photographs of the tare model were taken and the completion of the photographs of the loaded models. It thus became necessary to correct for this deviation by means of a mathematical correction. Unfortunately, this did not correct the situation entirely and so the value of the results was somewhat nullified.

Dynamic Tests

Only two pairs of photographs were taken of the model in a dynamic state. These were at 196 and 213 vibrations per second. A strobe light with a speed of 1/5,000 of a second synchronized with the maximum point of vibration of the model was used to obtain the photographs. The lighting for these models was not as good as with the static models, and it was not possible to use the same control points. The models were contoured however, and a distinct difference was observed in the surface of the models. It was noted that one model was in a state of tension while the other was in compression.

Conclusions

It is unfortunate that more time could not have been spent in experimenting with this project; however, the allotted time was very short and there was not sufficient justifications to proceed farther.

I believe the results, while possibly not being everything desired, do show that a definite solution to a very difficult problem is possible through the use of photogrammetry.

It is hoped that in the future it will be possible to expand upon the basic steps taken here. Lighting and control are two major problems, as well as the need for better cameras. All of these problems can be overcome, however, and when they are, a new and exciting field will be opened to the photogrammetrist.

*Continuous Strip Photography—An Approach to Traffic Studies**

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and
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(*Abstract is on next page*)

Introduction

The objective of the traffic engineer is to provide for the safe, rapid and efficient flow or movement of traffic, that is, people and goods. In carrying out this over-all objective, he must not only plan and design new traffic carrying facilities, but must insure efficient operation on existing ones. The planning, designing and operating phases all involve the extensive use of traffic data obtained from the present transportation system. Consequently, it is necessary that the present-day traffic data which are collected be accurate and as current as possible. At the same time it is necessary to keep data collection costs at a minimum.

Volume and speed data are of major concern to the traffic engineer. The current methods of collecting these data involve manual or mechanical field testing or recording. Their main advantage is the simplicity of the data-collection process. On the other hand, they include one or more of the following disadvantages:

a) The collection process is time-consuming (placing the automatic counters, picking them up, removing the tape, etc.).

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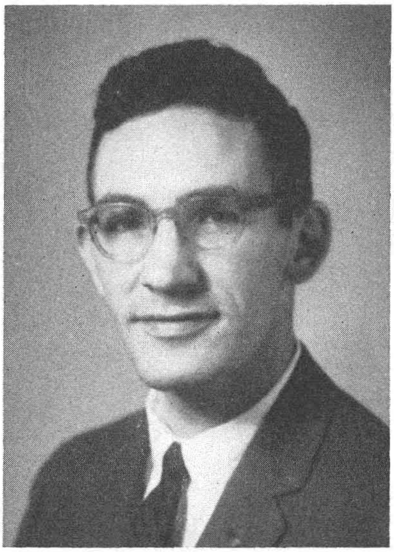

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b) The personnel requirements are large.
c) The collection process for a metropolitan area often takes several months to complete.
d) The basic data gathered must be adjusted to a common base (Average Annual Daily Traffic—AADT) because of the seasonal and daily variations in traffic flow. This step introduces large errors and would be unnecessary if all the data were gathered during the same period of time.
e) Separate collection processes are required for each type of data.
f) Traffic data collection and reduction is expensive.

Various attempts have been made to develop new methods of gathering traffic data which will eliminate these disadvantages. Most of these experiments have utilized photography, either in the form of time-lapse (serial) pictures taken from some vantage point, or normal aerial stereo-pairs. With both these methods, the speeds and time and distance spacings of vehicles can be readily determined if the time intervals are known, and if the movement of specific vehicles is noted. However, there are three principal disadvantages.

First, the task of assimilating and analyzing the data becomes almost insurmountable

ABSTRACT: *The traffic engineer has the responsibility of providing for the safe, rapid and efficient flow of people and goods. Much of his success in planning and designing new traffic carrying facilities and in operating existing ones to meet this over-all objective depends on his ability to collect and process traffic data accurately, quickly and cheaply. Current data gathering techniques offer none of these advantages. Also, the urgency for improving our traffic data handling techniques is emphasized by the estimate of 100,000,000 motor vehicles in use by 1975.*

Continuous-strip photography, because of its time-lag between adjacent halves of the strip, its continuous accumulation of ground data on one photograph, and its rapid collection of large quantities of ground data, appears to be ideally suited for application to traffic studies.

It seems entirely reasonable that the traffic engineer will be able to use continuous strip photography as a medium for obtaining traffic speeds, volumes, time and distance spacings, etc. Formulas have been derived for some of these quantities, and remain to be proven or disproven by further research.

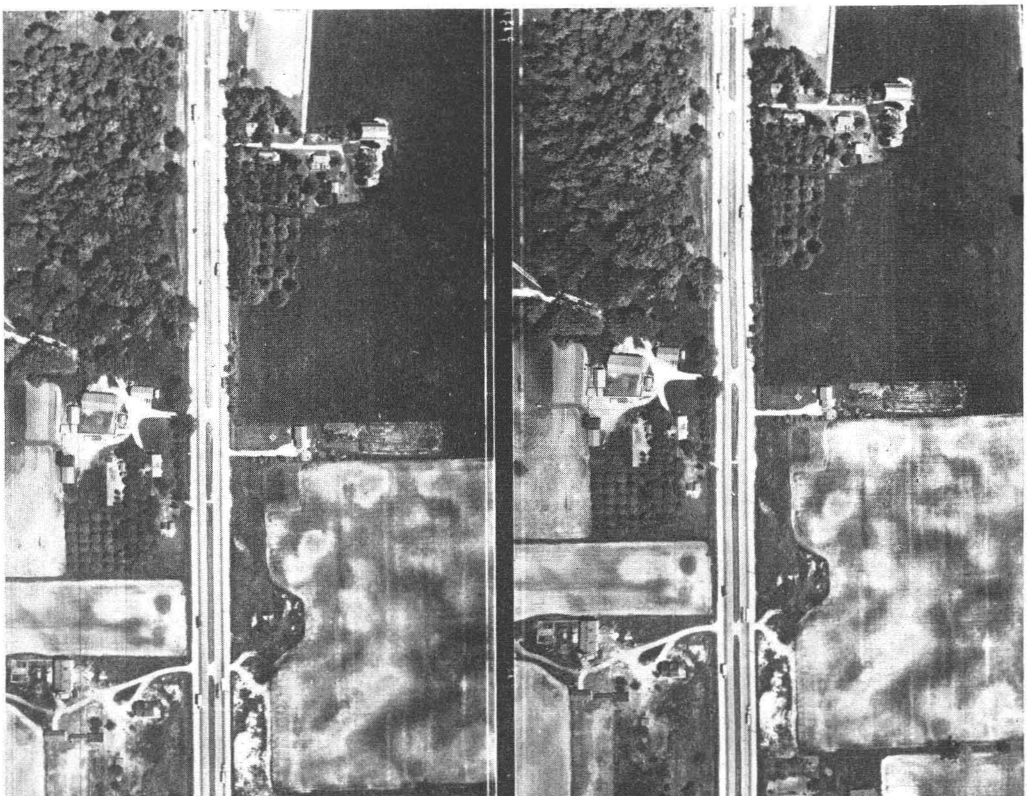

FIG. 1. Sonne continuous strip stereoscopic photography (reduced from $9\frac{1}{2}''$ negative width). Flight height = 1,000 feet; focal length = 4 inches; parallax angle = 5 degrees.

if the area being surveyed covers more than a couple of city blocks.

Second, it is often difficult and time-consuming to identify the same vehicle in two succeeding photographs.

Finally, the aerial views of vehicular traffic are often obscured by shadows and by buildings on either side of the plumb point.

Definition of the Problem

While the use of normal aerial photography or serial pictures offers the advantage of gathering large quantities of data quickly, the difficult and time-consuming problem of reducing the data from separate photographs is still a serious disadvantage. Thus, it does little to solve the problem of developing a method by which we can sample the traffic, obtain accurate volumes and speeds, use only one data collection process, and minimize time, effort and expense. It is also important that such a method allow us to collect *all* the data for a given study area during the *same* period of time.

Advantages Offered by Strip Photography

Continuous strip stereoscopic photography offers all of the advantages of normal aerial and serial photographs, and in addition enables us to eliminate the problem of assimilating separate photographs. Figure 1 is an illustration of this type of photography; the two adjacent strips provide the stereo effect, which may or may not be used to determine traffic speeds and volumes (this will be shown in a later section).

Using strip photography, approximately 90 miles of highway can be shown as one *continuous* and unbroken photograph. More important, it is possible to obtain a continuous strip photograph of about 136 miles *in one hour* (at present-day plane speeds). This strip would represent linear coverage of every street of a four square-mile downtown area with 300-foot blocks. With longer blocks, such as in the suburbs, even larger coverage could be obtained in an hour.

Description of Sonne Continuous Strip Stereo Camera

Plan and elevation views of the Sonne camera are shown in Figure 2. The equipment consists of an aerial camera in which the film being exposed is continuously moved past a narrow slit-type aperture. The film velocity is based upon the ground speed of the plane and its height above the ground. The film and image velocities are synchronized so that little or no image blur occurs, and so that each point along the ground is photographed as the line-of-sight passes over it.

The camera includes two matched lenses, with the right lens ahead of the slit and the left lens to the rear. Each lens while photographing ground objects continuously exposes only *half* of the film width; the right lens "sees" an object before the plane passes over it, and the left lens after the passing of the plane.

The narrow slit-aperture and longitudinal displacement of the two lenses (as shown in side and top views of Figure 2) represent two lines-of-sight, one forward and the other rearward, intersecting at a parallax angle ϕ.

Time-Lag Between Front and Rear Pictures

The parallax angle ϕ between the front and rear lines-of-sight can be considered to represent an interval of time, or constant airbase time-lag, for any flight height. This is illustrated in the left-hand portion of Figure 3 between times t and t'.

At time t, the front lens records the fixed object A, while the rear lens "sees" the same object later at time t'. During the interval of time $(t'-t)$, the plane has flown a distance D, commonly called the airbase.

$$D = 2H \tan \phi/2 \qquad (1)$$

where

D = Airbase
H = Flight Height
ϕ = Parallax Angle

Let

S_p = Plane Speed
$D = S_p(t'-t)$

and combining with formula (1),

$$(t' - t) = \frac{2H \tan \phi/2}{S_p} \qquad (2)$$

where $(t'-t)$ is the *airbase time-lag.*

Moving Vehicle Speed Determination

The right-hand portion of Figure 3 illustrates the relationship between the front and rear lens and a moving vehicle B, where the front lens records B at time t_1 and the rear lens at time t_2. In the interval of time (t_2-t_1) the plane has flown a distance D_p and the vehicle B has moved a distance D_B. Thus, if both plane speed S_p and moving vehicle speed S_B can be expressed in terms of the time interval (t_2-t_1), a useful relationship is developed, as follows:

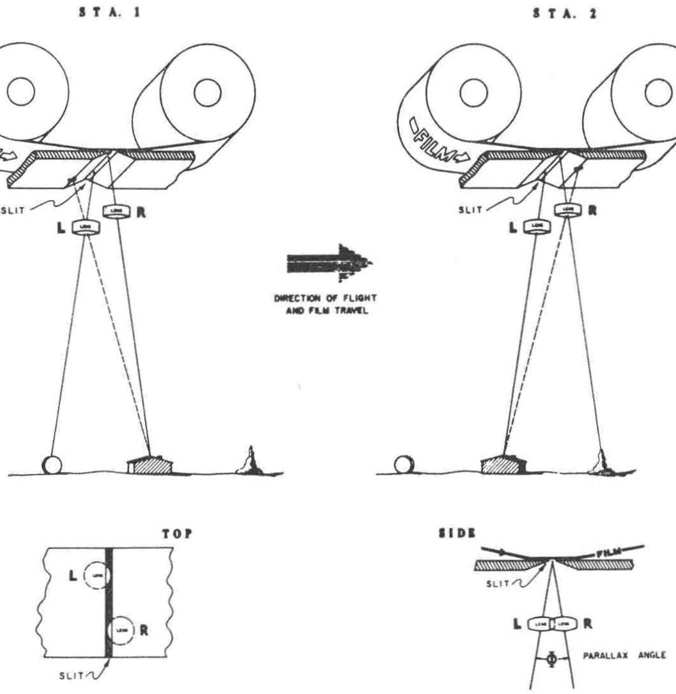

FIG. 2. Plan and side views of the Sonne Camera (with stereo lenses).

$D_B = S_B(t_2 - t_1)$, and $D_p = S_p(t_2 - t_1) = D_B + D$

$$\therefore\ S_B = S_p\left(\frac{D_B}{D_B + D}\right) \quad (3)$$ [1]

where

S_B = Moving Vehicle Speed
S_p = Plane Speed
D = Airbase
D_B = Distance Vehicle B Moves Between Times t_1 and t_2

Figure 4 represents a portion of a stereo strip, showing relative positions of a moving vehicle at times t_1 and t_2. Because of the airbase time-lag, any fixed object or point (such as the cross road) will be offset in the two halves of the strip by a distance D. Similarly, any moving object, such as vehicle B, would be offset by both the airbase D and the distance D_B it moved between the times t_1 and t_2. Therefore, the speed of any moving vehicle S_B can be determined by scaling D and $(D_B + D)$ directly from the strip, subtracting the two quantities to get D_B, and using formula (3).

This method of calculating moving vehicle speed can be used regardless of the relative direction of the plane and vehicles if certain factors are considered. In formula (3) the distance D_B takes a *negative* sign when the direction of the plane and moving vehicle are *opposite*. If the movements of the plane and car are exactly perpendicular (or crossing), the speed S_B of the moving vehicle is:

$$S_B = S_p\left(\frac{D_B}{D}\right)$$

However, if the relative direction of the plane and vehicle is "skewed," this must be taken into account with a cosine function.

VARIOUS APPROACHES TO VEHICULAR VOLUME DETERMINATION

Vehicular volume or flow (vehicles per hour, for example) is normally determined by counting the number of vehicles that pass a given "point" during a unit of time. This volume is a function of density and the average over-all speed of the vehicles, and is directly proportional to both variables.

Another way to obtain the volume might

[1] Mr. Daniel R. Schurz, Instructor in Photogrammetry at M.I.T., developed a method of measuring moving vehicle speed using a comparator attachment on the Sonne Stereo-Viewer. The formula for speed is:

$$S_B = \frac{S_p(\Delta p)}{(\Delta p + D)}$$

where Δp is parallax difference of auto and road.

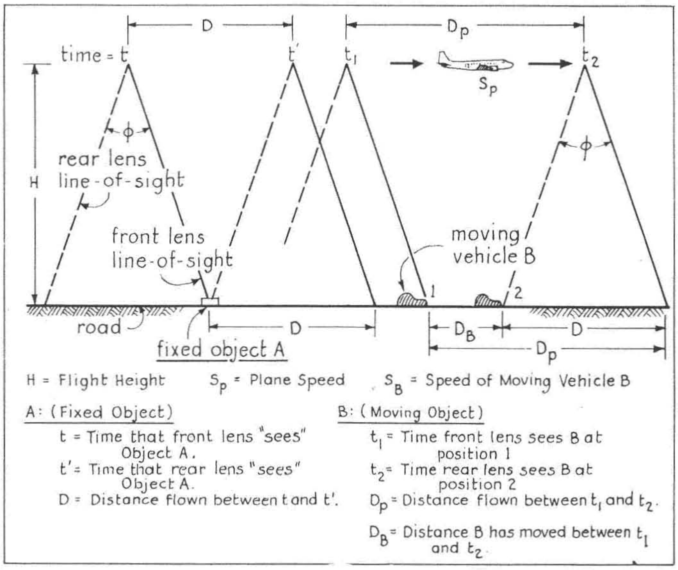

FIG. 3. Side views of Sonne Camera at various times during flight.

be to "stop" all the vehicles on a route at one instant of time (such as in a normal aerial photo), move a "point" past them and count the number of cars passed. If the "moving point" speed is greater or less than that at which the vehicles normally move past a fixed point, the resultant volume will, of course, be greater or less than the true volume.

Continuous strip photography is, for all practical purposes, a picture taken by a "point" moving past the vehicles, where the speed of the "moving point" is the plane speed S_p. Therefore, a volume developed from strip photography using this analogy must take into account both plane speed and average vehicle speed. Also, since the strip photo is taken as the point moves along the route and not at one instant of time, the distance between the end vehicles is greater (if the plane and cars are moving in the same direction) than if all the vehicles were "stopped" at the same time.

Figure 5 shows one-half of a strip-photo, with four vehicles recorded at four different times between t_B and t_A. Since volume is vehicles per unit time, we get:

$$\text{"Moving Point" Volume} = \frac{(n-1)}{(t_A - t_D)}$$

where n = Number of Vehicles Passed (including end vehicles) and since

$$D_T = S_p(t_A - t_D)$$

where D_T = Distance Between End Vehicles (Scaled from photo)[2]

$$\therefore \text{"Moving Point" Volume} = \frac{(n-1)S_p}{D_T}$$

Earlier it was mentioned that a volume based on the "moving point" analogy would

[2] Note that in this case a photo scale *must* be used (Photo Distance×Photo Scale); this step is not necessary in the speed formulae, however, as the distance relationships are dimensionless.

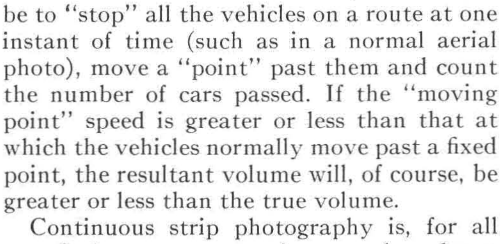

FIG. 4. Diagram of continuous strip stereoscopic photography.

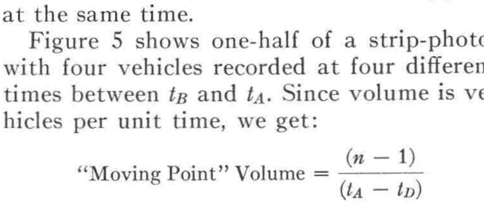

FIG. 5. Diagram of one-half of a continuous strip stereoscopic photograph.

be correct *only* if the vehicles were stopped at the same instant of time, *and* if the plane speed were equal to that of the moving vehicles. The first factor is taken into account by reducing (if the plane and vehicles are moving in the same direction) the distance D_T between end vehicles by the amount they have spread out during the interval $(t_A - t_D)$. The corrected volume is then as follows:

$$\text{Corrected "Moving Point" Volume} = \frac{(n-1)(S_p)^2}{(S_p - S_D)(D_T)}$$

where S_D = Speed of last vehicle in line (or vehicle D).

The second factor is taken into account by multiplying the volume by the ratio of the average over-all vehicle speed to the plane speed. Therefore,

$$V = \frac{\bar{S}(n-1)S_p}{D_T(S_p - S_D)} \qquad (4)$$

where

V = Actual Vehicular Volume (vehicles per unit time)

$\bar{S}$ = Average Over-all Speed of n vehicles.

Other Applications of Strip Photography

The paper thus far has considered only the applications of strip photography to gathering traffic speed and volume data. The traffic engineer, of course, finds it necessary to obtain other data, such as time and distance-spacing between vehicles, lateral placement of vehicles, or accumulation of vehicles (moving or parked) in a downtown area, to give but a few examples.

It should be possible to obtain the time and distance-spacing information by measuring directly from the strip photo, and by using the time-distance-speed relationships pointed out earlier in this report. It should be noted again, though, that the spread between vehicles as the plane passes over them must be taken into account.[3] Data on transverse movement of vehicles, on parking accumulation, on traffic density (vehicles per mile), and possibly on parking space turnover rates can also be determined from continuous strips.

Continuous strip photography does not find its usefulness limited to the traffic engineer. Other papers on this type of photography have pointed out its applications with regard to earthwork considerations, pavement and general roadway condition, right-of-way planning, etc. It seems then that we have just begun to realize the advantages and potential offered by this powerful photogrammetric tool.

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[3] See Martin Mohl, "Vehicle Speeds and Volumes Using Sonne Stereo Continuous Strip Photography," *Traffic Engineering*, January 1959, pp. 18–19.

Closure by the Moderator

I thank the participants of this panel for their excellent presentations and the horsepower they represent.

The panel expresses its appreciation to this very attentive audience for the interest shown in the special applications of photogrammetry.

Fully realizing that prognostications are always dangerous, nevertheless, I stated in the 1956 Commission V Report presented at the Stockholm meeting that "the national gross product in the United States of specialized applications and measurements will exceed that of aerial topographic mapping within the next generation." You are all well aware of the progress that has taken place in the field of photogrammetry since 1956. I would like to say in closing, relative to the one generation prediction, "It will not take that long."