

EFFECT OF VEHICULAR ROLL ON A POLARIZED HEADLIGHTING SYSTEM

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Experimental research explored the effect of vehicular roll on driver comfort and performance of a polarized headlighting system. This system relies on the phenomenon that two polarizers with their planes of polarization perpendicular to each other permit only a negligible amount of light to pass through to an observer. As these planes rotate away from being perpendicular due to vehicular roll, an increasing amount of light leakage results. This leakage was shown to have an insignificant effect on the ability of drivers to detect pavement markings at night, thus adding further support to the use of a polarized headlighting system. The conventional high-beam lighting system was also not significantly affected by vehicular roll. In the meeting situation the data obtained showed that the polarized headlighting system improved target detection distances by 32 percent over the high-beam system. The same data were also used to analyze the relationship between lateral position of the pavement markings (centerline or shoulder) and detection distances. Findings of this analysis support the use of pavement edge markings and may be considered an additional benefit obtained as a result of the study.

•THE high-intensity polarized (HIP) system of vehicular lighting has been proposed to improve the night driving environment by reducing glare from approaching vehicles' head lamps (1, 2, 3). The system consists of dichroic filters that are placed with their planes of polarization at 45 deg to the horizontal in front of high-intensity head lamps (100+ watts) such that planes of vibration of the emergent light are also 45 deg to the horizontal. An analyzing filter placed in front of the driver's eyes on the same axis as the filters on the head lamps completes the HIP system. A vehicle equipped with the HIP system approaching from the opposite direction emits light whose planes of vibration are perpendicular to the planes of the original vehicle. Theoretically, with perfect polarizers the opposing car when viewed through an analyzer should appear to have no lights. With no opposing headlights, the problem of nighttime glare caused by other vehicles would be eliminated. In the real world, this theoretical case does not exist. The filters are not perfect and perfect perpendicularity rarely exists. However, this imperfect polarization has proved to be beneficial rather than detrimental. The small amount of light leakage that results due to imperfect filters aids in identifying approaching vehicles while producing a negligible amount of glare.

In the HIP system, when the planes of an opposing head lamp's fillers are not perpendicular to the planes of the viewer's analyzing filter, an additional amount of light leakage is realized. The amount of this light leakage is dependent on the degree of misalignment that exists between the two filters (Fig. 1). In previous studies of the polarized lighting system this misalignment has been kept to a minimum. Most of these studies were run on airport runways or other surfaces where vertical geometric characteristics (crown and superelevation), bumps, holes, etc., are either nonexistent or marginal. The prime objective of this study was to produce experimentally this misalignment or "roll" and to measure its effects on a group of test drivers.

A simple measurement of the effectiveness of a vehicular lighting system is the distance at which a driver can detect a target illuminated by the system. This method has

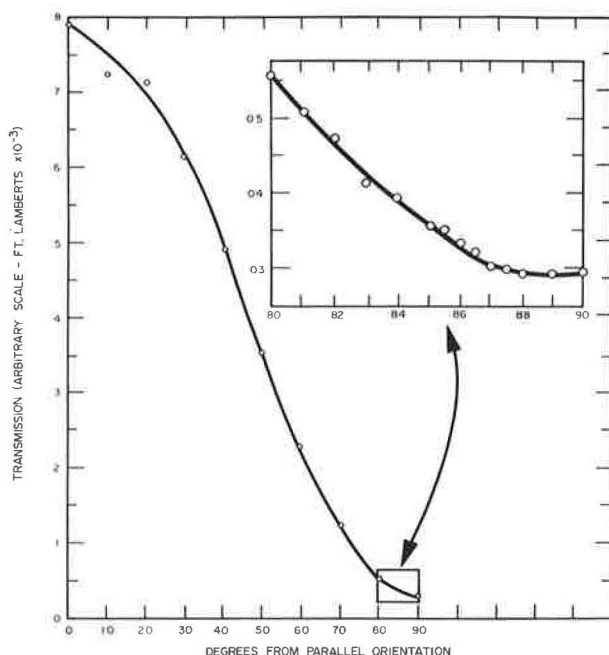


Figure 1. Transmissivity of a typical polarizer or analyzer.

been used extensively in the evaluation of the polarized headlighting system (4). The value of this measurement relies on the fact that the need to see objects at a distance is one of the basic tasks that must be performed by a driver. If a driver can see objects at a great distance, his time to react to a situation is lengthened and the driving task is made easier. Detection distances will therefore be one of the measurements to determine whether or not vehicular roll has an effect on the HIP system.

Dynamic studies of vehicular roll have shown that a practical maximum of 7 deg of roll occurs in moving vehicles on a highway (5). This practical maximum of 7 deg represents an occasional occurrence. Observation of an average roadway in the United States would substantiate the presence of vehicular roll that is inherent because of vehicular instability and the road's geometric characteristics. When a vehicle passes from a superelevated section (horizontal curve) to a crown section (tangent) of highway, the transitioned pavement causes a vehicle to roll. Typically on rural highways, a maximum superelevation of 0.08 ft per ft of pavement width is employed, corresponding to a roll angle of almost 6 deg if the normal crown of 0.02 ft per ft of pavement width in the opposite slope direction is also considered. In addition, roadway bumps, potholes, vehicle suspension, and other factors contribute to vehicular roll. Therefore, two levels of roll angle were employed in this experiment: 7 deg as a practical maximum and 15 deg as the theoretical maximum that might occur for short durations where two curves with maximum superelevation met (full cloverleaf interchanges) or where roll due to vehicle suspension and superelevation are additive. In addition a condition of no roll was employed as a control.

In an effort to generalize the data from this study, the conventional high-beam (HB) lighting configuration was included in the test runs as a control system. Thus the data obtained may also be used to study the overall benefits of the HIP system. The control system was also used to determine whether the simulated roll, as produced in the study, had any side effects on a conventional lighting system. The results of this determination could then be used in the final analysis of the effect of vehicular roll on the HIP system to correct for any effects attributable to simulation. One of the possibilities

that existed was that the simulated roll would distract the subject driver more than would the real-world vehicular roll and thus might significantly affect his detection ability.

To vary the detection task, four target positions were chosen. A fixed glare source was used with four separate target positions, which produced four different glare conditions for each lighting system and roll angle. In addition, the test runs were randomized, which prevented the subjects from becoming keyed to detecting any one target. For each of the eight subjects employed, 24 different combinations of the three variables were used ($2 \times 3 \times 4 = 24$). It was considered desirable to repeat each condition once and add 8 control runs for a total of 56 runs. The 8 control runs were divided between four no-opposing glare situations to obtain base data and four no-target situations to inhibit the subjects from guessing and to determine whether in fact they were guessing. In summary, design of the experiment involved four variables:

1. Vehicular lighting systems (HB and HIP),
2. Roll angle (0, 7, 15 deg),
3. Target position (four)—lateral position and longitudinal position, and
4. Subjects (eight).

The data collected were subjected to analyses of variance procedures to determine the statistical significance of the results obtained. This type of statistical procedure is useful in determining whether the difference among variables could have occurred by chance alone.

TEST PROCEDURE

Field work for this experiment was done at the Beltsville Agricultural Research Station Airport in Beltsville, Maryland. A simulated stretch of tangent highway approximately $\frac{3}{4}$ -mile long was utilized as a test track. The bituminous-surfaced test track was marked to provide two 12-ft lanes with 4-in. nonreflecting white solid edge markings and dashed centerline. Although the simulated roadway lacks the geometric characteristic of roadway crown and some environmental features (nearby trees, fences, mail boxes, etc.), it is felt that for the subject experiment the test track very closely resembles a dark rural highway situation. The only possible source of lighting interference was from nearby facility buildings. These buildings were not in active use during the testing hours. The few lights that were on were well offset from the test track and remained unchanged throughout the experiment.

The test runs were preceded by a short instruction period for the subject. The subject was told he was taking part in a highway research study. To prevent biasing his performance the basic intent of the study was not discussed until the experimental procedures were completed. Only details relative to his actual performance during the study were provided. At this time and also at the end of the test runs, the subject's reaction times were determined. Average reaction times were used during the data reduction process to correct the subject's detection distances.

Simulation of vehicular roll was achieved by mounting two sets of head lamps (HIP and HB) on a mechanical stand (Fig. 2). The stand was motor driven, and the roll angle was controlled by an eccentric cam. The roll-angle frequency was 1 cycle per second, which gave the

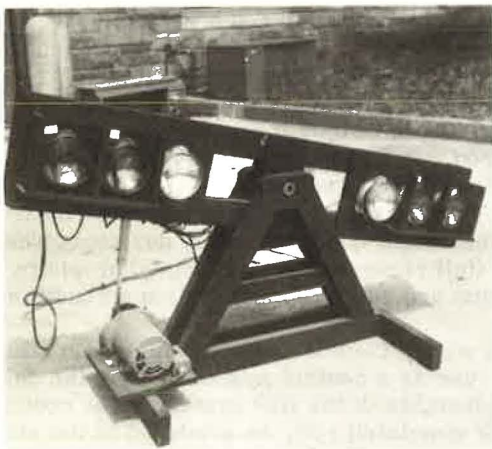


Figure 2. Mechanical headlight stand used in experiment to simulate vehicular roll at night.

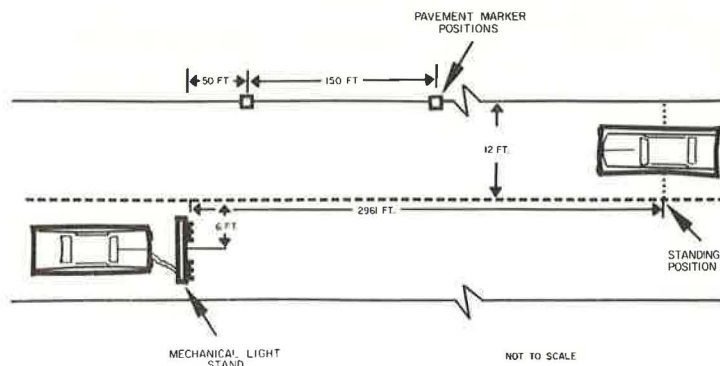


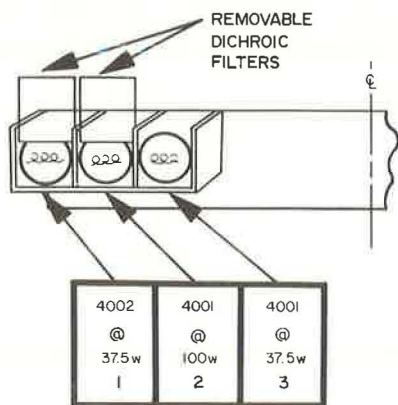
Figure 3. Test track.

subject sufficient repeated exposures to the full roll condition so that he would experience the roll effect during the critical period of target detection. Because no crown existed on the test track, the three angles produced by the cam, 0, 7, and 15 deg, were also the misalignment angles between the analyzer of the subject's car and the headlights on the mechanical stand. The mechanical headlight stand was placed in the center of the lane and simulated an opposing passenger car as shown in Figure 3. The head lamps on the stand were powered by connecting them directly to the electrical system of an auxiliary vehicle whose engine was idled at a constant speed. The input voltage to each head lamp was therefore maintained at approximately 12.5 volts.

The detection target used was a commercially available 4-in. by 4-in. two-faced retroreflective corner cube pavement marker button. The reflective surfaces are in the shape of an isosceles trapezoid measuring $3\frac{1}{8}$ in. by $3\frac{5}{8}$ in. on the bases with an altitude of $1\frac{1}{16}$ in. The larger base rests on the pavement and the smaller base was elevated $\frac{1}{2}$ in. above the pavement. The marker was located at any of four positions; two of the marker positions were on the shoulder edge stripe and two on the centerline, as shown in Figure 3. The subject approached the target at a constant speed of approximately 40 mph after accelerating from a fixed starting position. Upon detection of the target, the subject was asked to sound the vehicle's horn. This action stopped a digital measuring device that recorded distance traversed to the nearest 0.0002 mile or approximately 1 ft. With the distance traversed and reaction time corrections available, a corrected detection distance could be determined for each run. The subject was allowed one practice run to become familiar with the appearance of the target.

After completing each test run, the subject was asked to evaluate subjectively the discomfort he experienced from the opposing glare source. This evaluation was reported to an observer in the back seat of the test vehicle. The subject was then instructed to return to the starting position while appropriate adjustments were made to the lighting stand, target positions, and measuring device.

Both the test vehicle and the mechanical stand were equipped with three pairs of head lamps (Fig. 4). The high-beam system was composed of pairs of standard type 4001 and 4002 sealed-beam lamps. The HB system operated in the conventional manner and employed four filaments, each of which used 37.5 watts. The HIP system was composed of a pair of type 4001 sealed-beam lamps with special filaments rated at 100 watts plus a pair of 4002 lamps using the standard 37.5-watt filaments. Dichroic filters placed in front of the HIP light sources produced the high-intensity polarized light. The analyzer that completes the HIP system was in the form of special polarizing glasses similar to polarized sunglasses except in the orientation of the polarizing material. The observer in the test vehicle referred to the glasses as "sunglasses" and informed the driver when he was to wear or remove the "sunglasses." This was done to avoid influencing the subjects in their subjective evaluations of the two types of lighting systems. These "sunglasses" were used only during the HIP system's test runs.



HIGH BEAM SYSTEM:

LAMPS 1 & 3 LESS FILTERS

HIGH INTENSITY POLARIZED SYSTEM:

LAMPS 1 & 2 WITH FILTERS

Figure 4. Lighting systems.

TABLE 1
SUBJECTS' DRIVING EXPERIENCE

Subject	Age	Years Driving Experience	Miles Driven per Year
1	18	2	20,000
2	22	3½	17,000
3	21	4	10,000
4	21	3½	15,000
5	18	1½	6,000
6	23	6	6,000
7	20	4	10,000
8	22	6	20,000

A copy of the pre-arranged random order of runs was available to the observer. The observer also changed the lenses and lamps of the vehicle and recorded the distance measurement and the subject's discomfort glare evaluation for each run. The observer otherwise played a passive role in the rear seat of the vehicle, restricting communication with the test driver to the necessary minimum. During the instruction period, each subject was advised that, of the many runs to be made,

some runs would omit target or opposing headlight conditions. These were considered to be control runs and were included in order to encourage subjects to be alert at all times. It was theorized that a knowledge of the inclusion of control runs would deter a subject's inclination to act from sheer habit as the study progressed.

EXPERIMENTAL DRIVERS

Eight University of Maryland students, ranging from 18 to 23 years of age, were chosen to be subject drivers in the experiment. The subjects' driving experience, in years and miles driven per year, is given in Table 1. It was not considered necessary to obtain a heterogeneous group of drivers or to obtain the visual acuity of each driver because the object of the experiment was to determine differences in detection distances between an individual's runs rather than the differences that existed among subjects. The homogeneous group that was used was further justified by data collected by Hemion (4). Hemion provided an additional subdivision of his line target data by age groups (under 30 and over 30). Detection distances for the two groups were about equal, with the older group having slightly longer detection distances:

Subjects	HIP		HB	
	Average (ft)	Range (ft)	Average (ft)	Range (ft)
9 Drivers over 30	263.2	184 to 346	168.8	89 to 294
11 Drivers under 30	254.4	175 to 343	135.5	59 to 173

RESULTS

The statistical procedure known as analysis of variance was used to determine whether differences in detection distances were real or caused by variations due to experimental error. A general discussion of the results will be presented first, followed by a more detailed discussion of some of the principal variables of interest.

Table 2 gives the results of a five-way analysis of variance that contains the following independent variables:

1. Lateral position of pavement marker target (centerline or shoulder),

TABLE 2
FIVE-WAY ANALYSIS OF VARIANCE

Source of Variation ^a	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio	Significance Level
A (Lat Pos)	1	25,410,126	25,410,126	2,206.61	0.01
B (Longi)	1	32,083	32,083	2.79	N.S.
AB	1	34,163	34,163	2.97	N.S.
C (Roll Ang)	2	4,609	2,304	0.20	N.S.
AC	2	19,183	9,591	0.83	N.S.
BC	2	29,304	14,652	1.27	N.S.
ABC	2	23,486	11,743	1.02	N.S.
D (Litg Sys)	1	7,986,834	7,986,834	693.42	0.01
AD	1	7,455	7,455	0.65	N.S.
BD	1	645	645	0.06	N.S.
ABD	1	13,324	13,324	1.16	N.S.
CD	2	22,879	11,439	0.99	N.S.
ACD	2	75,545	37,772	3.28	0.05
BCD	2	73,408	36,704	3.19	0.05
ABCD	2	69,017	34,508	3.00	N.S.
E (Subj)	7	18,491,949	2,641,707	229.35	0.01
AE	7	1,779,094	254,156	22.07	0.01
BE	7	593,679	84,811	7.36	0.01
ABE	7	240,403	34,343	2.98	0.01
CE	14	186,587	13,327	1.16	N.S.
ACE	14	164,227	11,730	1.02	N.S.
BCE	14	111,728	7,980	0.70	N.S.
ABCE	14	347,159	24,797	2.15	0.05
DE	7	1,865,890	266,555	23.14	0.01
ADE	7	291,468	41,638	3.62	0.01
BDE	7	83,539	11,934	1.04	N.S.
ABDE	7	185,152	26,450	2.30	0.05
CDE	14	229,511	16,393	1.42	N.S.
ACDE	14	81,145	5,796	0.50	N.S.
BCDE	14	457,789	32,699	2.84	0.01
ABCDE	14	109,567	7,826	0.68	N.S.
Within SS	192	2,211,445	11,517		
Total		480,737,224			

^aA = Lateral position (centerline, shoulder)

B = Longitudinal position (50 ft, 200 ft)

C = Roll angle (0 deg, 7 deg, 15 deg)

D = Lighting system (HIP, HB)

E = Subjects (8).

2. Longitudinal position of pavement marker target (50 ft or 200 ft from the glare source),
3. Roll angle (0 deg, 7 deg, 15 deg),
4. Lighting system (HIP or HB), and
5. Subject drivers (8).

Of these, the variable of principal interest, roll angle, C, was not significant (Table 2) and its first-order interactions were also not significant. Two second-order roll interactions, ACD and BCD, were significant at the 0.05 level of confidence. To further analyze these and other interactions, the foregoing analysis was reduced to two four-way analyses of variance, in which the data for each lighting system (HB and HIP) were considered separately (Tables 3 and 4). The second-order ACD and BCD interactions of the five-way analysis of variance were thus reduced to two first-order interactions, AC's and BC's. The AC interaction was not significant for the HIP system and only significant at the 0.05 level of confidence for the HB system. The BC interaction was not significant for either lighting system.

In summary, the results of these analyses indicate that roll angle has no effect on the HIP system but does have a minor effect on the conventional high-beam lighting system when roll angle and lateral position interact.

The lateral position of the pavement marker target (A), lighting systems (D), and subjects (E) were significant main variables of the five-way analysis of variance at the 0.01 level of confidence (Table 2). The only significant first-order interactions of these variables were those that interacted with subjects (E). This is an expected result that

TABLE 3
FOUR-WAY ANALYSIS OF VARIANCE—HIP SYSTEM

Source of Variation ^a	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio	Significance Level
A (Lat Pos)	1	13,144,040	13,144,040	839.75	0.01
B (Longi)	1	11,812	11,812	0.75	N.S.
AB	1	2,408	2,408	0.15	N.S.
C (Roll Ang)	2	4,280	2,140	0.13	N.S.
AC	2	42,523	21,261	1.34	N.S.
BC	2	90,381	45,190	2.85	N.S.
ABC	2	84,836	42,418	2.68	N.S.
D (Subj)	7	15,149,990	2,164,284	136.63	0.01
AD	7	993,492	141,927	8.96	0.01
BD	7	383,910	54,844	3.46	0.01
ABD	7	219,272	31,324	1.98	N.S.
CD	14	251,193	17,942	1.13	N.S.
ACD	14	115,939	8,281	0.52	N.S.
BCD	14	341,615	24,401	1.54	N.S.
ABCD	14	310,012	22,143	1.40	N.S.
Within SS	96	1,520,698	15,840		
Total		304,295,870			

^aSee Table 2 for definitions.

is due largely to differences in visual acuity and glare sensitivity among subjects. The remaining variable, longitudinal position (B) of pavement marker target, did not have a significant effect on detection distances. This finding is consistent with earlier work by Hemion (4). More detailed results relative to the principal variable are presented in the following sections.

Vehicular Roll

As stated previously, three simulated roll conditions were considered in the study. The maximum simulated roll of 15 deg was well above probable real-world occurrences. Therefore, determination that detection distances were not affected by exposure to roll angles up to 15 deg indicates that the overall effect of roll on the system is negligible. As noted earlier, the four-way analysis of variance of the HIP data given in Table 3 indicated no significant differences in detection distances among the three roll angles. These data are summarized as mean values in Table 5 and Figure 5. The analysis of

TABLE 4
FOUR-WAY ANALYSIS OF VARIANCE—HB SYSTEM

Source of Variation ^a	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio	Significance Level
A (Lat Pos)	1	12,273,541	12,273,541	1705.84	0.01
B (Longi)	1	20,916	20,916	2.91	N.S.
AB	1	45,080	45,080	6.27	0.05
C (Roll Ang)	2	23,209	11,604	1.61	N.S.
AC	2	52,204	26,102	3.63	0.05
BC	2	12,331	6,165	0.86	N.S.
ABC	2	7,667	3,833	0.53	N.S.
D (Subj)	7	5,207,850	743,978	103.40	0.01
AD	7	1,077,070	153,867	21.39	0.01
BD	7	293,307	41,901	5.82	0.01
ABD	7	206,283	29,469	4.10	0.01
CD	14	164,905	11,778	1.64	N.S.
ACD	14	129,432	9,245	1.28	N.S.
BCD	14	227,903	16,278	2.26	N.S.
ABCD	14	146,714	10,479	1.46	N.S.
Within SS	96	690,747	7,195		
Total		176,441,354			

^aSee Table 2 for definitions.

variance of the HB data also showed no significant difference in detection distances at the three roll angles. The mean values for the HB system are also summarized in Table 5 and Figure 5.

Target Position

Although target position was included as a variable primarily to prevent subjects from guessing, it also contributed useful information to the study. Laterally, the target was located on either the centerline or shoulder line. The detection distances of the target when it was located on the shoulder line averaged over 500 ft longer than when it was positioned on the centerline; Figure 6 shows cumulative distributions for each position. The mean values for detection distance versus target position are shown in Figure 7. This magnitude of improved detectability was present regardless of which lighting system was used. Statistically, the 500-ft improvement of shoulder edge markings compared to centerline markings was significant at the 0.01 confidence level for each lighting system tested. These results support the use of pavement edge markings in highway delineation.

Four "no-target" runs per subject were included to discourage the experimental drivers from guessing. All 32 of these runs were recognized as such, and no false responses were recorded. Therefore, it can be assumed that the subjects followed instructions and indicated detection only when they were sure that a target was present.

Glare Discomfort Evaluations

Data were also collected and analyzed regarding the subjective glare discomfort evaluations. These evaluations were made and recorded immediately following each run and were based on any glare discomfort the driver had encountered during any part of that run. The evaluations were based on the following 0 to 6 rating scale:

Rating No.	Glare Discomfort	Rating No.	Glare Discomfort	Rating No.	Glare Discomfort
0	No problem	2	Bothersome	4	Quite uncomfortable
1		3		5	
				6	Practically blinding

TABLE 5

MEAN VALUES OF DETECTION DISTANCES FOR OPPOSED GLARE CONDITIONS

Condition	HIP	HB	Δ (HIP - HB)	
			(feet)	(percent)
Roll angle				
0 deg	1,181	916	265	29
7 deg	1,198	895	303	34
15 deg	1,189	892	297	33
Target position				
50 ft, centerline	928	654	274	42
200 ft, centerline	933	643	290	45
50 ft, shoulder	1,438	1,128	310	27
200 ft, shoulder	1,458	1,180	278	24
All data	1,189	901	288	32

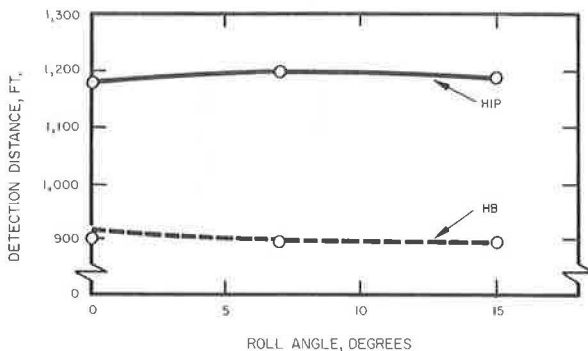


Figure 5. Effect of roll angle on detection distances.

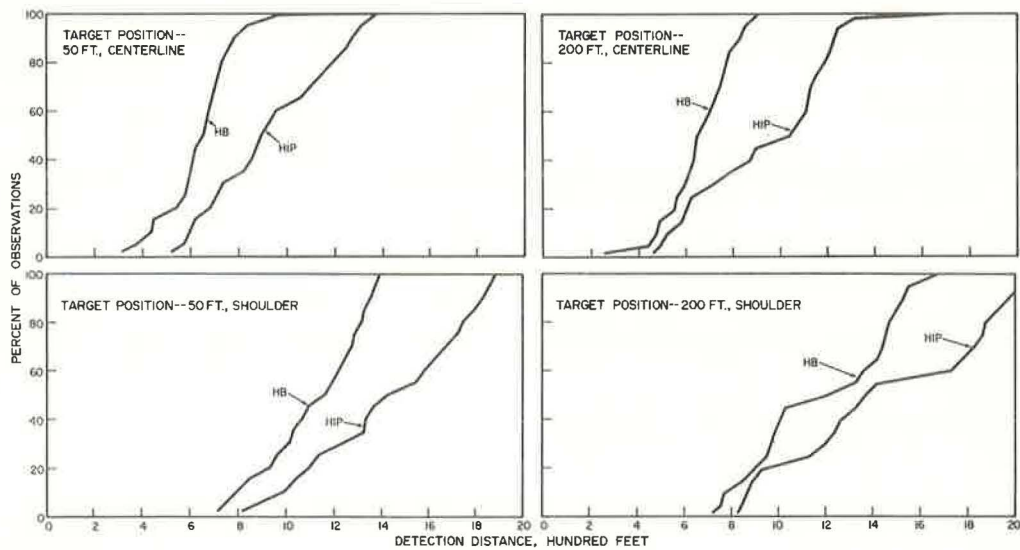


Figure 6. Cumulative distributions for each of four target positions.

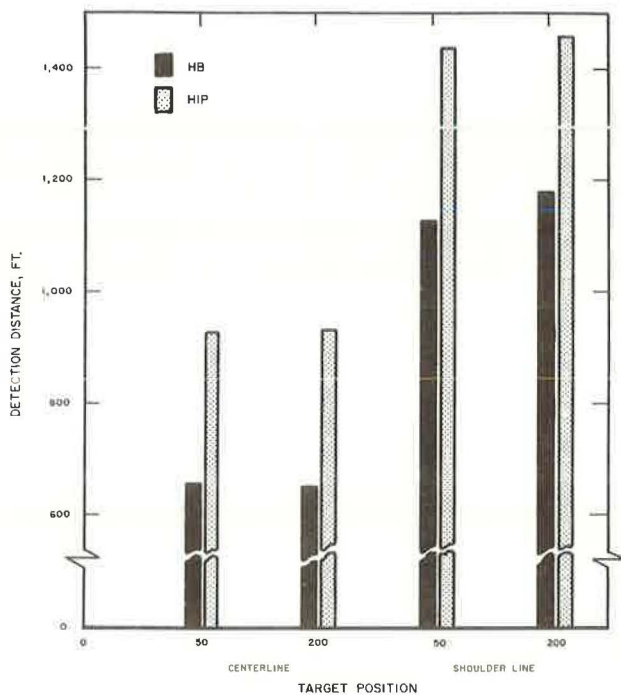


Figure 7. Effect of target position on detection distance.

The HIP system's mean value was approximately two points less bothersome than was the HB system on the 6-point scale. These values compared well with studies done by Hemion (4). The subjective glare evaluations (mean values) for the eight subjects are summarized as follows:

<u>Roll Angle</u>	<u>HIP</u>	<u>HB</u>	<u>HIP and HB</u>
0 deg	1.44	3.69	2.25
7 deg	1.55	3.58	2.03
15 deg	1.81	3.75	1.94
All	1.60	3.68	2.08

For both the HIP and HB lighting systems, the magnitudes of differences in subjective glare evaluations among the three roll conditions are small in comparison with the 2-point difference that was noted between 0 deg and 15 deg of roll angle for the HIP system, but this was only one-third of a point on the 6-point scale. These results clearly indicate that vehicular roll has only a minimal effect on the subjective glare discomfort evaluations of either the HIP or HB lighting systems.

Lighting Mode

Although this experiment was not designed to determine the differences between the two lighting systems (HIP and HB), such a comparison involving vehicular roll, a variable not explored in earlier studies, may be of interest. As shown in Table 5, an overall improvement in detection distance of 32 percent was realized by using the HIP system rather than the HB system during the meeting situation. These data were statistically significant at the 0.01 level of confidence. The eight subjects while using the HIP system averaged 288 ft or 32 percent of additional detection distance over the 901 ft realized when using the HB system. These averages were computed from each subject's 48 opposed glare runs, of which 24 were HB and 24 were HIP runs.

The foregoing comparison of the two lighting modes is in line with similar studies by Hemion that showed a 54 percent improvement in detection distances with the HIP system in the opposed glare condition. Differences between the two studies (54 percent versus 32 percent) can be primarily attributed to use of different targets and target positions (sign, pedestrian, and no-passing beaded paint stripe), whereas the subject study employed a highly reflective corner cube marker target.

An approximate comparison of detection distances for beaded paint and corner cube markers is possible by analyzing appropriate data from the two studies. In Figure 8, data are plotted from both studies representing pavement markings that were located on the centerline in the opposed-glare condition. (The Hemion study did not employ shoulder targets.) Figure 8 shows that the 50th percentile detection distance when the HIP system is used is 223 percent greater with the corner cube reflective marker target than with the beaded paint marker. The comparable value with the HB system is 265 percent greater. Therefore, it appears that the more widespread use of corner-cube reflectors on centerline markings may be desirable where snowplow blades are not likely to remove the reflectors. The comparison shown in Figure 8 also makes possible a more direct comparison of the two lighting systems. The HIP system provided 42 percent greater detection distances (50th percentile) than the HB for the studies' centerline data and 64 percent greater detection distances for Hemion's centerline beaded-paint pavement marking data.

No-Glare Condition

The analysis of the no-glare condition data was not considered during the design of this experiment. Thus the limited number of no-glare test runs resulted in an unbalanced set of data. For some conditions data did not exist, whereas for others one, two, or three data points were available. Although the data as collected cannot provide a statistically sound analysis of the no-glare condition, it appears that both lighting systems (HIP and HB) produce distances of the same relative magnitude (± 10 percent).

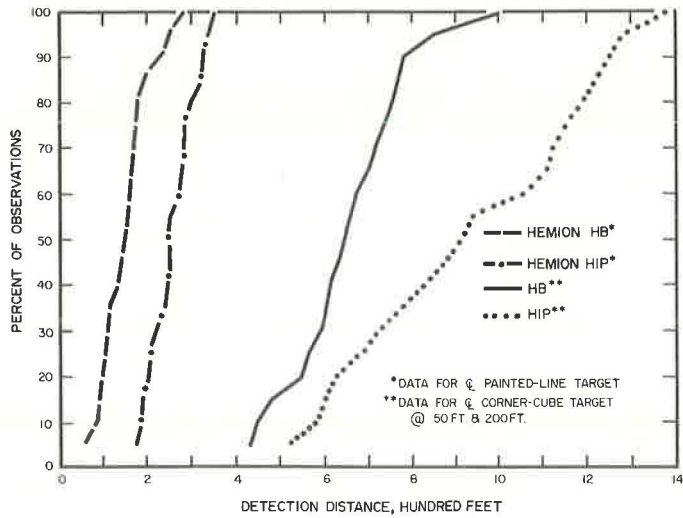


Figure 8. Comparison of detection distances for beaded paint and corner cube centerline targets.

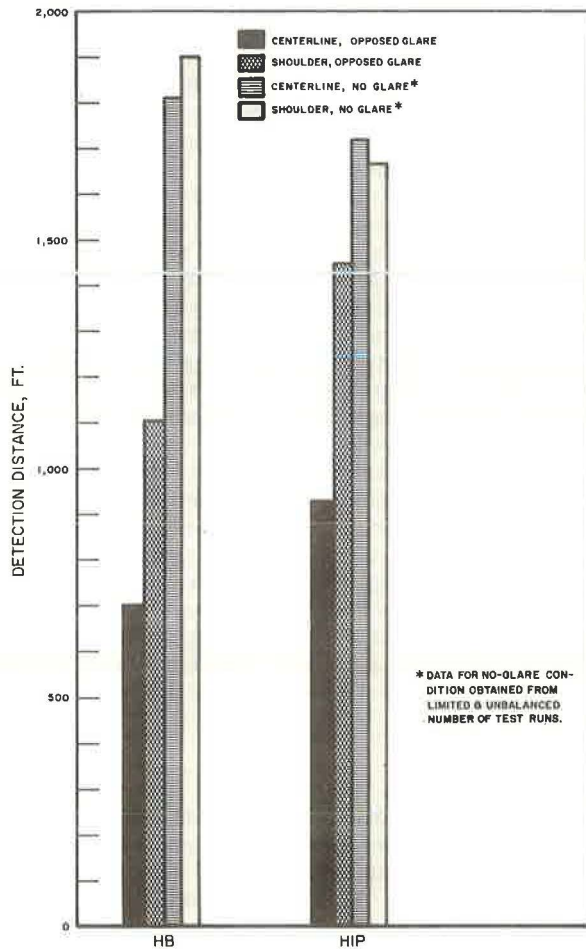


Figure 9. Comparison of detection distances for centerline and shoulder targets, opposing-glare and no-glare conditions.

Detection distances for these runs were 42 and 106 percent greater for the HIP and HB systems respectively than for comparable opposed-glare runs. These differences may be in part attributable to the distraction effect of the oscillating opposing glare source.

A comparison plot of opposed-glare and no-glare conditions is shown in Figure 9. To obtain a more meaningful comparison of the two glare conditions, the no-glare values that are plotted are not the averages of the available detection distances for any particular condition. All of the subjects were not exposed to each condition, and an average derived from only a portion of the subjects may have resulted in nonrepresentative points due to varying visual acuities among subjects. To help correct for this imbalance, the no-glare values plotted are the mean of the differences of detection distance between the available subjects' no-glare and opposed-glare runs for a particular condition added to the eight subjects' mean value for the comparable opposed-glare condition.

DISCUSSION OF RESULTS

Within the bounds of this experiment's design, vehicular roll has no detectable effect on the high-intensity polarized lighting system. The amount of light leakage resulting from vehicular roll or imperfect lenses that the system can tolerate without causing significant glare problems to the driver is a question that remains unanswered. Further studies of the system should consider the maximum light leakage the system can tolerate and how this leakage could be put to beneficial use. It is evident that a perfect system is not necessary and in fact may prove undesirable. Small amounts of light leakage aid in vehicle detection and could possibly be employed to improve illumination. Additional illumination could be made available by altering the polaroid lenses to admit passage of directionally controlled unfiltered light rays. These unfiltered rays could possibly be those illuminating the area directly in front of the extreme right of the vehicle. Driver appreciation research by Jehu (6) would appear to support this position.

Improved detection distances and less bothersome subjective glare evaluations were encountered by the eight test subjects while using the HIP system. The HIP system as tested in this experiment proved superior to conventional high beams by improving detection distances by 32 percent during meeting situations and by reducing glare from opposing vehicles. It appears that refinements can be made to the system that will make it even more beneficial and acceptable to the motoring public.

In the subject experiment, the only measurements that were related to comfort and fatigue were the subjective glare evaluations. What effect vehicular roll or light leakage has on comfort and fatigue is considered as important as any significant changes in detection distances. A study is now being conducted by the Federal Highway Administration to explore more meaningful ways to assess the dollar value a driver assigns to nighttime visual comfort.

The data obtained from target position produced results that were unrelated to lighting modes and vehicular roll but were very applicable to questions related to highway delineation. In recent years highway departments in the United States have been increasing the use of pavement edge markings. The use of this type of roadway delineation has been considered desirable. However, only limited proof of its accident benefits exist (7, 8), and the traffic operation studies have been inconclusive. The target position data of this experiment substantiate the belief that shoulder markings are beneficial, at least in the opposed-glare case. The mean value of detection distance was over 500 ft greater for shoulder targets than for centerline targets. The driver's need for roadway delineation is normally greatest when meeting opposing vehicles, i. e., in a glare situation. The use of shoulder-line marking with its consequent additional detection distance characteristics (Fig. 7) fulfills drivers' needs during these critical situations.

CONCLUSIONS

The following conclusions apply to the detection of a raised corner cube pavement marker when two vehicles, both of which are equipped with high-intensity polarized headlights or alternatively with conventional high-beam headlights, meet at night on a two-lane rural highway:

1. Vehicular roll has an insignificant effect on detection distances and a minimal effect on subjective glare evaluations.
2. The high-intensity polarized system significantly improves detection distances by 32 percent and reduces discomfort glare over the conventional high-beam headlighting system.
3. The lateral position of the pavement marker target has a significant effect on detection distances. Targets located on the shoulder line provided 500 ft of additional detection distance over the same target under the same conditions that were located on the centerline. These results support the use of pavement edge markings in roadway delineation.

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