Use of Aerial Photography in Freeway Traffic Operations Studies

F. A. WAGNER, JR., and ADOLF D. MAY, JR.*, Thompson Ramo Wooldridge

For years, traffic engineers have recognized aerial photography as a potential tool to be used in solving traffic operations problems. In studying a specific problem location, however, this tool was often passed over as being too expensive, and yielding data which required difficult and time-consuming analysis; data could be collected by more conventional traffic engineering procedures.

The recent recognition and increasing use of a systems approach, as opposed to the isolated problem approach, has caused the traffic engineer to review study procedures to find the ones most appropriate for use with this new philosophy. Problems on urban freeways have had much to do with this development. Often the traffic engineer would expend much time, energy, and money to solve a problem at a particular point where congestion was regularly observed, only to find out later that the real source of the problem was some distance away. Advanced technology in the coordination of large traffic signal networks also has prompted greater attention to system considerations.

An experimental study of obtaining time-lapse photographs from the air was undertaken in Los Angeles to determine the feasibility and application of such techniques for studying traffic operation along a considerable length of freeway. In general, the experiments proved highly successful, since it was determined that a certain type of freeway study can be made which yields important results, and which utilizes the advantageous features of aerial photography and minimizes the time in which an analysis can be made. This paper describes the procedures used in making aerial photographic density studies and presents sample photographs and sample analytical results. A new method of presenting freeway operations data, the density contour map, is described and illustrated, and the use of the map in determining origin, duration, and extent of congestion is discussed.

•ONE AREA of traffic engineering in which significant application of aerial photography has been made is the study of freeway traffic operations. Freeways, much maligned as they are, form the backbone of urban transportation systems. They serve tremendous volumes of persons and goods at speeds once possible only in intercity travel, at levels of safety many times that on surface streets, and with personal convenience and flexibility not known in other modes of mass movement. The knowledge that serious freeway operational malfunctions do exist, however, is by no means the exclusive property of the traffic engineer, as any city dweller is quick to point out. It is

Paper sponsored by Committee on Photogrammetry and Aerial Surveys.
*Now associated with the Illinois Division of Highways as Director of the Expressway Surveillance Project.

generally believed ways and means can be developed to minimize both the frequency and the detrimental effects of freeway malfunctions. Much concentrated engineering effort is currently under way with the objective of optimizing freeway traffic operation.

In dealing with the problem, the engineer must first gain a comprehensive understanding of the nature of freeway operations by collecting, analyzing, and interpreting factual traffic data. Study techniques commonly applied to other types of traffic facilities often do not meet the freeway information requirements, and their inflexible application in this changed environment can lead to faulty interpretation of the problem. This paper discusses the application of aerial photography, a well known but (in the past) not a commonly used traffic study tool, which has added to the understanding of freeway operations.

The use of aerial surveys in traffic studies was reported by Johnson (1) in 1927, well before the traffic engineering profession was formally organized. Greenshields (2) was an early proponent of photography in general, and in 1947 (3) he reported experiments in which aerial photographs were taken from a blimp and a helicopter. Several types of cameras were used successfully, and interesting discussion was set forth regarding the analysis of traffic data contained on the photographic records. In 1952, Forbes and Reiss (4) discussed the application of 35-mm time-lapse photographs for the study of driver behavior. A recent interest of Forbes has been the development of a technique for taking photographs from a low-speed light aircraft in order to study vehicle interaction within platoons. In an award winning paper (5), Wohl suggested the use of Sonne stereo continuous-strip photography for traffic studies. He indicated that both volume and speed data could be collected simultaneously over a large area during a short period of time, but pointed out the need for elimination of tedious manual reduction of photographic records.

Difficulty of film analysis, probably more than any other single factor, was responsible for the limitations in use of aerial photography by traffic engineers. One reason for the difficulty was that the type of data extracted from the films was often directed along the same lines followed in analyzing data from other sources. Traffic performance parameters such as volume, speed, and headway can be measured from the air, but alternate techniques are available to do the job more quickly and economically. Another factor was that traffic engineers in the past were often able to concentrate their studies at rather well-defined, isolated problem locations. For such study requirements, aerial photography cannot be justified. On the other hand, when field study manpower is limited, or when the objectives of study are research oriented, photographs provide a permanent record of traffic conditions on which a variety of analyses can be performed without returning to the field. Consequently, the bulk of the photographic work done in the past has been oriented toward research rather than to operations.

FREEWAY AERIAL PHOTOGRAPHY STUDY

During 1961, a freeway operations study was conducted in Los Angeles for the California Division of Highways. One phase of this work was an experimental study of obtaining time-lapse photographs from the air to determine the feasibility of such techniques for studying traffic movement along a considerable length of freeway. In general, the experiments proved highly successful, since it was determined that a certain type of freeway study can be made which yields practical results, and which utilizes the advantageous features of aerial photography without the drawback of time-consuming analysis. The traffic parameter measured was density.

Density

Several earlier studies (6, 7, 8) have indicated that traffic density, in vehicles per lane-mile, is an excellent single measurement of the level of freeway operation. Difficulty has arisen regarding this measurement, however, primarily because it has a distance base and traffic measurements are usually made at a fixed point. In early work independent ascertainment of the number of motor vehicles and their speed were made at a fixed point and density was computed:

$$\text{Density} = \frac{\text{No. of vehicles}}{\text{Speed}}$$

in which

Density = vehicles per mile;
No. of vehicles = vehicles per hour** (often called traffic volume or traffic density); and
Speed = miles per hour.

Electronic equipment is now available for measuring both traffic volume and speed with a single sensing unit and performing the computation of density on line with an analog device.

A second method for determining density is ground photography. Here, time-lapse photographs are taken from a freeway overpass and density determined by counting the number of vehicles contained within a relatively short roadway length of several hundred feet. Because of the short distance base used, individual density measurements have a high degree of variability; hence, several frames must be analyzed and data combined to stabilize the results. The use of either of these methods is restricted, for if a whole freeway is the object of study, many stations must be established and a substantial outlay of equipment and manpower is required. Comprehensive research efforts of a long-range nature, where the ultimate objective is a positive regulation of freeway traffic to optimize performance and thereby protect the capital investment, can justify expenditures of this nature.

There remains the need, however, for an economical method for measuring level of operation on a whole freeway, locating approximate sources of recurring congestion, and determining the extent of congestion in both time and distance. An aerial photographic density study is one method which meets these requirements.

Study Procedure

The general procedure used in taking aerial photographs for the purpose of measuring freeway traffic density involved flying an aircraft repeatedly through a corridor directly above the freeway section under study, and taking time-lapse photographs in such a manner that complete photographic film coverage of the freeway was obtained during each pass of the aircraft and aerial cameras over the section of freeway.

Cameras. — Three types of cameras equipped to operate in a time-lapse mode were used, providing photographs at sizes of 16 mm, 70 mm, and 5 × 5 in. Although all three cameras yielded successful results, the K-24 camera (with format size of 5 × 5 in.) was found to be preferable for this type of work, primarily because data could be extracted from the film negatives without the use of a special projector. In addition, the K-24 camera, built for and used extensively by the military for taking aerial reconnaissance survey photography in earlier days, is a commonly available and inexpensive surplus item. It is rugged, relatively dependable, and appears to have wide application in traffic movement surveys.

Aircraft. — Two types of aircraft were flown during the experimental study, a Bell Model G-2 helicopter and a Cessna 170 fixed-wing light aircraft. The fixed-wing aircraft was selected for extensive use because of its greater speed and stability in flight. It was considered more important to cover a longer segment of freeway, duplicating measurements at 5- to 10-min intervals, which can be accomplished best with a fixed-wing aircraft, than to obtain more frequent measurements over a shorter segment, which a helicopter could handle more efficiently.

Flight and Camera Operation Plans. — The approximate mathematical relationships between the variables of film size, focal length of camera lens, frame rate, ground

---

**This method of computing density usually employed one-minute sampling periods, with the traffic count during the minute converted to an hourly rate.

coverage, aircraft speed and altitude, as subsequently presented, are employed to formulate the desired flight and camera operation plans.

$$\text{Film scale} \cong \frac{\text{flight height (ft)}}{\text{focal length (in.)}} = \text{feet per inch} = s'$$

$$\text{Coverage} \cong \frac{\text{flight height}}{\text{focal length}} \times \text{photograph dimensions}$$

$$\cong \text{scale in feet per inch} \times \text{photograph dimensions, in inches}$$

$$\underset{\text{(50\% overlap)}}{\text{Frame rate}} \cong \frac{\text{flight height}}{\text{focal length}} \times \frac{\text{photograph dimension in line of flight}}{\text{aircraft speed}} \times 0.50$$

$$\cong \frac{\text{coverage in line of flight}}{\text{aircraft speed}} \times 0.50$$

As an example for flying an aerial photography strip at a height of 6,000 ft above the ground and at a speed of 95 mph, using a K-24 camera equipped with a 7-in. focal length lens, the following flight plan information can be calculated. (Approximate figures are given.)

1. Film scale is 850 ft per in.
2. Ground coverage is 4,250 ft per photograph, both in line of flight and perpendicular thereto.
3. Photography rate (for 50 % overlap) = 15-sec interval between exposures.
4. Filming time (for one 125 photographs per film roll) = 31 min.
5. Number of miles of freeway included on one roll of film = 50.

With this information at hand, a fully-detailed photographic flight and aerial camera operation plan can be formulated for a specific freeway traffic survey section. An experienced operator can reload the camera with a new roll of photographic film while in flight quite easily. Consequently, with careful planning and execution, flight time need not be wasted for this purpose.

Film Negative Analysis

If these methods are to be widely accepted as practical traffic survey procedures, analysis of the aerial film negatives must be straightforward and consume as little time as possible. Bottlenecks in data flow are often more oppressive than those encountered in traffic. In this study, analysis of the film negatives was devoted to the measurement of traffic density, based on what were considered two sound reasons. First, traffic density is a significant indicator of level of traffic service (speed) and level of throughput (number of motor vehicles) on the freeway. Second, the measurements and calculations necessary in analyzing the film negatives for traffic density are very simple, and can be obtained rapidly.

Traffic density was determined by establishing freeway subsections, usually ranging from 1/4 to 1/2 mi in length, counting from the photographic film negatives the number of vehicles contained within each subsection, and then applying the equation:

$$\text{Traffic density} = \frac{\text{vehicle count (number of vehicles)}}{\text{subsection length} \times \text{number of lanes}}$$

For example, given a four-lane freeway subsection 0.44 mi long containing 85 vehicles:

$$\text{Traffic density} = \frac{85}{0.44 \times 4} = 48 \text{ vehicles per lane-mile}$$

It is convenient to use freeway overpasses as the subsection boundaries since they are quickly recognized on the film negatives. Furthermore, the exact distances between structures are available from plans already on file, which eliminates the difficult task of attempting to measure distance by use of an engineer's scale on the photographs. Both directions of the freeway are open to analysis, but they are usually treated separately.

The ease with which the analysis of film negatives can be accomplished depends in part on the level of traffic density. Under free movement conditions, analysis is simplified because fewer vehicles are in the subsections and the longer spacing between vehicles makes counting easier. With congestion, there are more vehicles to count and the shorter spacing makes counting more difficult. In any case, the film negatives can be placed on a light table and examined directly, and as personal preference dictates, either with or without the assistance of a magnifying lens.

RESULTS

Aerial photography was taken on five separate days. Three of the days were devoted to development of the techniques during which experiments were made with different aircraft, cameras, and flight plans. During the two other days, the traffic survey aerial photographs were taken, using the preferred 5- × 5-in. size format camera and light aircraft. Overall, some 10 hours of total flight time were logged and over 10,000 photographs were taken. It is not the intention here to present results in depth or to interpret the results from the operations as regards a particular freeway. Rather, sample photographs are presented to illustrate the type of data collected by their use, and a new method of presenting traffic data, the density contour map, is explained and illustrated by typical examples.

Sample Photographs

Figures 1, 2, and 3 are typical of photography obtained by use of the camera taking 5- × 5-in. size photographs. These photographs were taken with a 7-in. focal length lens from a fixed-wing aircraft flying at a flight height of 6,500 ft above the ground and at a speed of 95 mph. The three figures include prints of the full 5- × 5-in. size and enlargements of the portion of each photograph which shows the freeway subsection for which traffic density was determined. The same freeway subsection is contained in all three illustrations, and interest is centered on the upper half of freeway subsection number nine, traffic moving from right to left on the photograph.

Figure 1 shows the freeway subsection in the state of free flow (free movement of traffic). There are 44 vehicles contained in the 0.31-mi, 4-lane, subsection yielding a traffic density of 36 vehicles per lane-mile. Free moving conditions are generally characterized by traffic densities ranging from zero to 40 vehicles per lane-mile. For this range of densities, speeds range upward from 40 mph and the number of vehicles per hour range from zero to slightly below maximum.

Figure 2 shows the subsection in the state of impending congestion. There are 60 vehicles contained in the 0.31-mi, 4-lane subsection for a density of 49 vehicles per lane-mile. Traffic densities ranging between 40 and 60 vehicles per lane-mile are generally characteristic of impending congestion, with speeds ranging between 40 and 30 mph, and the number of vehicles per hour at or near maximum.

Figure 3 shows the freeway experiencing congestion. There are 94 vehicles contained in the subsection for a density of 76 vehicles per lane-mile. Traffic densities exceeding 60 vehicles per lane-mile are usually indicative of congestion during which time speeds range downward from 30 mph and the number of vehicles per hour is less than the maximum attainable at lower traffic densities.

Construction of Traffic Density Contour Maps

A means for studying traffic density level variations over both distance and time simultaneously appeared to be desirable. Because of the use of topographic contour maps to exhibit variations in ground elevation both transversely and longitudinally, it was suspected that a similar technique could be used to illustrate variations of traffic movement characteristics in two dimensions, distance and time.

The first step in constructing a traffic density contour map is to lay out a system of rectangular coordinates with distance on one axis and time on the other. The full length

of a freeway subsection in the state of free flow.

Figure 2. Sample photographs of a freeway subsection in the state of impending congestion.

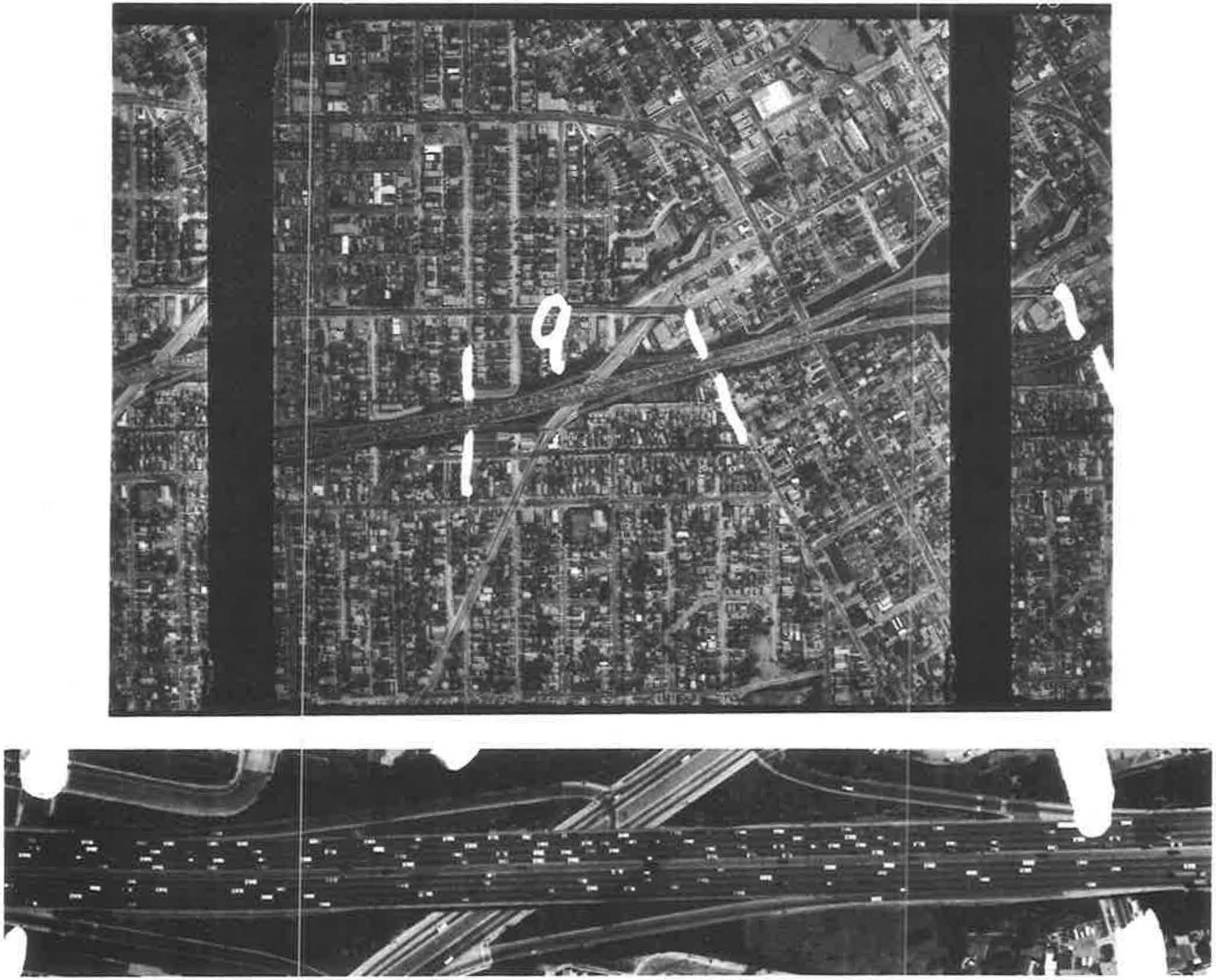

Figure 3. Sample photographs of a freeway subsection in the state of congestion.

of freeway and period of time studied may be included on the map. For the sake of standardization and to simplify interpretation of the map, it is suggested that distance and time should always be plotted in the same manner. In the examples presented, distance appears along the horizontal x-axis with direction of travel from left to right, and time is plotted along the vertical y-axis increasing upward.

The second step is to plot the traffic densities, computed for each subsection photographed during each flight over the freeway, on the graph in the proper time and distance positions. Contour lines joining points of equal traffic density are then constructed. Selection of the contour interval to use depends on the degree of detail and concentration of data and on the amount of detail desired in the completed traffic density contour map.

Sample Traffic Density Contour Maps

Sample traffic density contour maps are shown in Figures 4 and 5 to illustrate the results of this photographic analysis technique. Both maps depict traffic operation on a 7-mi freeway section during a 2½-hr period The individual traffic densities plotted on a working map and used for establishing the contour lines are deleted from the completed maps. This procedure is consistent with that used in the construction of contours on topographic maps by use of data from surveys made on the ground.

A contour interval of 20 vehicles per lane-mile is used in the examples, and certain ranges are shaded to help clarify the maps. The times and locations where smooth steady flow conditions exist (densities less than 40 vehicles per lane-mile) are shown in white. Areas of impending congestion (densities between 40 and 60 vehicles per lane-mile) are shown in light gray. Congestion (densities exceeding 60 vehicles per lane-mile) is depicted by a darker shade of gray.

Important information which can be determined by reviewing the traffic density contour maps include:

1. Approximate locations which act as sources of congestion.
2. The duration of congestion at any point along the freeway.
3. The length of freeway under congestion at any time of day .

Figure 4 is a traffic density contour map on which isolated areas of congestion are depicted. Several observations can be made:

1. One area of congestion has its source at approximately the 1¼-mi point at 4:10 PM.
2. The congestion persists for about one hour at the 1-mi point.
3. The congestion extends for a distance of approximately three-quarters of a mile beginning at the ½-mi point.
4. A second major area of congestion slightly more than one mile long begins at 4:40 PM centered at about the 4½-mi point.
5. This congestion also persists for one hour at its source, lasting until 5:40 PM.
6. Congestion extending over the 1-mi section was not backed up into the area in which earlier congestion was experienced.

Figure 5 is another example showing heavy congestion. Several observations can be made:

1. Congestion has its source near the 4¾-mi point at approximately 4:20 PM.
2. Congestion persists at this point for more than two hours, lasting until 6:30 PM.
3. Congestion extends backward to nearly the 1-mi point at 5:30 PM, and forward movement of traffic is affected to the 5½-mi point.

Other Potential Uses

In addition to the basic freeway operations information which the traffic density contour maps yield — the source, duration, and extent of congestion — other applications of the maps come to mind. For example, a single figure of merit, average

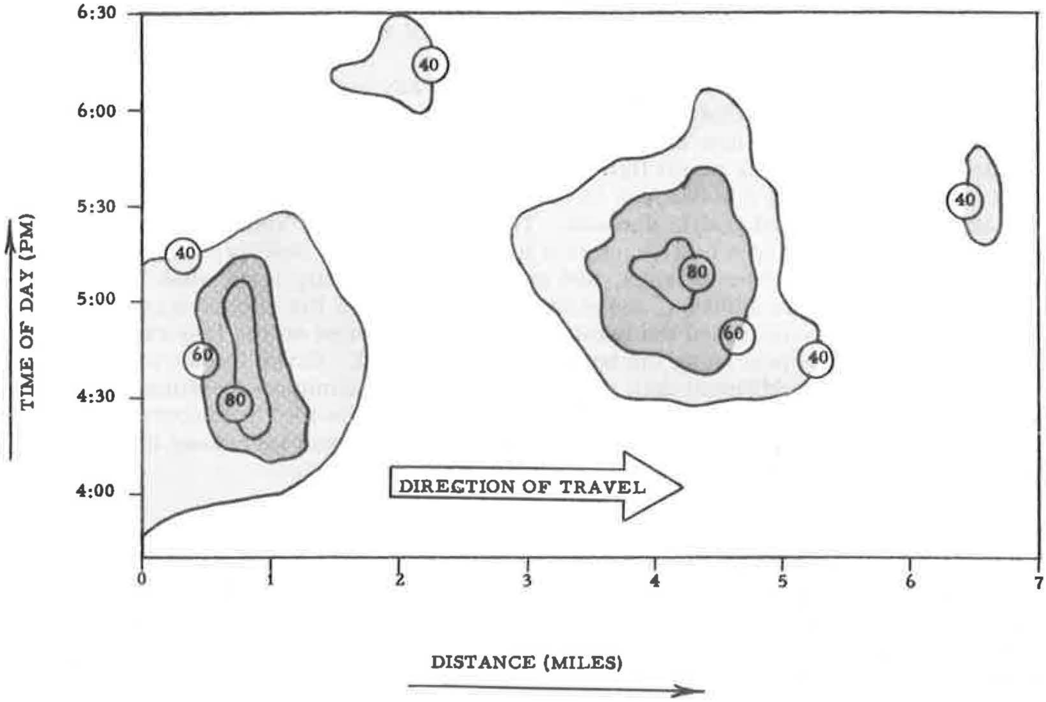

Figure 4. Freeway density contour map showing isolated areas of congestion.

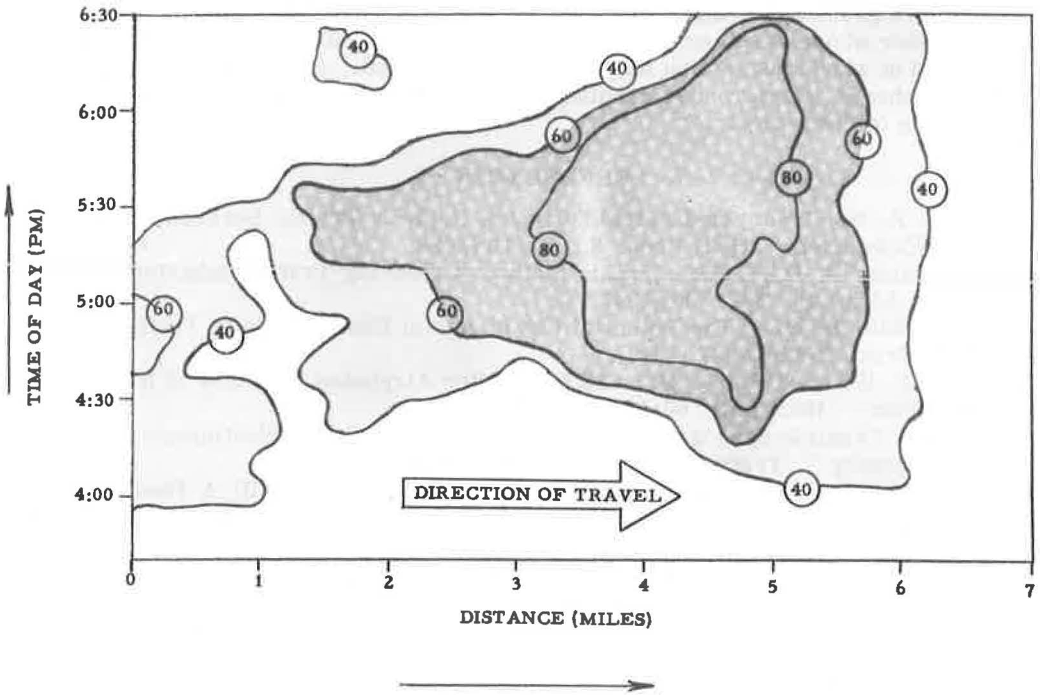

Figure 5. Freeway density contour map showing heavy congestion.

density during the time period and for the length of freeway shown could be computed by determining the areas enclosed by the contour lines, multiplying by the average density between lines, and dividing by the total area of the map. This procedure could be completed quite easily with the use of a planimeter.

Another type of analysis, the application of which has not yet been fully developed, involves the estimation of traffic demand. The number of vehicles passing through a bottleneck is indicative of how many are getting through, but this number does not indicate how many vehicles would like to pass this point (demand). The increase in traffic density preceding a bottleneck is essentially a measure of the difference between the maximum number and traffic demand. The total number of vehicles "stored" on a freeway seation preceding a bottleneck is a function of traffic density, length of the section in question, number of lanes, and selection of a density level when "storage" is assumed to begin. In addition, the storage of vehicles on the entrance ramps upstream from the bottleneck and the number of vehicles stored on the freeway desiring to leave at exit ramps preceding the bottleneck are needed. Given the aerial photography results, the only additional data needed to apply the technique of estimating traffic demand are the ramp counts. Traffic demand information is highly important for it is a basic requirement in an evaluation of the effect that proposed increases in freeway capacity will have on the level of traffic operation.

CONCLUSIONS

It is hoped that experiences in the use of aerial photography in freeway operations studies reported herein have been of interest to traffic engineers and all other users of aerial photographs and that some good has been done in the promotion of accelerated application of aerial photography for such purposes. With the rapid development of sophisticated aerial survey reconnaissance methods which have recently received broad publicity, as regards military applications, significant advances in use of aerial photography by traffic engineers seem highly probable.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the cooperation of the California Division of Highways under whose auspices the studies of freeway operation was performed in Los Angeles, and at whose suggestion this paper was prepared. Appreciation is also extended to Stephen R. Craig whose excellent photographic work contributed immeasurably to the success of the project.

REFERENCES

1. Johnson, A. N., "Maryland Aerial Survey of Highway Traffic Between Baltimore and Washington." HRB Proc. 8:106-115 (1928).
2. Greenshields, B. D., "Photographic Method of Studying Traffic Behavior." HRB Proc. 13 (pt. I): 382-396 (1933).
3. Greenshields, B. D., "The Potential Use of Aerial Photographs in Traffic Analysis." HRB Proc. 27:291-297 (1947).
4. Forbes, T. W., and Reiss, R., "35 Millimeter Airphotos for Study of Driver Behavior." HRB Bull. 60:59-66 (1952).
5. Wohl, M., "Vehicle Speeds and Volumes Using Sonne Stereo Continuous Strip Photography." Traffic Engineering (June 1959).
6. Lighthill, M. J., and Whitham, G. B., "On Kinematic Waves II: A Theory of Traffic Flow on Long Crowded Roads." Proc. of the Royal Society, Series A, Vol. 229 (1955).
7. Edie, L. C., and Foote, R. S., "Traffic Flow in Tunnels." HRB Proc. 37:334-344 (1958).
8. May, Jr., A. D., and Wagner, Jr., F. A., "Headway Characteristics and Interrelationships of the Fundamental Characteristics of Traffic Flow." HRB Proc. 39:524-547 (1960).