Direct Evaluation of Geometric Highway Design

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This paper is part of a comprehensive study on the feasibility of evaluating geometric highway design conducted by the Joint Highway Research Project at the Massachusetts Institute of Technology. The nature of geometric design, and its influence upon the driver and traffic behavior, are outlined and it is shown how driver behavior can be used for evaluation.

"Direct evaluation" was found to be a simple and reliable method for evaluating geometric highway design features. An experienced designer compares actual traffic patterns with those desired and expected by the designer of the road. The difference between desired and actual traffic patterns serves as a very valid basis for evaluation. Uniformity for several observers and locations is assured through standard procedures and evaluation forms for each site.

The feasibility of this method of evaluation is demonstrated. Direct evaluation and conventional methods for evaluation are applied to a series of acceleration lanes of several design periods. The results are compared first for each acceleration lane, showing the variations between evaluation methods; then for the different acceleration lanes, demonstrating the need for design improvements and coordinating evaluation results with actual changes in traffic patterns.

• GEOMETRIC highway design is an art which depends largely, if not entirely, on judgment. As with any art, there are varied schools of thought, each of which produces different designs. As long as there is no accepted method of measuring them there is no positive way of differentiating between the merits of the various designs. As a consequence, drivers become confused when they encounter different designs for what appear to be identical situations.

Design practices presently used have been developed over the years from experience and in an attempt to meet the obvious needs of highway traffic. Although uniform design standards have been recommended by such agencies as the American Association of State Highway Officials, the individual states still have their own standards and policies. Experience and personal preference largely influence design.

It is the purpose of this paper to present a rational approach to highway design. Actual evaluation is to be the basis of judgment.

CONVENTIONAL EVALUATION PROCEDURES

Geometric highway design can be evaluated only if the relative merits of the design as a whole or of the individual design features can be measured in some fashion. That such measurement is possible is demonstrated by the fact that drivers have a definite preference for one design over another. An even more convincing argument is that accident rates for one design can be substantially different from those of another design. Thus, if differences in design are so obviously recognizable, they must also be measurable.

In the past, evaluation procedures have consisted mostly in detailed analyses of

one or several factors which constitute portions of the value of a design. Some of these factors are travel-time, traffic capacity, cost of vehicle operation, and safety features. More or less elaborate methods have been developed and published for the measurement of these items.

Accident analyses have been used extensively in the past. The main reason for the use of accident data was the extensive publicity usually cast upon severe highway accidents. Unfortunately, accidents often are inconclusive for a complete analysis of a design, and in all cases the time required to accumulate accident information and to permit these accidents to happen is too long.

The evaluation of individual factors usually is based on an economic comparison of the cost of design improvements with the savings derived from them. In all cases, evaluation procedures based on measurement of individual factors are tedious. If only one factor is used the method may be less cumbersome, but it will afford only a partial result.

All methods involving physical measurement of traffic data are cumbersome. Instrumentation for them is difficult to install and to run, and the evaluation of results is rather time consuming. The expense in time and money is so great that only a very limited number of tests can be run. A simple evaluation method which can be applied quickly to a wide range of tests and which will give results without delay is highly desirable. Such a method, even though it may be less precise, will be of great value.

FUNDAMENTALS OF PROPOSED METHOD

Direct evaluation is an extremely simple method for the evaluation of geometric highway design. The concept of evaluation is based on the presumption that the optimum geometric highway design provides for the most efficient operation of traffic. The valuation of the design is made by comparing actual traffic performance with the traffic behavior intended by the design. As long as a difference between the two exists, the optimum design has not been reached and an improvement is possible.

It is thus believed that traffic performance is a good representative of all factors which are involved in the measurement of the value of design. For instance, accident hazards depending on design are reflected in hazardous driving conditions, which in turn result in a large number of "near" accidents. Similarly, variations in speed, or swerving in the traffic path, point out the uneasiness of a driver and his uncertainty about the roadway, which in turn indicates some shortcoming in the design.

Instead of collecting data in the field for evaluation in the office, the data are evaluated on the spot in the field. Rather than measuring factual data of performance and recording it for later evaluation, the performance is mentally registered and evaluated as a complete picture in the observer's mind. To do this properly, the person doing the work must be capable of this mental evaluation. Preferably he should be the person who would otherwise master-mind a quantitative evaluation procedure. Not every technician could do this field work correctly. He should have experience in both design and traffic engineering.

The fundamental difference between the proposed method and what has been called "experience" in the past is that a certain logical sequence of steps is followed, which will make it possible for different people to obtain the same results. The steps are listed as follows and are described in detail later on:

1. Select the observation point.
2. Make a sample observation of a few cars on the test section.
3. Compare actual traffic performance with design intent.
4. Define the critical difference between actual traffic performance and design intent.
5. Verify the critical difference by a representative number of observations.
6. Deduce changes in design necessary to eliminate the critical difference.

The foregoing list shows clearly that results are obtained immediately. However, it is necessary to have an observer of high caliber who not only will be able to perform the steps correctly but also has enough prestige or authority to carry out the needed changes in design.

FIELD PROCEDURE

The method is somewhat difficult to describe in detail step by step, as much depends on the observer's ability to see and visualize traffic patterns and variations. A guide can be given in the following paragraphs:

1. Observation Point

The observer goes to the test location and surveys the roadway features carefully. Then he selects an observation point from which he can easily view the roadway and properly determine vehicle maneuvers within the section on which the test is to be made.

2. Sample Observations

The observation begins immediately. First a few cars (10 to 25) performing on the test section are observed and an impression of their performance is obtained.

3. Comparison with Design Intent

The actual traffic performance is then compared with the desired pattern. The desired pattern is either the path as assumed or suggested by the existing design or it is a pattern dictated by safety requirements, signs, etc.

4. Critical Difference

The difference between actual traffic performance and desired pattern is now derived from the foregoing steps. This difference is a yardstick of the traffic performance on the design feature tested and a measure of the effectiveness of the design.

5. Verification

A larger number of cars is now watched with special emphasis on the variation of their performance from the critical difference previously observed. This observation serves to check the critical difference and also to determine the scatter of variations from it.

6. Evaluation

After establishing the critical difference carefully and definitely, the observer can make an evaluation. Changes in design are then recommended to make the existing traffic pattern conform to the desired pattern. These changes are usually quite obvious in the field once the critical difference between actual and desired traffic performance is visualized.

In some cases it is conceivable that these corrections could be tried out directly in the field by blocking off traffic lanes with horses or cones, setting up signs, or applying manual traffic control.

The results of direct observation are often as good as the results of much more elaborate investigations. They are certainly obtained faster, easier, and with fewer man-hours of time. They bring the designer in close contact with the field work because it should be he who does the observation work.

It is also possible by this method to estimate some factual information such as (a) speed as compared with average through-traffic speed, (b) traffic path, (c) variations in lateral positioning of moving cars, (d) effect on surrounding traffic, and (e) accident potentials.

BENEFITS OF DIRECT EVALUATION PROCEDURE

Field measurement of the value of a design is a process which can be undertaken only on an existing design. Improvements based on evaluation may then be incorporated in design policies and built into new designs. As soon as the new design is in operation, an evaluation of it can be made and further improvements recommended, if necessary. In this manner the best possible design will eventually be developed. But it is evident that a considerable time lag

exists between evaluation and incorporation of its results in new construction. It is of utmost importance to reduce this time lag to a minimum.

To obtain optimum results from evaluation of geometric highway design it is necessary to continue evaluations for each new design put into service. The characteristics and benefits of such continuous evaluation can be summarized as follows:

1. Continuous evaluation of geometric highway design will eventually produce the most efficient design for existing traffic.
2. A design based on proper evaluation of previous designs will meet the desires of the driver and the performance of the vehicle more closely than earlier designs.
3. Consequently, new design features based on evaluation will be more easily understood by the driver.
4. Increased understanding of the design will reduce hazardous driving behavior and so increase safety.
5. When design is fitted to driver desires, the variations throughout the country will become small and will appear logical to the majority of drivers.
6. The time delay required to translate changes in driving habits into design policies will be a minimum.
7. By using rational evaluation methods the designer's attention will become focused on the driver and his behavior.

SAMPLE APPLICATION TO ACCELERATION LANES

To demonstrate the feasibility of the direct evaluation method of geometric highway design, it was tried on several acceleration lanes of varying design on Massachusetts Route 128, the circumferential highway around Boston. This road was built in stages during the last 20 years and employed acceleration lanes of three different design standards. Because traffic in general was nearly uniform on this road, a direct comparison of the different designs was considered representative.

The acceleration lane layouts of the three design periods are shown for comparison in Figure 1. In the 1936 designs the entrance ramp opens into the through roadway on a relatively sharp curve without demarkation of any acceleration distance on the shoulder.

In the 1952 designs, the shoulders are slightly widened at the ramp entrance. The widening decreases at a very slow rate along the acceleration distance and a solid white line between shoulder and first lane helps to distinguish the acceleration lane from through traffic lanes.

In 1955 the design of interchanges was changed radically, especially the speed change lanes. The acceleration lane begins at the end of the last curve of the entrance ramp as an individual roadway, separated from the through road by a green-strip. It then joins the through road at a very flat angle.

On the 1936 design, most cars stopped at the entrance. All went into the through lane or straddled the dividing line between through lane and shoulder as soon as they entered. Some returned towards the shoulder, fewer entered the through lane gradually. At the end of the observation distance (1,300 ft from the entrance) most cars had not yet reached the average speed of the through traffic.

Although the design intent is hard to determine for these old designs, it can be stated definitely that entering cars should not enter the through lanes immediately after entering the expressway. The "critical difference" between actual traffic performance and intended patterns, therefore, is that traffic enters the through lanes too soon at too slow a speed.

The remedy for this situation can be deduced from the pattern as sketched in Figure 2. Sketch A shows the actual pattern as observed and previously described. The dotted line indicates the desired safe driving path as it should be. To correct the actual path, a physical barrier should be placed as shown in B so that the cars cannot swing as wide as they do. Naturally, such a barrier is not realistic; it would be hazardous to through traffic. Actually, this tongue

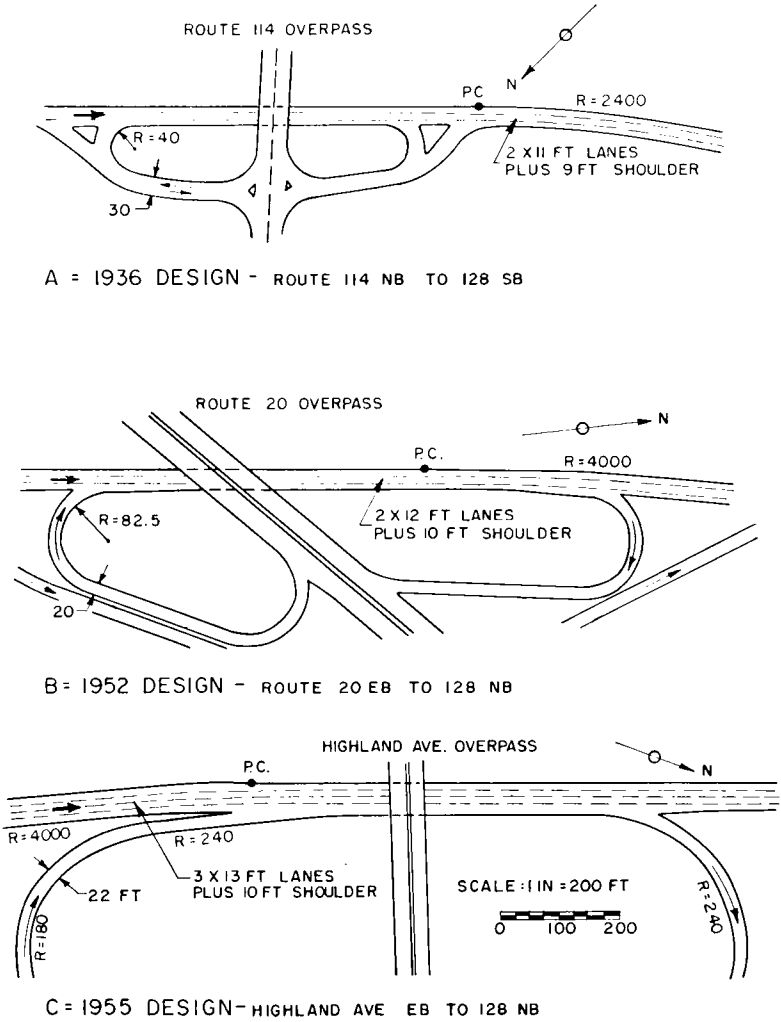

Figure 1. Typical layouts of acceleration lanes from three design periods.

should be straightened out from the ramp nose for a sufficient distance to prevent direct turns into the through lane (C). This could be done with very little change in layout.

On the acceleration lanes designed in 1952, there is a distinct use of the shoulder for acceleration purposes, but some traffic still enters directly into the through lane. Some of these cars later return towards the shoulder. At these locations a hazard is created by the cars which enter the through lanes immediately at relatively low speeds. This behavior would induce rear-end collisions or sideswipes. Furthermore, cars which enter too fast around the last turn may have a one-car accident if the driver loses control of his car and jumps the median. Lastly, the cars entering properly on the shoulder (acceleration lane) and moving gradually into the through lane need an unobstructed shoulder lane, especially since their attention will be divided between front and rear for the entering maneuver.

The proposed design improvement here is similar to the one discussed previ-

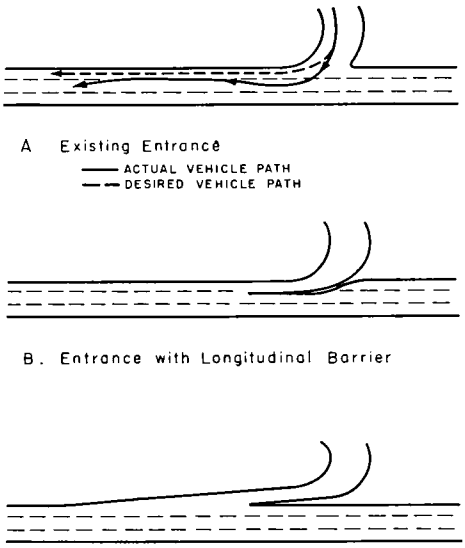

Figure 2. Results of direct evaluation.

ously; a physical barrier preventing immediate entrance into the through lane would be appropriate. Also, steps should be taken to prevent parking or stopping of vehicles on the acceleration portions of the shoulders in the vicinity of the interchange.

At these locations, a definite improvement is noticeable over the sites previously considered. This improvement can be attributed to better curvature and better designation of the entrance (solid white shoulder-lane line discourages swinging into through lane).

On the most modern design, opened to traffic only in the spring of 1956, a great improvement over the prior designs is noticeable. There seems to be in this design little hazard to the entering movement. Some improvement might still be possible on the entering ramp to induce people to stay on the shoulder until acceleration is completed.

But the possible interference on the shoulder between accelerating and decelerating or stopped vehicles has gained in importance at these sites, and could develop into a hazard because of the relatively high speeds and the divided attention of drivers who are trying to enter the main roadway.

To remove this possible difficulty, stopping on the shoulder at these locations should be discouraged. This can be accomplished by signs, or by adding a stopping lane. The last suggestion would in actuality make the acceleration lane a separate lane in addition to the shoulder.

COMPARISON WITH QUANTITATIVE METHODS

In addition to the "direct evaluation" of the acceleration lanes, evaluations by three quantitative methods were made. The results obtained by these other methods are used here to serve as a basis for discussion of the proposed direct evaluation method.

Traffic performance data, represented by speed and lateral position *vs* distance from ramp nose, were obtained by each of the alternate methods at all acceleration lanes included in the example.

The first of the three methods is called manual data collection, because the information was obtained by observers without aid of any special instrumentation. For this evaluation both speed and lateral position at several stations at predetermined distances from the ramp nose (point of joining of ramp and through roadway) was noted on prepared data sheets. Lateral position was determined easily with respect to pavement edge or dividing line between shoulder and first through lane. Speed was estimated whenever the accelerating car passed one of the stations. Although this estimation may not have been absolutely correct, it proved to be a reliable indication of the through traffic stream. Furthermore, each car was timed at the ramp nose and at each station. In this manner an average speed between stations was obtained.

The second method employed serial photographs, taken with a high-powered telephoto lens along the acceleration distance of the highway. Pictures were taken every 5 sec; in the evaluation both lateral and longitudinal positions of the cars in each picture were determined and speed was then calculated.

The third method consisted of traffic

observations from a moving car. Cars moving through the test section were trailed by the observing car and pictures were taken as the test car passed certain stations along the acceleration distance. The camera was mounted inside the observation car and showed superimposed on each picture a view of speedometer, odometer, and time. It was thus possible to determine from the photo the lateral position and speed of the car at that instant.

The results of the traffic observations at each site by the different methods are presented in comparable form as curves of speed and lateral position *vs* distance from the ramp nose at each entrance. The individual curves obtained by each method are presented together in one graph for each design period. The curves combine the results obtained from the two acceleration lanes studied for each design period (Figs. 3, 4, and 5).

Based on these curves, the evaluation

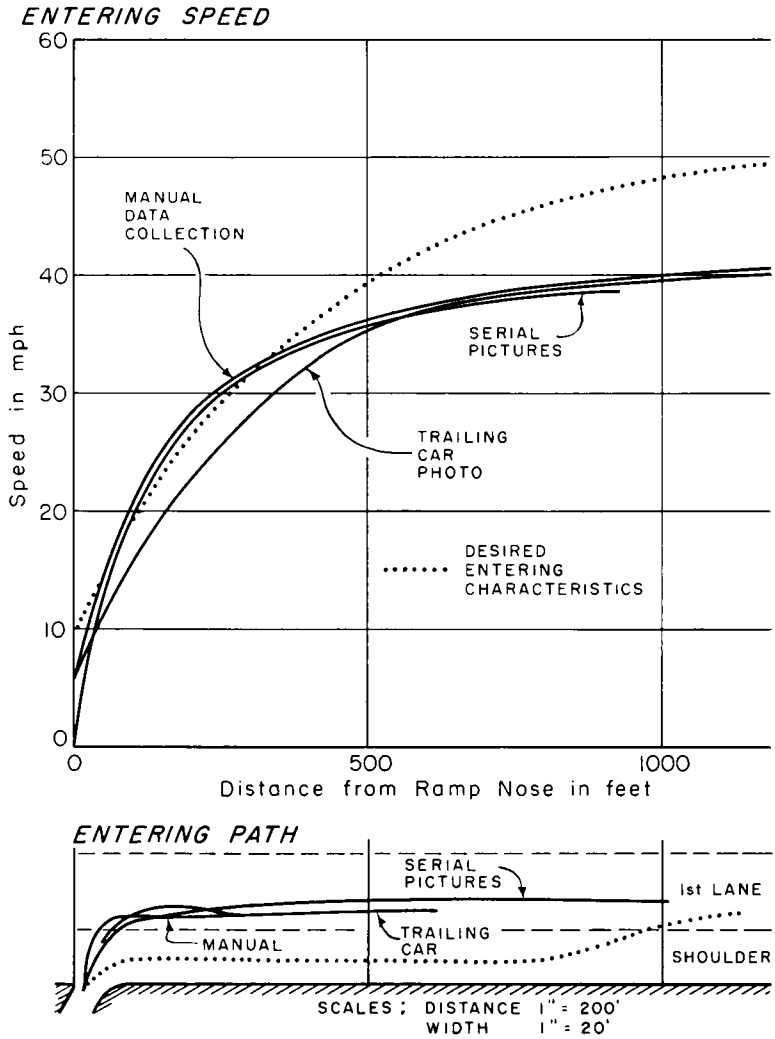

Figure 3. Comparison of results of different evaluation methods; 1936 design (entrance Route 128 SB from Route 114 NB).

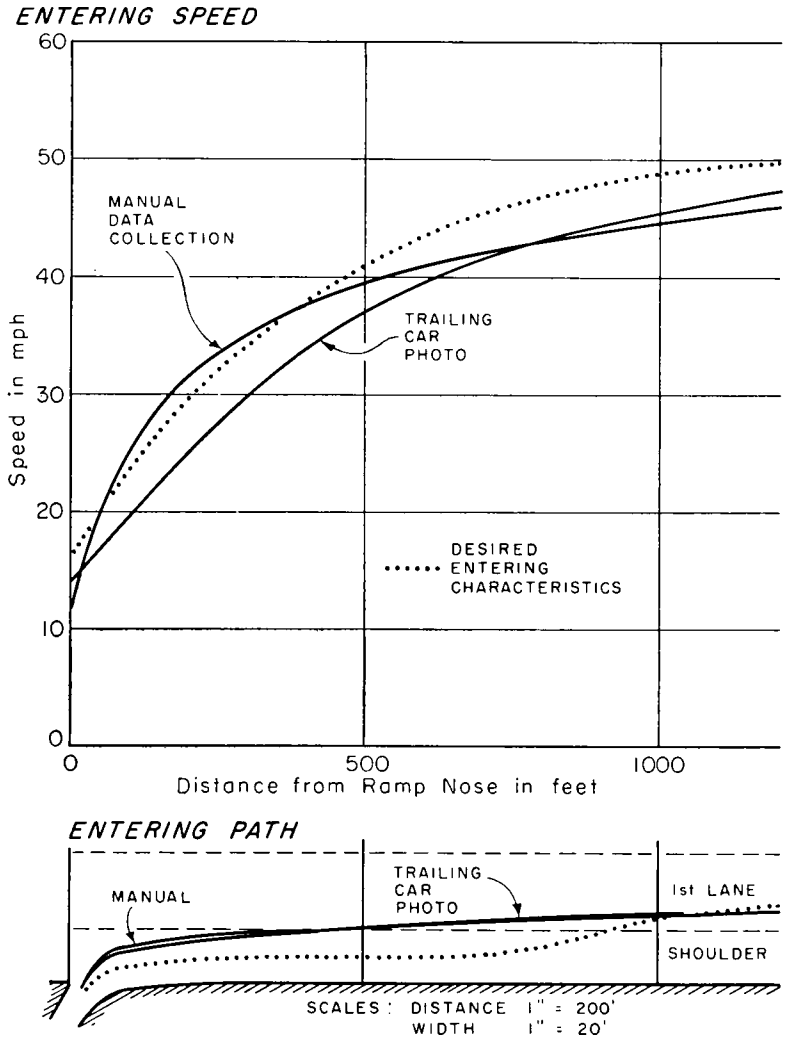

Figure 4. Comparison of results of different evaluation methods; 1952 design (entrance Route 128 NB from Route 20 EB).

of the acceleration lane design is obtained in two steps, as follows:

1. The intention of the design, or the optimum desirable traffic performance, is superimposed on each curve (dotted curve).
2. From the difference between intended and actual performance (full lines) the necessary improvements in the design are deduced.

The optimum traffic performance is defined by the condition that entering cars do not move into the through traffic stream until they have almost reached the through traffic speed.

Considering the acceleration lanes of 1936 design, no acceleration takes place before the car enters the through traffic lane. It is necessary at this location either to increase the actual entrance speed from 10 to 35 mph, or to retain the cars on the shoulder (acceleration lane) for about 1,000 ft, or a combination of both.

On the 1952 design, traffic performance

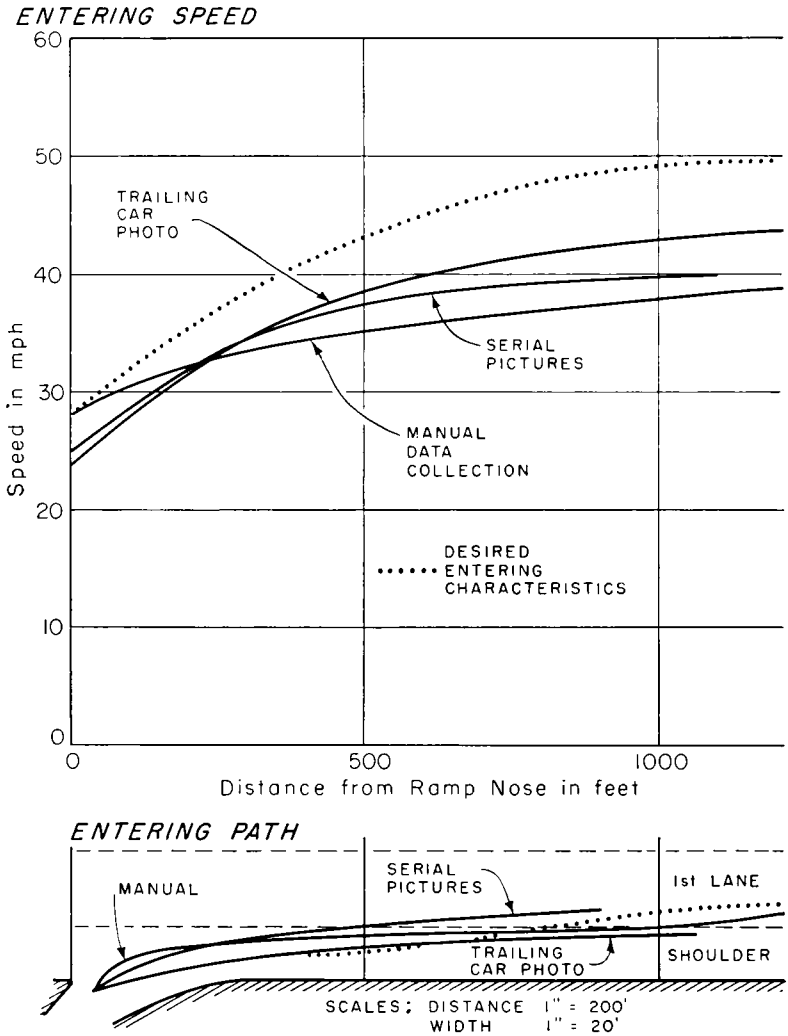

Figure 5. Comparison of results of different evaluation methods; 1955 design (entrance Route 128 NB from Highland Ave. EB).

is somewhat better, but still needs improvement. The evaluation results show that some cars still enter directly into the through lanes at the ramp nose.

The 1955 design has a partial barrier between acceleration and through lanes. The results show that traffic performance is nearly ideal on this design. Observation, however, does indicate a new hazard developing between entering cars and stopped cars, or decelerating cars, or decelerating cars and accelerating cars both using the shoulder.

RESULTS

The example demonstrates that satisfactory results can be obtained with direct evaluation of geometric highway dedesign. The improvement suggestions deduced from all methods of evaluation are essentially the same.

The proposed method offers a fast and reliable evaluation of design if a competent observer follows a standard procedure. The observer should be experienced in design and traffic engineering.

EVALUATION OF GEOMETRIC HIGHWAY DESIGN

FEATURE CHECKED .....

DAY OF WEEK ..... DATE ..... TIME: .....

ROUTE ..... TOWN .....

STATION ..... LOCATION .....

OBSERVATION DISTANCE ..... FEET. WEATHER .....

☐ PHOTO
☐ MAP } ON BACK OF SHEET (FIG. 9A)

1. DESCRIPTION OF TRAFFIC PATTERN

SUPPORTING EVIDENCE

☐ TRAFFIC STAIN ☐ TIRE MARKS ☐ TRAFFIC COUNT

☐ SAND PATTERN ☐ SNOW MARKS ☐ TRAFFIC OBSERVATION

2. "CRITICAL DIFFERENCE" BETWEEN ACTUAL AND DESIRED PATTERN

3. RANGE OF VARIATIONS IN ACTUAL TRAFFIC PATTERN

4. SUGGESTED CHANGES IN DESIGN OBSERVED

5. REMARKS FOR IMPROVEMENT OF DESIGN STANDARDS

NOTE: ACTION TAKEN DATE

P H O T O

VIEW OF TEST SECTION FROM OBSERVATION POINT

—— ACTUAL } TRAFFIC PATTERN
..... DESIRED }
X OBSERVATION POINT

SUGGESTED SCALE:
1" = 200' LONGITUDINAL
1" = 40' TRANSVERSE

PLAN (AND PROFILE) OF TEST SECTION

Figure 6. Standard form for direct evaluation, showing (left) front, and (right) back.

The evaluations can be an important aid to the design department if made on a routine basis as soon as possible after every new design has been opened to traffic.

With a continuous file of evaluations available, the designer can correct deficiencies much more readily than has been possible in the past.

RECOMMENDATIONS

It is recommended that direct evaluations of various design features be made on a routine basis by highway departments. The observer should be a responsible member of a design division, preferably with experience in traffic engineering. It is suggested that he follow a standard procedure such as outlined herein and shown in the proposed evaluation form (Fig. 6).

Evaluations should be made after each design is opened to traffic, allowing only sufficient time for traffic to become stabilized. The checks should be repeated at intervals as traffic patterns change.

With such a continuous file of evaluations available, the designer can correct deficiencies much more readily than has been possible in the past. Factual evidence can be used to support good designs and eliminate poor ones.

ACKNOWLEDGMENTS

This paper is based on a part of a thesis "Methods for Evaluating Geometric Highway Design with Application to Acceleration Lanes" submitted by the senior author in partial fulfillment of the requirements for the degree of Doctor of Science at the Massachusetts Institute of Technology, March 1957. The work was done under the sponsorship of the Joint Highway Research Project of the Massachusetts Institute of Technology and the Massachusetts Department of Public Works.