*Use of Photogrammetric Methods in Traffic Studies: I. Driver Eye Height**

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ABSTRACT: *This driver eye height traffic study illustrates that information concerning driver eye height and over-all vehicle height of passenger cars can be obtained photogrammetrically. A surplus aerial camera was converted for use in ground photography at close range. A simple but precise measuring scale was used for the basic measurements, and an analysis of the measuring process was used to determine the accuracy of the final results. With this procedure, difficult to obtain data were provided on a subject of potential value for future highway design.*

INTRODUCTION

For a number of years, the estimated value of 4.5 feet has been widely accepted as a representative driver eye height. Although a value for such height should be based upon measurements made when drivers are in their customary driving positions, and when they are operating their vehicles under normal roadway and traffic conditions, it has not been possible to actually measure and establish the value under operating conditions. Although in recent years the accepted design value for driver eye height has remained constant, the design of passenger cars operating on streets and highways has changed considerably, with a consequent proportional effect on the position of the driver's eyes. As cars have become progressively longer, wider, and lower—or smaller, more compact, and thus lower—there has been a resultant gradual lowering of the driver eye height. Restricted sight distance on crest vertical curves is an obvious consequence of such reduced vehicle and driver eye height, as is the restricted horizontal sight distance at other locations.

APPROACH TO THE STUDY

The recognition of a more representative driver eye height is important since this information is needed for accurately determining sight distance in the vertical and the horizontal planes, and for designing geometric features to provide adequate sight distance. Observations of any late model car would quickly indicate that the value of 4.5 feet is no longer realistic, and a closer observation would show that not only is there considerable variation in driver eye height, but that a few drivers are even viewing the road from heights of as little as 3.5 feet or even less. It has been noted that driver characteristics (*e.g.*, height, weight, and posture) as well as vehicular characteristics (*e.g.*, make, year, loading, seat design, and seat position) account for driver eye height variation and complicate the problem of selecting a representative driver eye height for use in geometric design.

Obviously, the fact that nearly 60 million passenger cars are currently registered in the United States would readily indicate the scope of the problem of such a selection and would point up the impracticality of attempting to measure all driver eye heights. Under such conditions, a practical method of securing realistic data for establishing driver eye height would appear to be some type of sampling device.

For this study, photogrammetric methods were found to provide a convenient and accurate means for recording and measuring driver eye height and over-all vehicle height for a selected sample of passenger cars as they were operated routinely along streets and highways.

* The potential effect of driver eye height on highway design features as shown by the tests has been reported by Professor Lee in another paper published by the Highway Research Board (*Proceedings*, Vol. 39, 1960, pp. 46–60)—*Letter of Jan. 2 by Prof. Turpin.*

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FIG. 1. Camera used for making side-view photographs of passenger cars.

A camera, activated by a trip mechanism and placed at a known position with respect to the traffic lanes within which vehicles were operated, made side-view photographs of selected cars. From these photographs, then, accurate measurements of driver eye height and over-all vehicle height were made.

In the course of the project, nearly two thousand photographs were made. All of these were examined critically and were classified. A number of negatives were discarded because positive identification of vehicles as to make and year could not be established, or because eye height could not be determined.

For evaluating driver eye height and overall vehicle height, measurements were made on 761 selected side-view photographs of different passenger cars, each of which was identified as to make and year. On these photographs a simple but precise measuring scale was used for the basic measurements, with the accuracy of the final result determined by analyzing the quality of each step in the measuring process. With this procedure, excellent results which added much practical data were obtained. Previously, it had not been possible to explore this problem under anything like realistic conditions.

CAMERA

Because of the many desirable features which are incorporated into its design, a government surplus aerial reconnaissance camera, type K-24, was selected for use in this study. This sturdy and relatively compact camera could be operated either electrically or manually. Under electrical operation, the shutter was triggered by a solenoid activated simply by closing a switch. Although up to three pictures per second could be made if a 24-volt power source were used, experimentation showed that a 12-volt wet cell battery would drive the camera motor at speeds sufficient to produce two pictures per second. Since portability of equipment was a consideration and two exposures per second would be adequate for most traffic conditions, the shutter solenoid was rewound to operate on 12 volts, and an ordinary automobile battery was used as a power source to trip the shutter and to advance the film.

There were shutter speeds of 1/150, 1/450, and 1/900 second available on this focal-plane shutter. The latter shutter speed was used in this study to "stop" the motion of vehicles moving at high speeds. At this shutter speed, Tri-X film required an aperture setting of about $f=4.0$ for most bright days. Film magazines used with the camera held a 56-foot roll of $5\frac{1}{2}$ inch wide film which would make about 120 pictures. Each picture measured 5 inches by 5 inches—a size sufficiently large to permit making measurements directly from the photographic negatives without projection.

The nominal focal-length (f) of this camera lens was seven inches. Because the object distance (d) would be about 40 feet, the image distance (i) was set to satisfy the lens formula

$$\frac{1}{f} = \frac{1}{i} + \frac{1}{d}$$

thus making $i=7.1$ inches. (Figure 1 shows the camera mounted on a tripod and set up in the median of a divided highway.)

A device for triggering the camera shutter was made as inconspicuous as possible by suspending a length of 0.020 inch diameter piano wire about two inches above the roadway surface, between a fixed iron stake on one end and a spring-loaded plunger on the other. The wire was stretched across all traffic lanes so that anchor stakes could be placed off the pavement. On spans of over 36 feet, a small rubber disc was used as an intermediate support for the wire. A microswitch resting against the spring-loaded plunger activated the camera shutter solenoid each time the tires of a vehicle pressed the taut wire downward from its normal suspended position. Because the time lapse between activations by the front and rear tires of passenger cars was generally less than the camera cycling time, only the signal from the front tires was effective in triggering the shutter.

Trial exposures showed that a considerable variation in light intensity existed between the vehicle exterior and interior, especially when the car windows were closed. A relatively uniform intensity was needed to produce side-view photographs which would show sharp exterior vehicle details as well as clearly defined facial features of drivers. Photographs taken in early morning or late afternoon hours at locations where sunlight fell directly on the driver's face were found to be useless because a majority of drivers shielded their eyes from direct sunlight with either a visor or their hand, thus obliterating a view of their eyes from the photograph.

A satisfactory solution to the problem of light intensity proved to be an 18-inch by 48-inch mirror mounted on a tripod and oriented so that it reflected sunlight onto the driver's face at the instant the camera shutter was open. Since the mirror was placed at about 90 degrees to the driver's area of acute vision and the duration of the high intensity reflected sunlight was very short when the vehicle was moving at road speed, no driver reaction to the bright light was observed. Of course, this technique of using reflected sunlight necessitated the selection of study sites at which the camera and mirror could be properly oriented during certain hours of the day. (Figure 2 shows a contact print of a photograph made by this method.)

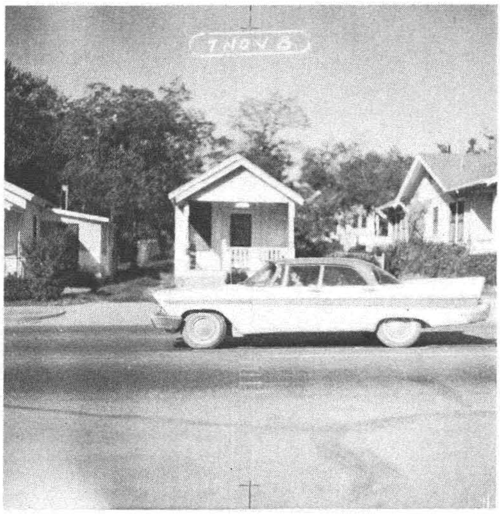

FIG. 2. Reduction of contact print of a photographic negative used for driver eye height and over-all vehicle height measurements.

MEASURING TECHNIQUE

At each site used for this study, strips of white plastic tape 1 inch wide and about 12 inches long were placed on the pavement surface at approximately 2-foot intervals across the traffic lanes to serve as reference points for determining the lateral placement of vehicles. (These strips of tape can be seen in Figure 2.) Photographs of a leveling rod were made at each new camera position to permit the determination of a scale factor for each photograph. The camera was positioned in each case so that it was between 25 feet and 50 feet from the vehicles to be photographed, and so that the optical axis was at right angles to the direction of vehicular movement, level, and about 4.5 feet above the roadway surface. (See Figure 3.)

On each photograph used for this study, a line was scribed between the points at which front and rear tires of the vehicle came in contact with the pavement surface, and another horizontal line at the driver's eye. The distance between these two lines on the photograph when multiplied by a scale factors (f_s) which corresponded to the lateral placement of the vehicle (or the distance of the vehicle from the camera) represented the driver eye height value in feet.

For this study, it was assumed that a vertical plane through the outer edge of the left wheel would also pass through the driver's eye so that a scale determined from the position of the wheel would also be correct at eye level. Any variation from this assumption was reduced by placing the camera so that the optical axis was approximately at the height of the driver's eye (say within one foot). A similar measurement was made for over-all vehicle height in each case. Measurements on the photographs were made with a glass scale graduated in 0.1-millimeter divi-

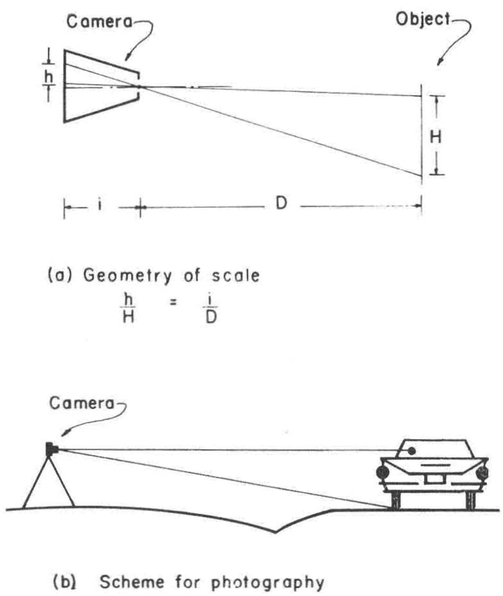

FIG. 3. Schematic relation between camera and passenger car.

sions. A 20-power microscope was used to read the scale graduations while the scale was held in place on the photograph by a jig. (See Figure 4.)

With an image distance of 7.1 inches and an object distance of 25 feet to 50 feet, the scale of the photographs varied from about 1:42 to 1:85. Thus, a 0.1 millimeter dimension on the photograph represented between a $\frac{1}{6}$-inch and a $\frac{1}{3}$-inch dimension on the object, depending upon the scale of the photograph. (See Figure 5.) With the microscope as an aid, readings could be made directly to the nearest 0.1 millimeter, or with a maximum error of 0.05 millimeter. For the scales used, the maximum error in the object dimension due to reading scale graduations was $\frac{1}{8}$ inch to $\frac{1}{6}$ inch.

Also considered was the accuracy with which the scale of the photograph could be found. With tape strips spaced at 2-foot intervals on the pavement surface, placement of the vehicle wheel could be determined by measuring the position of the image of the wheel with respect to the nearest tape or to a traffic-lane stripe which was 35 feet from the camera. Figure 5 was prepared as a graphical aid for determining the scale of photographs made with the wheels at any position between 25 feet and 50 feet from the camera. Data for plotting the scale line shown in Figure 5 were determined by photographing a surveying rod (Philadelphia rod) positioned

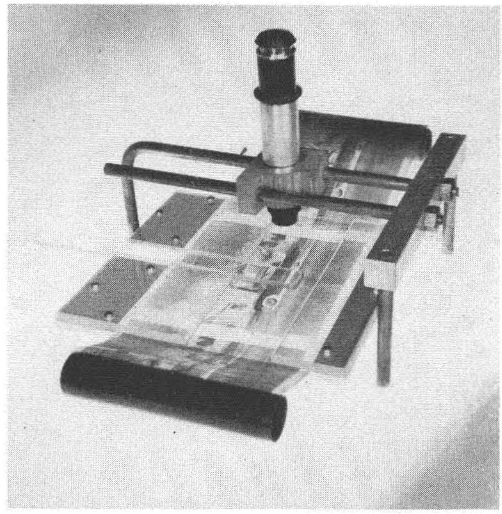

FIG. 4. Equipment used for making measurements on photographic negative.

27, 35, and 47 feet, respectively, from the camera.

Since the scale of a photograph will vary directly with the object-to-camera distance, the scale line as shown on Figure 5 represented the relationship between object-to-camera distance and scale factor, f_s. Distance from the camera to each tape strip as measured in feet in the field was then plotted against image displacement of each corresponding tape strip as measured in millimeters on the photograph. Some variation in this curvilinear relationship could be noted since the pavement surface was slightly irregular. Successive interpretation of these two curves yielded first the object-to-camera dis-

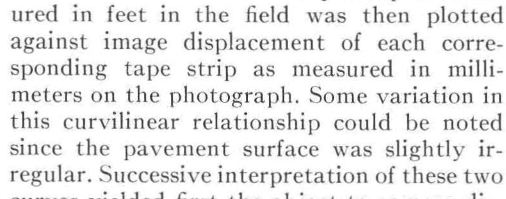

FIG. 5. Curves used in determining scale factor, f_s.

tance and then the appropriate scale factor, f_s.

Use of the curves to determine the scale factor for each photograph could be illustrated by the following example (see dashed line on Figure 5): If the scribed line on the photograph connecting the points of contact between the tires and the pavement were displaced 1.0 millimeter above the image of the traffic-lane stripe in the picture, then the vehicle was located at a distance of 36.6 feet from the camera. The scale factor, f_s, of 0.198 was used as a multiplier for converting dimensions measured in millimeters on the photograph to actual dimensions in feet on the object shown in the picture.

The accuracy with which the scale of the photograph could be found was thus dependent upon the quality of the measurement of the position of the vehicle wheel as shown on the photograph. If the maximum error in reading scale graduations were again taken as 0.05 millimeter, the maximum error in f_s would be 0.0005—an error of approximately $\frac{1}{8}$ inch in the measured eye height or over-all vehicle height.

In this study, the accuracy of the combined measuring process was evaluated by comparing dimensions as determined from the photographs with the same dimensions measured with a scale on several vehicles. The maximum variation noted by this process was $\frac{3}{8}$ inch. Also during the study, two photographs were made of the same 1959 Cadillac on different days. The over-all vehicle height was determined as 4.45 feet and 4.48 feet, or a variation of $\frac{3}{8}$ inch.

Thus, individual determinations of driver eye height and over-all vehicle height were considered to be correct to within $\frac{1}{2}$ inch. This order of accuracy was acceptable for determining representative values for the two physical quantities under study.

Conclusions

From the graph in Figure 6 can be found the average driver eye height and average vehicle height for each year and for all vehicles included in the sample regardless of make. These data revealed a trend to a lower vehicle and a lower eye height, with the average over-all *vehicle height* decreasing from 5.2 feet for the 1949 model cars to 4.7 feet for the 1959 models—the average *driver eye height* showing a corresponding decrease from 4.3 feet to 3.9 feet for the same models. This trend to a lower driver eye height could very well emphasize the need for changes in some of the criteria used for highway design.

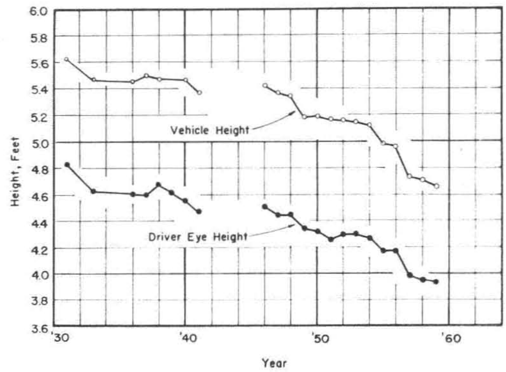

FIG. 6. Average driver eye height and average over-all vehicle height for each year as determined from 761 side-view photographs of passenger cars.

One major purpose of this study was the exploration and testing of a satisfactory photogrammetric method of obtaining this type of hard-to-measure data. The tests validated the point that valuable information concerning driver eye height and over-all vehicle height can be obtained from photographs.

The camera and measuring equipment were economical, generally available, and easily adapted for use in this study. The analysis of the quality of each step in the measuring process was found to be adequate for evaluating the accuracy of the final results, thus providing much usable data on a topic which has not been investigated extensively before by this technique.