

Effects on Speed and Accidents of Improved Delineation at Three Hazardous Locations

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Delineation has been recognized as a useful tool in attempting to counteract the decrease in visibility attendant with the hours of darkness. In some circumstances it can be used as an inexpensive substitute for illumination. Little work has been done, however, in regard to the relationship between visibility, speed, and safety.

This paper reports the results of a study at three distinctive locations of the combined effect of various forms of delineation on driver speed patterns and on accidents. The locations concerned were a narrow bridge, a hazardous intersection, and an adequate intersection, all in rural areas. The various forms of delineation under consideration were roadside reflectors, pavement edge lines, signing, and, in one case, channelizing islands. Only free-moving passenger cars traveling on dry pavement under optimum day or night visibility conditions were considered in the speed study. In the case of one location heavy commercial vehicles were also recorded; however, speed patterns for cars and trucks were analyzed separately. Spot speeds were recorded, using Electro-matic radar speedmeters, at various points at each location during the day, at night, and again at night after the additional delineation had been installed. From 30 (for heavy trucks) to 300 or more observations, depending on the estimated variability of the speeds and prevailing traffic volumes, were made for each movement.

Accidents were also analyzed for a like period before and after placing the delineation, with proper delineation maintained during the after period.

The results were variable, but indicated a slight increase in speed and a slight reduction in accidents after the delineation.

●THE MAJOR LIMITATIONS on the speed of a vehicle are those imposed by the driver, by limitations of the vehicle, or by legal statute. There are many locations, however, where the characteristics of the highway do, or should, impose an additional limit on speed, particularly at night when visibility is sharply decreased.

It has been shown by many researchers that most drivers vary their driving characteristics according to existing conditions rather than according to traffic controls. It follows that motorists must be made aware of highway and traffic conditions before they can react to them. Although warning signs, advisory speeds and other information are posted at many hazardous locations, the information on conditions ahead may not be adequately supplied to the motorist at all times.

Where there is doubt as to the nature of conditions ahead, caution would dictate a policy for the driver of going slow. Most drivers, however, prefer to drive at a uniform speed, and when they do not know of conditions ahead, continue at a speed too great for conditions, not realizing the hazard until too late. Such situations are especially prevalent at night when visibility is restricted and motorists are traveling at a

high speed. The hazard of the situation is further increased by the large speed differential which exists between the overly cautious motorist and the incautious one.

One remedy for this situation would be to attempt to reproduce daylight conditions by means of highway illumination, as in urban areas. The cost of providing adequate illumination for a large extent of the rural highway system is, however, prohibitive. Some other means of enabling the driver to "see ahead", therefore, needs to be provided at many locations.

A method which has found considerable favor is the use of roadside reflectors, pavement edge lines, and other media as aids to the discernment of the course of the roadway. These devices serve not to illuminate the roadway but to outline or delineate it.

It has been found that the installation of illumination at high accident intersections has reduced the night accident rate at many of these locations. In addition to enhancing visibility, lighting may serve as a warning indication, thus alerting the driver to critical areas. The distant lamps at an illuminated intersection may also indicate to the approaching motorist the alinement of the roadway ahead.

Delineation also provides advance warning and an indication of the roadway and contributes to motorist recognition of conditions ahead.

SPEED-VISIBILITY STUDIES

This study was the first of several which are planned by the Joint Highway Research Project at Purdue University to investigate the relationship between visibility and speed at roadway friction points. This initial study was concerned with the effect of delineation on speed patterns and accidents at three hazardous or potentially hazardous rural locations: a narrow bridge, an inadequate intersection, and an adequate intersection. Illumination was eventually planned for these locations and a comprehensive study in the area of speed and visibility was developed for the period prior to and subsequent to the date of illumination.

DESCRIPTION OF STUDY

Variables

The various forms of delineation used in this study were roadside reflectors (delineators), pavement edge lines, signs, and, in one case, channelizing islands.

The types of vehicles studied were passenger cars and, at one location only, heavy trucks (primarily semi-trailers).

Only free-moving through vehicles were recorded at each location, a free-moving vehicle defined for the purposes of this study as one whose speed was not affected by the immediate presence of other vehicles in its path. In accordance with this definition, only the lead vehicle in a platoon was recorded. The minimum allowable headway for a following vehicle to have been considered free moving was about five seconds. Vehicles in the act of passing, or initiating or completing a pass were also not included in the sample. Similarly, vehicles which were not traveling at a free-moving speed because they had just turned onto, or were about to turn off, the through roadway were not included.

The major variable under investigation for the study reported in this paper was the degree of delineation. Accordingly, speeds were measured under three conditions: during daylight hours with existing delineation (considered to be the condition of optimum visibility), at night with the existing delineation, and again at night after additional delineation had been placed (the condition of optimum practical delineation). These three phases of the study were known, respectively, as the day, night-before, and night-after phases.

To further reduce the number of variables, data were collected on week days only and, as far as possible, at the same time each day. Data collection took place only when the pavement was dry, and under optimum atmospheric conditions (that is, absence of fog or haze). For the before phases, measurements were taken in the afternoon with data collection ceasing not later than one hour before sunset and at night after darkness was complete. The before phases were conducted during the months of July and August

1958. Optimum delineation was then placed and speed data for the after phases were collected in September and October 1958.

Equipment

Spot speeds were recorded by means of radar speed meters at various points along the roadway legs approaching the study locations. The radar meters were placed well back from the pavement so that the effect of their presence would be negligible. A result of this precaution was that the radar meter indicator readings represented only a component of the true vehicle speed. To correct for this factor, for calibration corrections, and for errors due to continuously changing voltage, a control car was constantly used. Comparisons between the control car's accurate speed and the corresponding meter indication yielded corrections for the remainder of the data.

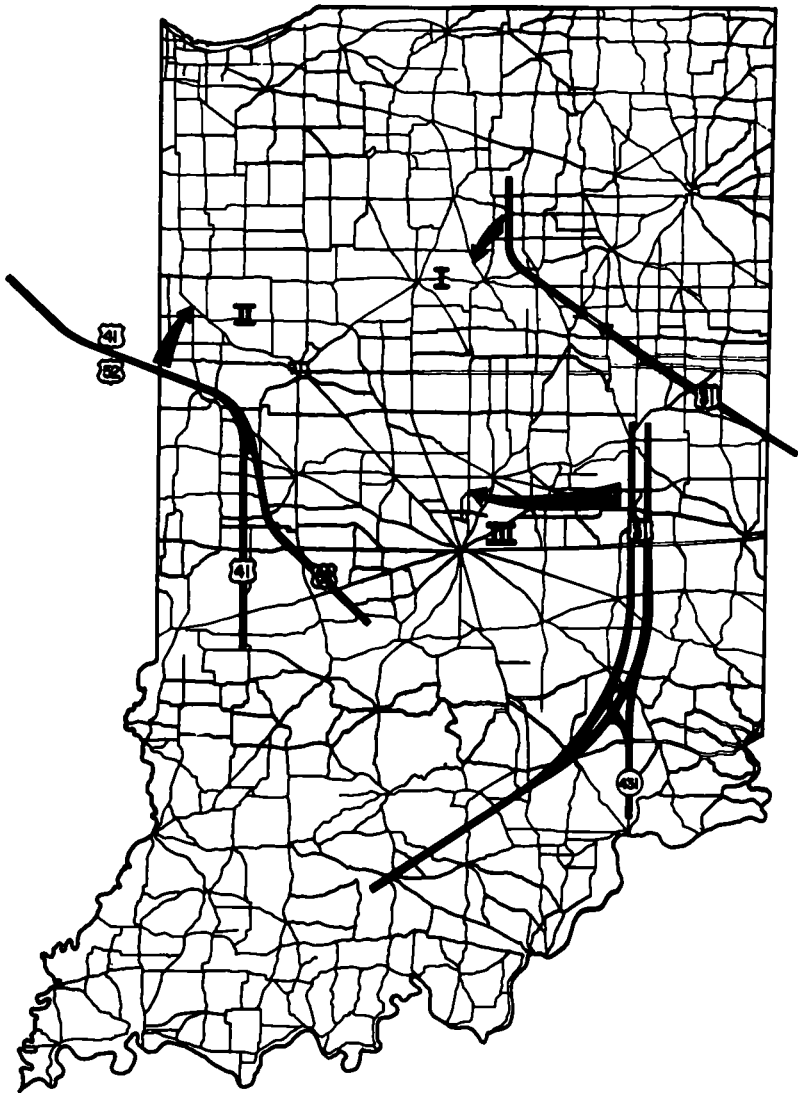


Figure 1. Study locations.

Speed Measurement Stations

Those points at which speeds were measured were termed stations and were situated in predetermined zones. On each roadway leg connecting with a study location, one station was operated at a point far enough removed from the immediate site of the study location so that motorists at that point could not see the changes in delineation. The purpose of these stations was to obtain data on the normal (open-highway) speeds of vehicles approaching or leaving the locations. These were termed, respectively, open-

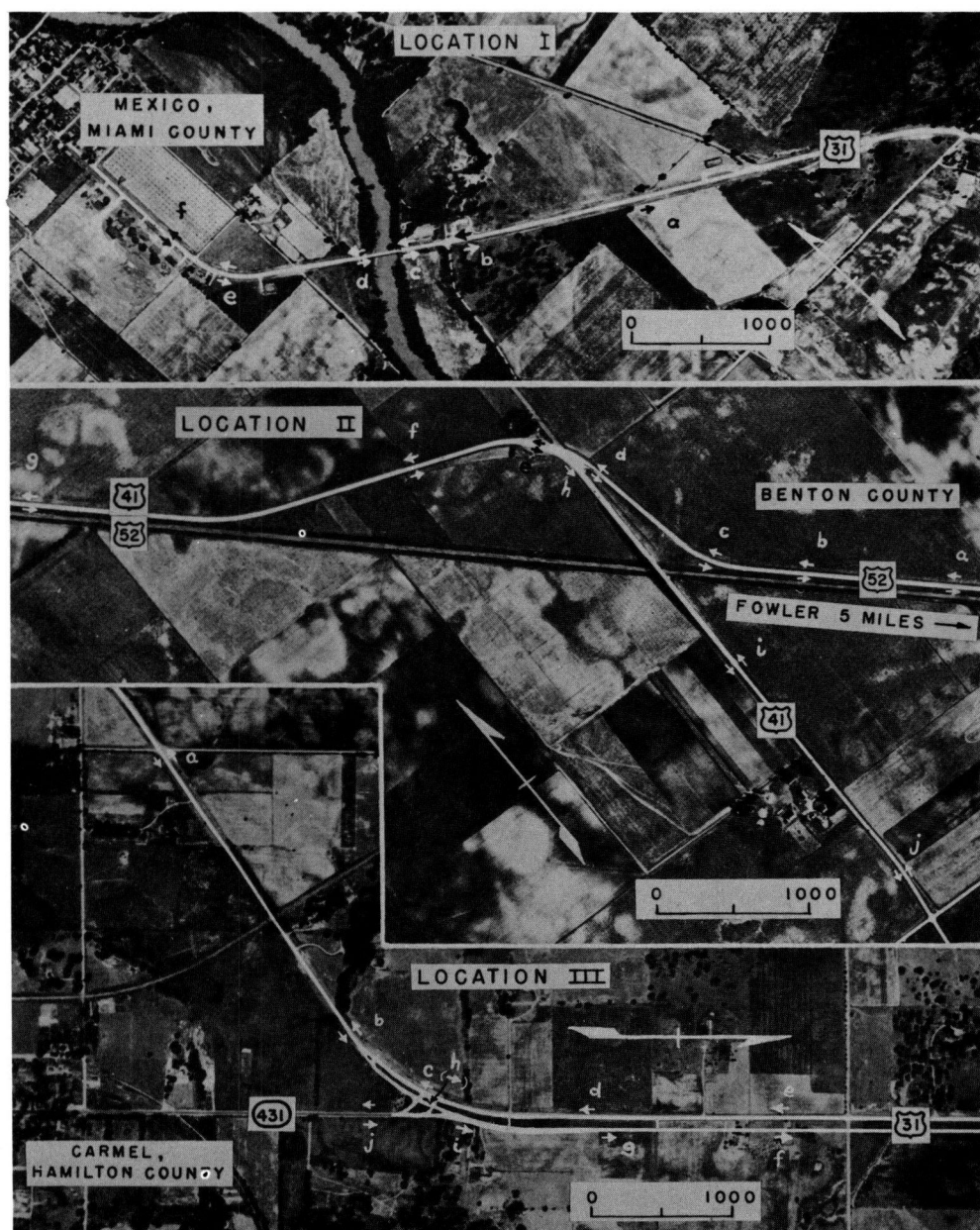


Figure 2. Study locations showing speed measurement stations.

highway approach and open-highway leaving stations in zones of the same name. The open-highway approach stations were also control stations as vehicle speeds at these points should not have been affected by any changes in delineation.

Other stations were operated in the approach and recovery zones 500 to 1,000 feet on either side of the study location. Finally, one or more stations were operated at the entrance, exit or center (whichever was most feasible) of each specific study loca-

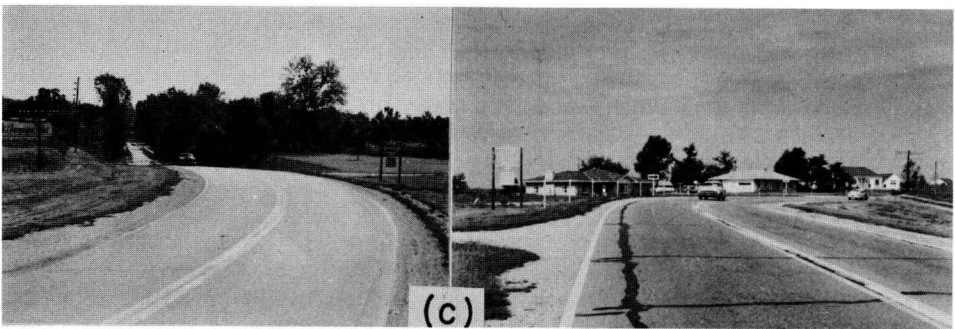
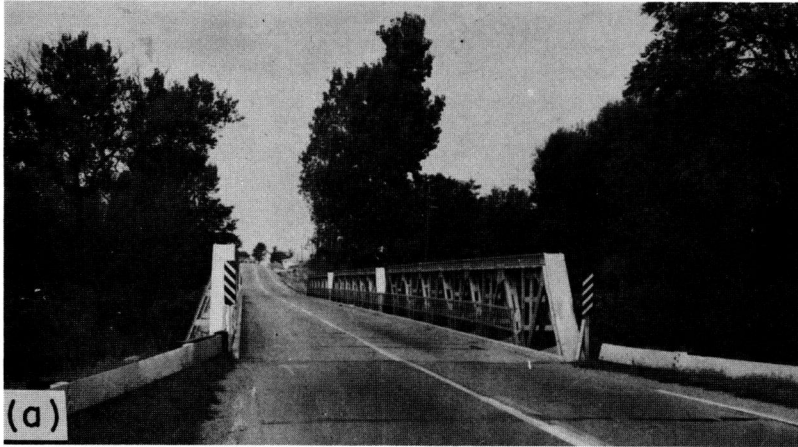


Figure 3. Location I: (a) entrance to bridge from south, (b) approach to bridge from south, and (c) curve north of bridge.

tion. These were grouped together for the analysis and are referred to as "critical" stations.

In consideration of a possible future illumination study, stations in the approach and recovery zones were situated so as to coincide with the probably limits of future illumination.

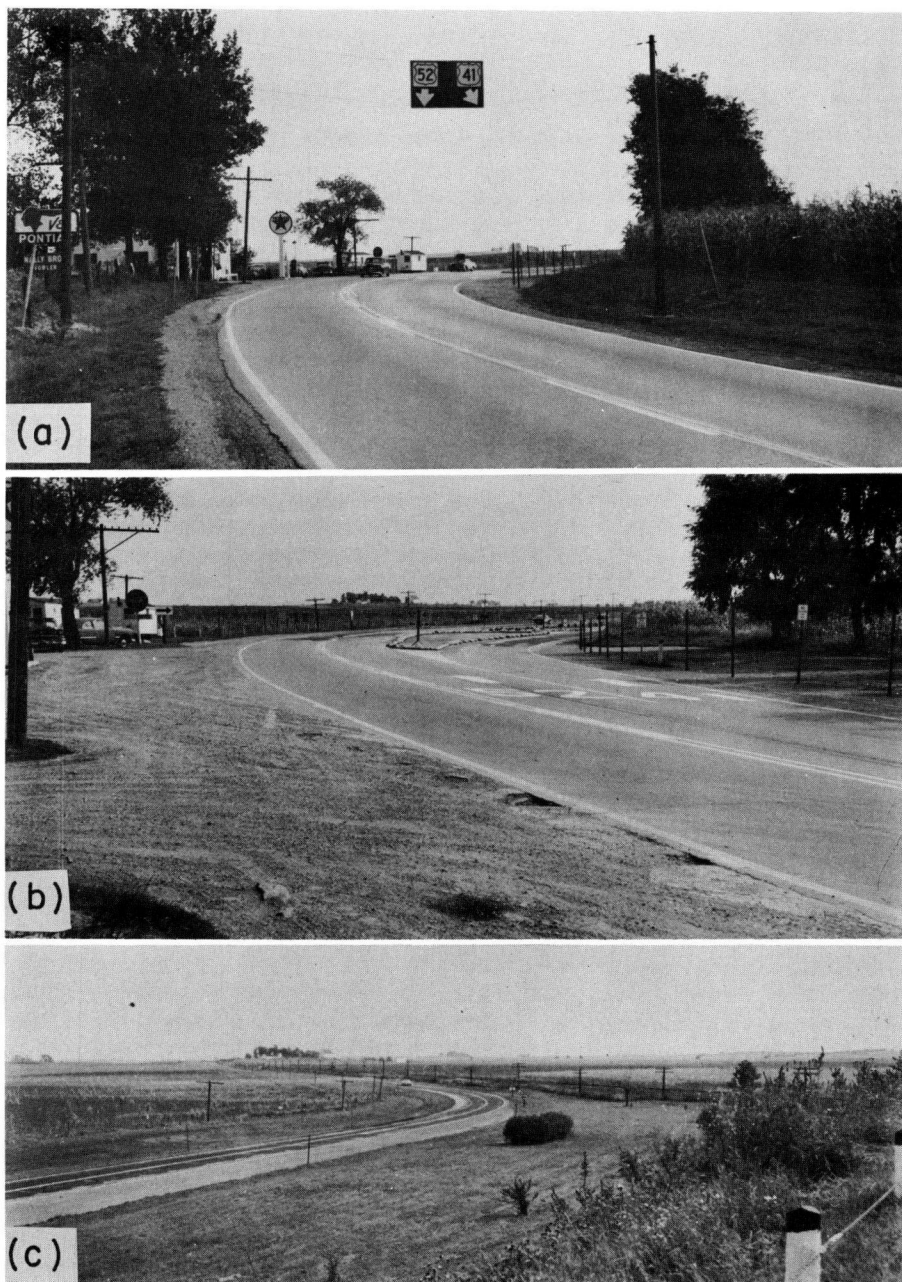


Figure 4. Location II: (a) approach to intersection from north, (b) intersection with temporary islands in place, and (c) curve south of intersection.

STUDY LOCATIONS

Figure 1 shows the outlines of the three study locations in relation to Indiana's highway system. Aerial views of the three study locations are shown in Figure 2. The lower case letters identify the speed measurement stations and the arrows indicate the directions in which speeds were measured.

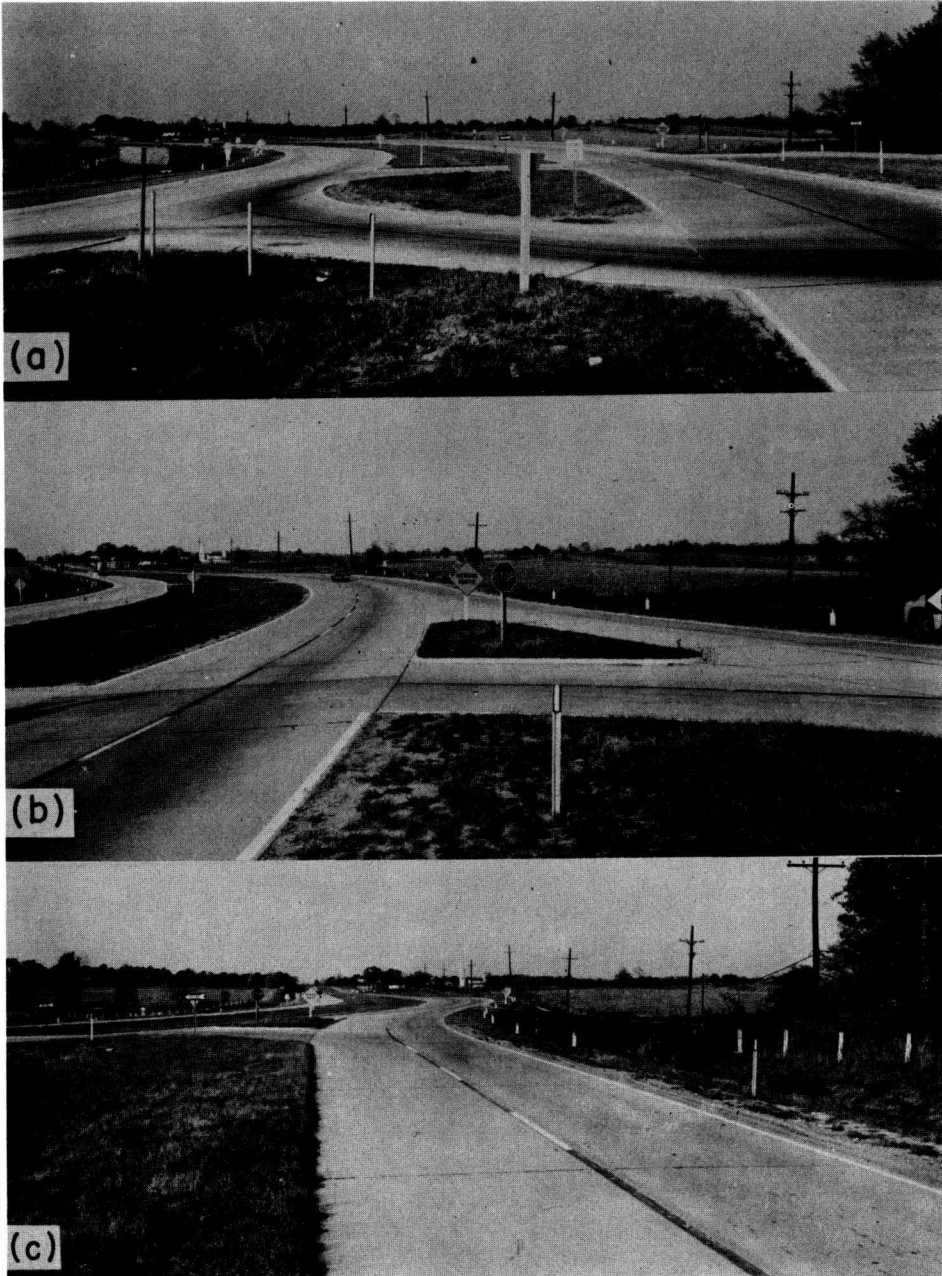
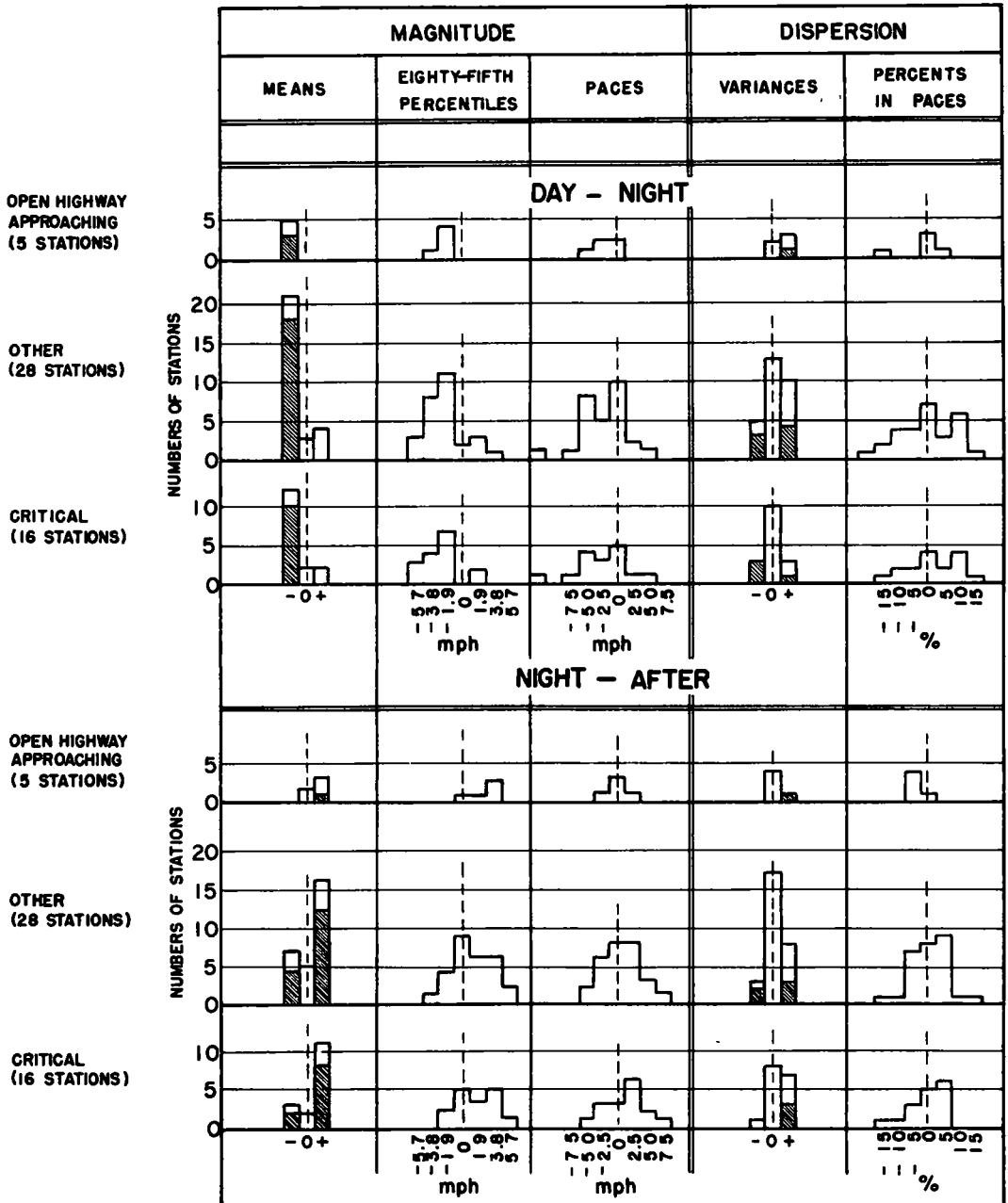


Figure 5. Location III: (a) center of intersection, (b) merging area for traffic traveling north, and (c) approach to intersection on State Route 431.

FREQUENCY POLYGONS

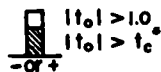
CHANGES IN PARAMETERS

PASSENGER CARS



LEGEND:

Means



Variances



* i.e. significant at 5% level

Figure 6. Frequency diagrams for passenger cars.

Location I

Location I is a narrow bridge on a 2-lane section of US 31. The bridge is 256 feet long and 3 feet narrower than the adjacent roadway. The size of the trusses and their proximity to the roadway accentuate the feeling of constriction. Beyond the bridge in one direction is a 5 percent grade at the crest of which is a horizontal curve. The new delineation installed at this location consisted of edge lines throughout the area and supplemental delineators on the curve. No-passing barrier lines on the bridge approaches were also extended and the bridge centerline and curbs were painted yellow. Figure 3 is a view of the approaches to the bridge.

Location II

Location II is the southern junction of US 41 and 52, both of which are 2-lane highways in this area. Both routes are relatively straight in alinement in advance of the intersection, but at this point US 52 makes a semicircular arc so as to connect in a Y intersection with US 41 as it descends from a railroad overpass. Travel through this section is complicated by the presence of fairly sharp curves to the north and south and at the intersection itself. Further hazard arises from the fact that the two roadways merge at a very small angle resulting in a wide expanse of paved area at the junction. Because of this large open area and poor sight distance on the inside of the curve at the intersection, southbound drivers had difficulty in locating their proper route.

Edge lines were placed throughout this area and delineators were placed on the curves and on the approaches to the intersection. Directional and warning signing was also improved. Figure 4 (b) is a view, facing south, of the center of the intersection curve showing the channelizing islands which were added at the intersection to reduce the open area and to outline the traffic ways for the two routes.

It was only at Location II that trucks were present in sufficient numbers to permit including them in the study.

Location III

Location III is the junction of US 31, a four-lane divided highway, and State Route 431. US 31 becomes a two-lane highway 800 feet southwest of the intersection. The intersection is a recently constructed, channelized, bulb-type, Y intersection and is considered to be a good design. Although this intersection is also on a curve, the curvature of the through roadways is about 3 and 4 degrees and sight distances are adequate. Delineation changes at this location consisted primarily of the addition of edge lines and delineators. Figure 5 shows three views of this intersection.

ANALYSIS

For each station by direction of travel and condition of delineation, the mean speed and the variance of the spot speed distribution were calculated.

Statistical tests of significance were performed on the observed changes in mean speeds and variances at each station between phases of the study. Frequency polygons for qualitative observation were also constructed for stations in different types of zones. These frequency polygons for the speed parameters of passenger cars are shown in Figure 6. The classes for the means and variances labeled -, 0, + indicate a decrease, no change, or increase, respectively. The shaded portions for the means and variances denote the number of stations where the statistical test indicated evidence of an actual change in the parameter at the five percent level of significance. The unshaded portions of the - and + classes indicate the number of stations where the absolute value of the *t* statistic used in the test on the difference of means was 1.00 or more and the absolute value of the *F* statistic used in testing the variance was 1.2 or more. This was incorporated into the analysis as a further aid in spotting any trends. The criteria chosen correspond to a lower level of significance (roughly 30 percent).

The observed *t* statistics used in testing the differences between means were also regarded as random variables and the average for each of the types or combinations of zones calculated. The first series of tests along these lines was designed to deter-

mine, to a specified probability, whether \bar{t}_0 (the mean t statistic for all stations in a zone class) differed from zero for the individual zone; that is, to determine whether there was any statistical significance to the apparent changes in mean speeds for each zone between conditions of the study. (A second series of tests along these lines is noted in the section on "Results of Speed Study".)

The 85th percentile speeds, pace and percent in pace were also graphically illustrated by frequency polygons (Fig. 6). In Figure 6 the changes from the day to night-before and night-before to night-after conditions are grouped on the basis of the change experienced. For example, a change in the pace from 36-46 mph to 34-44 mph was a change of minus 2 mph in the pace and would have been included as one of the stations plotted under the minus 2.5 grouping. Similarly a change in the percent in the pace from 55 to 65 percent was recorded as a plus ten percent change and would be plotted under plus ten percent, while an increase in the 85th percentile speed at a station from 46.0 to 46.3 mph, a plus 0.3 mph, would have placed that station in the zero-mph change group. All groups are identified by the midpoint value of the change for that group. These polygons were prepared to determine the character of the changes in these characteristics for each of the phases of the study.

Figure 6 shows, by number of stations, the frequency polygons of changes which occurred in the parameters for passenger cars from day to night, and from night-before to night-after, at stations in the open-highway approach zones; all other stations (the approach, recovery and critical zone stations) and the critical zone stations alone.

Speed profiles of mean speeds at each location were also drawn and are shown in Figures 7, 8, 9, and 10.

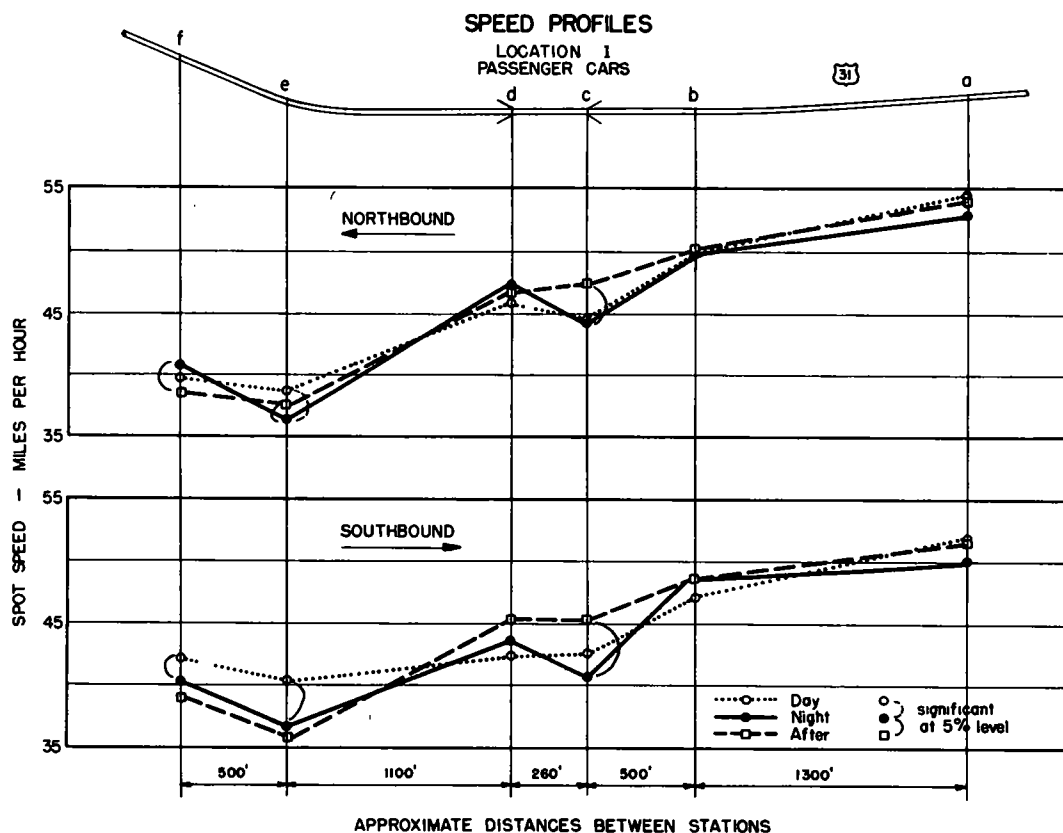


Figure 7. Speed profiles — Location I, passenger cars.

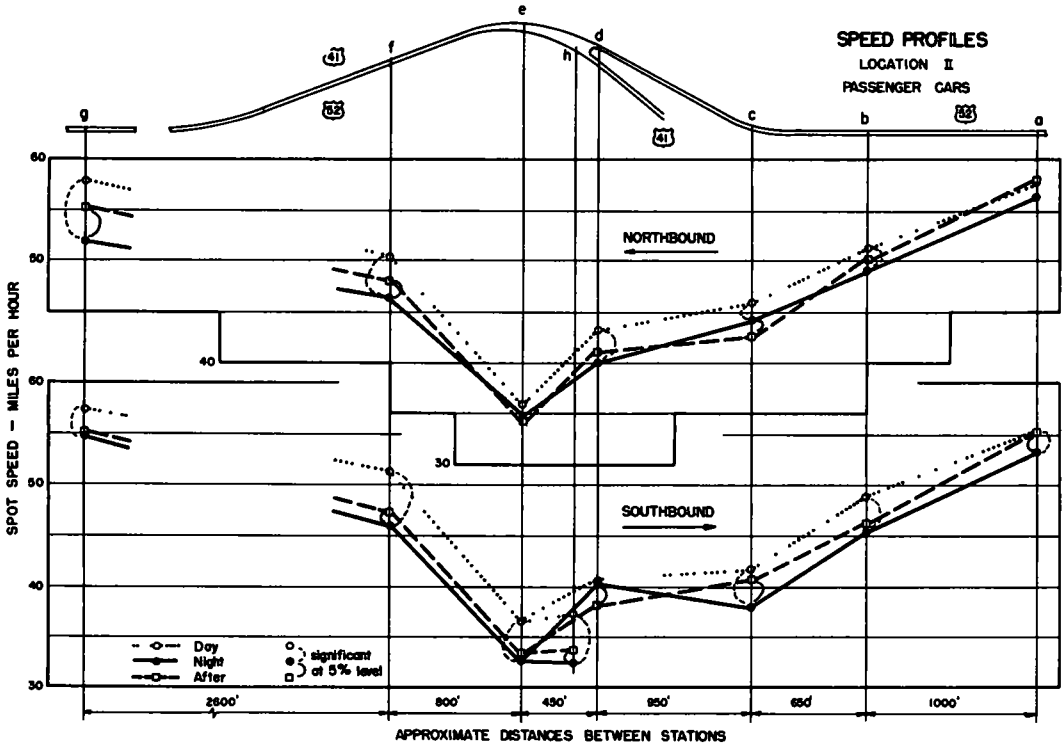


Figure 8. Speed profiles — Location II, passenger cars.

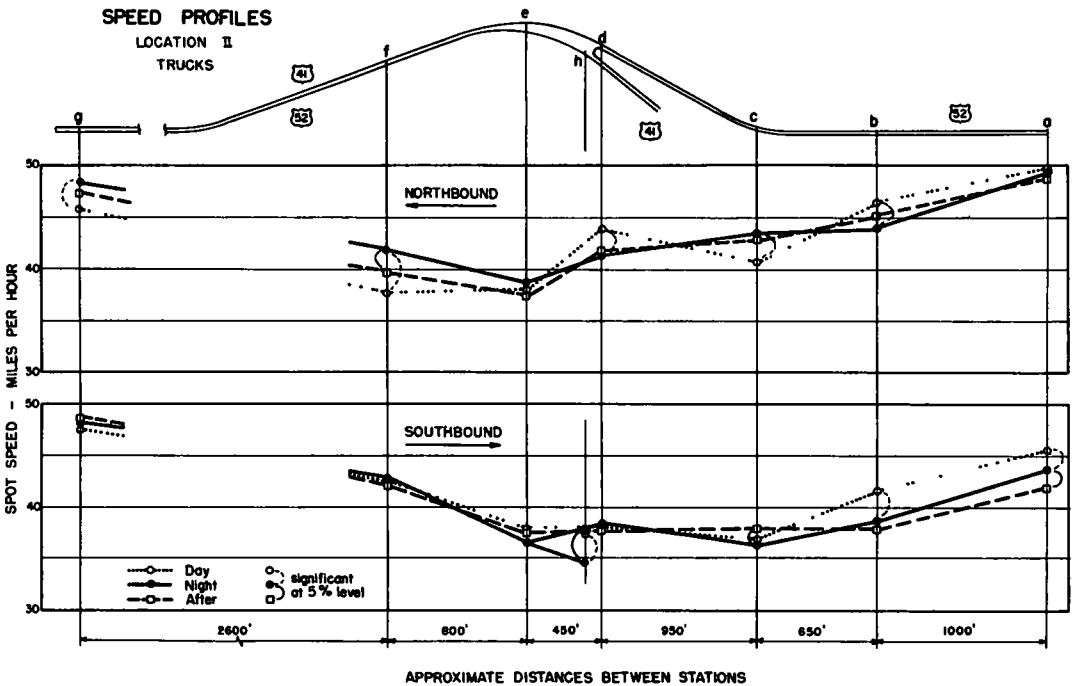


Figure 9. Speed profiles — Location II, trucks.

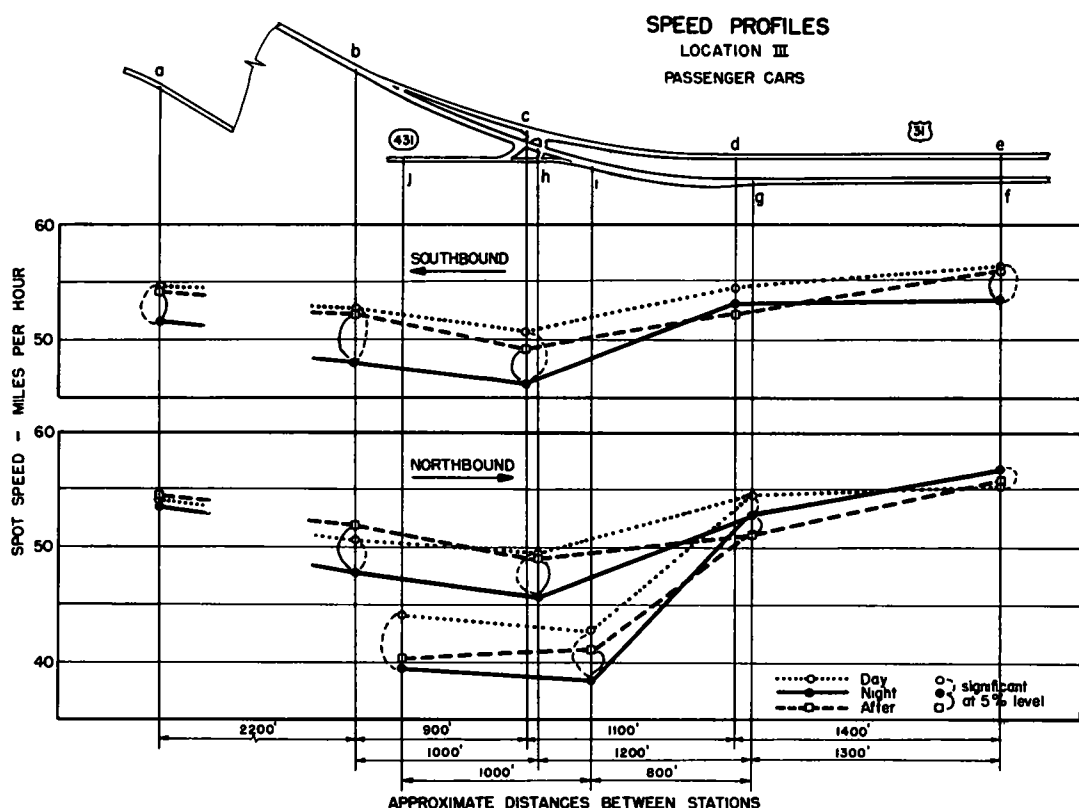


Figure 10. Speed profiles — Location III, passenger cars.

RESULTS OF SPEED STUDY

Inspection of the frequency polygons indicated that mean speeds of passenger cars tended to be less at night than during the day, with the decreases ranging from 1 to 5 mph. Statistical tests on the zones indicated that, at the five percent level of significance, there was sufficient evidence to conclude that night mean speeds were lower than day mean speeds for all zones except the recovery and open-highway-leaving zones. (The test on the latter was significant at the ten percent level).

The effect of darkness on truck speeds, however, was not consistent, with increases as well as decreases observed.

With the added delineation in place, mean speeds of passenger cars showed a tendency to increase slightly at the critical zone but were inconsistent in the other zones. Statistical tests on the zones yielded sufficient evidence at the five percent level to conclude that mean speeds were slightly higher with the added delineation than without it for all zones except the approach and recovery zones.

Truck mean speeds were not affected by the added delineation.

There also did not appear to be any significant effect on the variances of spot speed distribution due to the day, night, and added delineation factors. The results of statistical tests on the variance of the combined truck and passenger car spot speed distributions at the location where both trucks and cars were studied also showed no significant effect.

Observation of the frequency polygons indicated a slight decrease in the 85th percentile speed and a slight decrease in the pace for the day to night-before condition and a slight increase in the 85th percentile speed for the night-before to night-after condition. Observation also indicated no important changes in the pace for the night-before to

night-after condition and in the percent in the pace for any conditions.

Inspection of the speed profiles (Fig. 7, 8, 9, and 10) showed no consistent effect of delineation on acceleration or deceleration rates through the locations. In many places, acceleration and deceleration were apparently delayed or diminished in rate after the addition of delineation. However, in those cases where the delineation resulted in a decrease in speed at a critical feature it was because the opposite was true — the deceleration rate, and often the acceleration rate beyond the feature, was greater.

There was evidence, however, of an increase in speed at the open-highway approach zones where the added delineation should not have had an effect. Because this could have been due to a normal increase in speed during the period of the study, it was desired to determine whether there were any differences in degree between the speed changes at each type of zone. Additional statistical analysis was made of these differences, but the results were not illuminating, possibly because of the small differences being tested or the small number of stations in each class of zone.

It is suggested, however, that there may have been a slight change in the speed characteristics of the traffic being sampled between the times that the before-and-after field studies were conducted. This suspicion is strengthened by the results of Shumate and Crowther's study (18). Even if this possibility is discounted, it appears that the additional delineation tended to increase night speeds only slightly at some stations and in an amount that was not of practical significance.

ACCIDENT STUDY

Accident records for the three study locations were studied, for the 20-month period January 1, 1957, to August 31, 1958, prior to the addition of delineation and compared with a similar 20-month period January 1, 1959 to August 31, 1960. These two periods encompass the same variety of seasons.

A summary of the number of accidents for the two 20-month periods is given in Table 1. At Location I, accidents are only shown for the before delineation period as conditions at the location changed during 1960 when construction began on a new bridge to replace the existing narrow bridge. This, of course, is a better solution to this problem than delineation or illumination and was welcomed by everyone.

TABLE 1
COMPARISON OF ACCIDENTS

Location Number	Number of Reported Accidents	
	20-month Before Period	20-month After Period
I	11	^a
II	23	16
III	8	7

^aLocation removed from study due to construction of new bridge which replaced the hazardous narrow bridge, the subject of study.

Note: 20-month before period—January 1, 1957 to August 31, 1958

20-month after period—January 1, 1959 to August 31, 1960

At Location II there were 23 accidents in the before 20-month period, 9 of them at night. The accidents were mainly concentrated at the northern end of the intersection curve and at the junction. Seventy percent of all the accidents occurred under slippery pavement conditions. These data would seem to indicate that excessive speed for conditions played a large part in accident causation at this location.

In the 20-month period after delineation, 16 accidents occurred, of which eight were at night. Some reduction in accidents occurred in the former large open area,

which is now in the "shadow" of the island, and at the northern end of the intersection curve. Fifty percent of the accidents occurred when the pavement was slippery.

Of the nine night accidents in the before period, three resulted from failure to negotiate the north or south curves (under dry pavement conditions). The other six involved vehicles southbound on the intersection curve.

All eight night accidents in the after period occurred at the island channelizing northbound vehicles on US 41 into the intersection. Of these, four were involved in collisions with cross traffic as they attempted to enter the through highway. The other four came to grief at or in advance of the island.

In the before period there were eight accidents at Location III, four of them at night. However, there was no pattern to these accidents of a type susceptible to correction by delineation. Seven accidents occurred in the after period with four of them at night. As in the before period there was no pattern to these accidents.

These accident data were too limited and too nearly similar for the before-and-after periods to permit the drawing of conclusions. They are presented in the hope that the accumulation of evidence of this type in this and other studies will provide an indication of the safety value of delineation.

CONCLUSIONS

With few exceptions, night passenger car average speeds were lower than daytime speeds, most of the differences being in the range of 1 to 5 mph.

With added delineation, night passenger car average speeds showed a tendency to be slightly higher, particularly at critical points such as at the bridge, at the centers of the intersections, or on sharp curves. Such speed increases were probably of little practical significance. The average change for all stations was less than $1\frac{1}{2}$ mph.

The limited data for trucks showed no appreciable or consistent effects on speed due to conditions of visibility or delineation.

There did not appear to be any significant effect on the dispersion of speed due to conditions of visibility or delineation.

The results of this study suggest that the practical effects of delineation do not, at least in the case of the locations studied, manifest themselves in significant changes in speed patterns.

It is anticipated that an accident speed-illumination study will be performed at two of the sites reported on herein. Such a study should prove to be very profitable as it would compare speed patterns and accident rates under conditions of optimum delineation with speed patterns and accident rates under conditions of optimum lighting and delineation (inasmuch as some measure of delineation will be necessary even with illumination). The results of this planned accident-speed-illumination study when compared with the results of the study reported in this paper should provide important information on the relative value of optimum delineation and illumination at hazardous locations.

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