Effectiveness of Reflectorized Headlamps

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One factor which contributes to the well-established hazards associated with night driving is the problem of encountering vehicles with only one lighted headlamp. Attempts to alleviate problems of this type have included compulsory and voluntary vehicle inspection. However, the 1964 National Vehicle Safety Check of passenger cars found front headlights to be the second most prevalent defect.

Recent investigation into the problem of "one-eyed" vehicles has led to the proposed use of reflex-reflective materials included within a headlamp to act as a safety device. Should headlamp failure occur, reflected light would permit early discrimination of the unlit lamp position, thus affording positive vehicle delineation. A headlamp of this type has been developed which provides 6.9 candlepower per incident footcandle per unit at 0.2 degrees divergence and 0 degrees incidence, somewhat higher than the minimum value of 4.5 candlepower per footcandle value specified for Class A red reflex-reflectors by the Society of Automotive Engineers for identical conditions.

This paper reports the findings of a research study designed to evaluate the effectiveness of the reflectorized headlamp under realistic night driving conditions. The established parameter was the distance at which the unlit side of an approaching one-eyed car could be detected for vehicles equipped with reflectorized headlamps and for vehicles equipped with conventional headlamps. Variables considered were dry and simulated rain conditions, three rates of closure, and both sides of the vehicle.

Mean detection distances established were 472 ft and 288 ft for the reflectorized and conventional headlamp conditions respectively; the difference in means was highly significant. As expected, all detection distances during conditions of simulated rain were reduced, but relative values were maintained. Comparison of detection distances obtained for reflectorized headlamps to motorist perception-reaction distance established a significant improvement in time available for evasive action.

•ACCORDING TO published reports of the National Safety Council (1), the rate of motor vehicle fatalities during hours of darkness is 3 times as great as for daylight hours. It is well established that substantially reduced driver visibility, fatigue, and effects of alcohol are primary factors for this increased accident rate. Surveys in 3 states have shown that poor visibility is a causal factor in one-third of all night traffic accidents (2) and is an indirect, but certain, factor in a high proportion of the balance.

A hazard related to night visibility which has been recognized by both industry and safety officials is the meeting of an oncoming "one-eyed" car. Statistics of accidents

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related to this condition are not readily available; however, figures reported by the National Safety Council (1) indicate that improper lights were a contributing factor in approximately 36,900 accidents which occurred in 1964. Attempts to alleviate such problems have included compulsory as well as voluntary vehicle inspection in a number of states and cities, yet in 1964, following the voluntary national safety check of passenger vehicles, defective front lights were found to be the second most prevalent defect. A survey (3) of 2,800 cars operating on low beam found 1.64 percent with only one lighted headlamp. If this percentage exists nationally, there could be at any one given time 1.4 million automobiles constituting a hazard to the motoring public. Although long recognized as a hazard, the incidence of vehicles with only one lighted headlamp continues despite progressive efforts by enforcement agencies, safety officials, and others.

Recent investigation of the one-eyed car problem by a lamp manufacturer has led to the proposed use of reflex-reflective materials included within a headlamp to act as a safety device. Thus, if the headlamp were to fail, reflected light would permit earlier determination of the position of the one-eyed car. A reflectorized headlamp has been developed and this report presents the results of its effectiveness.

LAMP DESIGN

The reflectorized headlamp employs a specially designed reflex-reflective filament shield replacing the conventional shield of a low-beam lamp. Neither the position of the shield nor its design significantly change light output or distribution but provide effective reflex-reflection of the unlighted headlamp. The materials used in the reflectorized filament shield withstand the high operating temperatures in the vicinity of the tungsten filament without clouding the headlamp or shortening filament life. Although only the shield is reflex-reflective, reflection is obtained from the entire headlamp because of the parabolic shape of the reflector, as shown in Figure 1.

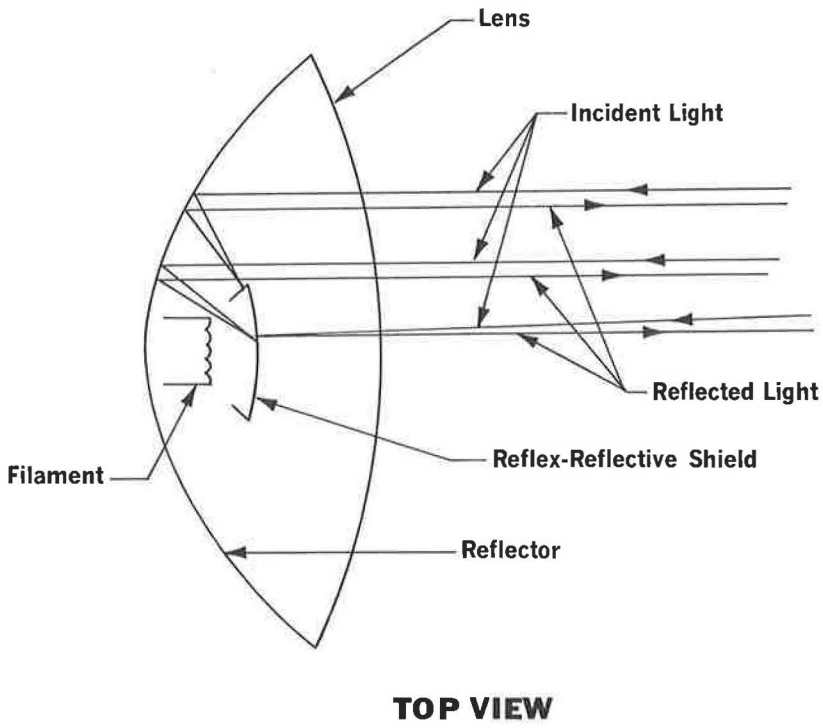

Figure 1. Schematic of reflectorized headlamp.

Using the procedures of Elstad, Fitzpatrick, and Woltman (4) and divergence angle tables by Johnson (5), it is possible to calculate the luminous intensity of the reflectorized headlamps used in this study. Figure 2 shows specific intensity in candlepower per incident footcandle per lamp as a function of divergence angle for the reflectorized headlamp, measured in accordance with photometric procedures established by the Society of Automotive Engineers (6). Distances used in the calculations are shown in Figure 3. At a distance of 472 ft, the mean detection distance for the reflectorized side of an approaching one-eyed vehicle, and an illuminance of 0.0043 footcandles, the luminous intensity of the reflectorized headlamp is 0.027 candlepower. This approximates the luminous intensity of a reflectorized headlamp which has burned out due to normal failure. Even higher luminous intensity is possible with further lamp modification.

The values of the reflectorized headlamp exceed the minimum requirements for Class A red reflex-reflectors as specified by the Society of Automotive Engineers (6). The SAE value at 0.2 deg observation angle and 0 deg entrance angle is 4.5 cp per ftc. The reflectorized headlamp value at the same observation and entrance angle is 6.9 cp per ftc (Fig. 2).

EVALUATION STUDY

The basic objective in evaluating the effectiveness of the reflectorized headlamp as a safety device was to determine if the distance at which the unlit side of an approaching one-eyed vehicle could be detected was greater for a car equipped with reflectorized

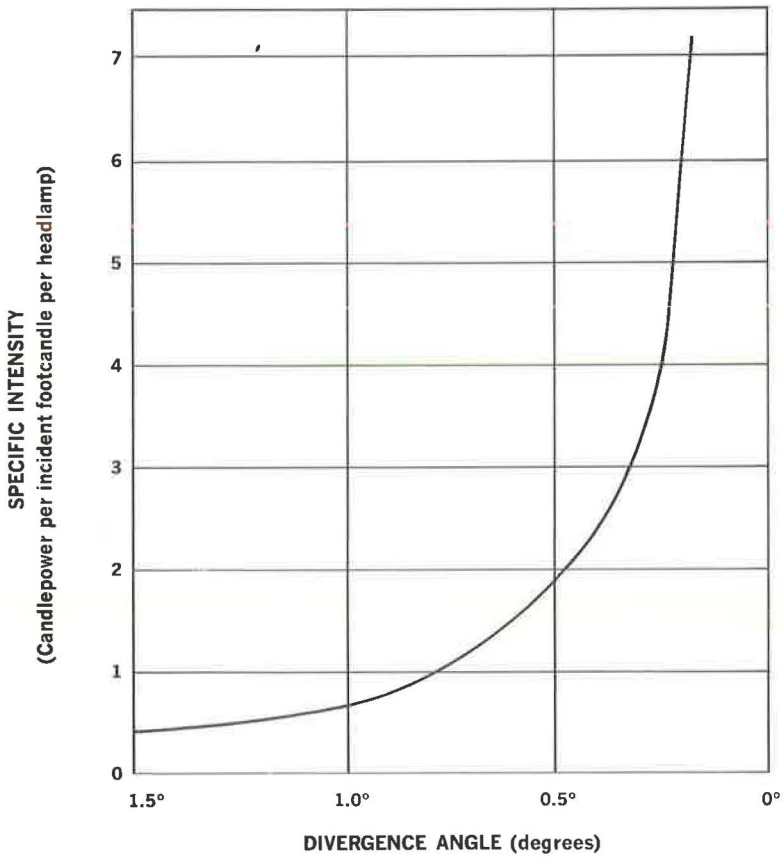

Figure 2. Specific intensity of a reflectorized headlamp as a function of divergence.

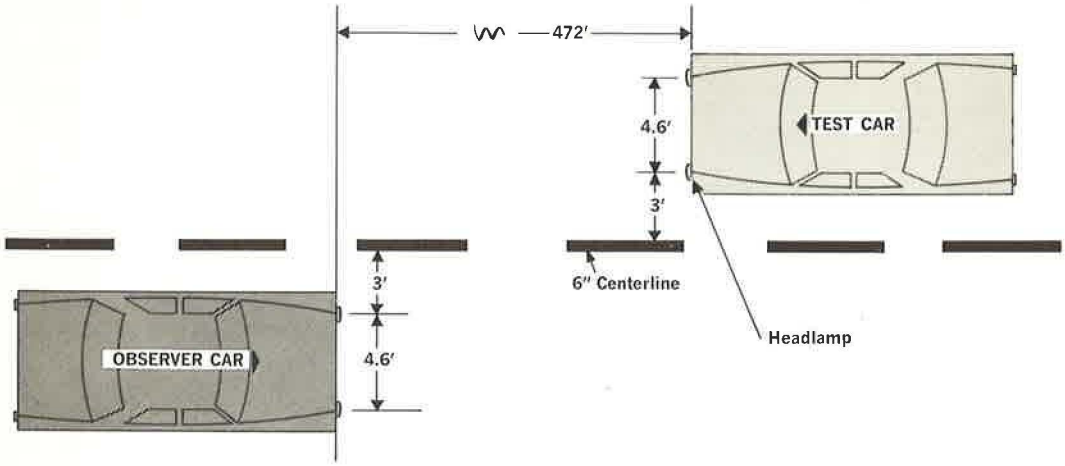

Figure 3. Study car positions used for headlamp luminous intensity calculations.

headlamps than for a car equipped with conventional headlamps. The test procedures were developed from experience gained in a preliminary evaluation of vehicles equipped with conventional and reflectorized headlamps under realistic night driving conditions.

The study was conducted on an inactive section of straight, level airport taxiway which closely approximated a rural paved roadway. A standard 6-in. centerline was installed to provide proper vehicle orientation. Two 1962 automobiles of identical make and model were used as test cars. One was conventional in every respect, the other had both low-beam headlamps replaced with the previously described reflectorized headlamps. The test cars were converted to one-eyed cars by disconnecting either low-beam headlamp.

Observers, each equipped with a stopwatch, were seated in a stationary car positioned as shown in Figure 3. Headlamps of the observer car were on low beam, as this is the condition prevalent when encountering vehicles at night, and engine rpm was maintained at a high level to assure normal headlamp output. Headlamps of all cars used in the study were clean and properly aligned. One-eyed test cars were driven one at a time toward the observers at a specified constant rate of speed starting at a distance of approximately ¾ mile. (At this distance only the lighted headlamp could be seen.) As the one-eyed car approached, observers scanned the immediate vicinity left and right of the oncoming lighted headlamp. When the observer detected the unlit side of the approaching car he started his stopwatch; when the approaching car was abreast of the observer, he stopped the watch and recorded the elapsed time. The test car then rejoined the other test car at the starting point. With this procedure, observers had no knowledge as to which car would approach next.

Observations during dry, clear, nighttime conditions were made of both test cars with left headlamp unlit, right headlamp unlit, and at indicated closure speeds of 30 mph, 45 mph, and 60 mph. In all cases speeds, unlit lamp position, and test car sequence were randomized to provide statistical validity. The study was partially replicated to obtain an estimate of experimental error variance.

In addition to the dry, clear, nighttime observations, a duplicate series of observations was made under simulated rain conditions. Numerous attempts to observe were made during actual rain conditions; however, rain duration was insufficient to obtain valid data, so a study was conducted under simulated rain conditions. This was accomplished by positioning a scaffold tower to the rear and slightly to the right of the observer car as shown in Figure 4. At the top of the tower a water nozzle created a rainfall rate of approximately 1¼ in. per hour uniformly over a 30-ft diameter circle. With the observer car in simulated rain, windshield wipers were required and some headlamp light diffusion occurred. Each of the test conditions described was viewed by 15 observers.

Figure 4. Apparatus used to create simulated rain condition.

RESULTS AND ANALYSIS

The indicated rates of closure (Table 1) maintained by the test car drivers were corrected to actual rates by calibrating the speedometers of the 2 test cars. Using actual closure rates, elapsed times recorded by observers were converted to detection distances. The procedure used to detect significant differences between levels of each variable, and also to establish if significant interaction existed between variables, was the analysis of variance (7) which considered the following:

Variable	Level
Headlamp type	Reflectorized—conventional
Rate of closure	30 mph—45 mph—60 mph
Unlit headlamp position	Left side—right side
Weather conditions	Dry—simulated rain

Where significant interaction between variables was found the method of least significant difference (LSD) as described by Duncan (7) was employed to quantify the interaction. This test, based on the "t" distribution, is used to determine if significant differences exist between means at combinations of the levels of variables. If the dif-

TABLE 1

MEAN DISTANCE AT WHICH UNLIT SIDE OF APPROACHING ONE-EYED VEHICLE WAS DETECTED

Indicated Rate of Closure	Simulated Wet Condition				Dry Condition			
	Conventional Headlamp		Reflectorized Headlamp		Conventional Headlamp		Reflectorized Headlamp	
	Left Side	Right Side	Left Side	Right Side	Left Side	Right Side	Left Side	Right Side
30 mph	331	147	442	387	411	267	582	555
45 mph	302	173	363	372	395	248	568	551
60 mph	332	171	357	433	420	262	547	507

NOTE: Left or right side refers to the side of the test vehicle in relation to its driver.

TABLE 2

ANALYSIS OF VARIANCE FOR LISTED VARIABLES

Variable	Mean Square	"F" Ratio Calculated	"F" Ratio Allowable[a] at 99.9%	Conclusion
Headlamp type (reflectorized or conventional)	3043306.8	479.61	10.83	Significant
Rate of closure	10842.3	1.71	6.91	Not Significant
Unlit lamp position	598714.7	94.35	10.83	Significant
Weather condition	1411057.3	222.38	10.83	Significant
Headlamp type—rate of closure	10472.4	1.65	7.20	Not Significant
Headlamp type—unlit lamp position	472831.1	74.52	11.20	Significant
Headlamp type—weather condition	104148.5	16.41	11.20	Significant
Residual	6345.39			

[a]"F" Ratio allowable from Duncan (7).

ference between means exceeds the LSD this difference is judged to be significant; otherwise, no such conclusion can be reached.

The analysis of variance for the variables listed above is shown in Table 2. The hypothesis tested was that means at the different levels or combinations of levels were equal; the significance level for rejection was set at 99.9 percent.

The analysis of variance established that a significant difference existed in all comparisons with the exception of rate of closure, which had no effect. The overall mean detection distances established by the study for conventional and reflectorized headlamp conditions were respectively 288 feet and 472 feet, an improvement of 62 percent. This difference is highly significant, as shown in Table 2, "Headlamp type (reflectorized or conventional)."

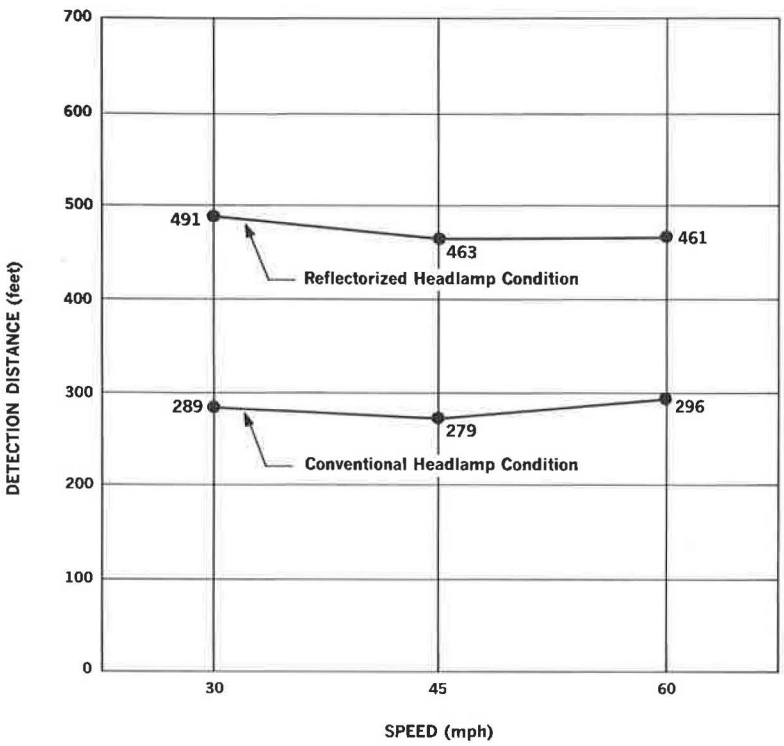

Figure 5. Mean detection distance for reflectorized and conventional headlamp condition at 3 rates of closure.

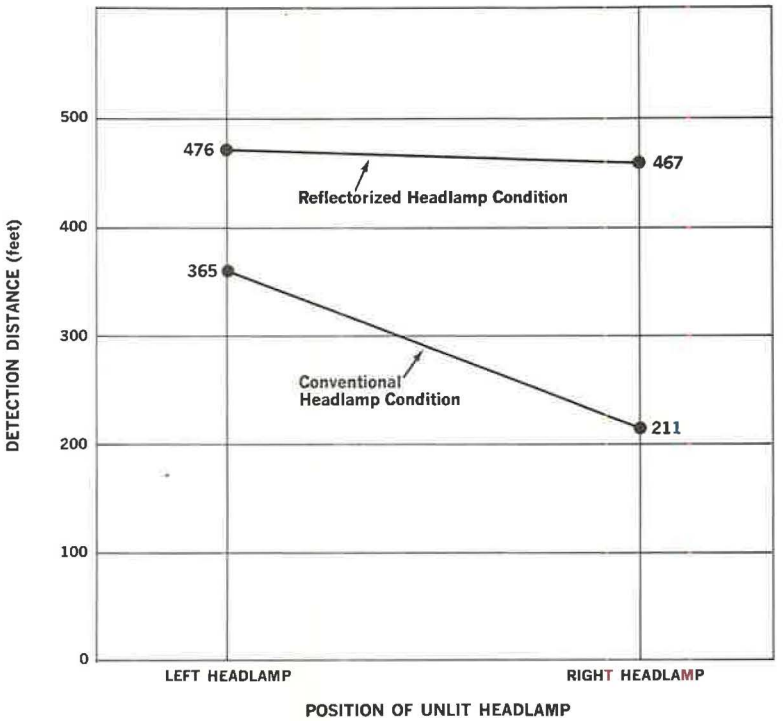

Figure 6. Mean detection distance for reflectorized and conventional headlamp condition by position of unlit headlamp (left or right refers to the test car in relation to its driver).

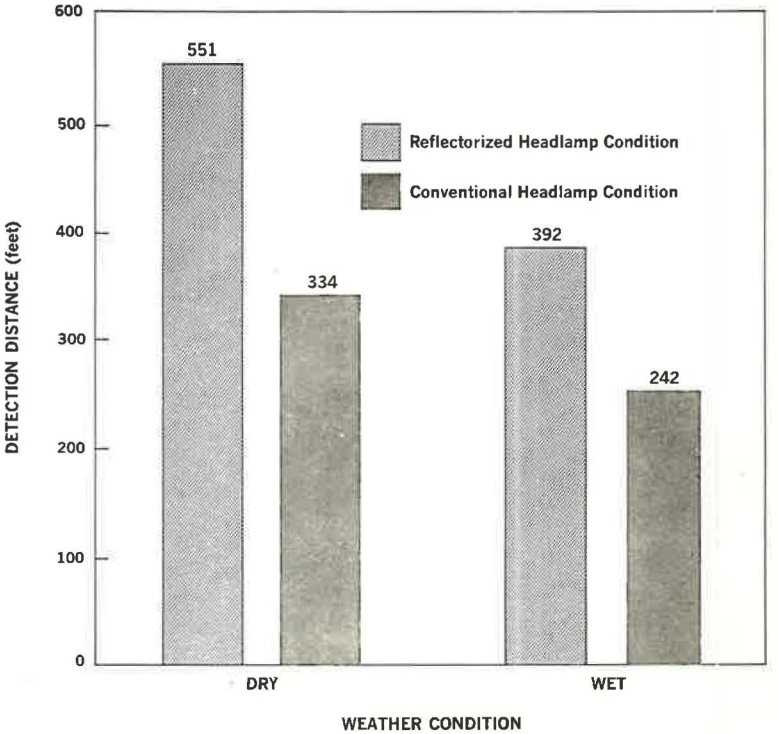

Figure 7. Mean detection distance for reflectorized and conventional headlamp condition during dry weather and simulated rain.

In determining detection distance, rate of closure was found to be insignificant. This is apparent in Figure 5, which shows mean detection distances for 3 rates of closure. Differences between means of the 2 headlamp conditions were significant at any given speed; however, the mean detection distance by type of headlamp was found to be equal for all speeds.

Figure 6 illustrates the mean detection distances by headlamp condition and unlit lamp position. The "F" ratio establishes a significant 2-factor interaction as indicated on the graph by the nonparallel slopes. These combinations were further evaluated by the method of least significant differences. The LSD at the 99.9 percent level is 39 ft. Applying this value to the means shown establishes that, with the reflectorized headlamp condition, mean detection distances were not significantly different for either side of the car. For the conventional headlamp condition there is, however, a significant difference between the left and right side.

Figure 7 shows the detection distance means for the 2 weather conditions. The LSD value of 39 ft establishes that detection distances for the reflectorized headlamp condition were significantly greater under both dry and simulated wet conditions. As expected, detection distances were reduced for the simulated rain condition.

Table 1 summarizes the mean detection distances for reflectorized and conventional headlamp conditions by speed, weather condition, and unlit headlamp position. In all direct comparisons of mean detection distances the reflectorized headlamp condition has a greater absolute value than the conventional headlamp condition.

DISCUSSION

A problem and acknowledged risk of night driving occurs when meeting a one-eyed motor vehicle. Its relative position is uncertain and hazard exists, particularly on

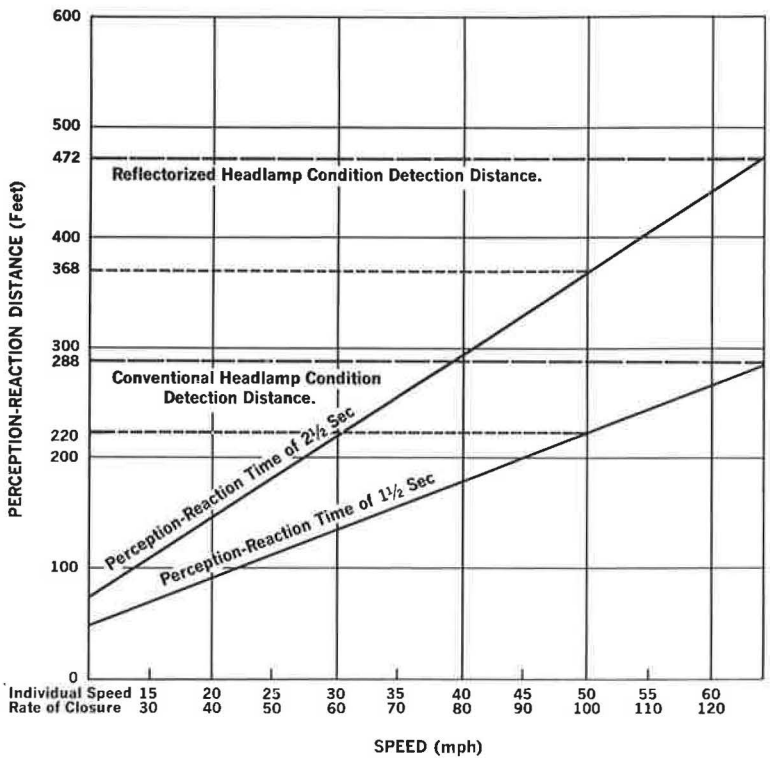

Figure 8. Distance required for perception and reaction by rate of closure for 2 time periods—perception-reaction of 1½ sec from Stalder and Lauer (9); perception-reaction of 2½ sec from AASHO (10).

2-lane roads where relative clearance is unknown until the last moment of closure. The distance required for a motorist to react when a hazardous situation impends is dependent upon rate of closure and the time required for the motorist's response. Response, as described by Matson, Smith and Hurd (8), is the psychological process of perception, intellection, emotion and volition. Rate of closure is strictly a function of relative speed; however, response can vary substantially when modified by the many factors of fatigue, alcohol, weather, disabilities, desires, skills, and attitudes, and greatly by the complexity of the confronting situation.

Because recognition and discrimination of relative motion is required at the lower thresholds of visibility, it is important to employ an allowance for time based on studies of perception of relative motion at such illumination levels. Stalder and Lauer's research of this type (9) reports mean perception time to be 1½ sec for reflectorized target forms at relative closure speeds in excess of 30 mph. Other values may pertain; based on the evaluation of numerous studies, AASHO (10) suggests 2½ sec for combined perception and brake reaction time for use in determining total braking distance.

Figure 8 shows rate of closure vs perception-reaction distance for both Stalder and Lauer's minimum 1½-sec value and AASHO's suggested 2½-sec value. A rate of closure of 100 mph, a typical nighttime condition legal in many jurisdictions, requires a minimum of 220 ft before evasive action can be initiated should a hazardous situation appear. Using the AASHO time requirement of 2½ sec, the distance consumed would increase to 368 ft. The study has shown that the mean detection distance for the unlit conventional headlamp condition is 288 ft. Should danger impend, a motorist could not, on the average, maneuver to a safe condition in the time required by AASHO and would have only 68 ft, or just under ½ sec, to maneuver using the Stalder and Lauer figure. The mean detection distance for the reflectorized headlamp condition of 472 ft provides an average of from 104 to 252 ft within which evasive action could be taken, depending on the perception-reaction time used.

This study utilized ideal conditions of roadway alignment, clean, properly aimed headlamps and driver awareness, so distances reported may be optimum. Actual road conditions where dirt, misalignment of roadway or headlamps, as well as the condition of the driver or vehicle, will reduce detection distances. Thus, consideration should be given to the reflectorization of headlamps to provide some margin of safety.

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