archive (H.F.)

UM-HSRI-79-92

ACCIDENTS AND THE NIGHTTIME CONSPICUITY OF TRUCKS

Paul Green
Michael Kubacki
Paul L. Olson
Michael Sivak

DECEMBER 1979

THE UNIVERSITY OF MICHIGAN
HIGHWAY SAFETY RESEARCH INSTITUTE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UM-HSRI-79-92		

4. Title and Subtitle Accidents and the Nighttime Conspicuity of Trucks	5. Report Date January 1980
	6. Performing Organization Code
7. Author(s) Paul Green, Michael Kubacki, Paul L. Olson, Michael Sivak	8. Performing Organization Report No. UM-HSRI-79-92
9. Performing Organization Name and Address Highway Safety Research Institute The University of Michigan Ann Arbor, Michigan 48109 (U.S.A.)	10. Work Unit No.
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address Motor Vehicle Manufacturers Association 320 New Center Building Detroit, Michigan 48202 (U.S.A.)	13. Type of Report and Period Covered Final July 1978 - July 1979
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Three papers related to the conspicuity of trucks and collisions between cars and trucks are published together in this report. The first paper, a review of the Fatal Accident Reporting System (FARS) data, indicates that most fatal car-into-truck accidents occur during hours of darkness, pointing to a potential lack of nighttime truck conspicuity. The second paper, a review of literature on conspicuity and retroreflectorization, suggests that retroreflectorization of trucks is likely to increase their nighttime conspicuity. The third report, an exploratory field study, indicates that conspicuity-enhancing retroreflective treatments applied to the rear and sides of trucks caused drivers to look at the trucks more often and at greater distances.

17. Key Words	18. Distribution Statement
trucks, fatal accidents, conspicuity, FARS, vision/perception, retroreflectorization	Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	54	

CONTENTS

SUMMARY

Considerable research evidence suggests that car-truck collisions at night frequently occur because the car driver doesn't see the side or rear of a truck or semitrailer soon enough to avoid it. To examine that subject, three independent but related studies were conducted in 1979 at the Highway Safety Research Institute (HSRI) by staff members of Systems Analysis and Human Factors.

The first study examined data in the 1977 NHTSA Fatal Accident Reporting System file to discover the conditions under which cars collide with the side or rear of tractor-semitrailers. The chief finding--that such collisions occur more frequently at night--suggests that conspicuity of the semitrailer is a problem. Adding lights or reflective paints could prevent some of those collisions.

The second study was a review of the literature on nighttime conspicuity and effects of retroreflectorization. It, in general, confirmed that increasing the size or contrast (luminance) of targets enhances conspicuity. Therefore, retroreflectorization of vehicles is likely to make them more conspicuous at night.

The third study was an experiment that examined the attention-getting properties of various retroreflective treatments of a semitrailer. Paid volunteer drivers wearing the HSRI eyemark recorder repeatedly drove past a parked truck at night. Subjects were told they were participating in a highway sign study. The truck was not mentioned. It was found that subjects saw the standard semitrailer at a distance of 300 to 400 feet on low beams. When additional retroreflective materials were mounted on the trailer exterior, sight distances increased to 1,000 feet. The findings indicated that eye fixation times are a useful measure in conspicuity investigations.

These three studies all imply that enhanced conspicuity of trucks may reduce car-into-truck collisions. They do not, however, suggest any "best" designs to do this, nor has a precise estimate of the expected accident reduction been made.

1. COLLISIONS OF CARS WITH TRACTOR-SEMITRAILERS

1.1 INTRODUCTION

Collisions of cars with semitrailers comprise a small but serious class of accidents. Whether the car impacts with the side or the rear of the trailer, underride is a possibility. Most fatal car-into-trailer accidents involve underride.

One approach to the reduction of fatal underride crashes is the installation of an underride guard, a plate or series of bars which prevent a car from passing under the bed of the trailer. Federal interest in this problem has focused on the rear underride guard as a means of reducing crash severity (Dynamic Science, Inc., study in progress).

In October of 1977, Minahan and O'Day of the Highway Safety Research Institute (HSRI) reported (in Car-Truck Fatal Accidents in Michigan and Texas) that most such guards at present are non-standard and of varying size and strength. They seldom inhibit underride at higher impact speeds. Indeed, the high impact speeds encountered in their study suggest than an underride guard, to be completely effective in reducing fatalities, would have to have a high energy-absorbing capability. Further, since almost half of the fatal underride accidents involve impact with the side of the trailer, the installation of rear underride guards alone can do little or nothing to reduce the severity of these side accidents.

Another finding from the October 1977 study was that two-thirds of underrides occur at night. This, along with the high impact speeds, suggests an additional countermeasure. Minahan and O'Day emphasize that underrides are surprise events in which (generally) car drivers do not see the truck trailers in time to stop, and they suggest that increasing the conspicuity of truck trailers at night may prevent some of these accidents from occurring. Possible improvements include additional running lights, flashing side lights, or reflective paints or plastic strips.

The scope of the Minahan-O'Day study did not permit any estimation of the number of accidents that increased conspicuity could prevent. Also, though some work has been done on reflective materials for trucks (3M Corporation, 1978), objective measurements are needed of the extent to which visibility can be increased under conditions of darkness, fog, etc.

1.2 FINDINGS

The 1977 data from the Fatal Accident Reporting System (FARS) were examined with a view to discover whether car/TTST (Truck Tractor and SemiTrailer) rear-end and angle accidents were overrepresented under conditions of adverse visibility. One measure of this is the percentage of rear-end and angle accidents at night as compared with the percentages of other collisions between cars and TTST's at night. The FARS codes four degrees of light--dark, dark but lighted, dawn/dusk, and daylight. For the purposes of this analysis, HSRI deemed "night" to be the first two categories plus one half of the third.

The figures are given in Table 1 and illustrated in Figures 1-4. They show clearly that rear-end and angle collisions are more apt to occur at night than are other car/TTST collisions.

TABLE 1

Car/TTST Fatal Accidents by Light Condition

Light Condition	Rear-End	Angle	Other	Total
Day	75 (33.4%)	180 (53.3%)	962 (62.4%)	1216 (57.9%)
Night	149 (66.6%)	158 (46.7%)	579 (37.6%)	887 (42.1%)
TOTAL	224 (100%)	338 (100%)	1541 (100%)	2103 (100%)

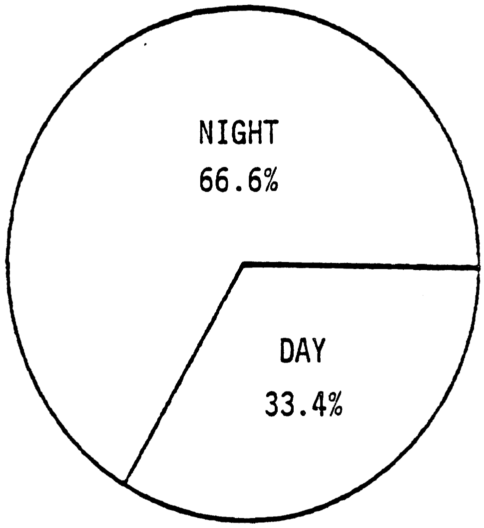


FIGURE 1
Car and Tractor-Trailer Fatal Accidents (Rear-End)

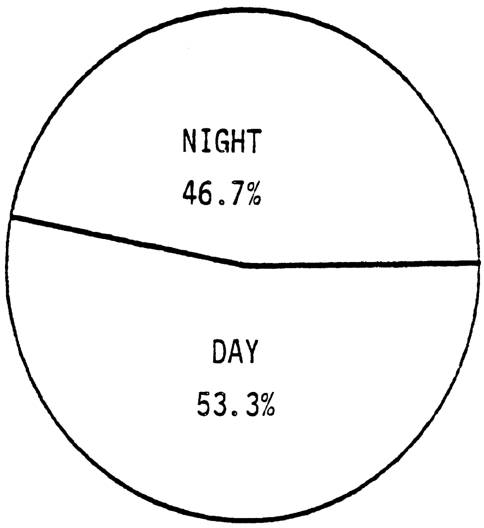


FIGURE 2
Car and Tractor-Trailer Fatal Accidents (Angle)

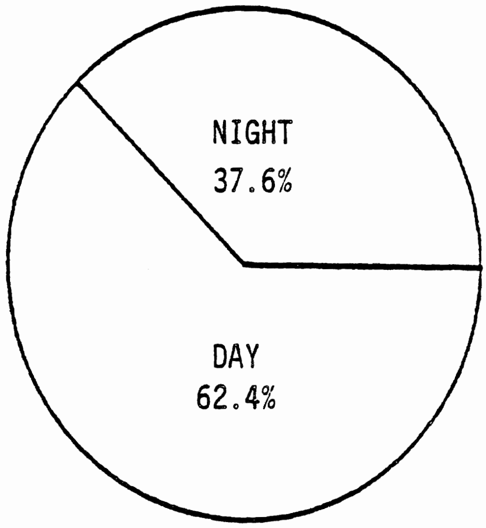


FIGURE 3
Car and Tractor-Trailer Fatal Accidents (All Other)

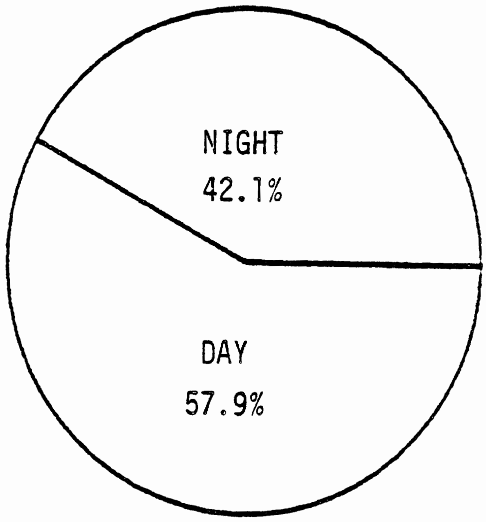


FIGURE 4
Car and Tractor-Trailer Fatal Accidents (All)

Next HSRI looked at rear-end and angle accidents to discover whether drinking had been involved in a disproportionate number. While approximately one-third of angle and rear-end car/TTST collisions involve drinking, less than one-fifth of all car/TTST accidents do. The percentages in all categories are increased when only those accidents that occur at night are considered, as shown in Table 2 and Figures 5-8. These results agree with other evidence. Drinking alcohol increases reaction time (Moskowitz and Burns, 1971) and impairs vision (Brown et al., 1978). This, as will be shown later, may create an unusually dangerous situation at night when trucks make up a larger percentage of vehicles on the road.

TABLE 2
Car/TTST Accidents by Light Condition
Drinking Involvement

	Rear-end	Angle	All
DAY	75	180	1216
Drinking Involved	11 (14.7%)	21 (11.7%)	88 (7.2%)
NIGHT	148	153	852
Drinking Involved	67 (45.3%)	73 (47.7%)	280 (32.9%)
TOTAL	224	338	2103
Drinking Involved	78 (34.8%)	94 (27.8%)	368 (17.5%)

As shown in Tables 1 and 2, the national FARS data for 1977 contain a total of 224 rear-end and 338 angle fatal collisions of cars into TTST's. How many of these accidents involve underride?

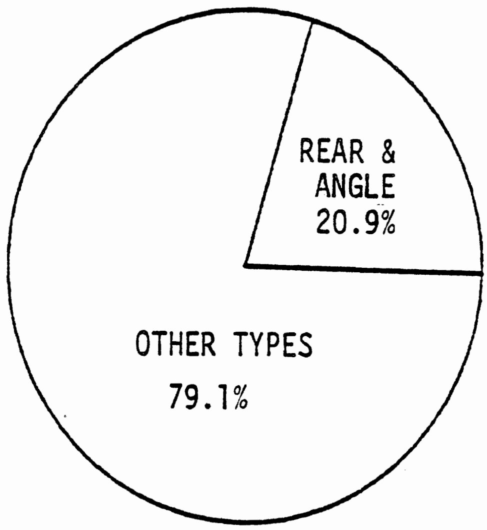


FIGURE 5
All Daytime Car/TTST Collisions

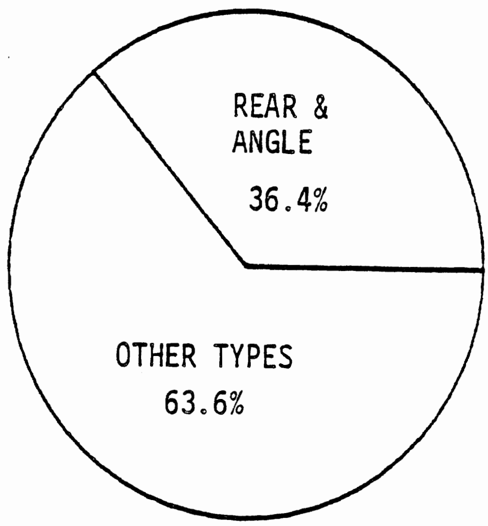


FIGURE 6
Daytime Car/TTST Collisions Involving Alcohol

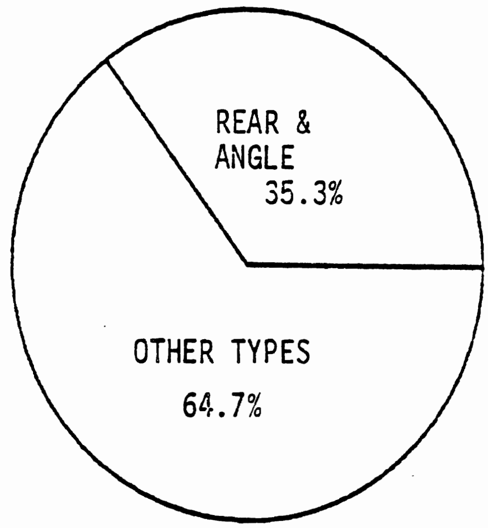


FIGURE 7

All Nighttime Car/TTST Collisions

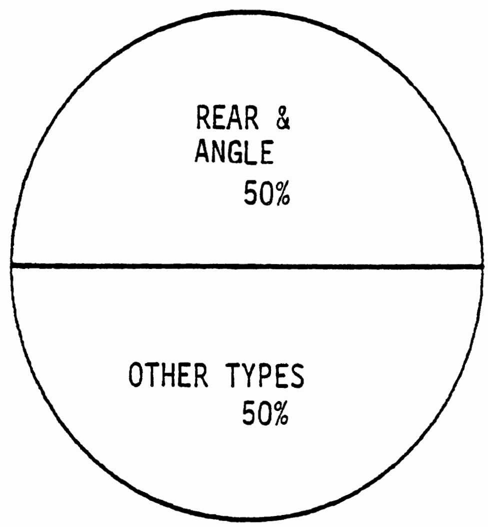


FIGURE 8

Nighttime Car/TTST Collisions Involving Alcohol

Underride is not explicitly coded by the FARS, and in the absence of photographs of each of these crashes, it is impossible to tell exactly how many involved underride. The Minahan-O'Day study, however, did examine photographs of rear and angle car/TTST fatals from Michigan and Texas, and found that the majority of these accidents are indeed underrides. Given a rear-end car/TTST fatal collision, they found underride was present in 93% of the cases. Similarly, given an angle car/TTST fatal collision, underride occurred in 75% of the cases. Applying these percentages to our totals from the FARS, HSRI estimates 208 fatal rear underrides and 254 fatal side underrides. Thus, in 1977, there were approximately 462 TTST underride fatals in the United States. Minahan-O'Day, extrapolating from Michigan and Texas data, estimated 423 TTST (and 148 straight truck) underrides nationally per year.

Table 3 contains figures from the 1977 FARS file for all car/car, TTST/TTST, and car/TTST collisions (a total of 12,245 accidents), distributed by the light condition under which they occurred.

TABLE 3

1977 FARS Accidents Involving Cars and TTSTs
(by Light Condition)

Light Condition	Car/TTST	Car/Car	TTST/TTST	Total
Day	1216 (57.9%)	5035 (52.0%)	56 (46.7%)	6480 (52.9%)
Night	887 (42.1%)	4814 (48.0%)	64 (53.3%)	5765 (47.1%)
TOTAL	2103 (100.0%)	10,022 (100.0%)	120 (100.0%)	12,245 (100.0%)

As a yardstick for evaluating these data, it would be useful to have some measure of exposure. Since the volume of traffic varies during a day, it is important to know how accidents would be distributed throughout the day if they were random events (i.e., based solely on the number and types of vehicles on the road). There is evidence (U.S. Department of Transportation, 1974) that TTST's account for 6% of the total vehicle miles in this data set and further, that this traffic is evenly distributed over the 24-hour day. (This estimate is based on Indiana turnpike data of Scott and O'Day, 1971, p. 135.) Cars, on the other hand, accumulate most of their mileage in daylight (U.S. Federal Highway Administration, 1972). From these assumptions, a model can be constructed to distribute our universe of 12,245 accidents involving cars and trucks by the types of vehicles and the time of day. This has been done in Table 4. The expected accidents in any four-hour time span are generated by the following three formulas:

1) For TTST/TTST accidents:
   Expected Accidents = col 1 x col 2 x 12,245

2) For car/car accidents:
   Expected Accidents = col 2 x col 4 x 12,245

3) For car/TTST accidents:
   Expected Accidents = 2 col 1 x col 2 x col 3 x col 4 x 12,245

Actual 1977 FARS accidents and expected accidents are shown together in Table 5. It would be overambitious to draw too many conclusions from these figures, inasmuch as HSRI's accident model is based solely on exposure and assumes that accidents are random events. Two observations, however, can be made.

First, in all categories involving trucks, the number of FARS accidents exceeds the number of expected accidents. Second, all categories of nighttime accidents show more collisions than expected.

Neither of these results are especially surprising. Trucks are, in a sense, easier to hit than cars. They're larger, and a maneuver to avoid colliding with a car might succeed while the same maneuver to avoid a truck might fail. Under conditions of

TABLE 4

Car and TTST Fatal Accident Model

Time	(1) TTST As % of Total Vehicle Miles	(2) Cars As % of Total Vehicle Miles	(3) TTST As % of Vehicles During Time Per.	(4) Cars As % of Vehicles During Time Per.	Expected Accidents			
					Car/ TTST	Car/ Car	TTST/ TTST	Total
0000-0400 Night	.01	.0454	.181	.819	201	456	22	679
0400-0800 Day-Nt	.01	.0601	.143	.857	210	631	17	858
0800-1200 Day	.01	.2322	.041	.959	234	2726	5	2965
1200-1600 Day	.01	.2388	.040	.960	234	2807	5	3046
1600-2000 Day-Nt	.01	.2704	.036	.964	238	3190	5	3433
2000-2400 Night	.01	.0932	.097	.903	222	1030	12	1264
Total	.06	.94	--	--	1339	10840	66	12245

low visibility, trucks pose an added danger. In the dark, they are evidently not much more visible than are cars, and parts of the vehicle (notably the trailer) may be less so. This combination of massiveness (requiring quick reactions by other drivers under the best of circumstances) and low visibility may be especially lethal for the drinking driver examined in Table 2, since he/she may suffer impaired vision in addition to increased reaction time.

TABLE 5

Real vs. Expected Accidents

	Day	Night	Total
FARS TTST/Car	1216	887	2103
Expected TTST/Car	692	647	1339
FARS Car/Car	5208	4814	10022
Expected Car/Car	7444	3396	10840
FARS TTST/TTST	56	64	120
Expected TTST/TTST	21	45	66

Tables 6-9 illustrate further runs on the 1977 FARS file to discover the places and conditions that favor car/TTST collisions. The two populations examined for these tables are car/TTST rear-end collisions and, for comparison, the entire FARS Two Vehicle Accident File.

Table 6 and Figure 9 show the distribution of accidents by region along with the 1977 population of those regions. Note especially the figures for regions five and six, which include the "heartland" states of Arkansas, Illinois, Indiana, Louisiana, Michigan, Minnesota, New Mexico, Ohio, Oklahoma, Texas, and Wisconsin. These eleven states contain 31.4% of the population and account for 28.7% of all fatal accidents. Over 40% of the fatal car/TTST rear-end collisions, however, occur within their borders. Chi-square analyses were run on these rear-end collisions versus population and the number of all fatals, and in both cases,

TABLE 6

Fatal Accidents and Population by Region

Region	Car/TTST Rear-end Collisions	All FARS Accidents	Population
1	6 (2.2%)	1603 (4.1%)	12,242 (5.7%)
2	14 (5.1%)	3333 (8.4%)	25,253 (11.7%)
3	27 (9.9%)	3944 (10.0%)	24,190 (11.2%)
4	52 (19.0%)	8226 (20.8%)	35,738 (16.5%)
5	71 (25.9%)	7615 (19.3%)	45,032 (20.8%)
6	40 (14.6%)	3711 (9.4%)	22,897 (10.6%)
7	18 (6.6%)	2294 (5.8%)	11,567 (5.3%)
8	2 (0.7%)	1682 (4.3%)	6,296 (3.0%)
9	33 (12.0%)	5337 (13.5%)	25,720 (11.9%)
10	11 (4.0%)	1748 (4.4%)	7,298 (3.4%)
Total	274	39,493	216,332

the results were significant at the <0.00001 level. It is most unlikely that this is a chance finding.

This is a curious result. It conjures an image of thousands of cars and trucks lined up on the perimeter of the U.S. and, at some prearranged signal, all racing toward the center of the country to crash into one another. Why so many of these truck accidents should occur in regions five and six is, at present, anybody's guess. It may be that a larger proportion of the truck traffic in these states is cross-country traffic since the

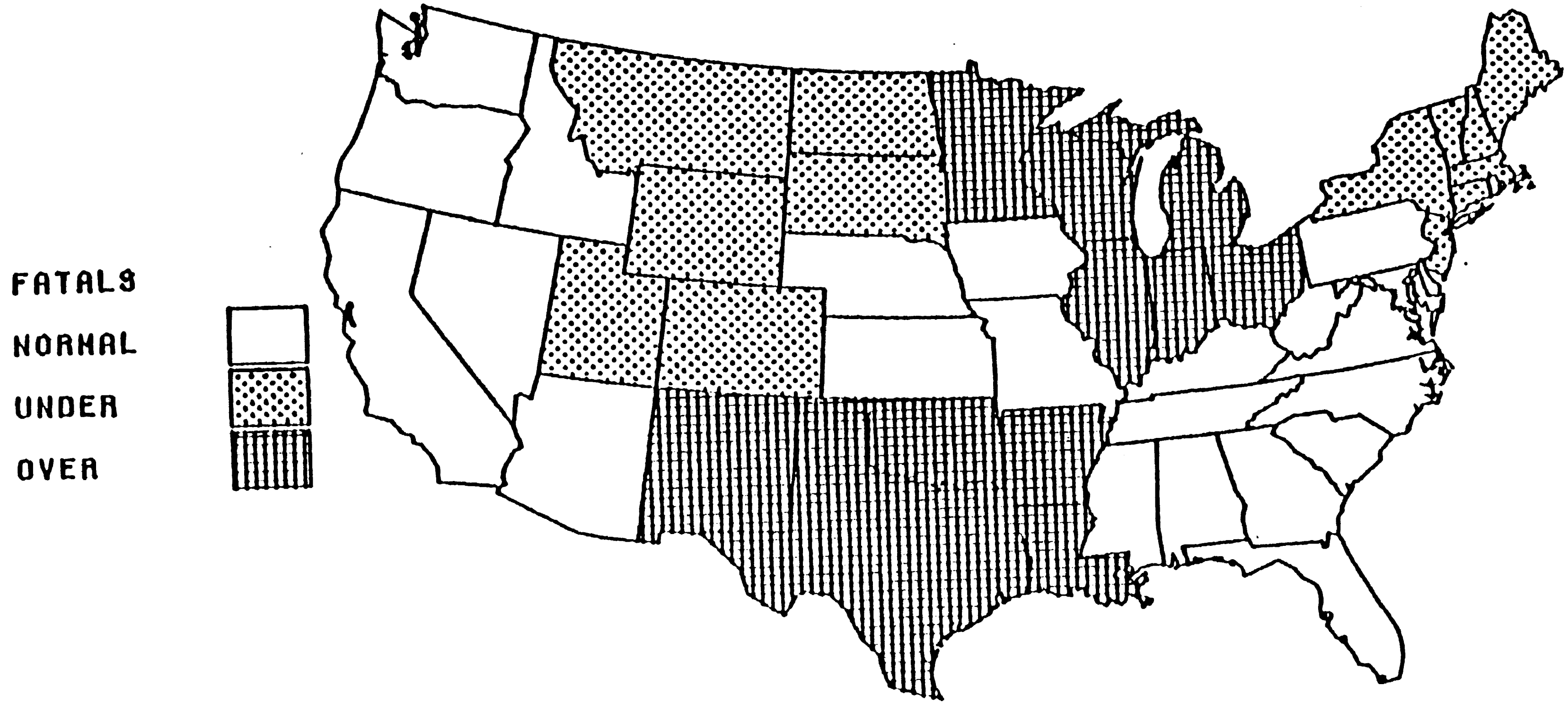


FIGURE 9
Over and Underrepresentation of Car/TTST Rear-end Collisions (by NHTSA Region)

interstate highways there operate as a funnel for east-west traffic from major coastal cities. Further, a driver en route from, say, Pittsburgh to San Francisco will likely be in Indiana by the time he has driven for ten hours. Perhaps these states get a lot of truck (and car) traffic involving drivers who have been on the road for a number of hours.

Tables 7 and 8 and Figures 10 and 11 describe the type of road on which most of these accidents take place. Interstate highways, limited access roads, and U.S. routes carry most of our truck traffic, so it is not surprising that they should account for 54.7% of this particular type of truck accident. Similarly, divided highways (like interstates) are usually major truck routes. Further, when collisions occur on divided roads, they are almost always between vehicles traveling in the same direction. Hence the preponderance of rear-end collisions.

TABLE 7

Fatal Accidents by Road Type

Road Type	Car/TTST Rear-end Collisions	All FARS Accidents
Interstate	79 (28.8%)	3176 (8.0%)
Limited Access	6 (2.2%)	494 (1.3%)
U.S. Route	65 (23.7%)	6527 (16.5%)
State Route	88 (32.1%)	12,986 (32.9%)
Major Artery	7 (2.6%)	1161 (2.9%)
County Road	4 (1.5%)	6374 (16.1%)
Local Road	25 (9.1%)	7645 (19.4%)
Other	0 (0.0%)	1130 (2.9%)
Total	274	39,493

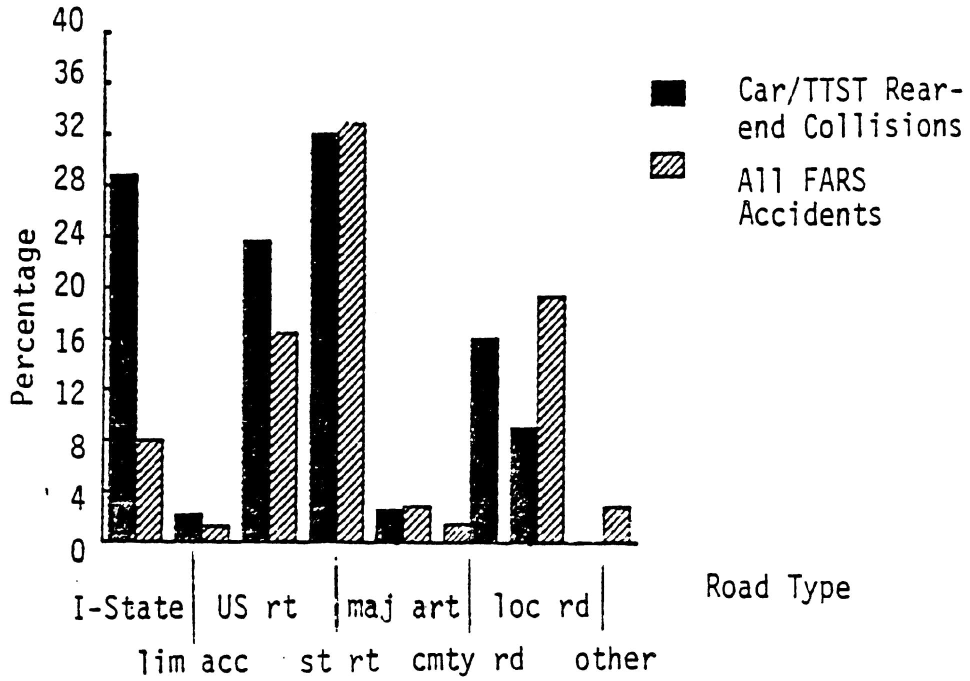


FIGURE 10
Fatal Accidents by Road Type

TABLE 8
Fatal Accidents by Type Road Divider

Divider	Car/TTST Rear-end Collisions	All FARS Accidents
Median	98 (35.5%)	5828 (14.8%)
Guardrail	9 (3.3%)	599 (1.5%)
Other	15 (5.5%)	1261 (3.2%)
Not Divided	150 (54.7%)	30,917 (78.3%)
One-Way	2 (0.7%)	410 (1.0%)
Unknown	0 (0.0%)	478 (1.2%)
Total	274	39,493

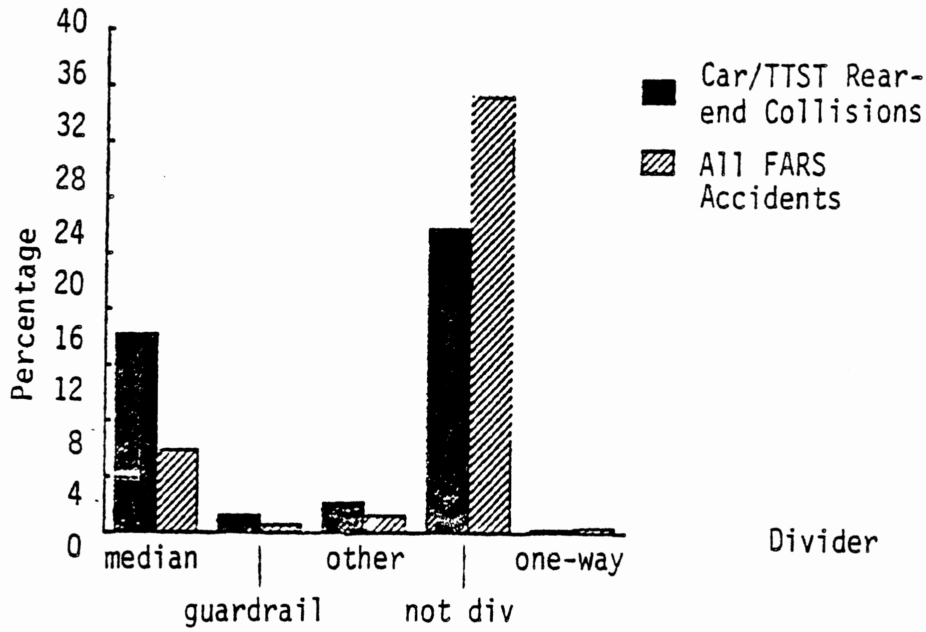


FIGURE 11
Fatal Accidents by Type Road Divider

The effects of surface condition are shown in Table 9. Our category "Non-dry" is the sum of FARS codes for water, snow, ice, sand, grease, and other hazards to traction. A chi-square analysis of these figures shows a significance level of 0.06. Poor surface conditions would seem to be overrepresented in the population of car/TTST rear-end collisions.

TABLE 9
Fatal Accidents by Surface Condition

Surface Condition	Car/TTST Rear-end Collisions	All FARS Accidents
Non-Dry	63 (23.1%)	7265 (18.4%)
Dry	211 (77.0%)	31,951 (80.9%)
Other	0 (0.0%)	277 (0.7%)
Total	274	39,493

1.3 SUMMARY OF FINDINGS

The statistical profile of car/TTST rear-end and angle collisions (i.e.--those which can result in underride), based on 1977 FARS data, is as follows:

-Rear-end and angle fatal collisions are more likely to occur at night than are other types of fatal car/TTST collisions. Two thirds of rear-ends happen at night while only 42.1 percent of all fatal accidents do.

-Drinking involvement is overrepresented in rear-end and angle collisions, compared with other types of collisions. This is true both day and night.

-The 1977 FARS file contains more nighttime accidents and more truck accidents than would be expected from a model based on the mix of cars and TTST's on the road at different times of day. There are many possible explanations for this. One of them, however, is that massive vehicles that are difficult to see pose substantial dangers to other motorists.

-Over 40 percent of fatal car/TTST rear-end collisions occur in DOT-regions five and six. These eleven states contain 31.4 percent of the population and account for only 28.7 percent of all traffic fatalities.

-More than half of these collisions take place on interstates, limited access roads, and U.S. routes. This type of accident is also overrepresented on divided highways.

-Non-dry driving surfaces and bad weather foster car/TTST rear-end collisions to a greater extent than other types of fatal accidents.

1.4 CONCLUSIONS

-The Minahan-O'Day (1977) estimate of 423 TTST underride fatals nationally per year is probably a bit low. A better estimate is 462.

-Since car/TTST collisions are overrepresented at night, making trucks and trailers more conspicuous through the addition of lights or reflective paints would reduce the frequency of accidents.

-Low levels of nighttime conspicuity for trucks may pose added danger to those other motorists whose vision is already impaired (e.g.--by alcohol).

1.5 REFERENCES

Brown, B., Adams, A. J., Haegerstrom-Portnoy, G., Jones, R. T. and Flom, M. C., "Effects of Alcohol and Marihuana on Dynamic Visual Acuity: I. Threshold Measurements," Perception and Psychophysics, December 1975, 18, 441-446.

Dynamic Science, Inc., "Compliance Test and Procedure for Truck Rear Underride," U.S. Department of Transportation Contract No. DOT-HS-5-01905, in progress.

Minahan, D. J. and O'Day, J., Car-Truck Fatal Accidents in Michigan and Texas, University of Michigan Highway Safety Research Institute, Report No. UM-HSRI-77-49, Ann Arbor, Michigan, 1977.

Moskowitz, H. and Burns, M., "The Effect of Alcohol Upon the Psychological Refractory Period," Quarterly Journal of Studies on Alcohol, September 1971, 32, 782-790.

Scott, R. E. and O'Day, J., "Statistical Analysis of Truck Accident Involvement, " U.S. Department of Transportation, Report No. DOT/HS 800 627, Washington, D.C., December 1971 (available from NTIS as PB 208 139).

3M Corporation, "Night Demonstration on Conspicuity of Trucks and Trailers," at 3M Center in St. Paul, Minnesota, November 9-10, 1978.

U.S. Department of Transportation, 1972 Census of Transportation, Volume II, Truck Inventory and Use Survey, Washington, D.C., March 1974.

U.S. Department of Transportation, Federal Highway Administration, Highway Statistics - 1978, Washington, D.C., 1979.

2. LITERATURE REVIEW ON NIGHTTIME CONSPICUITY AND EFFECTS OF RETROREFLECTORIZATION

2.1 INTRODUCTION

Minahan and O'Day (1977) in their analysis of fatal car-truck accidents found that such accidents usually occur at night with frequent car underride. One of the conclusions reached by Minahan and O'Day was that enhanced conspicuity of trucks and trailers would reduce car-truck accidents. Similar conclusions were reached in the previous section of the report. This review deals with the following issues:

- Lexical and operational definitions of conspicuity
- Conspicuity and visual information processing
- Retroreflectorization as an aid for increased nighttime conspicuity of vehicles

2.2 DEFINITIONS OF CONSPICUITY

Conspicuity is defined by IES Lighting Handbook (1972) as, "the capacity of a signal to stand out in relation to its background so as to be readily discovered by the eye" (p. 1-6).

Webster's Third New International Dictionary (1968) defines conspicuous as:

1. obvious to the eye or mind: plainly visible; MANIFEST
2. attracting or tending to attract attention by reason of size, brilliance, contrast, station: STRIKING, EMINENT
3. undesirably noticeable by reason of violation of good taste or sense
   syn. see NOTICEABLE (p. 485).

Implicit in the IES and Webster's definitions is the notion that conspicuity applies especially to peripherally located objects and that a likely consequence of an object being conspicuous is its detection and consequent foveal fixation. As will be discussed below, this distinction between foveal and peripheral objects is helpful not only from a theoretical point of view of defining the problem (i.e., what is conspicuity), but also from an applied point of view of alleviating the problem (i.e., how to increase conspicuity). Therefore, conspicuity will be operationally defined in the present context as follows:

> Conspicuity is the property of a peripherally located object that is likely to lead to the object's detection and subsequent foveal fixation (and identification) by reason of its size, luminance, contrast, or other physical dimensions.

Size, luminance, and contrast were included in the current definition not only because they appear in the Webster's definition, but primarily (as will be shown below) because of the empirical evidence on the influence of these parameters on detectability and identification.

2.3 CONSPICUITY AND VISUAL INFORMATION PROCESSING

2.3.1 Structure and Functions of the Retina. The human retina (the light-sensitive part of the eye) is tightly packed with two types of light receptors: cones and rods. The foveal region of the retina (corresponding to the central 1-2° of the visual field) contains exclusively cones; the periphery (corresponding to the remainder of the visual field) contains primarily rods (Osterberg, 1935).

As a consequence of these and other structural differences, the fovea and the periphery vary in their capabilities. In terms of detection, the differences between the fovea and periphery depend on light conditions. In photopic and mesopic (i.e., relatively bright) conditions, the luminance threshold is lowest at or near the fovea. In scotopic (i.e., relatively dark) conditions, the threshold is lowest at 15-20° in the periphery (Aulhorn and Harms, 1972; Pirenne, 1967).

In terms of several processes needed for object identification, it is the fovea which excels. First, visual acuity (the ability to resolve small detail) is best in the fovea and worsens progressively with increasing peripheral eccentricity. This is true whether the target is moving or is stationary in relation to the observer (Brown, 1972; Feinberg, 1948; Gordon, 1947; Green, 1970; Hershenson, 1969; Klein,1947). Second, motion perception is most efficient in the fovea (Gordon, 1947; Klein, 1942; McColgin, 1960). This implies that to detect movement of an object, the angular speed of the object must be greater if the image of the object falls in the retinal periphery rather than the fovea. Third, color discrimination is most accurate in the fovea and decreases with the increased eccentricity from the fovea (Boynton et al., 1964; Moreland, 1972; Moreland and Cruz, 1958; Weale, 1953, 1956; Weitzman and Kinney, 1969).

The findings described above indicate that foveal identification (a function of visual acuity, motion perception, color discimination) is superior to peripheral identification. However, the fovea comprises less than 1% of the total active visual field. (As was noted earlier, the fovea includes the central 1-2° [Polyak, 1941], while the active visual field extends to about 175-180° in the horizontal meridan and 100-130° in the vertical meridan [Burg, 1968; Connolly, 1966; Schmidt, 1966]). Therefore, the likelihood of an object's image falling on the periphery as opposed to the fovea is high. The inefficiency of the periphery in the identification process, however, implies that most of the objects are identified in the fovea (Waldram, 1960).

In general then, detection (monitoring) takes place in the periphery (due to the size of the periphery) while identification takes place in the fovea (due to the efficiency of the fovea). It follows, that factors which will:

a) improve detection and/or
b) improve the likelihood of foveal fixation,

will improve conspicuity and be beneficial for identification.

2.3.2 Factors Affecting Detection Thresholds. The primary physical parameters affecting the detectability of targets are size, luminance, and contrast. In general, with an increase in the size of a target, there is a decrease in the luminance or contrast necessary for detection; conversely, with an increase in target luminance or contrast there is a decrease in the size necessary for detection (Blackwell, 1946, 1959; Brown, 1947; Hills, 1976; Kristofferson, 1954; Lamar, Hecht, Schlaer and Hendley, 1947; Riopelle and Chow, 1953; Taylor, 1964).

2.3.3 Factors Affecting Foveal Fixations. A consequence of the large size of the periphery is the essentially parallel nature of the detection process: detection can occur in several parts of the periphery simultaneously. On the other hand, as mentioned above, efficient identification is essentially a serial process. With parallel detection and serial identification there is the potential for a bottleneck, with detected objects "competing" for foveal attention in order to be identified. Several researchers (e.g., Boynton, 1960; Hochberg, 1970; Howett, Kelly and Pierce, 1978; Mackworth and Morandi, 1967; Mourant and Rockwell, 1970; Townsend and Fry, 1960) have postulated that the periphery alleviates the bottleneck by selecting where the future foveal fixations will be directed. In other words, they postulate the presence of a peripheral filter which passes to the fovea only objects of importance for the task at hand.

Recordings of actual eye movements in a free search situation indicate that peripheral objects having certain physical properties have advantage in passing the peripheral filter and thus in gaining foveal fixation. These studies indicate that such properties include high information content (Mackworth and Morandi, 1967; Notton and Stark, 1971; Yarbus, 1961), high contrast (Thomas, 1968), flicker (Thomas, 1968, 1969), motion (Thomas, 1968), or large size (Thomas, 1968).

In summary, size and contrast (luminance) positively affect both the likelihood of detection and the likelihood of consequent foveal fixation necessary for veridical identification. Therefore, a treatment leading to increased size and contrast (luminance) is likely to be beneficial. One such countermeasure involves the application of retroreflective material to various areas of vehicles. Retroreflectorization increases the nighttime visible area of the vehicle as well as the effective luminance (contrast) of such area. The following section reviews the research evidence on the safety-related benefits of retroreflectorization.

2.4 RETROREFLECTORIZATION AND INCREASED CONSPICUITY

Informal demonstration of the conspicuity of retroreflective treatments are often rather striking (e.g., 3M Corporation, 1978). Direct research evidence on the benefits of retroreflectorization comes from various sources, including accident investigations, analytical studies, as well as subject evaluations. In several respects these sources complement each other, as is apparent in Table 10.

TABLE 10

General Characteristics of Various Relevant Research Paradigms

	Research Paradigm		
General Characteristic	Accident Investigations	Analytical Studies	Subjective Evaluation
Dependent Variable	ACCIDENT RATE, ACCIDENT FREQUENCY	VARIOUS PERFORMANCE MEASURES	SUBJECTIVE ESTIMATES OF CONSPICUITY OR EFFECTIVENESS
Face Validity (Realism)	HIGH	LOW-INTERMEDIATE	INTERMEDIATE-HIGH
Difficulties (in Terms of Time and Cost) of Data Collection	HIGH (expect for studies utilizing pre-existint data sets)	LOW-INTERMEDIATE	LOW
Control of Potentially Confounding Variables	LOW	HIGH	LOW-INTERMEDIATE

Retroreflectorization as an aid for increased conspicuity and safety has been applied to a wide range of vehicles, including trucks (Transport and Road Research Laboratory, 1976), buses (Proulx, 1959), motorcycles (e.g., Burg and Beers, 1976), bicycles (e.g., Burg and Beers, 1978), and railroad boxcars (e.g., Hazlett and Allen, 1968). As there are few studies exploring the benefits of retroreflectorization of trucks, the present review deals with large highway vehicles (trucks and buses) as well as small vehicles (motorcycles) capable of highway speeds.

The location and size of the retroreflective treatments differ across various studies. However, there is substantial uniformity on these two dimensions in studies on the benefit of retroreflectorized license plates. Therefore, an additional section will be devoted to retroreflectorization of license plates.

2.4.1 Trucks and Buses. In general, the available evidence regarding larger vehicles comes from accident investigations as opposed to analytical studies or subjective evaluations.

One of the first studies on the benefit of retroreflectorization of vehicles was performed by Greyhound Bus Lines in the late 1940s (cited by Proulx, 1959). As Proulx reports, "in 1946 prior to reflectorization, the miles per collision accident [for Greyhound coaches] was 125,100. By 1950, after reflectorization was started, the miles per collision accidents where a vehicle hit a coach being reduced by 719 over 1946 (Proulx, 1957, p. 7)."

The United States Post Office Department reported in 1957 on the effect of a change of color of their fleet from olive drab to a combination of red, white, and blue, with the red being retroreflectorized tape. This study compared the accident rates for approximately 3,500 vehicles from each category. Each group of vehicles was operated approximately 10 million miles in 42 major American cities. The main results were as follows:

1. Overall, the olive drab fleet was involved in 849 accidents, compared with 622 for the red, white, and blue fleet.

2. The difference between the two groups was most pronounced for accidents where other vehicles rear-ended the postal vehicles (50 such accidents for the olive drab group, 24 for the red, white, and blue group).

While the obtained differences are impressive, it has to be pointed out that in addition to the difference in retroreflectorization, the two fleets differed in the brightness of the colors used. Therefore, the obtained differences cannot be attributed to the retroreflectorization treatment alone.

The most recent accident data come from England, where since November 1, 1971, heavy goods vehicles over three tons unladen weight have been required to display distinctive rear markings. The markings incorporate yellow retroreflective material (to improve nighttime conspicuity) and red flourescent material (to improve daytime conspicuity). The markings are of one of two patterns: diagonal (chevron) stripes for vehicles of less than 13m overall length and a LONG VEHICLE sign with the retroreflective and flourescent coating as a background for vehicles over 13m long (British Standards Institute, 1970).

The effects of the British Regulation was evaluated by the Transport and Road Research Laboratory (United Nations Economic Commission for Europe, 1973; TRRL, 1976). The second of these report (TRRL, 1976) provides data on injury-producing accidents for the two-year periods prior to and following the effective date of compulsory usage of the treatments. The accidents involving heavy trucks were analyzed according to time of the day, road lighting, movement of the truck, location of the damage of the truck, as well as type of environment.

While the results indicate reductions in the number of accidents across all conditions after the introduction of the markings, the only statistically significant reduction occurred for nighttime rear-end accidents on unlit rural roads involving parked heavy goods vehicles. However, that is precisely the type of accidents retroreflectorization should reduce.

In an analytical study, Reid (1977) investigated recognition distances of chevron-type markings designed to be used by heavy trucks (British Standards Institute, 1970). Mean recognition distance for standard material markings mounted on a board was 255m in a glare condition and 306m in a no-glare condition. The use of a "high-intensity" material in place of the standard material had little effect on recognition distance in the glare condition. In the no-glare condition the high-intensity material resulted in a 20% increase in the main recognition distance.

2.4.2 Motorcycles. Several analytical and subjective-evaluation studies have investigated the benefits of retroreflectorization of motorcycles or motorcyclists.

Burg and Beers (1978) utilized detection and recognition measures to estimate the effects of retroreflective tires and prismatic retroreflectors on side conspicuity of motorcyclists. The detection data indicate that high-reflectance tires were more efficient than either low-reflectance tires or prismatic reflectors. Furthermore, prismatic reflectors exhibited greater fall-off in detection distances as the orientation of the tires changed from a right angle (to the subject's line of sight) to a more oblique orientation.

The recognition data were collected for a separation distance of 500 feet between the motorcycle and observer with the motorcycle at a right angle to the observer's line of sight. The standard motorcycle with lights turned on yielded recognition rates of 45%. The addition of either high- or low-reflectance sidewall tires raised the recognition rate of 97%. This increase is statistically as well as practically significant.

The Highway Safety Research Institute recently completed an in-traffic motorcycle conspicuity study, utilizing a gap-acceptance methodology (Olson, Halstead-Nussloch, and Sivak, 1979). The results of this investigation indicate that, in general, the use of retroreflective garments increases the conspicuity of the rider.

In a subjective evaluation, Stoovelar and Groot (1978) tested various visibility-enhancing treatments. They concluded that, "the use of reflective devices is essential if two-wheelers are to be recognized at night" (p. 21).

Observers in another subjective-evaluation study (Bartol, Livers, and Miennert, 1975) estimated the effectiveness of retroreflective panels mounted on the front and rear of the motorcycle. The authors of this study concluded that the tested treatments "were marginally effective at night on a dark road, and were not effective at night in a lighted urban area" (p. A-5). However, the observers in this study "were seated on or next to a servi-car with the headlamp on and directed toward the test motorcycle" (p. A-4). This seating arrangement might have created a larger observation angle (resulting in less light being returned from the treatments to the eyes of the observers) than would be the situation for an actual driver. If that were the case, no substantial effect of retroreflectorization would be expected.

2.4.3 License Plates. A variety of studies on retroreflectorized license plates were recently summarized in several reviews (Cook, 1975; Hulbert and Berg, 1975; Olson and Post, 1977). Therefore, the current discussion will refer primarily to the findings and conclusions of these review articles.

The question of the benefits of retroreflectorized license plates has been the subject of numerous accident investigations (e.g., Baerwald, Karmeier, and Herrington, 1960; Campbell and Rouse, 1968; Iowa Department of Public Safety, 1960; Maine State Police, 1963; Sacks, Lenker, and Polanis, 1973; Stoke, 1974; Vaughn and Wood, 1975). In general, these studies compared the accident rates of vehicles with and without retroreflectorized license plates. In their literature review, Olson and Post (1977) note three main points regarding the data from accident studies:

1. Most studies show differences in accident rates consistent with the hypothesis that retroreflective license plates are a significant safety item. In some instances the differences in accident rates are very large indeed.
2. In general, the studies which had the more rigorous experimental controls report the smallest differences and, in one instance, no difference at all. This suggests (but does not prove) that the methods of some of the earlier studies were seriously flawed and the results, as a consequence, wrong or at least optimistic.
3. Despite the effort expanded and the relatively consistent results, the issues cannot be described as settled (p. 7-8).

Reviewing essentially the same group of studies as Olson and Post (1977), other investigators came to somewhat different conclusions. Hulbert and Berg (1975) argue that, "taken as a group these studies provide evidence of a significant, if perhaps not overwhelming, safety benefit associated with reflectorized plates" (p. 27), and Cook (1975) concludes that "the burden of the evidence is that use of retroreflective license plates can result in fewer nighttime rear-end accidents" (p. 95).

Various analytical studies dealt with the visibility (detectability) of the vehicles with and without the retroreflectorization (e.g., Carlson, 1958; Larimer, 1956; Rumar, 1966, 1967; Stoke and Simpson, 1971; Wortman, 1968). After reviewing several such studies, Hulbert and Berg (1975) reached the following conclusion:

> With regard to visibility, the benefits of reflectorized plates are clearly definable; compared with conventional plates they improve vehicle detection distance anywhere from two to seven times, providing absolute detection distances of from 1,000 feet to as much as 0.4 mile. This advantage is of both statistical and practical significance (p. 27).

2.5 CONCLUSIONS

The present review dealt primarily with the theoretical analysis of the nighttime conspicuity problem and with empirical data on the effect of retroreflectorization.

The theoretical analysis concluded that:

(a) A treatment resulting in an increased visible size or increased contrast (luminance) is likely to be conspicuity-enhancing and therefore,

(b) retroreflectorization of parts of vehicles would likely be beneficial for highway safety.

While the available empirical data are not extensive, they do suggest that retroreflectorization of highway vehicles in general and trucks in particular would increase their nighttime rear and side conspicuity and thereby reduce accidents.

2.6 REFERENCES

Aulhorn, E., and Harms, H. Visual Perimetry. In D. Jameson and L. H. Hurvich (Eds.), Handbook of Sensory Physiology, Vol. VII/4, Visual Psychophysics, Berlin: Springer-Verlag, 1972.

Baerwald, J. E., Karmeier, D. F., and Herrington, C. G. The function and design of motor vehicle license plates. University of Illinois, Engineering Experiment Station, Bulletin No. 457, 1960.

Bartol, J. A., Livers, G. D., and Miennert, R. Requirements analysis and feasibility studies for an experimental safety motorcycle. AMF, Inc., Advanced Systems Laboratory, Goletta, CA., 1975.

Blackwell, H. R. Contrast threshold of the human eye. Journal of the Optical Society of America, 1946, 36, 624-643.

______. Development and use of a quantitative method for specification of interior illumination levels on the bases of performance data. Illuminating Engineering, 1959, 54, 317-353.

Boynton, R. M. Optimal visual search techniques. Summary and discussion, Part I. In Visual Search Techniques, National Academy of Sciences--National Research Council, Publication 712, 1960.

Boynton, R. M., Schafer, W., and Neun, M. E. Hue-wavelength relation measured by color-naming method for three retinal locations. Science, 1964, 146, 666-668.

British Standards Institute, Rear marking plates for vehicles, British Standard BS AU 152:1970, London, U.K., 1970.

Brown, B. Resolution thresholds for moving targets at the fovea and in the peripheral retina. Vision Research, 1972, 12, 293-304.

Brown, R. H. Complete spatial summation in the peripheral retina. American Journal of Psychology, 1947, 60, 254-259.

Burg, A. Lateral visual field as related to age and sex. Journal of Applied Psychology, 1968, 52, 10-15.

Burg, A., and Beers, J. Motorcycle reflectorization for nighttime conspicuity. University of California Engineering, Report UCLA-ENG-76111, Los Angeles, CA., 1976.

________. Reflectorization for nighttime conspicuity of bicycles and motorcycles. Journal of Safety Research, 1978, 10, 69-77.

Campbell, B. J., and Rouse, W. S. Reflectorized license plates and rear end collisions at night. Traffic Safety Research Review, 1968, 12(2), 40-45.

Carlson, R. Reflectorized license plates report. Washington State Patrol, 1958.

Connolly, P. L. Visual considerations of man, the vehicle, and the highway, Part II. Society of Automotive Engineers, SP-279, 1966.

Cook, K. G. Reflectorized license plates: A review and analysis of research, technical data and documentation related to their use. Century Research Corporation, April, 1975.

Feinberg, R. A study of some aspects of peripheral visual acuity. Parts I, II, III, and IV. American Journal of Optometry, 1948, 26, 49-56, 105-118.

Gordon, D. A. The relation between the threshold of form, motion and displacement in parafoveal and peripheral vision at a scotopic level of illumination. American Journal of Psychology, 1947, 60, 202-225.

Green, D. G. Regional variations in the visual acuity for interference fringes on the retina. Journal of Physiology, 1970, 207, 351-356.

Hazlett, R. D., and Allen, M. J. The ability to see a pedestrian at night: Effects of clothing, reflectorization, and driver intoxication. Highway Research Record, #218, 1968, 13-22.

Hershenson, M. Perception of letter arrays as a function of absolute retinal locus. Journal of Experimental Psychology, 1969, 80. 201-202.

Hills, B. L. Visibility under night driving conditions. Part I. Laboratory background and theoretical considerations. Australian Road Research, 1976, 6(2), 3-8.

Hochberg, J. Components of literacy: Speculation and exploration research. In H. Levin and J. P. Williams (Ed.), Basic studies on reading. New York: Basic Books, 1970.

Howett, G. L., Kelly, K. L., and Pierce, E. T. Emergency-vehicle warning lights: State of the art. National Bureau of Standards, Special Publication 480-16, Washington, D.C. 1978.

Hulbert, S. F., and Burg, A. Are reflectorized license plates a good idea? Special Report, University of California, January, 1975.

IES Lighting Handbook, 5th Edition, New York: Illuminating Engineering Society, 1972.

Iowa Department of Public Safety, 1959 Motor Vehicle Accident Study, Polk County Iowa, August, 1960.

Klein, G. S. The relation between motion and form acuity in parafoveal and peripheral vision and related phenomena. Archives of Psychology, 1942, 39(275), 1-70.

Kristofferson, A. B. Foveal intensity discrimination as a function of area. Unpublished doctoral dissertation, The University of Michigan, Ann Arbor, Michigan, 1954.

Lamar, E. S., Hecht, S., Schlaer, S., and Hendley, C. D. Size, shape and contrast in detection of targets by daylight vision. I. Data and analytical description. Journal of the Optical Society of America, 1947, 37, 531-545.

Larimer, E. M. Visibility of retroreflectorized license plates. Highway Research Board Bulletin, #163, 1957, 27-32.

McColgin, F. H. Movement thresholds in peripheral vision. Journal of the Optical Society of America, 1960, 50, 774-779.

Mackworth, N. H., and Morandi, A. J. The gaze selects informative details within pictures. Perception and Psychophysics, 1967, 2, 547-552.

Maine State Police. A study of rural traffic accidents prior to and since, use of reflective registration plates, 1963.

Minahan, D. J., and O'Day, J. Car-truck fatal accidents in Michigan and Texas. Highway Safety Research Institute, Report No. UM-HSRI-77-49, Ann Arbor, Michigan, 1977.

Moreland, J. D. Peripheral color vision. In D. Jameson and C. M. Hurvich (Eds.), Handbook of sensory physiology, Volume VII/4, Berlin: Springer-Verlag, 1972.

Moreland, J. T. and Cruz, A. C. Colour perception with the peripheral retina. Optica Acta, 1958, 6, 117-151.

Mourant, R. R., and Rockwell, T. H. Mapping eye-movement patterns to the visual scene in driving: An exploratory study. Human Factors, 1970, 12, 81-87.

Notton, D., and Stark, L. Eye movements and visual perception Scientific American, 1971, 224(6), 34-43.

Olson, P. L., Halstead-Nussloch, R., and Sivak, M. Development and field testing of techniques for increasing the conspicuity of motorcycles and motorcycle drivers. Highway Safety Research Institute. Report No. UM-HSRI-79-76. Ann Arbor, Michigan. October 1976.

Olson, P. L., and Post, D. V. Review of research evidence bearing on the desirability of using retroreflective license plates in Michigan. Highway Safety Research Institute. Report No. UM-HSRI-77-24, Ann Arbor, Michigan, 1977.

Pirenne, M. H. Vision and the Eye, 2nd edition. London: Chapman and Hall, 1967.

Polyak, S. L. The retina. Chicago: The University of Chicago Press, 1941.

Proulx, A. Z. Red dot confusion. 3M Corporation. Internal Publication, 1959.

Reid, J. A. Recognition distances of vehicle rear markings at night. Transport and Road Research Laboratory, Crowthorne (England), Supplementary Report 321, 1977.

Riopelle, A. J., and Chow, K. L. Scotopic-area-intensity relations at various retinal locations. Journal of Experimental Psychology, 1953, 46, 314-318.

Rumar, K. The reflective registration plate. Paper presented at 5th World Meeting, International Road Federation, London, 1966.

_______. Reflectorized license plates. Traffic Engineering and Control, 1967, 8(9), 555-557.

Sacks, W., Lenker, H., and Polanis, S. An analysis of the efficacy of reflective license plates for highway safety and other social purposes. Highway Safety Foundation, Mansfield, Ohio, 1973.

Schmidt, I. Visual considerations of man, the vehicle, and the highway, Part I. Society of Automotive Engineers, SP-279, 1966.

Stalder, H. I., and Lauer, A. R. Effective use of retroreflectorized materials on railroad boxcars. Highway Research Board Bulletin #89, 1954.

Stoke, C. B. Reflectorized license plates: Do they reduce nighttime rear end collisions? Report No. VHRC 73-R32, Virginia Highway Research Council, January, 1974.

Stoke, C. B., and Simpson, C. H., Jr. A comparison of the legibility and visibility of enamel and reflectorized 1971 Virginia license plates. Report No. VHRC 71-R15 prepared by the Virginia Highway Research Council, December, 1971.

Stoovelar, F., and Groot, R. E. Visible motor-cycles and mopeds. Angemeene Nederlandsche Wielryders Bond, Netherlands, 1978.

Taylor, J. H. Use of visual performance data in visibility prediction. Applied Optics, 1964, 3, 562-569.

Thomas, E. L. Movements of the eye. Scientific American, 1968. 219(2), 88-95.

_______. Search behavior. The Radiologic Clinics of North America, 1969, 7, 403-417.

3M Corporation. Night demonstration on conspicuity of trucks and trailers, St. Paul, Minnesota, November 9-10, 1978.

Townsend, C. A., and Fry, G. A. Automatic scanning of aerial photographs. In Visual Search Techniques, National Academy of Sciences--National Research Council, Publication 712, 1960.

Transport and Road Research Laboratory, Crowthorne (England). The effect of rear markings on rear impact accidents involving heavy goods vehicles. Leaflet 624, 1976.

United Nations Economic Commission for Europe, Rear markings of lorries: cost/benefit analysis. August 20, 1973.

U.S. Post Office Department. Release No. 143, July 15, 1957.

Vaughan, R. G., and Wood, R. Reflectorized number plates and traffic safety in Australia. Traffic Accident Research Unit, Department of Motor Transport, New South Wales, February, 1975.

Waldram, J. M. Vision and eye movements of motor drivers. New Scientist, 1960, 8, 1264-1267.

Weale, R. A. Colour vision in the peripheral retina. British Medical Bulletin, 1953, 9, 55-60.

_______. Problems of peripheral vision. British Journal of Ophthalmology, 1956, 40, 392-415.

Webster's Third New International Dictionary. Springfield, Mass.: G & C Merriam Co., 1968.

Weitzman, D. O., and Kinney, J. S. Effect of stimulus size, duration, and retinal location upon the appearance of color. Journal of the Optical Society of America, 1969, 59, 640-643.

Wortman, R. H. An evaluation of reflectorized annual license plate materials. Prepared for the Office of the Secretary of State, State of Illinois by the Highway Traffic Safety Center, University of Illinois, May 1968.

Yarbus, A. L. Eye movements and vision. New York: Plenum Press, 1967.

3. THE EFFECT OF RETROREFLECTIVE TREATMENTS ON THE EYE FIXATIONS OF DRIVERS

3.1 INTRODUCTION

In this study data were collected to measure the attention-getting properties of a display as a function of the luminance and quantity of retroreflective material employed. The data were collected under conditions intended to approximate an "unalerted" set in the subject's mind.

3.2 METHODS

3.2.1 Equipment. Data were collected using HSRI's eye-mark recorder. This device is a corneal reflection instrument, head mounted and stabilized by a bite bar. It is video based and data are stored on tape for processing at a later time. A photograph of the device is provided in Figure 12.

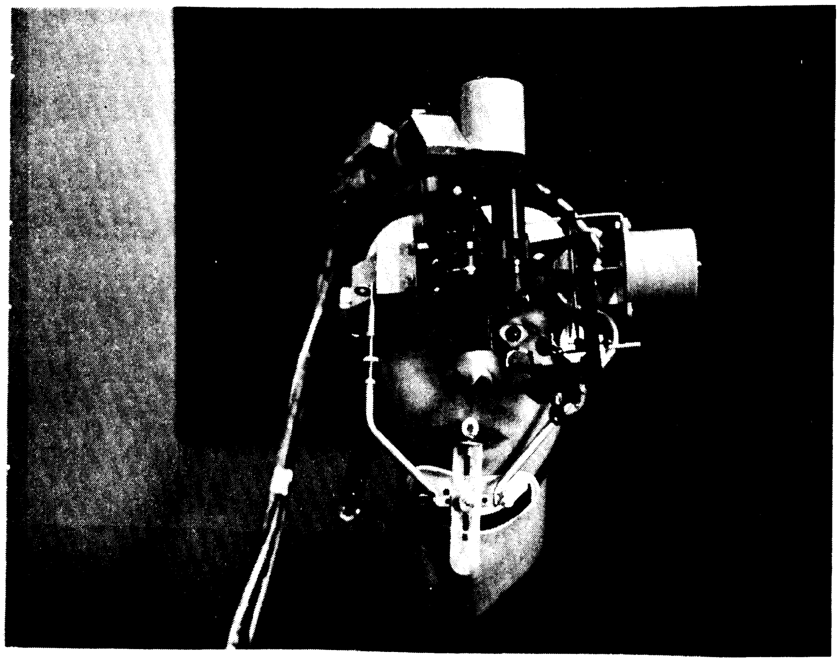


FIGURE 12
HSRI Eye-Mark Recorder

The eye-mark recorder was used in a vehicle which also uses the video system for recording speed, time, distance,and five channels of information for coding trials, etc. A special effects machine is used to combine these data with that from the eye mark into a single video frame.

The trailer used in the test was a 45-foot van on loan from the Fruehauf Corporation. It was equipped with standard retroreflectors on side and rear. The unit was otherwise unmarked. Its color was natural aluminum.

A sign panel, three feet square, was also used in the test. This was faced on each side with retroreflective materials having different specific luminance characteristics. Both appeared silver-white when viewed with headlamps.

The study was carried out on a private test track. The facility is oval in shape, 1.75 miles around, with 1500 foot straight sections on each side. There are three 15-foot-wide lanes. The surface is concrete. The entrance to the track is at about the center of one of the straight sections. Opposite the entrance, on the infield of the track, is a large paved storage area. The truck was set up in this area, to provide maneuvering room. The sign panel was placed along the opposite straight section (see Figure 13).

The retroreflective treatments for the truck were fabricated using white "Scotchlite" brand reflective sheeting, 580-10. The specific luminance of this material (at -4° entrance angle and 0.2° observation angle) is about 100 cd/ft c/ft^2.

Plywood panels, two feet by eight feet and one-quarter inch thick, were used to mount the retroreflective material. The panels were painted a medium gray and the retroreflective sheets applied after being cut to size. The panels, in turn, were either hung from hooks temporarily installed on the side of the van or supported by magnets.

Four levels of retroreflective treatment were applied to the

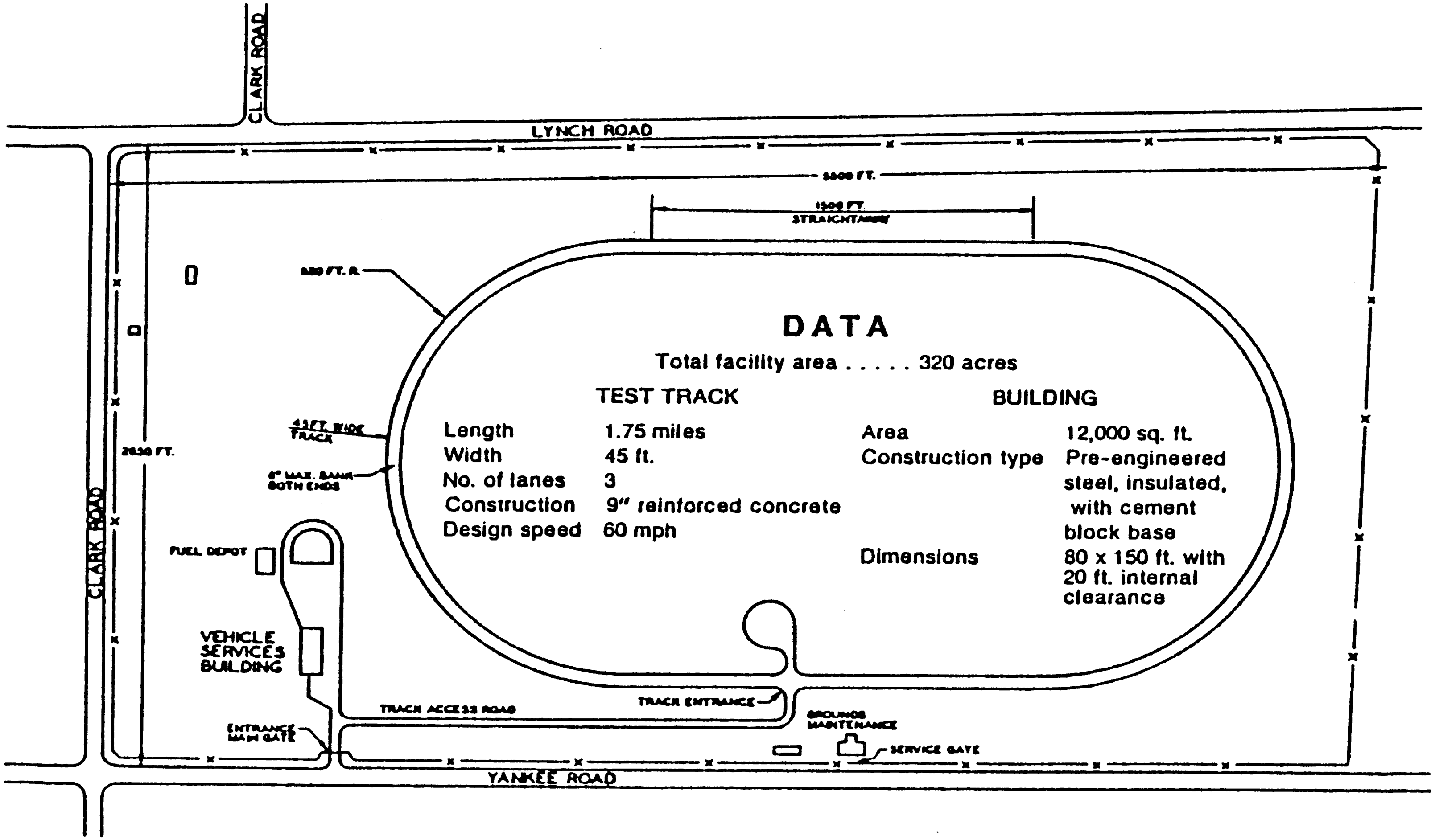


FIGURE 13

Diagram of Test Track Used

sides and rear of the trailer. These are described below and illustrated in Figures 14 through 17.

Level 1. None (Control). Only factory installed retroreflective buttons (Figure 14).

Level 2. Narrow. A single strip of retroreflective material, two inches wide, the length and width of the trailer (Figure 15).

Level 3. Wide. A single strip of retroreflective material, ten inches wide, the length and width of the trailer (Figure 16).

Level 4. Big U. The same as level 3, with the addition of vertical panels at each end (Figure 17).

Some idea of how the trailer appeared at night in the level 4 conditions is provided by Figure 18.

The four treatment levels, applied to the side and rear of the trailer, made eight test conditions.

The sign panel was faced on one side with 3M "high intensity" sheeting and on the other side with 3M "camouflage black" sheeting. The approximate specific luminance (at .4° and 0.2°) of these, respectively, was 250 and 33 cd/ft c/ft^2. A third treatment level for the sign was provided by removing it entirely from the field of view.

The two targets (trailer and sign panel) were marked with infrared sources, visible to the TV system but not to the subject. A single marker was employed for the sign panel and rear of the trailer and two markers for the side of the trailer, one at each end.

The subjects were told that the purpose of the study was to report the orientation (right or left) of various targets positioned around the track. A photograph of one of these targets is shown in Figure 19. Orientation was changed by moving the light colored square portion of the device to the right or left end of the bar. Six of these targets were set up, three at each end of the track.

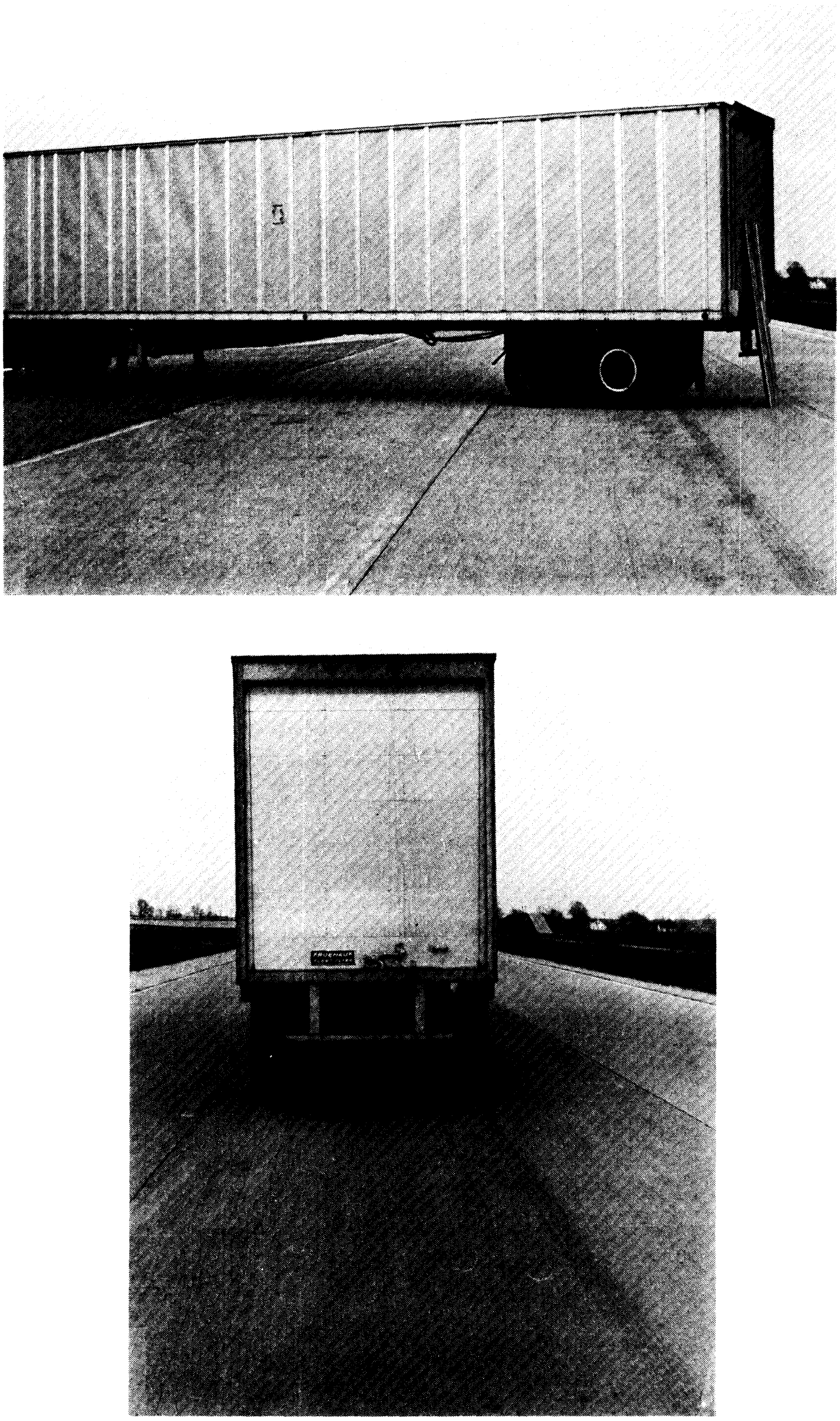
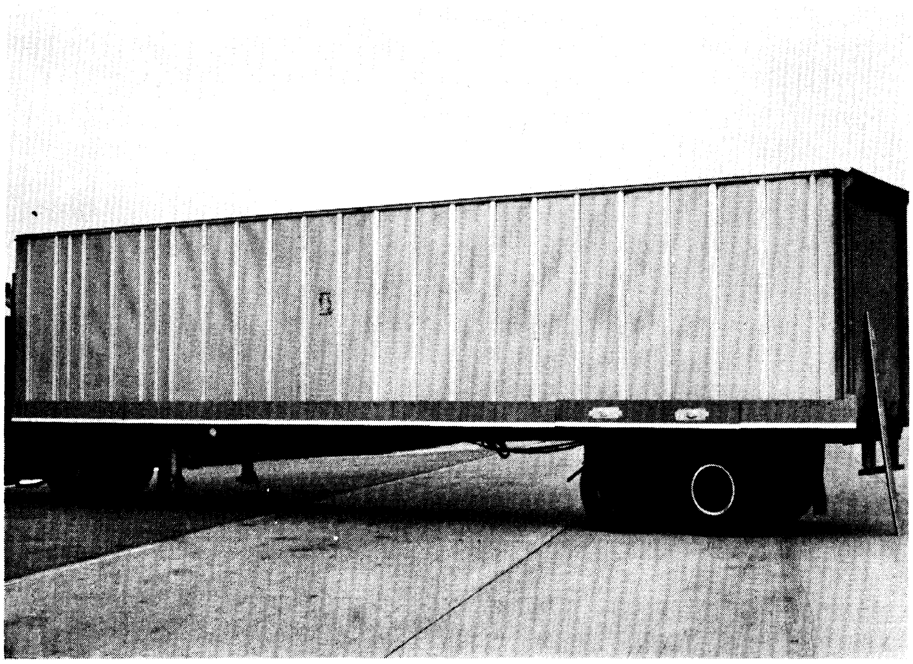


FIGURE 14

Side and Rear Views of Trailer in Control Condition



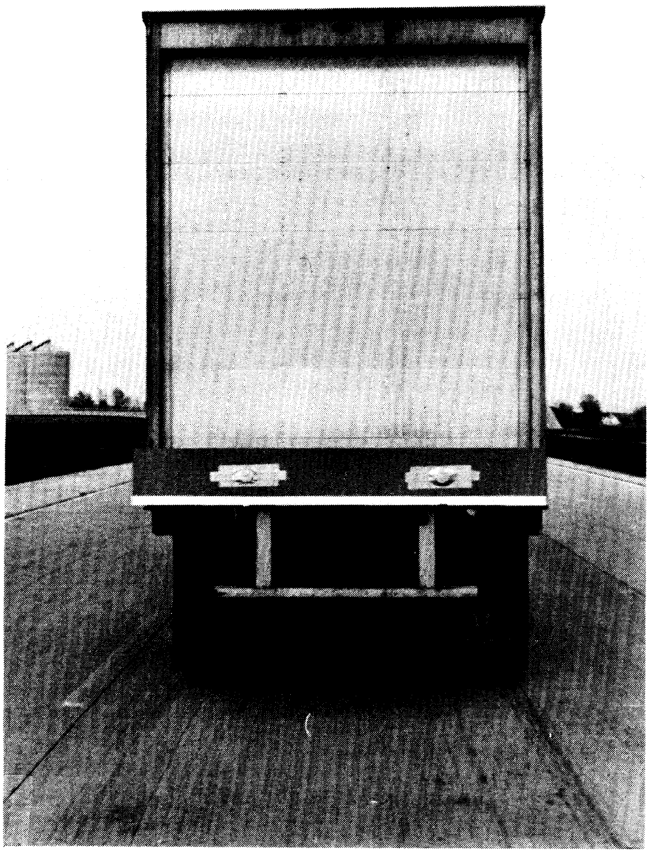


FIGURE 15

Side and Rear Views of Trailer in "Narrow" Condition

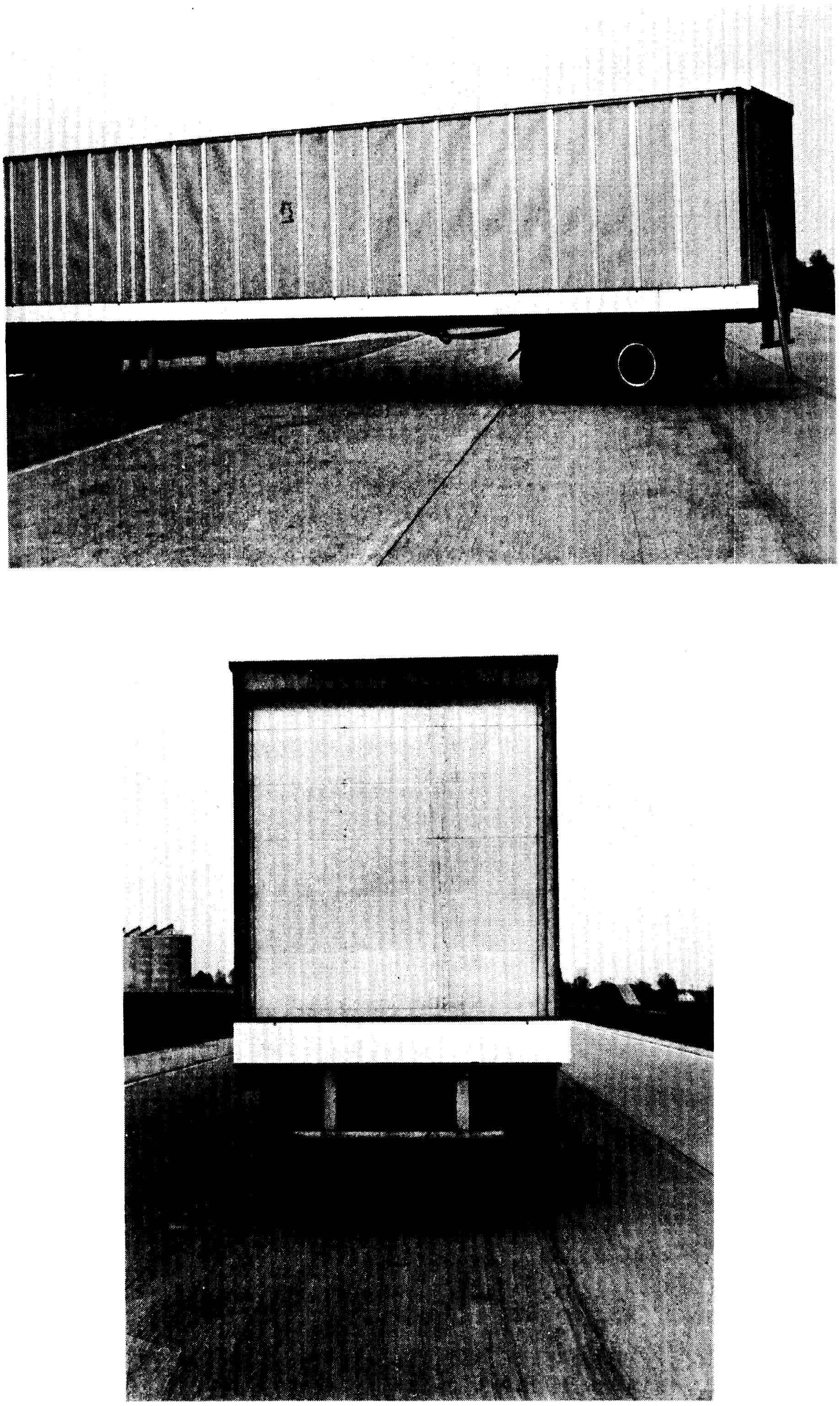


FIGURE 16
Side and Rear Views of Trailer in "Wide" Condition

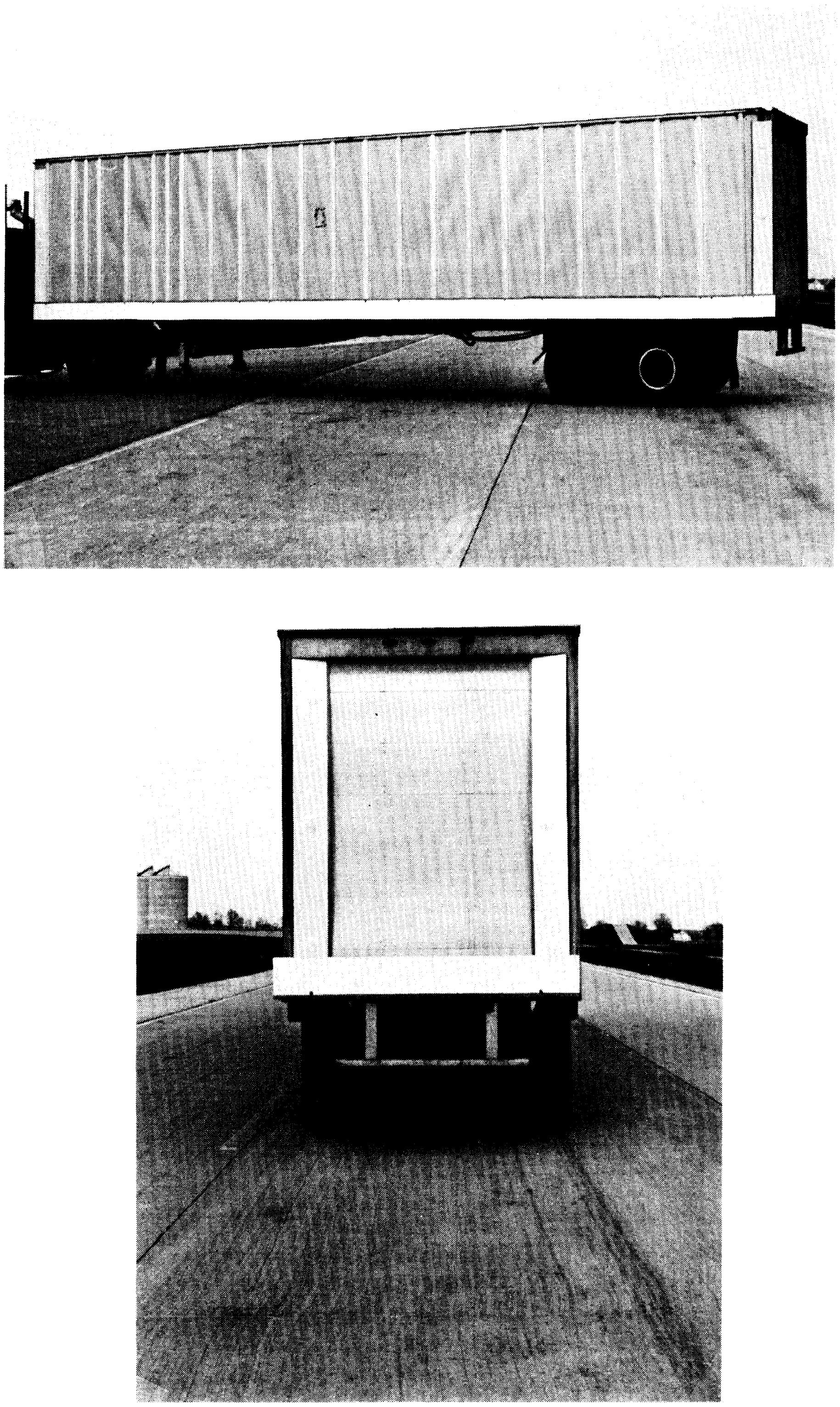


FIGURE 17
Side and Rear Views of Trailer in "Big U" Condition

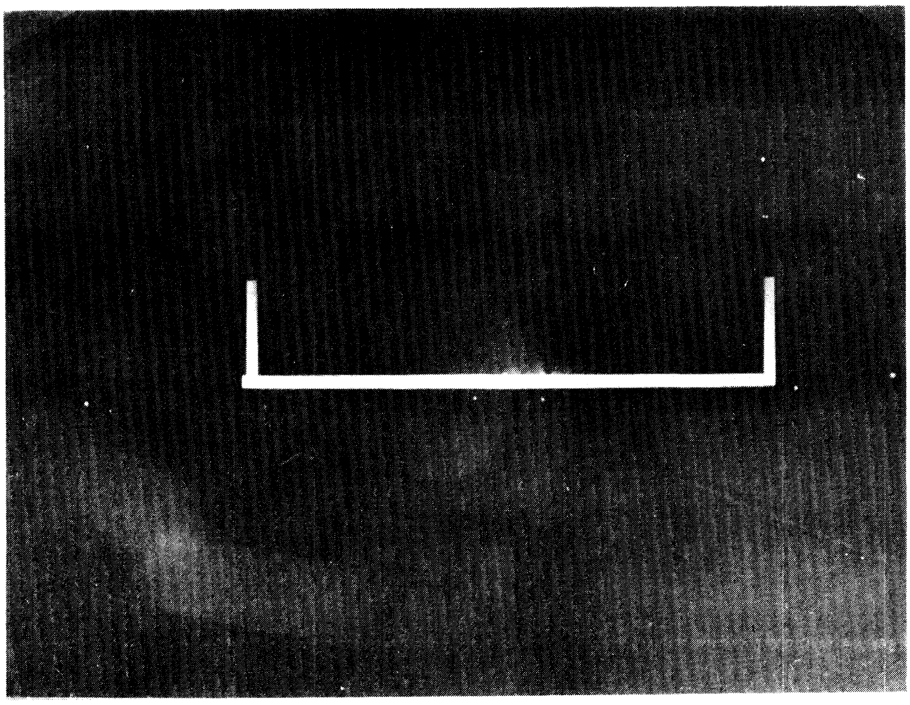


FIGURE 18
Night Photograph of Trailer in Level 4 (Big U) Condition, Seen From the Side

They were positioned well into the curves so as not to interfere with eye movements to the two targets (sign panel and trailer) of principal concern.

3.2.2 Subjects. Three University of Michigan students were paid to serve as subjects. They ranged in age from 20 to 25 years and had no known visual defects.

3.2.3 Procedure. For each subject, a complete test consisted of nine circuits of the track. The first was for practice, the final eight provided data on all truck configurations, two trials each of the two retroreflective sign levels, and four trials with the sign absent.

At the start of the test, the camera was fitted to the subject's head and calibrated. When this step had been completed, the following instructions were read:

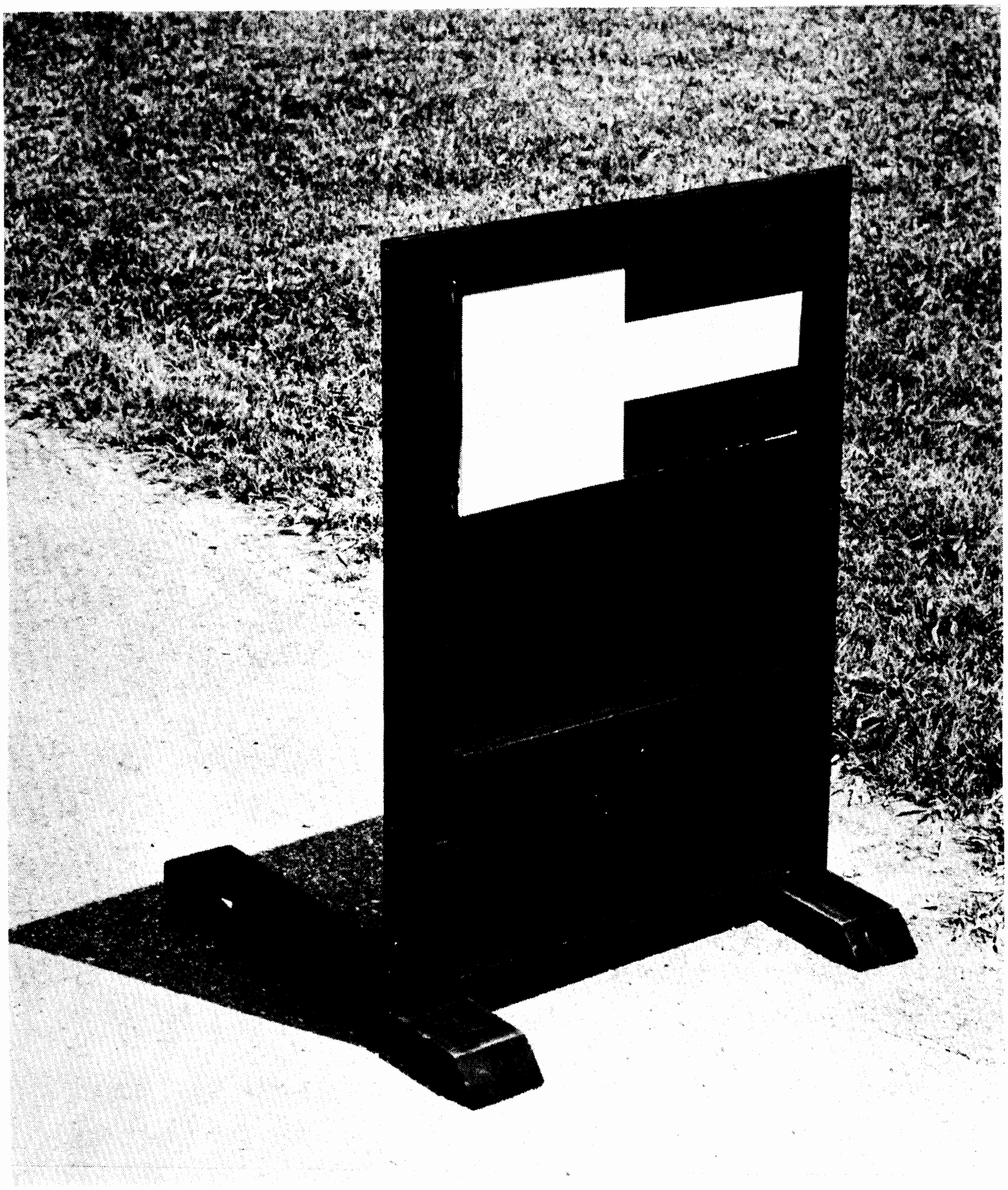


FIGURE 19

Photograph of Visibility Target Used in Test

The purpose of this study is to measure how people look for and interpret messages while driving at night. The device you will be wearing on your head provides a record of where you are looking. We will fit it on you. All you have to do is drive around the truck in the outside lane and look for several target signs. Those signs can either appear on your left or your right.

One of those signs is in front of you now. Note that it looks something like a letter 'T' resting on its side. Call out whether the wide part of the T is to the right or the left as soon as you can see it in each case. For example, for the sign you see in front of you, you would respond 'right.'

Please try to drive at a steady speed of about 25-30 mph. Continue to drive around the track until I tell you to stop. (That should be about 10 laps.) If the pressure caused by the device on your head becomes uncomfortable, please tell me so and I will adjust it or give you a break.

So, your task will be to drive about 10 laps around the track at a steady 25-30 mph while naming where the fat parts of the 'T' signs are. The track management had told us to stay out of the two inner lanes as there is a group from their firm that is using them for a test of their own. Any questions?

3.2.4 Data Reduction. Data were recorded on videotape and replayed in slow motion for the purpose of determining the distance intervals at which the subject fixated the truck or sign target. Fixations were classified as on or off target. The distance from the target was broken into 100 foot intervals and the percent time spent fixating the target for each condition determined by averaging across the subjects.

3.3 RESULTS - SIGN PANEL

Figure 20 shows percent time spent fixating the sign panel as a function of the treatment level at various distances. Due to the limited number of subjects, no statistical tests are possible. However, it appears that the low treatment and no sign conditions yielded similar fixation levels at distances beyond 600 feet and that the higher treatment resulted in higher

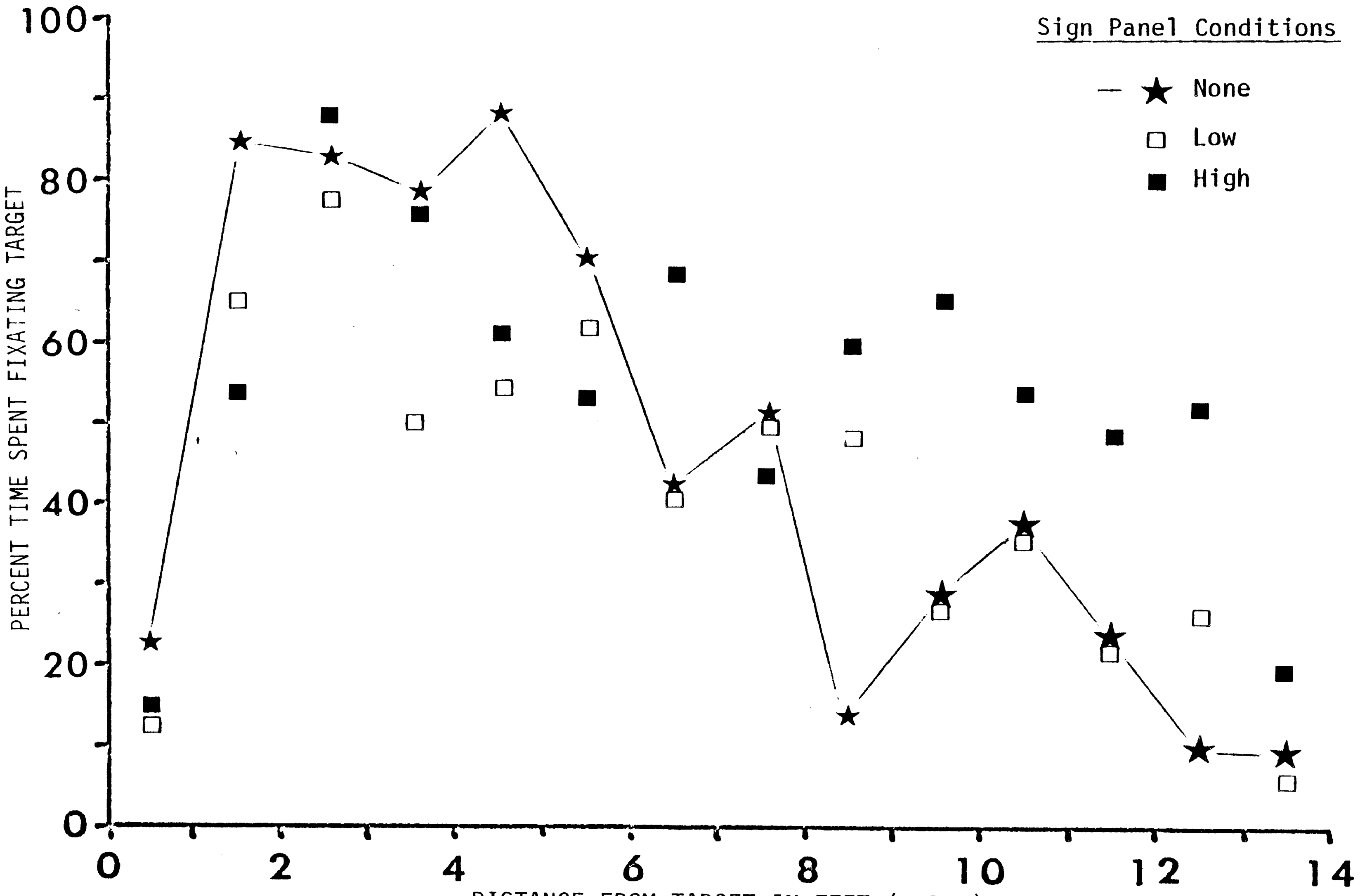


FIGURE 20

Percent Time Spend Fixating the Sign Panel Target at Various Distances as a Function of Retroreflective Treatment Level treatment resulted in higher probability of fixations than either at the far distances.

At distances closer to the target than 600 feet, the situation, if anything, reverses, with more fixations on the target site for the no target condition.

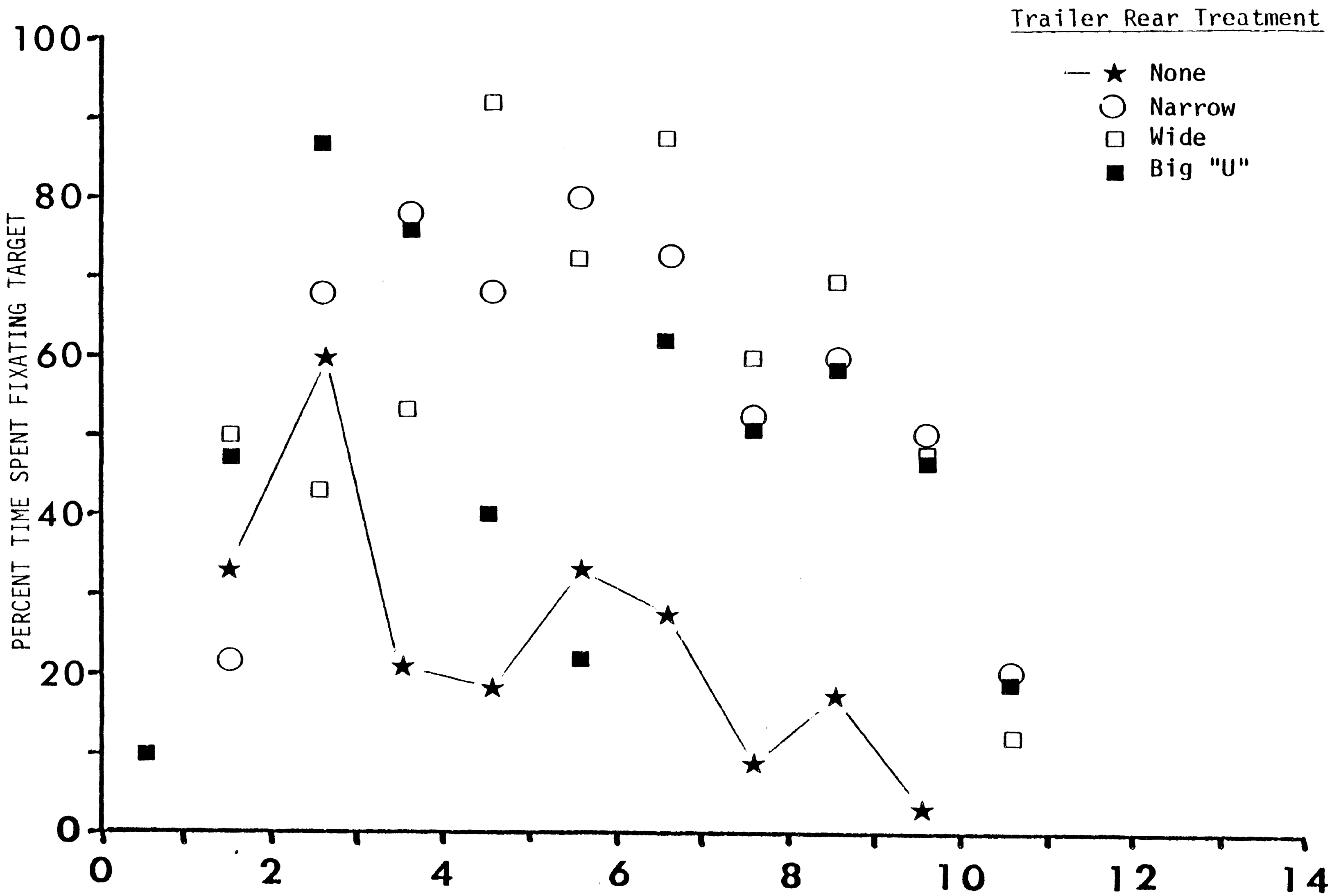
An obvious question is: "Why should the subject spend so much time looking at a site which has no target?" There are at least two possible answers. First, there was always something to see, the target marker fixture if nothing else. From three to four hundred feet this plywood device was visible, more so, as a matter of fact, when the sign was missing than when it was in place.

Second, the subjects' curiosity was probably aroused by the variable, unexplained panel which appeared now and then on the track. Having nothing much else to do on that part of the track, they would be expected to study the target site closely to see what might have been placed there since the last trial.

3.4 RESULTS - TRAILER

Figures 21 and 22 show percent time fixating the trailer in rear and side positions, respectively. The general format of the figures is the same as Figure 20.

In both side and rear conditions it seems clear that the added retroreflective treatments drew more eye fixations than the untreated trailer. There is more symmetry and smaller differences in the case of the side condition but it must be remembered that the trailer subtended about six times the angle (45 feet versus 8 feet) in the side condition. Further, and more important, the trailer was much easier to see in the side condition, due to specular reflections from the sides. It will be noted that the percent fixations for the various retroreflective conditions compare well for both side and rear presentations. However, for the rear, the percent fixations for the untreated condition are



DISTANCE FROM TARGET IN FEET (x 100)

FIGURE 21

Percent Time Spent Fixating the Rear of the Trailer at Various Distances as a Function of Retroreflective Treatment Levels

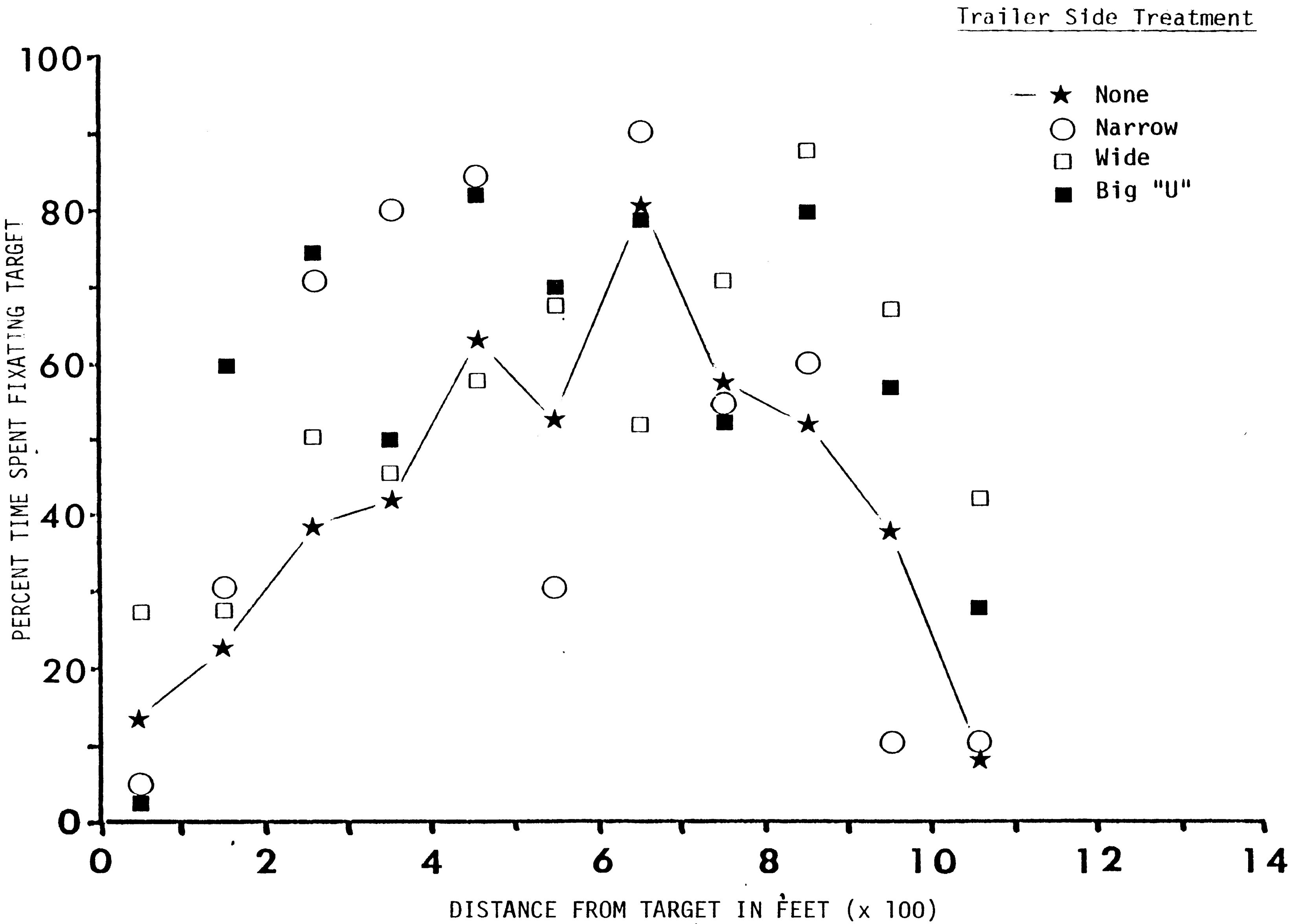


FIGURE 22

Percent Time Spent Fixating the Side of the Trailer at Various Distances as a Function of Retroreflective Treatment Levels

3.5 CONCLUSIONS

It is important to remember that this was an exploratory investigation, using a limited number of subjects. No firm conclusions can be drawn concerning the levels of retroreflective treatments required for optimum conspicuity.

It does, however, seem clear that increasing the amount of retroreflection material on the trailer in this test resulted in a substantial increase in eye fixations. This is especially evident in the case of the rear presentation. These data indicate that the trailer was seen with all three retroreflective treatments, at distances of 1,000 feet on low beams. The distance at which it became visible without special treatment is not clear from the data but, based on observation by the experimenters, is estimated at three to four hundred feet.

Some indication of the value of level of treatment can be had from the responses to the sign panel. The ratio of luminance differences between the two retroreflective sides was about 8:1. The data indicate that the brighter side was more effective in drawing fications at long distances (700 feet or more) than the less bright side.

The experience of this study provides some reason to regard eye fixations as a useful evaluative tool in conspicuity investigation. However, there were at least two key problems with the present study which limited the value of an eye fixation criterion. There was the fact that the subjects were alerted to the presence of the truck and sign, although not their purpose, and the very low driving load resulting from use of a private track. For example, time spent fixating the truck was often as high as 80%. That much attention diverted from the driving task is not necessarily good. However, in this test, the subjects had no cause for concern due to the types of problems that may be encountered in normal traffic. Running the test in a way that would restore typical driver loads is necessary to ensure that the subject is not paying excessive attention to the treated vehicle.

Thus issues associated with nighttime truck accidents and truck conspicuity were addressed in three studies. An analysis of the accidents showed that car-into-truck rear and angle collisions occur more frequently than if they were chance events. Several findings implicate inadequate truck conspicuity as the cause. The research literature suggests that adding more retroreflective material to truck and trailer exteriors should increase their conspicuity. Finally, in a field study, drivers noticed trailers on which additional retroreflective surfaces were mounted at much greater distances than standard trailers. The size and configuration of such surfaces deserves further investigation.