Traffic Flow Investigations by Photogrammetric Techniques

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This paper pertains to the development of a method designed to measure traffic movement in a manner which is appropriate for the testing and validation of most of the present theories of traffic flow. The primary objective was to develop a method for determining vehicle spacings and speeds for a platoon of vehicles at relatively short intervals of time.

The basic procedure consisted of placing a vehicle in the traffic stream and following it by a helicopter from which photographs were taken at fixed intervals of time.

The equipment and data reduction techniques are described and samples of resultant data are shown.

•THE PHENOMENA of traffic flow have been investigated from different angles and numerous models have been developed to predict the movement of vehicles on roads and streets. Two basically different areas have been covered in these studies. These areas are the microscopic investigations, made to determine the interaction between lead and trailing cars (car-following model), and the macroscopic models, which describe the principles governing the simultaneous movement of a great number of vehicles. Both fields have not been combined yet and, although the reactions of a trailing vehicle to changes in velocity of the lead car can be described fairly well by different theories, knowledge on the propagation of disturbances in a platoon of vehicles, the amplification or attenuation of such disturbances and their influence on velocity and traffic capacity is rather limited. It was felt that this is partly caused by the present methods used to measure the behavior of traffic and by the lack of a theory of traffic flow describing these phenomena explicitly. This paper is concerned with the development of a method designed to measure traffic movement in a way which is appropriate for the testing and validation of most of the present theories of traffic flow.

MEASUREMENTS OF TRAFFIC

The primary objective of developing a new method for data acquisition by aerial photography was to obtain data on the movement of vehicles as they progress along the roadway.

Figure 1 shows the trajectories of a platoon of vehicles progressing along a section of I71. Line A represents the data which can be obtained by gathering information from a fixed location at the roadway. These data comprise types of vehicles, number of vehicles per time interval, time gaps between vehicles and—by making use of suitable equipment—the velocity of vehicles when passing section A. No direct information can be obtained on traffic density. Calculating an average density of traffic from the relationship $k = q/v$, however, was found to give rather unreliable results. Line B represents the data which can be obtained from an aerial photograph which displays informa-

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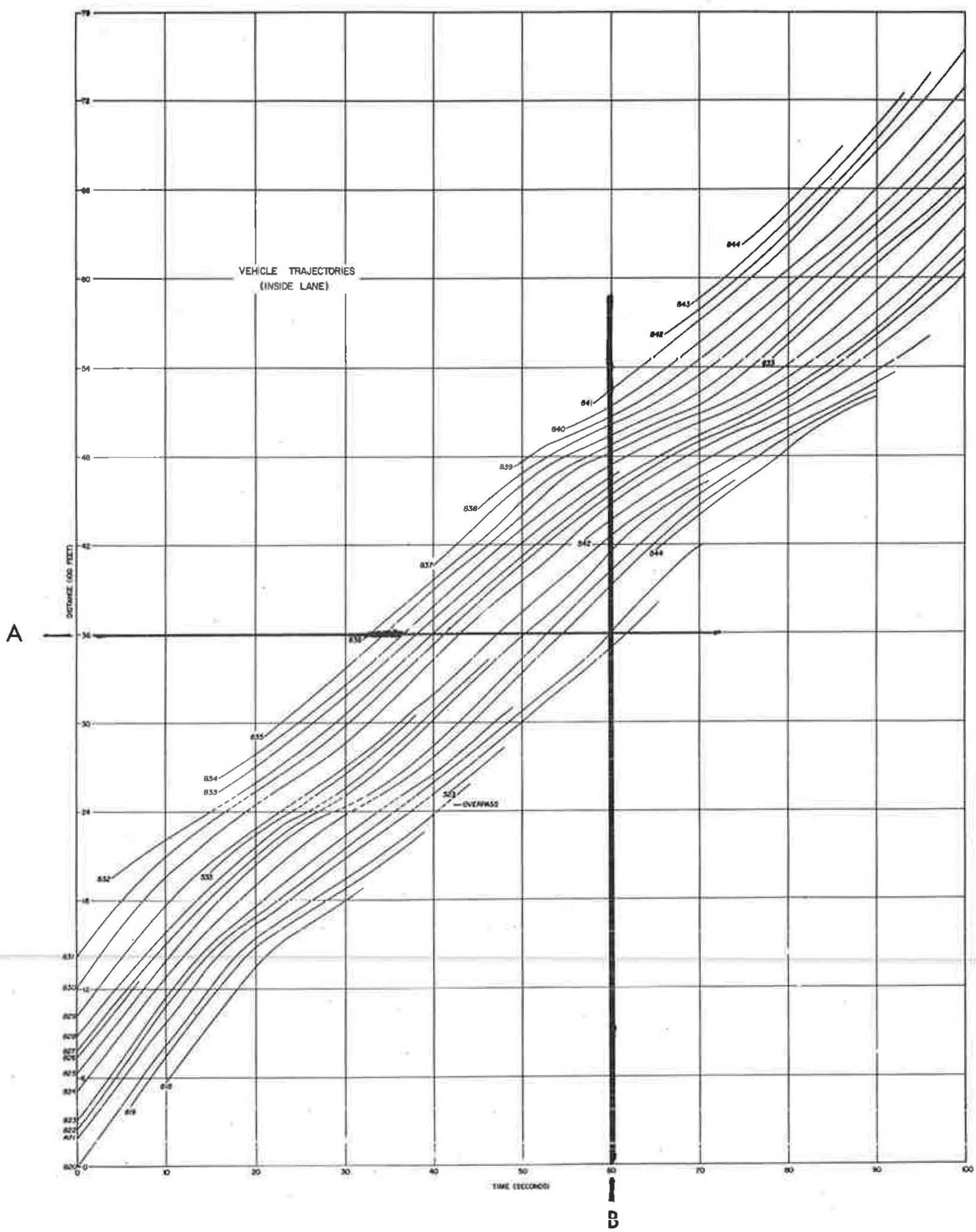

Figure 1. Traffic measurements.

tion on traffic density but no information on traffic volumes or velocity. The method chosen for aerial photography is actually a combination of the two methods described in a previous paper.

The basic procedure involves a test vehicle traveling with the traffic stream and followed by a helicopter from which photographs are taken at fixed intervals of time.

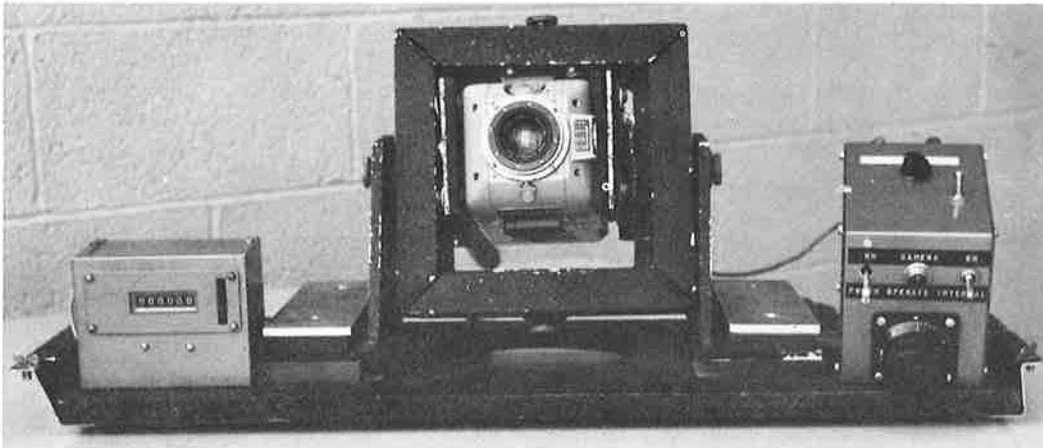

Figure 2. Frame counter, camera, mount, and intervalometer.

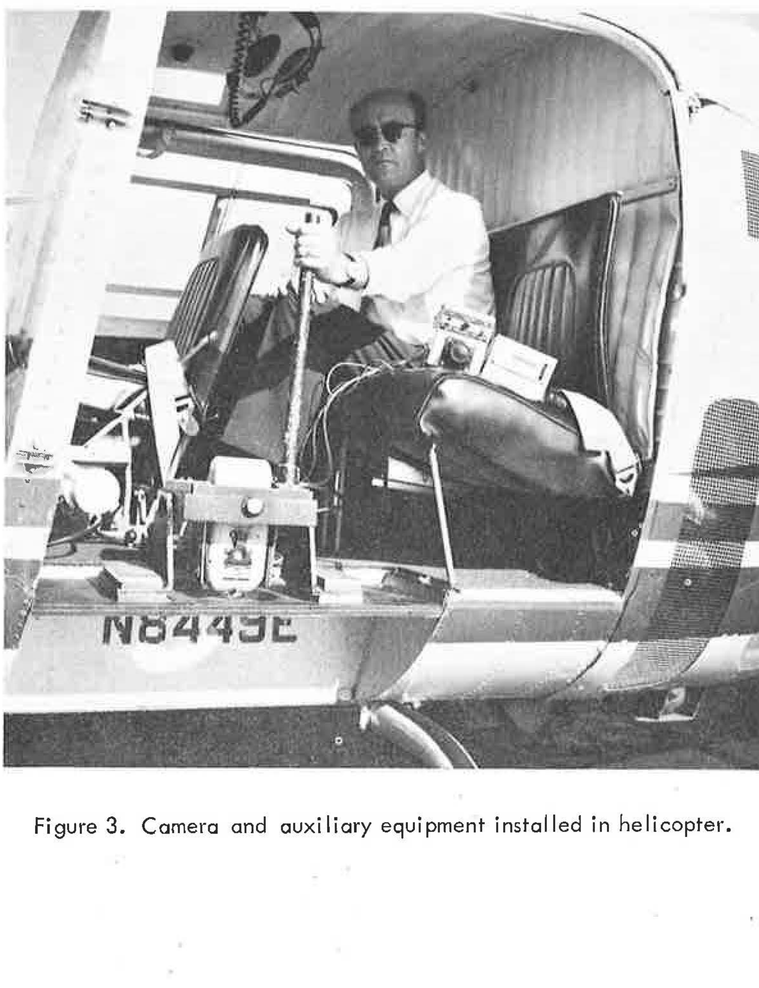

Figure 3. Camera and auxiliary equipment installed in helicopter.

The function of the test vehicle is threefold: (a) it serves as a guide for the helicopter pilot by carrying a distinctive mark or a light on its roof; (b) it serves as a generator for disturbances which can be initiated by radio contact from the helicopter to study certain traffic situations; and (c) some of the data obtained by aerial photography can be checked against data on velocity, accelerations and decelerations collected by a recorder in the test vehicle.

EQUIPMENT

Test runs carried out with a vehicle equipped with a multichannel recorder for recording velocity, accelerations and decelerations indicated the aerial photographs must be taken at intervals of one second or less in time if speed changes and the longitudinal propagations of disturbance are to be detected and if meaningful measurements are to be made. This basic condition ruled out the use of full-size format (9 × 9 in.) aerial cameras which would have been most suitable for the photogrammetric measurement of essential data.

To retain the largest possible film format for accurate measurements, a Maurer P-2 70 mm reconnaissance camera with a 76 mm f/2. 8 Kodak Ektar lens was finally chosen. It was found that frequently an aperture of f/2. 8 or larger is required for photography during the peak traffic periods before 8 a. m. and after 5 p. m. This is another restricting factor in selecting the camera.

A special mount was designed and built, and special care was taken to dampen the transfer of vibrations from the helicopter to the camera by mounting the camera and the support of the frame accepting the camera between rubber pads of different stiffnesses. The frame holding the camera consists of a universal joint so that the operator can maintain the optical axis of the camera near vertical during flights by using a control stick and a level. The camera, mount, intervalometer, and frame counter are shown in Figure 2. The mount with the camera can be placed in the Ohio Department of Highways helicopter by removing one section of the floor. The installed camera and its controls, consisting of the intervalometer with power and aperture control, the frame counter, and the control stick, are shown in Figure 3.

DATA COLLECTION

In order to obtain motor vehicle velocities with the desired accuracy, ground positions within approximately one foot were required. This consideration dictated a maximum flying height of about 3, 000 ft. Roadway coverage of approximately 2, 250 ft can be obtained with 70 mm camera at this height, with a photography scale of 1:12, 000, or 1 ft per 0. 001 in.

A total of seven 50-ft rolls of film was used to photograph traffic flow movement in the Columbus, Ohio, area. Six rolls were taken over I71 between Fifth Avenue and Morse Road during the evening when peak flow traffic conditions existed, and one roll was taken over the Olentangy Freeway just prior to an Ohio State University football game. Four rolls of film were Plus-X Panchromatic and the other three were Infrared Ektachrome. The infrared film exhibits decided advantages in sharpness and eliminates the shadow problem which is bothersome in the black-and-white photographs. Also, the color is of some help in vehicle and control point identification. An enlargement of a typical aerial photograph is shown in Figure 4.

Each of the seven rolls of film was examined and part of one roll was selected for detailed analysis. This film was selected primarily because the traffic density was initially low, then increased to the point where the vehicles nearly stopped, and then decreased again. This density-speed fluctuation occurred within a 100-sec interval of time. The photographs in this group were very sharp, but the photography flight height was somewhat lower than designed. Thus the roadway coverage per photograph was 1, 750 feet instead of 2, 250 feet.

Ground control points in the area adjacent to the freeway were selected from an inspection of the photographs. The majority of the points selected were light poles, although manhole covers, guardrail posts, and ends of curbs were used in a few instances. A total of 41 ground control points was necessary to provide eight to ten

Figure 4. Enlargement of typical aerial photograph.

points on each photograph. The average spacing between ground control points was 186 ft and the maximum was 260 ft. The ground coordinates of these points were determined from measurements made by standard ground surveying techniques.

DATA REDUCTION AND ANALYSIS

The negatives were mounted on glass plates with the emulsion out so they would be in focus when inserted in the Nistri Analytical (Stereoscopic) Plotter at the Ohio Department of Highways (Fig. 5).

The photograph x and y coordinates of each ground control point, the front-center of each vehicle, and the center of the photograph were measured with the AP/C for each of the 101 photographs used. Flight, photograph, lane, and vehicle identification numbers, as well as the photograph coordinates, were printed out by the electric typewriter of the AP/C. A sample printout page is shown in Figure 6.

The first line on the left side gives the photograph coordinates of the center of the grid on the photograph. This line is prefixed by 0000001, followed by the x-coordinate

Figure 5. Nistri Analytical (Stereoscopic) Plotter, Model AP/C.

in microns, the y-coordinate in microns, and finally the number 0030119. The coordinate system is arbitrary. The first three digits of the final number signify the flight number and the last four digits denote the photograph number.

Following this line are the ground control points, prefixed by a number with four zeros and then a three-digit number which identifies the ground control point. The other three numbers in the line represent the same items as for the center point.

The data for the vehicles in the inside lane follow the ground control points. The first number identifies the lane (first digit), vehicle being measured (second, third, and fourth digits), and the vehicle in front of the one being measured (fifth, sixth, and seventh digits). The vehicles were position-measured in order from the rear to the front in the direction of travel. A negative sign in front of the lane number indicates the vehicle was under a grade-separation structure. The last three digits of the first number are 999 when the front vehicle is being measured. The last three numbers in the line are for the same items as for the ground control points.

The numbers on the right side of the paper are the corresponding data for the vehicles in the outside lane (lane 2).

To reduce the photographic data to ground data and then compute headways and velocities of the vehicles, a computer program was written for the IBM 7094 computer.

The photograph coordinates of the vehicles in each photograph were transformed to ground coordinates using the transformation equations

$$X_G = Ax_p + By_p + C$$

$$Y_G = Ay_p - Bx_p + D$$

where X_G and Y_G are the ground coordinates, x_p and y_p are the photograph coordinates, and A, B, C, and D are transformation coefficients to be determined. The data from each photograph contain the photograph coordinates of from eight to ten ground control points. The transformation coefficients were calculated for each interval between successive ground control points by substituting the photograph and ground coordinates of the two ground control points in the transformation equations and solving

0000001	-0080027	-0075730	0030119
0000210	-0107794	-0078342	0030119
0000211	-0102246	-0077310	0030119
0000212	-0096792	-0076496	0030119
0000213	-0091288	-0075864	0030119
0000214	-0086974	-0075570	0030119
0000215	-0079846	-0075288	0030119
0000216	-0074304	-0075232	0030119
0000217	-0068156	-0075474	0030119
0000218	-0062074	-0075850	0030119
0000219	-0056726	-0075748	0030119
1818819	-0105237	-0079151	0030119
1819820	-0102799	-0078665	0030119
1820821	-0100525	-0078245	0030119
1821822	-0096447	-0077629	0030119
1822823	-0094073	-0077313	0030119
1823824	-0091051	-0076941	0030119
1824825	-0086321	-0076565	0030119
1825827	-0084289	-0076447	0030119
-1827828	-0082707	-0076277	0030119
1828533	-0080701	-0076277	0030119
1533829	-0077641	-0076313	0030119
1829830	-0075917	-0076293	0030119
1830831	-0070791	-0076411	0030119
1831832	-0066921	-0076655	0030119
1832833	-0064317	-0076833	0030119
1833834	-0060417	-0077071	0030119
1834835	-0058061	-0077161	0030119
1835999	-0054411	-0077431	0030119

2517518	-0104863	-0078648	0030119
2518519	-0102377	-0078192	0030119
2519520	-0099913	-0077734	0030119
2520539	-0098253	-0077428	0030119
2539521	-0096481	-0077072	0030119
2521522	-0095423	-0077120	0030119
2522523	-0094191	-0076884	0030119
2523524	-0092799	-0076712	0030119
2524536	-0090991	-0076526	0030119
2536525	-0089567	-0076342	0030119
2525826	-0088451	-0076274	0030119
2826534	-0086545	-0076178	0030119
2534526	-0084747	-0075964	0030119
-2526532	-0083471	-0075958	0030119
-2532527	-0081729	-0075898	0030119
2527528	-0080373	-0075896	0030119
2528529	-0078493	-0075818	0030119
2529531	-0075281	-0075832	0030119
2531530	-0069901	-0076000	0030119
2530535	-0068849	-0076114	0030119
2535537	-0067009	-0076164	0030119
2537538	-0063411	-0076460	0030119
2538540	-0060583	-0076624	0030119
2540541	-0056669	-0076828	0030119
2541999	-0053935	-0077020	0030119

Figure 6. Photograph coordinate data.

the resulting simultaneous equations. The first ground control point in the direction of travel of the vehicles was assigned the coordinates (1,000.00 and 1,000.00) for X and Y so negative ground coordinates for the vehicles would not occur. The x-axis was nearly parallel to the highway for each photograph. The ground control point interval in which the x photograph coordinate of each vehicle fell was found and the appropriate coefficients were used in the transformation equations to determine the ground coordinates of the vehicle. If the vehicle preceded the first ground control point or followed the last one shown on a photograph, the coefficients of the first or the last ground point interval were used, respectively.

L A N E 2

VEHICLE	FOLLOWING	GROUND X	GROUND Y	DISTANCE(FT)	HEADWAY(FT)	VELOCITY(MPH)
517	518	2763.40	1202.14	1770.25	77.86	32.52
518	519	2841.22	1198.70	1848.11	76.71	29.58
519	520	2917.98	1195.80	1924.83	51.68	23.20
520	539	2969.44	1193.65	1976.51	55.41	17.73
539	521	3024.63	1192.23	2031.92	31.28	15.88
521	522	3055.79	1183.58	2063.20	38.43	16.75
522	523	3094.07	1182.19	2101.62	42.77	16.47
523	524	3136.68	1177.80	2144.39	55.56	16.96
524	536	3191.79	1170.93	2199.95	44.18	18.04
536	525	3235.55	1166.70	2244.13	34.10	18.46
525	826	3269.33	1161.12	2278.23	58.11	17.75
826	534	3326.90	1151.04	2336.34	55.74	19.57
534	526	3381.91	1145.26	2392.08	******	19.13
526	532	*******	*******	*******	******	*****
532	527	*******	*******	*******	******	*****
527	528	3512.67	1117.73	2525.47	57.67	*****
528	529	3569.21	1107.21	2583.14	98.14	23.07
529	531	3664.91	1084.80	2681.28	163.72	24.69
531	530	3823.30	1043.63	2845.00	31.39	27.35
530	535	3853.66	1033.18	2876.39	55.89	25.57
535	537	3907.58	1019.41	2932.28	108.22	24.40
537	538	4011.45	986.45	3040.50	85.74	26.72
538	540	4093.74	963.02	3126.25	118.51	29.77
540	541	4207.49	931.86	3244.76	82.45	29.69
541	999	4286.62	908.54	3327.21	******	31.03

Figure 7. Traffic flow data.

To compute the headways and velocities of the vehicles, an origin was selected on the highway from which the accumulative distance traveled by each vehicle in each photograph could be computed. Using such a distance, the headway between two vehicles could be obtained simply by subtracting the accumulative distance of the following vehicle from that of the lead vehicle. The velocity of a vehicle was calculated by subtracting its accumulative distance obtained from one photograph from its accumulative distance obtained from the next photograph and dividing by the time interval between photographs.

To compensate for the curvature of the highway, straight-line segments were defined by selecting certain vehicles as distance or D-control points. In the curved section of the highway these D-points were selected close enough together so the distance along the chord between two D-points provided a close approximation to actual roadway distance along the curve. To calculate the accumulative distance traveled by a vehicle,

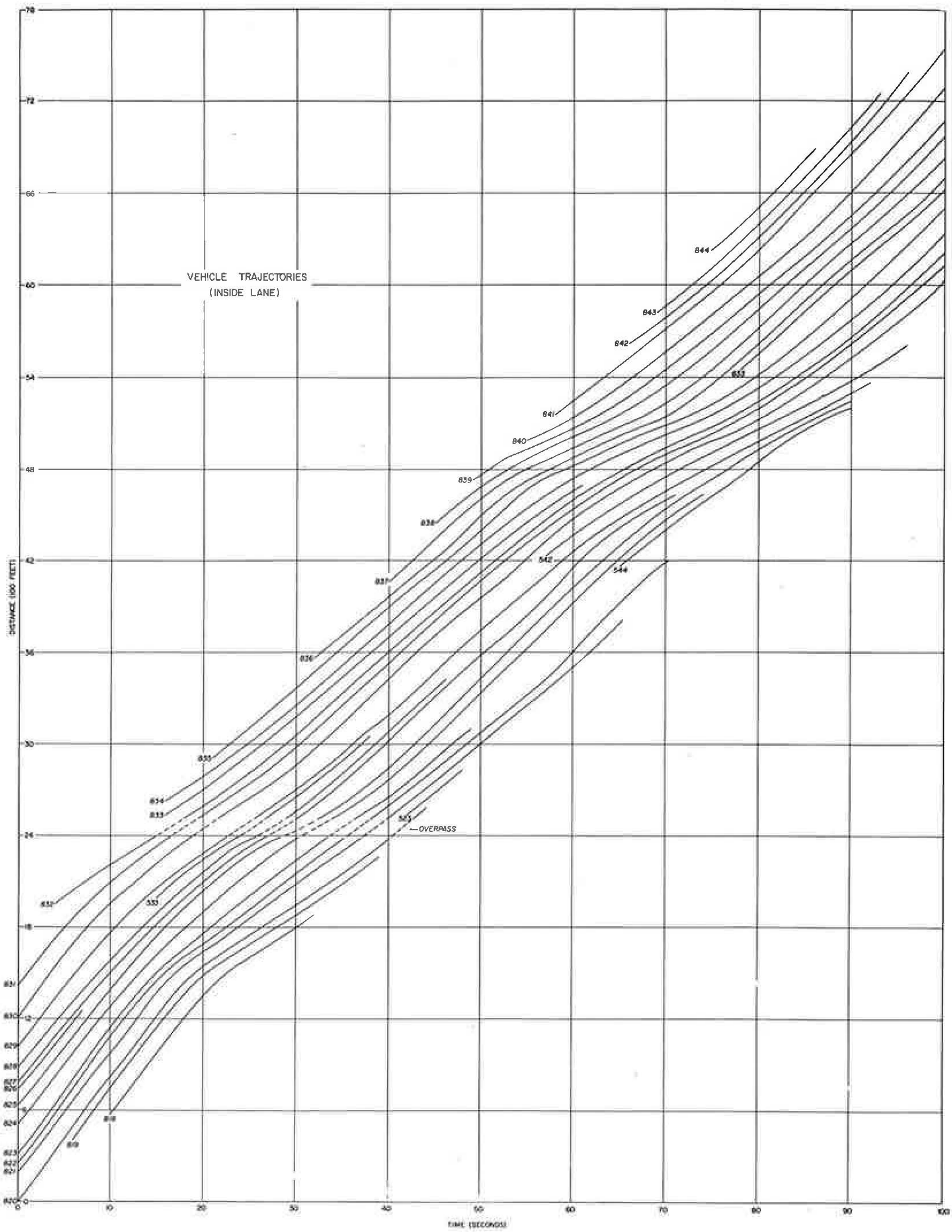

Figure 8. Vehicle trajectories (inside lane).

it was necessary to sum the distances between the D-points the vehicle has passed and add to this the distance to the vehicle from the last D-point passed. The distance between two D-points was calculated using the equation

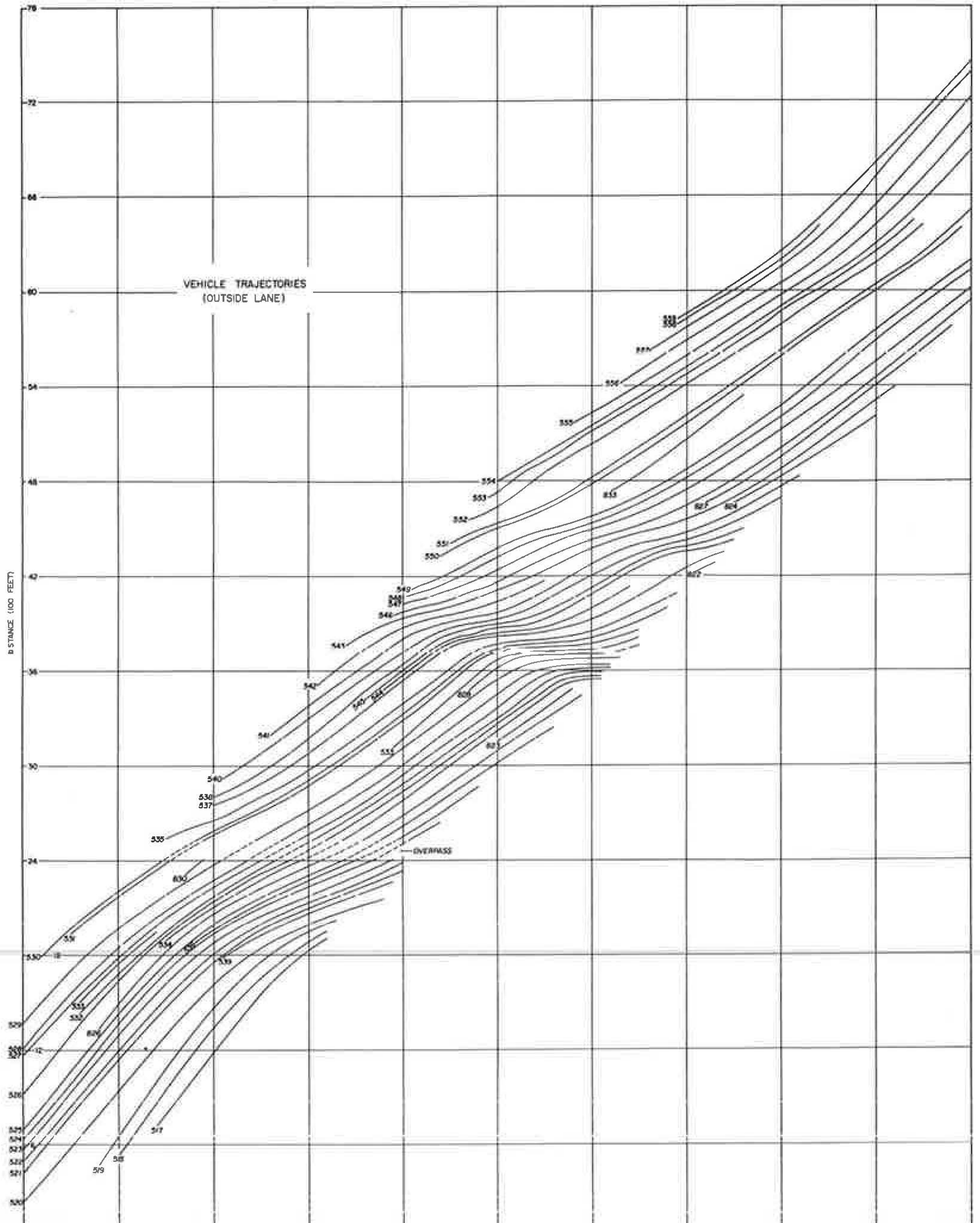

Figure 9. Vehicle trajectories (outside lane).

$$D = \left[(X_{i+1} - X_i)^2 + (Y_{i+1} - Y_i)^2 \right]^{1/2}$$

where X and Y are the ground coordinates of the D-points. To determine the distance a vehicle had traveled past a D-point, it was necessary to transform the X coordinate to distance traveled on the roadway using the transformation equation

$$D = AX + B$$

The coefficients A and B were determined by substituting the two appropriate X coordinates and D values and solving the resulting simultaneous equations.

The results thus obtained are shown on the sample output page, Figure 7. For vehicle 541, the asterisks in the headway column indicate it was the lead vehicle on that photograph and no headway calculation was possible. For vehicle 534 there is no headway calculated since it was following vehicle 526. For vehicle 527 there was no velocity calculation since it was under the overpass on the previous photograph.

Time-distance diagrams for each lane were constructed from the computer output data. These diagrams are shown as Figures 8 and 9. For each photograph, the accumulative distance to each vehicle was plotted in a vertical line at the corresponding time. The vehicle trajectories were drawn by connecting the consecutive accumulative distance points for each vehicle. The velocity of the vehicle at any time is equal to the slope of the trajectory at the corresponding time.

RESULTS

Accurate vehicle trajectories were obtained in this investigation by photogrammetric techniques. These trajectories cover a time period of 100 sec and a total distance along the roadway of 7,350 ft—approximately 1 ½ mi. An average of 40 vehicles appeared on each photograph, but only a few appear on all 101 photographs.

The average velocity over the past one second and the distance to the vehicle ahead was obtained for nearly every vehicle on each photograph; i.e., values of these parameters were obtained at time intervals of one second. Data could not be obtained in certain cases, such as spacing for the lead vehicle, velocity for a vehicle which did not appear on consecutive photographs, and data for vehicles under a grade-separation structure.

An error analysis (not included in this paper) indicates that the standard error in the velocity determinations is no more than 1.0 mph, and the standard error of the spacing determination is no more than 1.0 ft.

CONCLUSIONS

The objectives of the investigation were met. Accurate vehicle trajectories, and corresponding spacing and velocity data were obtained. The investigation provides a type of data not heretofore available to the traffic engineer—accurate flow data continuous in time and space. The aerial survey methodology necessary to obtain these data has been formulated and tested.

The major bottleneck was, and still is, data extraction from the photographs. This factor alone will determine the economic feasibility of the technique. Equipment costs and computer programming, which was time-consuming, were the expensive parts of this investigation, but this was due in large part to their developmental nature. The same equipment and programs could be used for further data determination with little additional expense.

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