S'_v = maximum expected vehicle speed in feet per second
t = time interval between exposures in seconds

Setting: l = 9 inches, s = 150 feet per inch,
S'_v = 100 feet per second and t = 3 seconds, a Q of 72 per cent results.

This interval-overlap combination was achieved by maintaining an aircraft ground speed of approximately 85 mph.

From four to eight tangent flight runs of one to two miles in length were made at each site during evening periods of high traffic volume in the summer and fall of 1962. By flying in a direction opposite to the major flow, the amount of data obtained per run was maximized. Four of the sites were recorded on Aerographic black and white film:

The Tri-State Expressway, a four-lane freeway in northwestern Indiana (Fig. 1).

The Indiana East-West Toll Road, a four-lane freeway in northwestern Indiana (Fig. 2).

Shadeland Avenue, a major arterial in suburban Indianapolis (Fig. 3).

Madison Avenue, a six-lane expressway in downtown Indianapolis (Fig. 4).

A fifth location, Indianapolis' Arlington Avenue, was studied using Aero-Ektachrome color film.

The date, time of day, duration of run, shutter speed, and lens

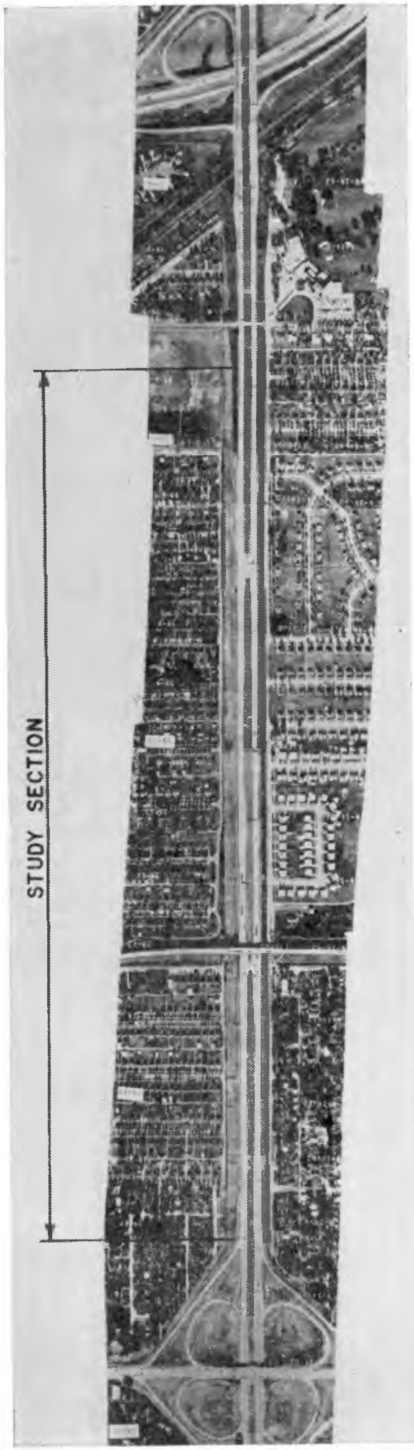

Fig. 1.

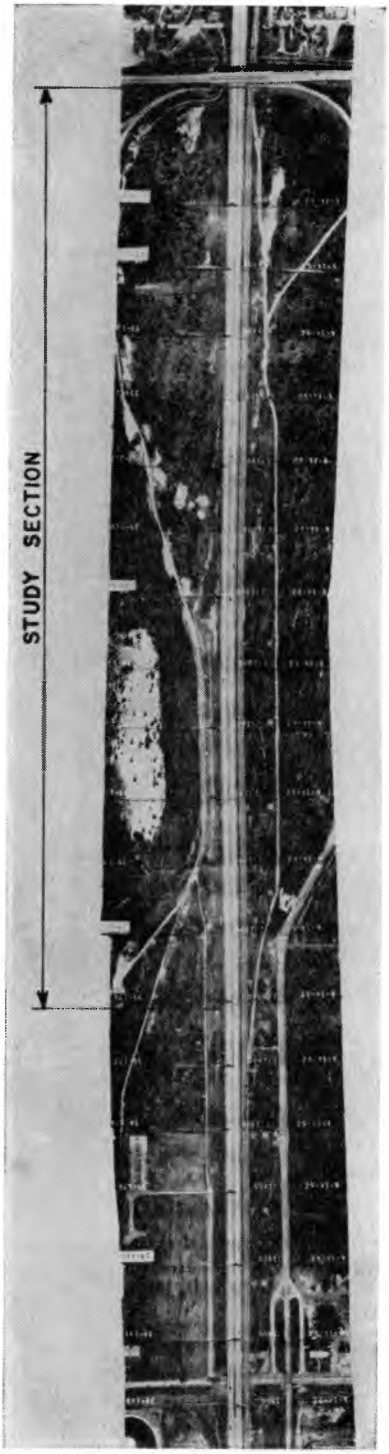

Fig. 2.

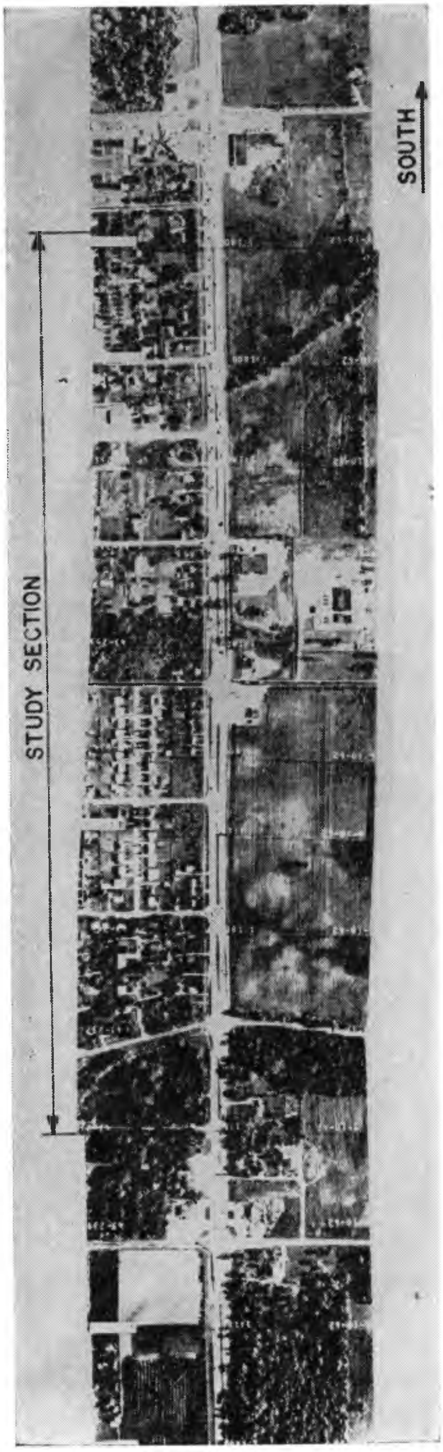

Fig. 3.

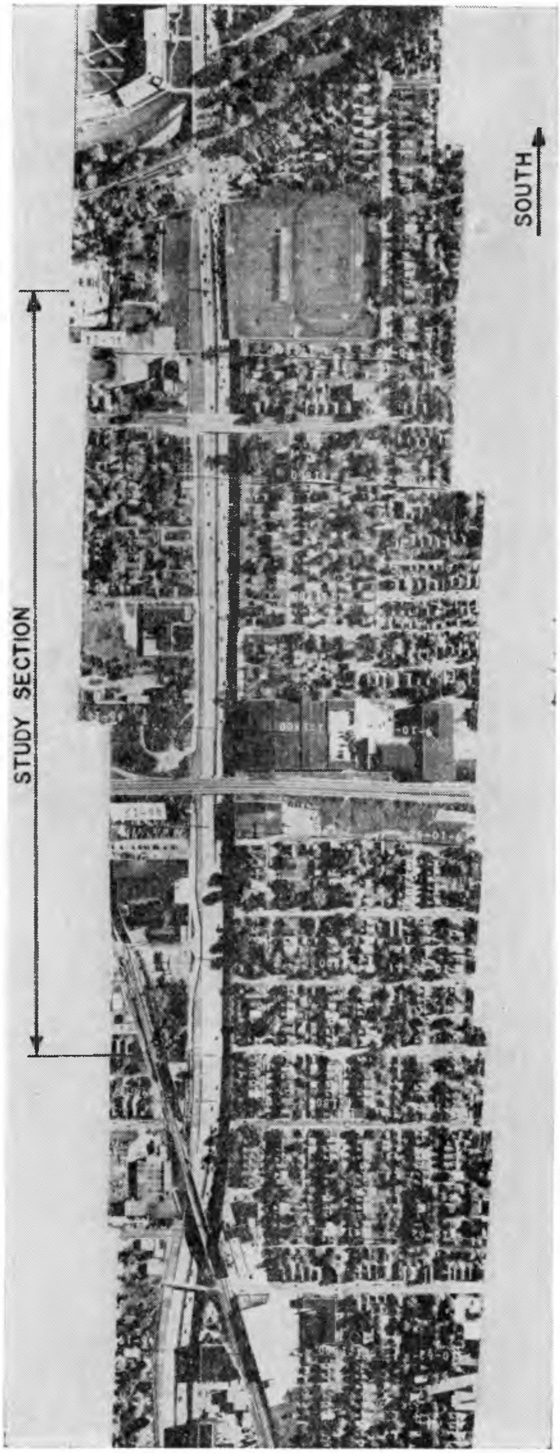

Fig. 4.

aperture were recorded for each flight pass. A two man crew of a pilot and photographer proved adequate for obtaining the desired data.

One set of double weight contact prints was made for use in data reduction and analysis. A second set of identical prints on lightweight stock was used for constructing a photo index of each study site. Fig. 5 illustrates, at a reduced scale, the standard nine inch by nine inch photographs. The color photography was developed as a roll of nine inch by nine inch positive transparencies.

Procedure—Data Reduction

Speed and distance headway quantities were obtained from the aerial photographs by simple linear measurements employing a 100 unit per inch engineers' scale. A hand or stand mounted magnifying glass was also used by some of the data processors to facilitate the precise measurements required.

The black and white photographs were first separated into sets representing individual flight passes over a specific highway location. Each exposure having been numbered at the time of processing, the segregation of prints was rapidly and accurately accomplished.

Each photo set was reduced independently. First, the scale of photography was determined from ground control afforded by the pavement expansion joints. Any significant change in scale over the length of flight was noted. Barring major variations, the mean scale value for all photos of a given site and day was used in the data analysis.

Viewing the photo pairs with a lens stereoscope permitted an approximately level section of tangent highway to be accurately defined for each site. The time duration of each flight run having been established in the field, the average time interval between successive exposures was readily computed. This quantity was then averaged over all the flight runs made at a given site and intervalometer setting.*

The vehicles of interest—those flowing freely on the through travel lanes—were identified on the photographs and numbered successively, by direction of flow, from the start of the photo run. Numbering was done directly on the prints with a lead or grease pencil.

Each vehicle appeared in at least two photographs. This permitted its speed to be obtained by measuring its progress along the roadway during the time interval between photos. A location on the highway common to both photographs served as a reference point to which the

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* The assumption that the photographs for a given intervalometer setting were equally spaced in time was verified by tests conducted on the aircraft-camera-intervalometer system under simulated flight conditions. Variations about the mean interval were found to be less than $\pm$ 0.05 seconds.

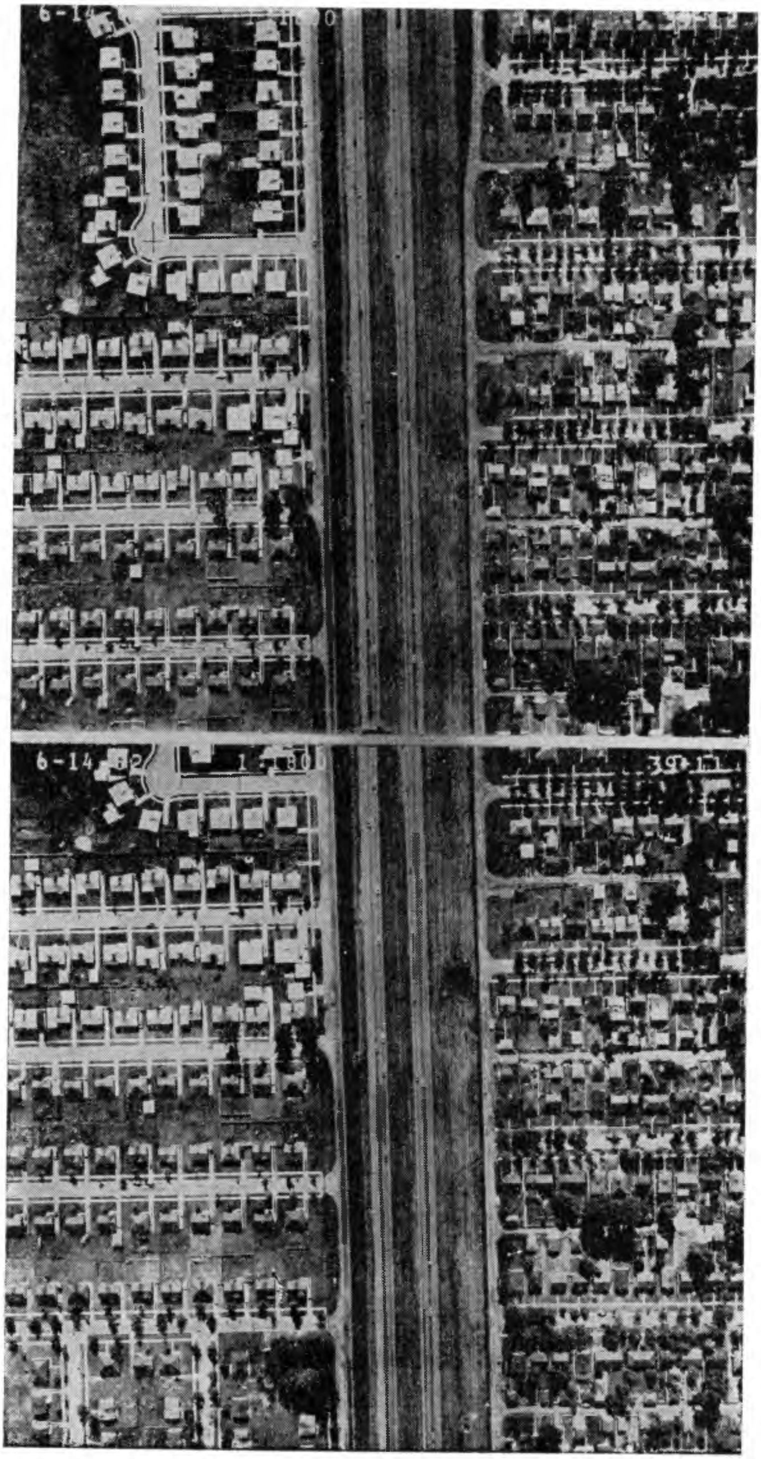


Fig. 5.

measurements could be scaled from the front bumper of the vehicle in question (see Fig. 6). The procedure yielded two values which were then added algebraically so as to give the distance traveled (D_v) in the photo interval.

"Headway" is commonly defined in traffic engineering as being the elapsed time between the passing of a fixed location on the highway of a common point (e.g. the front bumper) on two successive vehicles. The intermittent aerial photographic technique, being essentially a moving point that is recording vehicle positions as it surveys a route, cannot yield this quantity directly. Therefore, headways were initially determined from distance measurements as shown in Fig. 6. A division of the distance headway by the speed of the "following" vehicle (S_f) yielded a time headway (h_t):

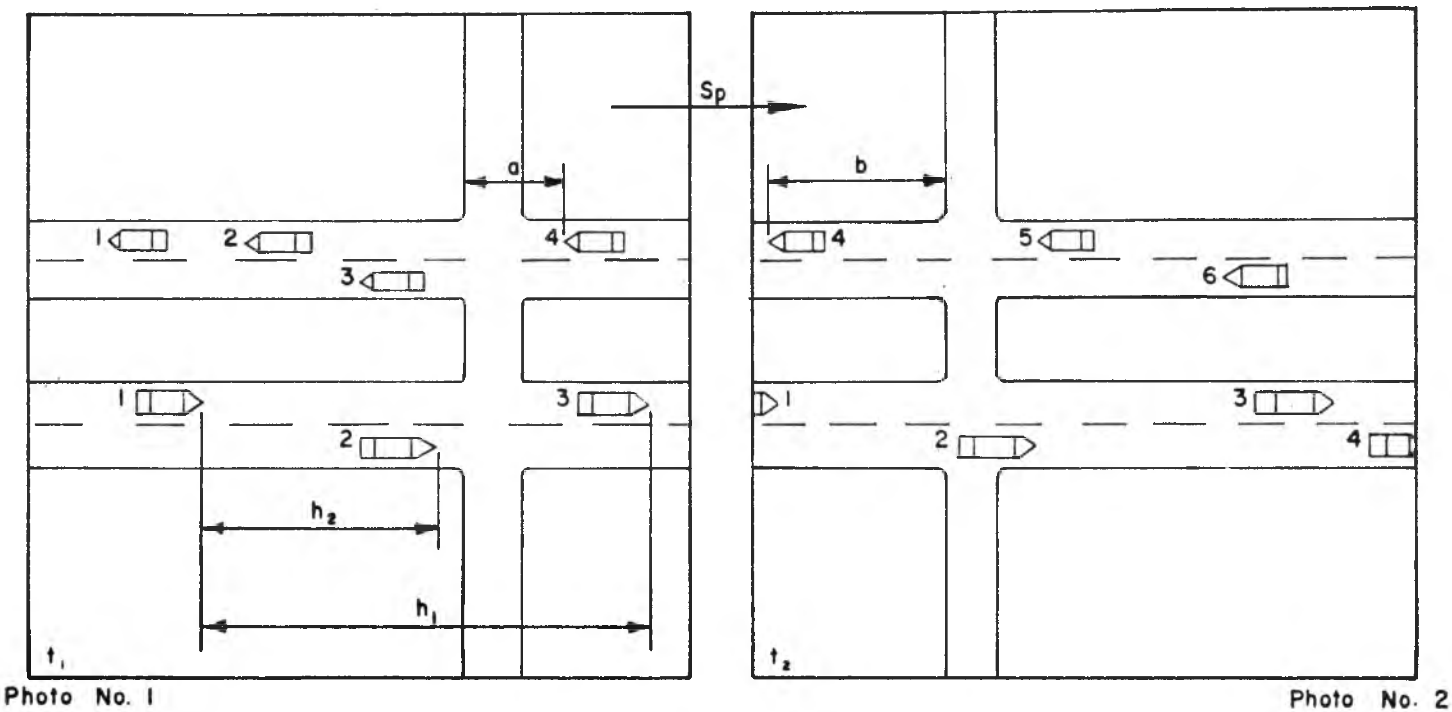
$$h_t = \frac{h}{S_f}$$

Traffic density (P) was established by simply counting the number of vehicles depicted in a photograph on either a "by lane" or "directional" basis.

Since each exposure was made at a slightly different point in time, traffic volumes could not be determined directly from a count of the vehicles pictured. However, a simple relationship between vehicle and aircraft velocities forms the basis of the "Speed Ratio" technique for estimating route volumes. This procedure considers volume as a function of average vehicle speed and route density.

Utilizing manual or automatic ground techniques, volumes are secured by recording the number of vehicles passing a fixed location during a specified period of time. However, when determining route volumes from aerial photographs, one must be cognizant of the fact that both the reference point (or aircraft) and the vehicles were in motion. Since the airborne camera did not photograph the entire section of highway, A-B, at the same instant in time, the total number of distinct vehicles depicted in a series of exposures represented not only those vehicles in the study section at the flight start, but also those which passed point B over the duration of the flight run (see Fig. 8). It was this volume at B during a time t_p which the Speed Ratio method approximated by Equation 1 when the aircraft was flying opposite the direction of traffic:

$$V_{t_p} = \frac{\overline{S_v}}{S_p + \overline{S_v}} (n_{t_p}) \text{............Eq. 1}$$

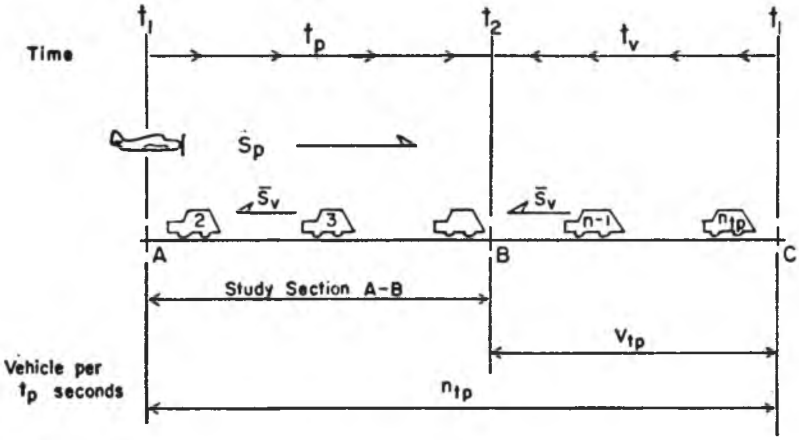


$a + b = D_V$ = distance vehicle travels in $(t_2 - t_1)$

h_1 = lane headway

h_2 = directional headway

Fig. 6. Travel distance and headway measurements from time-lapse aerial photography.



A = starting point of flight (photo principal point)

B = end point of flight (photo principal point)

BC = distance vehicles travel in time t_p

n_{t_p} = total number of distinct vehicles appearing on the airphotos between A and B (vehicles per t_p seconds)

S_p = speed of plane in feet per second

$\bar{S}_v$ = average vehicle speed in feet per second

$t_p = (t_2 - t_1)$ = time duration for flight from A to B in seconds

$t_v = (t_2 - t_1)$ = time, in seconds, required for vehicle n at point C to reach point B when traveling at $\bar{S}_v$ Defined as being equal to t_p.

V_{t_p} = vehicles passing point B in time t_p

Fig. 7. "Speed ratio" concept for traffic volumes from standard airphotos.

where V_{t_p} = volume of traffic passing a fixed point in time t_p.

$\bar{S}_v$ = average vehicle speed in miles per hour.

S_p = aircraft ground speed in miles per hour.

n_{t_p} = the number of vehicles appearing between principal points A and B.

Two assumptions were inherent in the development of equation 1. All vehicles were considered to be traveling at: (1) the calculated average speed ($\bar{S}_v$); (2) equal distance headways.

If the aircraft was moving directionally with the traffic but at a speed greater than $\bar{S}_v$, the volume of traffic passing location B in time t_p was found from the relationship:

$$V_{t_p} = \frac{\overline{S_v}}{S_p - \overline{S_v}} (n_{t_p}) \text{ ....Eq. 2}$$

It should be noted that Equation 2 is meaningless when $S_p < \overline{S_v}$.

Data reduction from the Ektachrome aerial photography was accomplished in essentially the same manner as described above. In this case, however, positive transparencies were viewed on a light table. All numbering and marking was done with a grease pencil directly on the "glossy" side of the photos.

TRAFFIC FLOW RELATIONSHIPS STUDIED WITH TIME-LAPSE AERIAL PHOTOGRAPHY

Nearly 500 aerial photographs were taken as a part of the present research. The nature of the data obtained prohibited a thorough statistical analysis of any particular traffic characteristic or highway site. However, a wealth of information revealed itself on the aerial exposures, indicating the potential of time-lapse aerial photography in the study of traffic flow.

To be of use to highway officials, the procedures must be capable of yielding basic information on traffic speeds, headways, and volumes.

Speeds

Fig. 8 depicts a cumulative frequency graph of individual vehicle speeds compiled from aerial photographs of the Tri-State Expressway.

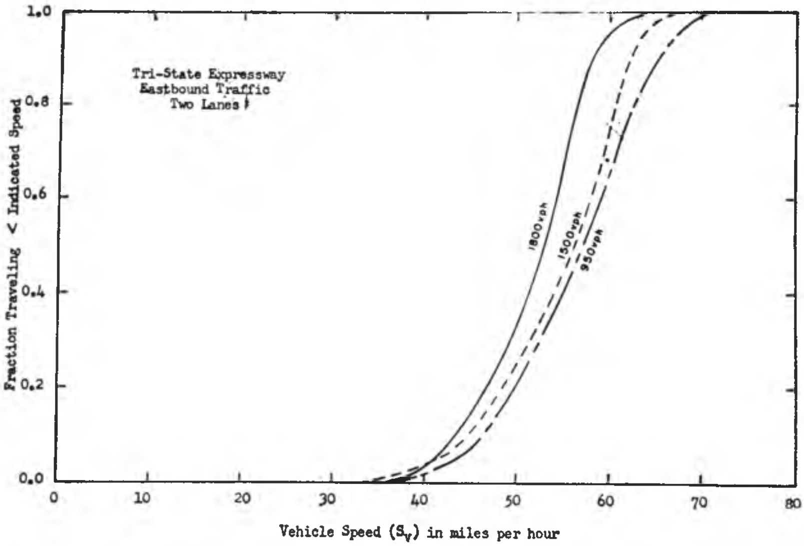


Fig. 8. Vehicle speed distribution at various directional traffic volumes on a four-lane freeway as measured on aerial photographs.

The data were gathered over a one-mile long homogeneous section of the highway so as to afford information comparable to a "spot" speed study. The vehicle speeds of Fig. 8 were plotted for several directional volumes to illustrate the tendency for velocities to decrease in magnitude and range with increasing traffic.

Many investigators have noted that average speed tends to vary as a function of the traffic volume. Mean speeds for various directional volumes of traffic on the Tri-State Expressway are shown in Fig. 9,

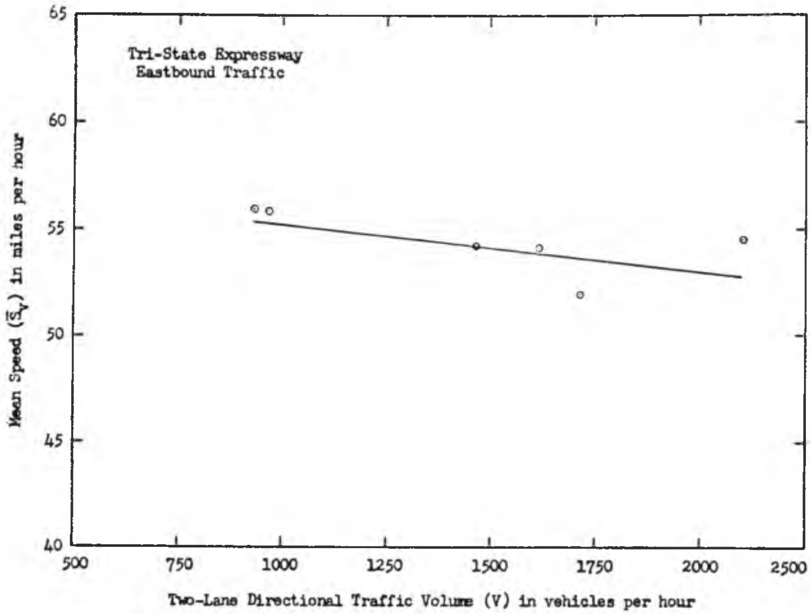


Fig. 9. Mean speed as a function of directonal traffic volume on a four-lane freeway as measured on aerial photographs.

along with a best fitting straight line constructed by the method of least squares. A slight decrease in speed with increasing volume was indicated.

Time Headways

Cumulative frequency distributions of time headways for two lanes of unidirectional traffic at three different free flowing volumes were constructed from the Tri-State Expressway photography (see Fig. 10). A comparison of these curves with the Poisson distribution seems to confirm the popular belief that vehicles are randomly distributed on the open highway. As expected, the frequency of short headways increased with mounting traffic volumes.

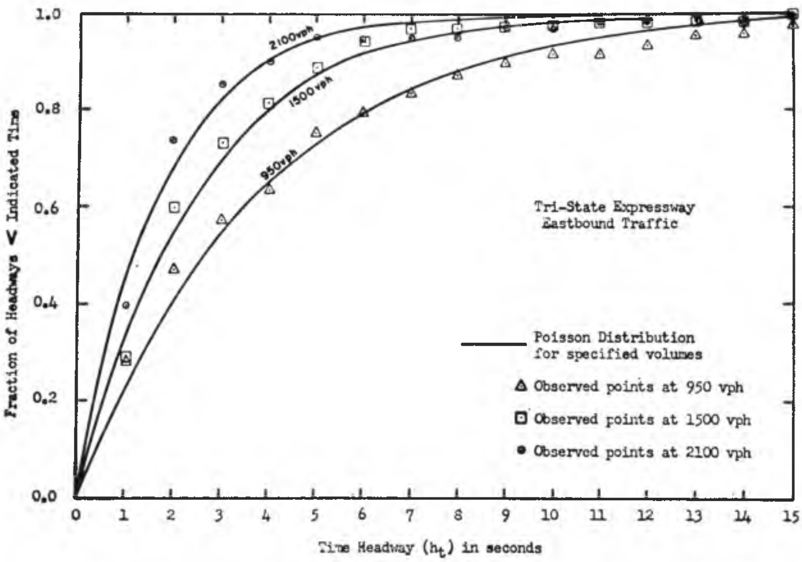


Fig. 10. Cumulative frequency distribution of vehicle time headways at various directional volumes on a four-lane freeway as measured on aerial photographs.

Lane Distributions

When studying highway capacity on multilane facilities, the investigator is often interested in lane usage characteristics. Fig. 11 relates

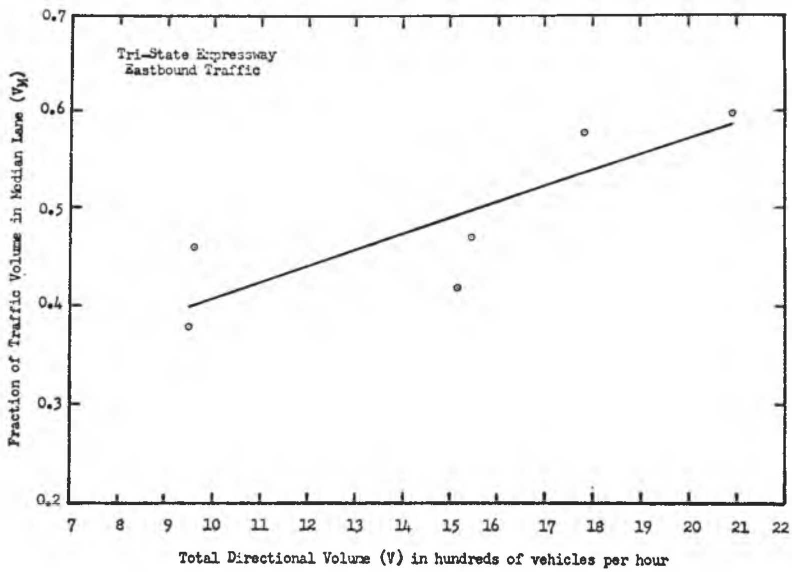


Fig. 11. Fraction of the directional traffic volume in the median lane at various volumes on a four-lane freeway as measured on aerial photographs.

the number of vehicles per hour traveling in the median, or passing, lane as a fraction of the total, two-lane directional volume.

The preceding discussion has been confined to relationships involving only the basic traffic flow quantities of speed, volume, and time headway. However, several investigators (5, 7, 10, et al.) have suggested the use of "spacial" variables as being more meaningful and accurate representations of traffic flow phenomena. Data for two of these variables—traffic density and acceleration—are readily obtained with time-lapse aerial photography.

Traffic Density

Wagner and May (10) have suggested a graphical method for pinpointing, in terms of traffic density, locations along an extended length of roadway which are particularly susceptible to congestion, and to determine, in units of time, the duration of these high density conditions. Utilizing time-lapse vertical photography, flight runs were made over the route at intervals throughout the study period. Every exposure afforded a density for each direction of traffic. These densities were plotted as functions of time and distance much as one would construct a topographic contour map. Connecting points of equal density, Fig. 12 depicts contour lines at intervals of 20 vehicles per lane mile.

For the Madison Avenue example illustrated, high densities, indicative of extreme congestion, occurred near the Pleasant Run Parkway signalized intersection. This condition was particularly severe at about 5:30 p.m. when vehicles were backed up nearly 1000 feet.

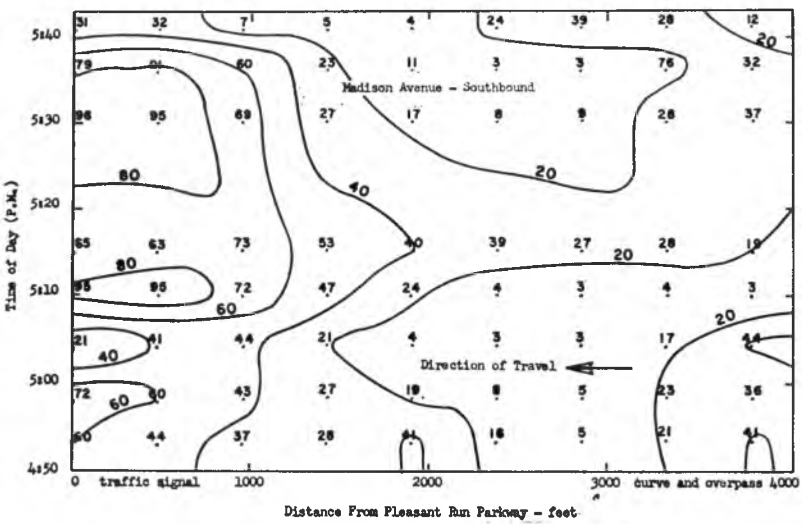


Fig. 12. Traffic density contour map prepared from aerial photographs.

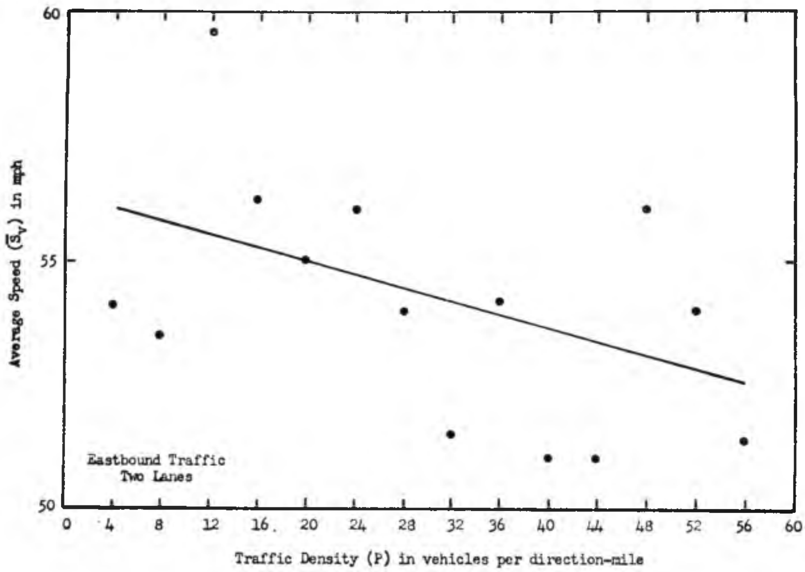


Fig. 13. Speed-density relationships on a four-lane freeway as measured on aerial photographs.

Fig. 13 presents average speed as a function of route density for eastbound movements on the Tri-State Expressway. Traffic densities were recorded on aerial photographs and converted into vehicles per direction mile (all lanes in one direction) for analysis. A slight decrease in speed was observed to accompany moderate increases in density.

Acceleration

Although traffic density is a function of both speed and route volume, it alone cannot adequately describe the nature of vehicle flow. At any given density, the facility is either approaching congestion or emerging from congestion. This dynamic component of traffic flow is probably best described by vehicle acceleration patterns. A net acceleration of vehicle speeds foretells a decrease in density, the absence of acceleration reveals an unchanging density, and a net deceleration is indicative of increasing density.

The time-lapse aerial photography technique is an ideal means for observing the acceleration patterns of individual motorists as they progress along the highway. Fig. 14 diagrammatically depicts the variations in speed for each of five vehicles traveling westbound on the Tri-State Expressway. Although in this example no vehicle was tracked for more than 2500 feet, longer traces could have been achieved by

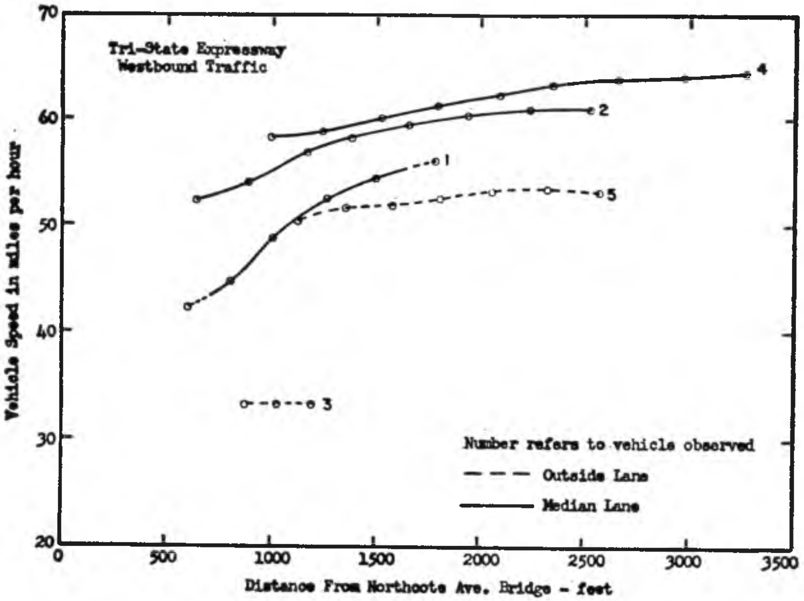


Fig. 14. Vehicle acceleration and speed patterns on a four-lane freeway as measured on aerial photographs.

minimizing the speed of the aircraft relative to the vehicle's velocity and/or by increasing the flight elevation.

Fig. 15 relates the positions of the five vehicles in point of time as well as space. Each vehicle's movement is represented by a line with the slope being a measure of speed as expressed in the equation,

$$\text{Tan}\ \Theta = \frac{\Delta\ \text{distance}}{\Delta\ \text{time}} = \text{vehicle speed}$$

Changes in slope (speed) yield vehicle acceleration:

$$\frac{\Delta\ \text{Tan}\ \Theta}{\Delta\ \text{Time}} = \frac{\dfrac{\Delta\ \text{distance}}{\Delta\ \text{time}}}{\Delta\ \text{time}} = \text{vehicle acceleration}$$

Lines crossing one another indicate that the vehicles in question were at the same longitudinal location on the highway at a concurrent moment in time. Thus, either the vehicles had collided or one was passing the other. The plot shows that vehicle number 1 accelerated from 41 mph to 56 mph in passing vehicle number 3 eight seconds after the start of the photo analysis and 1100 feet West of Northcote Avenue. The passing maneuver of vehicle number 1 involved its moving

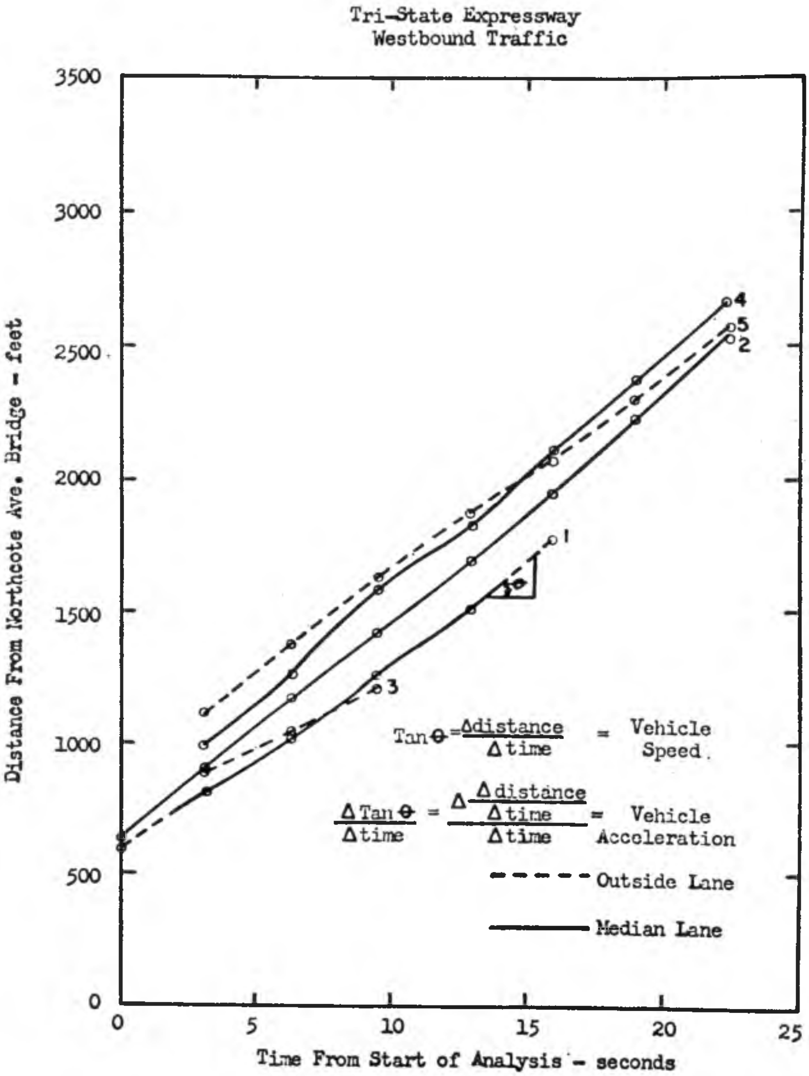


Fig. 15. Tracking the movement of individual vehicles in time and space by the use of aerial photography.

from the outside lane to the median lane and then returning. This was completed in approximately 13 seconds and in somewhat over 950 feet.

Average Speed

Traffic speeds also may be expressed in spacial terms by plotting the average speed of the vehicles appearing in each exposure as a function of the aerial photograph's location on the route. This is shown in

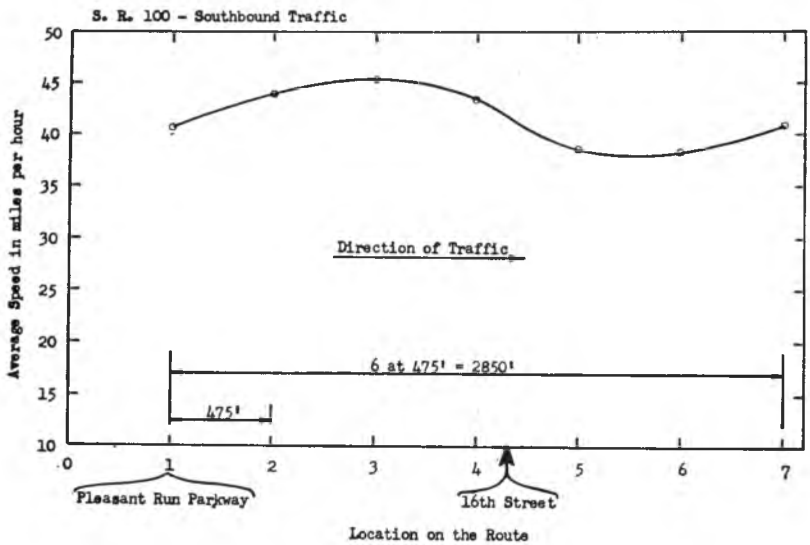


Fig. 16. Average vehicle speed for directional traffic as a function of the location on the route as measured on aerial photographs.

Fig. 16 for the Shadeland Avenue (State Route 100) site and reveals a decided increase in the average velocity of vehicles traveling south from the Pleasant Run Parkway intersection. The peak average speed occurred about 1000 feet beyond the Parkway, followed by a reduction in speed as the drivers approached and passed 16th Street.

Distance Spacing

An analysis of vehicle spacing patterns assists the investigator in describing the character of traffic density and, as such, represents an important part of any traffic flow study. Since the gap (g) between successive vehicles is a spacial quantity, aerial photography is particularly applicable to this type of survey. Fig. 17 depicts the mean minimum vehicle spacings allowed by passenger car mortorists when following vehicles at various speeds.

Lane Changing

Fig. 18 illustrates the results of a study of lane changing as a function of directional traffic volume on the Tri-State Expressway. The data were obtained from aerial photographic coverage of the site by noting the number of vehicles changing lanes as a fraction of the total vehicle count for each flight run. A regression line was statistically fitted to a few scattered points and indicated an increase in the frequency of lane changing with increasing traffic flow for the volumes shown.

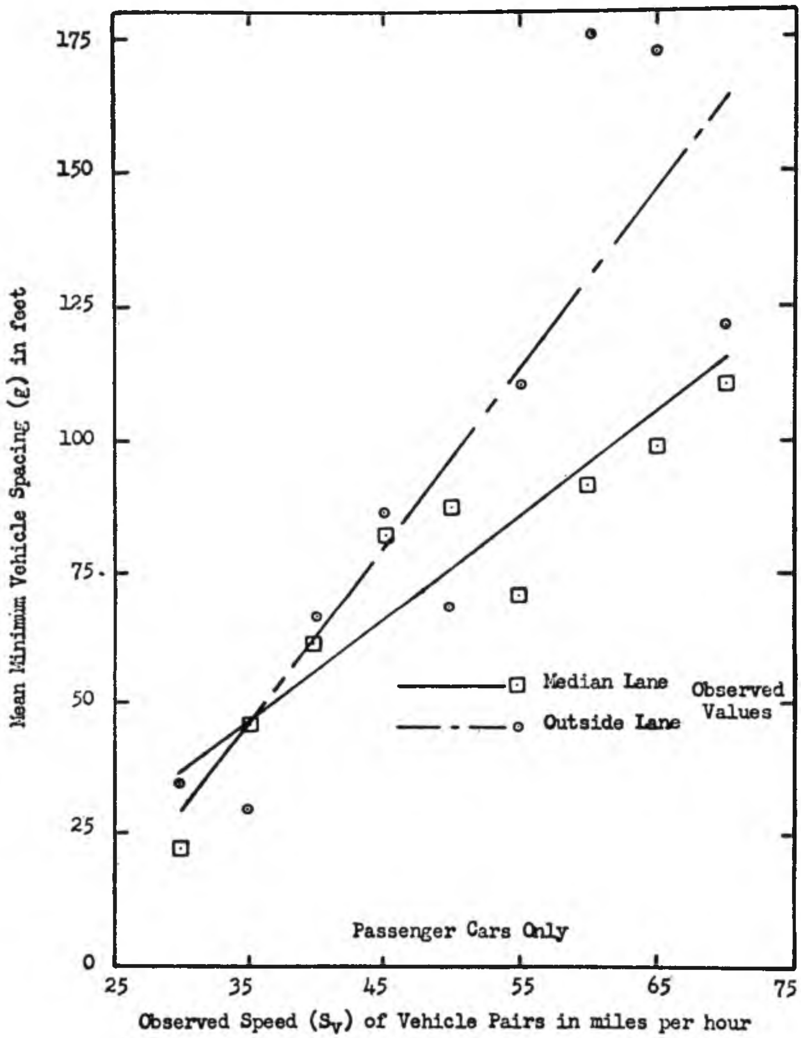


Fig. 17. Minimum spacings allowed by the average driver when trailing another vehicle at various speeds on four-lane divided highways as measured on aerial photographs.

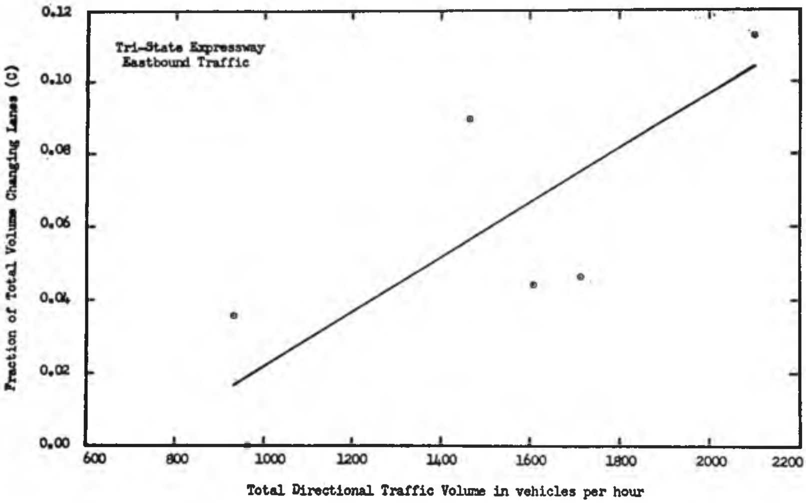


Fig. 18. Lane changing as a function of directional volume on a four-lane freeway as measured on aerial photographs.

GENERAL ANALYSIS OF THE AERIAL PHOTOGRAPHY METHOD

Data Gathering Characteristics

Data gathering, as the term is employed here, encompasses two components of any traffic surveying method: a detecting device and the recording technique. It is toward an analysis of the efficiency, accuracy, and measurement precision of the aerial photographic method that the following discussion is directed. Although the analysis deals primarily with the collection of speed, volume, and headway data, it is applicable to the study of all traffic flow characteristics recorded on the photographs.

Equipment, Supplies and Personnel

The previous discussion on methodology has indicated the equipment, supplies, and personnel employed in collecting data by the use of aerial photographs. These items are summarized, along with estimated costs, in Tables 1 and 2.

Costs may be expected to vary somewhat with the nature and scope of the study. For example, the costs per unit of data gathered would undoubtedly decrease as the survey period is lengthened.

Aerial photography can be employed to study, with a single complement of equipment and personnel, a large number of sites within close proximity of each other at essentially the same time. The method, therefore, becomes increasingly economical as the study locations become more numerous. Color photography, however, remains significantly more expensive than the standard black and white aerial photography.

TABLE 1

EQUIPMENT, SUPPLIES AND PERSONNEL USED IN GATHERING TRAFFIC DATA—BLACK AND WHITE TIME-LAPSE AERIAL PHOTOGRAPHY

Basic Equipment:

Piper Apache PA-23 aircraft
K-17C aerial camera
12″ precision lens
B-3B intervalometer (2-120 seconds)
Morse B-5 rewind type film processing unit

Major Supplies:

Eastman Kodak Super XX Aerographic 1623 black and white film (or Plux X Aerographic)
Film processing chemicals
Photographic paper

Personnel:

Aircraft pilot
Photographer
Film processor
Photo index compiler

Unit Costs:

Aircraft (with camera system and pilot)	$30.00/hour*
Photographer	$ 3.00/hour*
Film (150′ roll)	$57.75/roll*
@ 175 exposures	$ 0.33/exposure*
Film processing (labor, chemicals, etc.)	
heavyweight 9″x9″ prints	$ 0.26/print*
lightweight 9″x9″ prints	$ 0.23/print*
Compilation of index sheet (approx. 50 prints)	$ 5.00/sheet†

* Costs estimated by the Indiana State Highway Commission, Bureau of Photogrammetric and Electronic Processes, 1962.

† Does not include cost of the 9″x9″ prints making up the index.

TABLE 2

EQUIPMENT, SUPPLIES AND PERSONNEL USED IN GATHERING TRAFFIC DATA—COLOR TIME-LAPSE AERIAL PHOTOGRAPHY (TRANSPARENCIES)

Basic Equipment:

Piper Apache PA-23 aircraft
K-17C aerial camera
12" precision lens
B-3B intervalometer (2-120 seconds)
Morse B-5 rewind type film processing unit with seven 6 gallon tanks and reel

Major Supplies:

Eastman Kodak Aero-Ektachrome color film
Color film processing chemicals and supplies

Personnel:

Aircraft pilot
Photographer
Film processor

Unit Costs:

Aircraft (with camera system and pilot)	$30.00/hour*
Photographer	$ 3.00/hour*
Film (40′ roll)	$72.00/roll*
@ 45 exposures	$ 1.60/exposure
Film processing for transparencies	$46.90/roll*
@ 45 exposures	$ 1.04/exposure

* Costs estimated by the Indiana State Highway Commission, Bureau of Photogrammetric and Electronic Processes, 1962.

Precision of Recorded Data

For the procedures described in earlier sections of this report, the aerial photographic technique afforded precisions of ±0.6 feet for travel distances, ±0.3 feet for distance headways and approximately ±0.1 seconds for the photo interval. For meeting the requirements of a normal traffic study these levels of precision are considered adequate.

Accuracy of Data Gathering Methods

The aerial photographic method, when properly executed, affords the ±10 per cent accuracy required of most traffic surveys. Knowledge of the true interval between successive photographs and a precise determination of the scale of photography are fundamental to an accurate measurement of speeds, volumes, and headways from time-lapse photography. In the present study, the interval between exposures was approximately three seconds, with a maximum variance over a given flight run of ± 0.05 seconds or less than ± 2 per cent.

The scale of photography was most accurately determined by frequent reference to established ground control points. In the present studies of level highway sections, the employed scale ratio of approximately 1:1800, once precisely defined, was found to vary less than ± 5 per cent over the one to two mile flight run or across any individual photograph.

The normal pitch and roll effects associated with standard aerial photography are not considered significant sources of error in scale determinations provided the pilot is experienced in aerial mapping and has made a conscientious effort to minimize motion about these axes. It seems probable, however, that atmospheric conditions during the flight would have a profound effect on the degree of scale variations related to pitch, roll and changes in flight altitude.

Operational Problems and Limitations

During the course of the research, the operational problems and limitations associated with data gathering by aerial photography were noted. Chief among these were delays due to inclement weather, the method's restriction to daylight hours, obstructions to the aerial view, the necessity of maintaining a tangent flight path, and a fluctuating photo scale caused by changes in topography and/or flight elevation. In addition, variations in plane speed occassionally resulted in insufficient exposure overlap, the critical factor in assuring each vehicle's appearance in two successive photographs.

Data Reduction Characteristics

The reduction and tabulation of data are usually the most time consuming and costly phases of a traffic study. Thus, it is appropriate that some attention should be devoted to an analysis of the economics, precision and time efficiency of the data reduction techniques investigated. For discussion purposes, the analysis is limited to the reduction of speed, volume, and headway quantities.

Equipment and Supplies

In designing the data reduction procedures employed in this study, every effort was made to minimize the amount of special equipment and skilled labor required. Therefore, the methods described can be readily adopted by any highway organization with the hiring of an adequate clerical staff.

The use of grease pencils, drafting triangles, appropriate engineers' scales, and a magnifying glass brings the cost of reduction equipment for the black and white aerial photographic prints to about $13 per man. The necessity of a light table for viewing the transparencies increases the cost to $23 per man when obtaining data from color exposures.

Precision of Measurements

The precision of the data reduction technique associated with the photographic method was determined in light of the requirements common in traffic analysis and the capabilities of the equipment employed. For vehicle velocities of 30 miles per hour or greater, a reduction precision of at least ± 1 foot per second or ± 0.7 miles per hour was maintained for speed data obtained from 150 foot per inch photography. Likewise, a precision of ± 0.4 feet was realized for distance headways and other linear measurements. The precision of a volume count from aerial photography was a function of the time duration of the flight as well as systematic errors involved in determining vehicle and plane speeds. It is estimated that the calculated directional volumes were good to within ± 10 per cent, with the precision improving with increasing flows.

Man-Hour Requirements

A complete record was maintained of the man-hour requirements for reducing the speed, volume, and headway data from the aerial photographs. A statistical procedure (two-way classification, mixed model analysis of variance) was employed for comparing the efficiencies of the black and white versus the color aerials. Tests (F-test) were made, at a 0.05 level of significance, of the hypothesis:

$$U_A = U_B$$

where U_A = true mean rate of data reduction from black and white aerial photographs.

U_B = true mean rate of data reduction from the color aerial photographs.

Vehicle numbering, type classification, and velocity measurement rates were combined and a single "speed data" reduction rate computed in minutes per vehicle. At a 0.05 level of probability, the color and the black and white time-lapse aerial photography methods were not found to differ significantly in their efficiency of speed data reduction. The mean rates for the black and white photographs and color exposures were 2.73 and 2.74 minutes per vehicle respectively.

Testing the efficiency of the headway measuring task at a 0.05 level of significance, the black and white and the color photographs differed significantly, with the former being the more efficient. The respective reduction rates were 1.05 and 1.30 minutes per vehicle.

Variances in the rates of volume determinations were analyzed and both aerial photographic methods were found to have an average rate of data reduction of 0.53 minutes per vehicle.

Problems and Limitations

Many problems unique to the aerial photographic method were observed during the data reduction phase of the research. In addition to "losing" vehicles under bridges, the pronounced tree and building shadows of the late afternoon often complicated vehicle identification and impaired the precision of measurements from the photographs. Similarly, on routes running East-West shadows cast by the vehicles themselves rendered measurements to the darkened bumpers difficult to obtain. Shadowed vehicles were only slightly more distinct on the color transparencies than on black and white prints.

Most of the workers found a small magnifying glass helpful in identifying vehicles and measuring distances on the photos. However, several complained of eye strain and attributed it to optical distortions in the lens. Tiring of the eyes was also reported following a prolonged viewing of the color transparencies on a light table.

All of the workers admitted being distracted by the roadside culture depicted on the photos (e.g. a large outdoor swimming pool adjacent to the Tri-State Expressway), and each found the judgments required in deciding questionable cases of vehicle type or lane usage to be time consuming. The individual black and white prints were somewhat cumbersome to work with and required tedious orientation before measurements could be obtained. Considerable care was required when measuring distances on the photographs so as to avoid distortions due to parallax; the safest procedure was to measure only between points on or very near the ground.

CONCLUSION

The aerial photographic method proved capable of effectively detecting and recording the basic traffic flow elements of speed, volume, and headway.

In obtaining a wide variety of additional data, the time-lapse aerial photographic technique, when adopted to a specific survey's requirements, would appear to be particularly useful. Such physical characteristics as vehicle classification and roadway geometry and condition are readily and permanently recorded by the photographic method. Since intermittent aerial photographs afford a "view" of a vehicle's movement over both space and time, the combined physical and psychological phenomena in traffic flow may be studied in terms of traffic density; acceleration and deceleration practices; passing behavior; lateral placement; spacing habits; and merging, diverging, and weaving patterns.

Among the most important assets of the aerial photographic method is its ability to pictorially record the environment in which traffic data is obtained. This attribute enhances the value of the data by affording the investigator with possible reasons for unusual traffic behavior.

Standard aerial photography, however, cannot be efficiently employed for a "spot" study of but one or two elements of traffic flow at a few sites. Photography begins to have practical application only when it is desired to procure, concurrently, a permanent record of a variety of traffic and roadway information at a large number of locations.

The use of standard aerial photography is impeded by the necessity of having daylight, good flying weather, and an absence of major obstructions to the vertical view. In addition, the cost of collecting and reducing basic traffic data on aerial photographs is considerably greater than with conventional ground techniques in all but the most complex and extensive surveys.

Color photography yields in the greatest detail a complete view of the study route, its vehicles, and the surrounding culture. The advantages of color over black and white exposures, however, rarely justify the additional cost.

Aerial photography is not the "ultimate" in techniques for surveying vehicle traffic characteristics. In common with the more conventional methods, photography suffers from several practical limitations. Nevertheless, the technique affords the traffic engineer a valuable tool for investigating many of the most important and complex elements of traffic flow.

BIBLIOGRAPHY

1. *Manual of Photogrammetry,* American Society of Photogrammetry, Washington, D. C., 2nd Edition, 1952.
2. Committee on Highway Capacity, *Highway Capacity Manual,* U. S. Department of Commerce, Bureau of Public Roads, Washington, D. C., 1950.
3. Duncan, A. J., *Quality Control and Industrial Statistics,* Richard I. Irwin, Inc., Homewood, Illinois, 1959.
4. Greenshields, B. D., "The Photographic Method of Studying Traffic Behavior," *Proceedings,* Highway Research Board, Vol. 13, pp. 382-399, 1933.

5. Greenshields, B. D., "A Study of Traffic Capacity," *Proceedings,* Highway Research Board, Vol. 14, pp. 448-477, 1934.
6. Greenshields, B. D., "The Potential Uses of Aerial Photographs in Traffic Analysis," *Proceedings,* Vol. 27, pp. 291-297, 1947.
7. Greenshields, B. D., "The Density Factor in Traffic Flow," *Traffic Engineering,* Vol. 30, No. 6, pp. 26-28, March 1960.
8. Johnson, A. N., "Maryland Aerial Survey of Highway Traffic Between Baltimore and Washington," *Proceedings,* Highway Research Board, Vol. 8, pp. 106-115, 1928.
9. "Aerial Study of Tunnel Approach Traffic Problems," *Public Works Magazine,* Vol. 92, No. 7, pp. 97-98, July 1961.
10. Wagner, F. A. and May, A. D., Jr., "The Use of Aerial Photography in Freeway Traffic Operations Studies," Paper presented at the 42nd Annual Meeting of the Highway Research Board, January 7-11, 1963.
11. Wohl, M. and Sickle, S. M., "Continuous Strip Photography—An Approach to Traffic Studies," *Photogrammetic Engineering,* Vol. XXV, No. 3, pp. 397-403, June 1959 and Vol. XXV, No. 5, pp. 704-743, December 1959.