PERFORMANCE REQUIREMENTS FOR LARGE TRUCK CONSPICUITY ENHANCEMENTS

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16. Abstract

The purpose of this program was to define a range of minimally acceptable large truck conspicuity enhancements that could be used as a basis for revised Federal regulations. The report begins with a review of the literature in the area of truck visibility and includes an analysis of truck crash statistics intended to show the magnitude of the problem and suggest how upgraded markings might prove beneficial.

The investigation considered upgrading marking systems on large trailers by use of retroreflective materials. A number of laboratory and field studies were carried out. These assessed the value of using a pattern in the marking material, the form the pattern should take, the placement of the treatment on the trailer, the effect of retroreflective markings on the detection and identification of stop and turn signals, and the trade-off between the width and retroreflective intensity of the treatment material. In addition, field surveys were conducted to assess the effect of environmental dirt on the performance of the marking systems and the durability of retroreflective materials when used on trucks.

Recommendations were developed for an upgraded marking system using retroreflective tape a minimum of two inches in width. The pattern recommended is red and white. A continuous or broken strip of this material is recommended along the bottom of the trailer on the sides, with a continuous strip along the bottom in the rear, together with white corner markers at the top on units having an appropriate structure. Recommendations are also offered for minimum retroreflective efficiency levels, taking into account the effects of environmental dirt, aging, and orientation of the marked vehicle.

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EXECUTIVE SUMMARY

PURPOSE OF THE PROGRAM

The purpose of this program was to define a range of minimally acceptable large truck conspicuity enhancements that could be used as the basis for Federal regulations, if the decision is made to proceed in that manner. Conspicuity, as used here, is defined as those characteristics of an object that will result in its being detected with a high level of probability at a distance adequate to allow an approaching driver to take appropriate evasive action. Using existing information and data as a foundation, additional research was conducted to establish the bases upon which to make decisions concerning the use of retroreflective markings to enhance the conspicuity of large trucks. These decisions concern issues such as the configuration and pattern of materials, the maximum and minimum reflectivity, the minimum width of materials, interference with signals, etc. A preliminary examination of the large truck crash data revealed that combination unit trucks, and specifically the trailer in the combination, were associated with the largest proportion of potentially conspicuity related crashes and are most likely to benefit from conspicuity treatments. For this reason the recommendations that follow are directed specifically towards treating the sides and rear of trailers (both full and semitrailers) and any reference to the treatment of "trucks," "heavy vehicles," or "large trucks" is therefore referring to the trailer component of combination trucks.

ISSUES ADDRESSED AND METHODS EMPLOYED

Previous research sponsored by NHTSA indicated that the use of retroreflective tape markings systems enhanced the conspicuity of large trucks and, therefore, had the potential to reduce the number and seriousness of car-into-truck crashes. This earlier research specifically examined the effectiveness of enhanced conspicuity on the crash experience of approximately 2000 van trailers over a period of 23 months and found a significant reduction in conspicuity relevant crashes for the treated vehicles as compared to control vehicles (untreated). Based on this earlier research and the need to develop a set of specific recommendations for establishing minimum performance and functional specifications for these systems, a research program was developed, guided by the following assumptions and constraints:

- Only the enhancement of trailers would be considered

  - While single-unit trucks make up a substantial proportion of the heavy truck population, they were not included because of their minimal exposure to situations typically associated with conspicuity related crashes and their relatively low frequency of involvement in such crashes.

- Upgraded markings would consist of passive retroreflective treatments.

  - Use of passive markings would address situations involving parked trailers, unlit trailers, electrical failures, etc.

- The allowed markings would be a minimum of two inches in width.

  - Two inches was found to be a width that could be accommodated by most trailer types.

- A standard message set (i.e., colors, pattern, configuration) would be adopted.

  - A standardized message set was felt to be important to maximize effectiveness.

- The colors of materials would be limited to only red and white.

  - This color combination was selected because of the established value of the color red as a hazard and the good visibility of the combination in both daytime and nighttime environments.

- Only nighttime visibility would be considered.

  - Based on earlier research, the nighttime benefits of enhanced conspicuity alone are sufficient to justify the additional materials. Daytime benefits would simply be an added bonus.

The specific issues that were addressed by the research included the following:

- Using crash statistics, the research determined the potential value of enhancing heavy vehicle conspicuity in reducing car-into-truck collisions.
- The research determined the maximum and minimum reflectivity values for the proposed treatments.
- The value of using color patterns, in terms of identifying a marked object as a potential hazard, as an aid in identifying relative movement, and in judging changes in distance was determined.
- Different treatment configurations were evaluated to determine the optimum arrangement and amount of material that should be employed.
- The tradeoffs between reflectivity values and treatment widths were assessed.
- A survey of operating vehicles assessed the effect of environmental dirt and grime on the performance of retroreflective markings.
- A survey of operating vehicles was carried out to assess the durability of reflective materials used on heavy vehicles.
- Recommendations were developed for using retroreflective materials to create an upgraded marking system for large trucks.

Both laboratory and field investigations were conducted to address the issues of interest. For example, two laboratory studies were carried out to establish reasonable upper limits for glare from retroreflective surfaces. Field measurements of glare from retroreflective panels positioned at various distances were then taken from different vehicles to relate the laboratory measurements to actual driving conditions.

Minimum reflectivity values were determined from field studies that related material reflectivity values to detection distance. Full scale presentations of various treatment configurations were employed on an actual trailer. The distance at which subjects could detect the trailer were measured on each trial. Final recommendations were based on values corrected for subject expectancy.

The recommendations for pattern and configuration of retroreflective enhancements were based on several field and laboratory studies. The first laboratory investigation involved a paired comparison of various combinations of red and white retroreflective materials viewed at two distances. Two field studies were also carried out in which subjects, who were instructed to look for "potential hazards," detected and identified various retroreflective treatments in a normal driving situation. Finally, using computer presentations of stimuli, two additional laboratory studies were conducted to evaluate the relative importance of different configurations of retroreflective treatments in estimating relative vehicle speed and changes in vehicle spacing.

The tradeoff between treatment width and reflectivity value was assessed in a field study in which subjects drove toward different retroreflective displays and indicated when they could detect them. Measures were taken of detection distance.

Finally, surveys of trucks in use were conducted to assess the effects of environmental dirt and grime as well as degradation due to aging. To measure the effects of dirt, 17 trailers were fitted with retroreflective patches on the sides and rears. The reflective values of these were measured at regular intervals for a period of one year. The effects of aging were assessed by measuring the reflectivity value of retroreflective material that had been in place on trailers for various periods of time. The oldest material measured had been in place for more than 20 years.

KEY FINDINGS

Maximum Reflectivity: The determination of maximum reflectivity values was based on discomfort glare measurements experienced by drivers exposed to various levels of glare from retroreflective sources. It is clear from the results of the investigations conducted that existing retroreflective materials do not present a problem when used in treatments such as those recommended. Far greater amounts of material would have to be incorporated into the treatments before a glare problem would be evident.

Minimum Reflectivity: Recommended minimum reflectivity values were based on an analysis of detection distance as a function of treatment reflectivity values. When consideration is given to variables such as dirt, aging of the material, and vehicle orientation, it was found that only high performance retroreflective material will provide adequate visibility distance.

Pattern and Configuration: A major concern in the program was whether a particular pattern (i.e., color scheme and arrangement) and configuration (i.e., how the material is distributed on the trailers) should be specified for retroreflective materials. Previous studies (e.g., Burger et al., 1981) recommended a red-white pattern outlining the sides and rear of the trailer. It was felt that such a pattern and configuration would enhance hazard recognition and improve daytime conspicuity as well.

In a paired-comparison investigation subjects had the opportunity to evaluate various combinations of the red and white patterns, ranging from all red to all white, in terms of their value as hazard markers. The subjects expressed a strong preference for a red-white pattern with about equal amounts of each color. The laboratory studies of detection of movement and changes in distance suggest that there is value in having a full or partial outline of the vehicle as opposed to a simple bar on the frame rail.

Interference With Vehicle Signals: Investigations of the effect of retroreflective materials placed close to a signal source indicated that they have little or no effect on the speed of response to brake and turn signals, but had an adverse effect on the identification of brake signals under conditions where the transitions from a presence indication to brake signal had not been observed. These findings suggest a minimum separation distance between signals and retroreflective materials.

Material Width and Conspicuity: In the investigation of the relationship between material width and conspicuity it was found that the treatments behave as point sources. Thus, changing material width alters detection distance exactly as does changing the reflective properties of the material. For example, doubling the width of the material or doubling its specific intensity per unit area (SIA) has the same effect on detection distance.

Effects of Dirt and Grime: The findings of the survey of environmental dirt indicate it has a very large effect on the performance of retroreflective markings, particularly on the rear of the unit. Recommendations are based on performance at the 85th percentile, i.e., the SIA value below which 15 percent of the trailers fell. Even trailers that were washed regularly showed a 60 percent loss in reflectivity at the 85th percentile on the rear of trailers. The loss was about 90 percent on trailers that were washed less regularly. The sides of the units fared better. At the 85th percentile, the units that were washed regularly showed a 28 percent loss, the others a 70 percent loss. The situation was markedly worse during cold-weather months. The trailers that were washed regularly showed a 36 percent loss on the sides and 70 percent on the rears, at the 85th percentile. The other trailers showed an 85 percent loss on the sides and 95 percent on the rears, also at the 85th percentile.

Durability: The durability survey provided encouraging evidence indicating that retroreflective materials can be expected to last the life of the trailer.

Results of Data Analysis: A series of analyses was conducted in an attempt to characterize conspicuity-related large truck crashes and the factors associated with them. In one analysis, the Michigan data suggested that 26 percent of all crashes involving a tractor-trailer and one other vehicle were related to the conspicuity of the truck. An analysis of TIFA data indicated that 16 percent of all fatal crashes (including single-vehicle crashes) involving a tractor-trailer, were conspicuity related. Among fatal conspicuity-related crashes, the data indicate that 57.5 percent are rear-ends and 42.5 percent are side impacts. Four years of Michigan data further indicated that conspicuity-related crashes were more severe than nighttime, two-vehicle crashes in general; more than 47 percent of the conspicuity crashes resulted in a casualty, compared to only 34 percent for two-vehicle crashes in general.

RECOMMENDATIONS

Uniformity: It is recommended that treatments be as uniform as possible within the constraints imposed by the variety of configurations in the population of trailers. Uniformity will aid in identifying the marked object as a truck. This, in turn, will reduce error and confusion on the part of drivers, and improve average response time.

Maximum SIA: The recommended maximum SIA is 60 at an observation angle of 1.8°. Currently, there are no retroreflective materials available that exceed this limit.

Minimum SIA: The minimum SIA for two-inch material is a weighted average SIA of 70 for the sides of the vehicles, and 140 for the rears. These values are for an observation angle of 0.2° and an entrance angle of 30°. Adjustments to these minimum values are given for treatments of different width and those incorporating gaps. Currently there are materials available from different manufacturers that meet these performance requirements.

Pattern: An alternating red-white pattern is recommended, with approximately equal amounts of each. While the amount of white should not exceed the amount of red, the red can be allowed to exceed the white by several inches (e.g., 7"W x 11"R, 8"W x 12"R). This will provide good visibility and a pattern that will be easily recognizable as a hazard and, in time, come to be associated with large trucks.

Configuration: The treatment does not need to be continuous along the sides of the vehicle. Gaps can be incorporated in the pattern to reduce material used by up to 50 percent. However, the research did indicate value in providing a partial outline of the rear of the unit, where structure is available to do so. Doing so assists other drivers in estimating relative speed. There are no data that provide a justification for either a full or partial outline on the side of the unit; treatment of the bottom rail alone will be sufficient.

Proximity to Signal Sources and Other Markers: It is recommended that a minimum edge-to-edge separation of six inches be maintained between retroreflective materials used in treatments and stop and turn signal lamps. Interference with marker lamps is not a problem.

Treatment Width: The research program was carried out under the assumption that the minimum allowable width would be two inches. Wider treatments could be allowed. Where wider treatments are used, the minimum reflectivity values can be adjusted downward in proportion to the increased area of the treatment.

1 INTRODUCTION

BACKGROUND

The severity of impact resulting from the collision of two vehicles and the probability of injury to occupants depends on factors such as closing speed, vehicle orientation, and relative vehicle mass. Given these relationships, one would expect car-truck collisions to be relatively serious (for the car and its occupants at least), due to the great discrepancy in mass between the two vehicles. Compounding the problem is the fact that the configuration of large trucks is such that the first part of the car to encounter the relatively unyielding bottom rail of the truck or trailer may be the hood or A pillars. As a result, even a relatively low-speed impact may result in serious injury or death for the car's occupants.

Underride guards on the rear of trailers partially address this problem. These fixed structures are intended to reduce the trauma outcomes/consequences of rear-end crashes. However, several interesting studies by Minahan and O'Day (1977, 1979) noted that a complementary approach existed for reducing the incidence and severity of this type of crash.

Minahan and O'Day found that collisions with the side of the truck were nearly as frequent as those with the rear. The analysis also indicated that many of these collisions came about because the driver of the car simply failed to see the truck in time. As much as anything, these two reports stimulated an interest in determining the desirability and feasibility of improving the nighttime visibility and identifiability of large trucks.

The word "conspicuity" is often used when discussing the visibility of an object or condition. Conspicuity has been defined as "the attribute of an object within a visual context which ensures that its presence is noticed at the pre-attentive level of processing" (CIE-Division 4, 1986). The expression "pre-attentive level of processing" refers to operator expectancy. If conditions are such that an individual expects to encounter a particular situation (which is typically the case in an experimental setting) lower levels of conspicuity will suffice than if the encounter is unexpected.

Individuals carrying out research or having an interest in applications would benefit from a more specific definition than that given by the CIE. For purposes of this investigation conspicuity will be defined as characteristics of an object that will result in its being detected with a high level of probability at a distance adequate to allow the approaching driver to take appropriate action. The issues of probability values and distances will be taken up later in this report.

The word conspicuity is used at times to refer to object identification as well as or instead of object detection. Undoubtedly object identification is important in determining how quickly and effectively an individual responds to a given situation. Identification will be a significant concern in the work described in this report. When the word conspicuity is used, however, it will refer only to detection.

Truck lighting and marking regulations are covered in Federal Motor Vehicle Safety Standard (FMVSS) 108. As an example, FMVSS 108 calls for a minimum of three lights and three reflectors on the side of a truck body or trailer that is 30 feet or more in overall length. One light and reflector are to be red and mounted at the rear. The other lights and reflectors are to be amber. One pair is to be mounted at the front, the other in the middle. In years past these regulations resulted in a standard configuration where (on vans and other types of trailers that had an upper structure) the three lights were mounted near the roof line, and the three reflectors were mounted near the bottom rail. More recently (1984) the National Highway Traffic Safety Administration (NHTSA) modified FMVSS 108 to specify only a minimum mounting height for marker lights, with the result that they are commonly mounted near the bottom rail on all types of cargo platforms.

The adequency of truck marking standards has always been an issue of concern since they were formulated based on observational tests and subjective judgment. While marker lights may be visible at a thousand feet or more under good viewing conditions, it is difficult for humans to assess the distance to isolated light sources. Further, such sources may not always be associated with a truck or trailer, particularly in an area where there are other lights. The problem has only been compounded by the fact that trailers have grown longer over the years. Some of these units are now more than 50 feet long. Such a trailer could span an entire two-lane highway and not show a light or reflector in either lane.

The general recognition that truck marking standards are not adequate to ensure timely detection and identification under all reasonable operating conditions has led to a number of investigations to effect improvements. These studies fall into two categories, depending on the criterion employed. There have been a number of investigations of the effect of improved markings on collision involvement. These will be discussed first. Most of these studies leave something to be desired in terms of design and analysis, but they are the only data presently available in which the collision-reducing potential of the marking systems was examined.

Perhaps the earliest study of the benefits of improved markings was carried out by Greyhound Corporation (Prolux, 1959). They experienced a rate of collision (other vehicles impacting the rear of their coaches) of about 8 per million miles in 1946. This number dropped during the transition period, while a reflectorization program was being implemented, and finally stabilized at about 6 per million miles when the program was completed in 1950, a reduction of 25 percent.

The U.S. Post Office (1957) changed the colors of its vehicles from olive drab to red, white, and blue (with the red being reflective tape), and recorded the effect on collisions with a fleet size of 3,500 in each category. The total mileage for each group was about 10 million. The findings were that the olive drab fleet was involved in 849 collisions of all types, compared to 622 for the red, white, and blue fleet. The greatest percentage difference was for collisions in which the postal vehicle was struck in the rear (50 versus 24). Unfortunately, the fact that the entire paint scheme on the vehicles was changed makes it impossible to separate the effects of the retroreflective red material.

The Toronto Transit Commission experimented with the addition of a black-on-yellow retroreflective barricade marking on the rear of their vehicles. Apparently, no formal report is available. Burger et al. (1981) quote from an advertisement from 3M, which claims that the newly marked vehicles experienced no rear impacts during the test period, while vehicles without the markings were struck a number of times.

Introduction

Since November 1971 trucks in England having an empty weight over three tons have been required to display distinctive rear markings. These markings use yellow retroreflective and red fluorescent materials to improve both night and day conspicuity. The effect of these treatments was studied by the Transport and Road Research Laboratory (TRRL) and reported in 1976. The data show a reduction in the number of collisions across all conditions after the introduction of the markings. The only statistically significant reduction occurred for nighttime rear-end collisions on unlighted roads involving parked trucks, certainly a category in which the markings should be of maximum benefit.

One way of adding markings to a vehicle is by means of a retroreflective license plate. Retroreflective license plates have been in use in many states for a number of years. There have been several attempts to evaluate their effectiveness as aids in reducing rear-end collisions. This work has been reviewed by Cook (1975), and by Olson and Post (1977). Most of the studies report positive results (i.e., favoring use of retroreflective license plates). The general trend, however, is that the more carefully controlled the study, the smaller the difference and the greater the likelihood of finding no difference. Viewed objectively, the license plate cannot be reasonably expected to have a large effect, since about the only condition where it could be beneficial would be at night with an unlighted vehicle. Even there, the license plate is only a supplement to reflex reflectors required by FMVSS 108.

Recently, Carsten et al. (1987) compared the collision experience of van and flat-bed trailers. It was anticipated that the relative rate at which each type was struck in the rear would reveal something about conspicuity, since the van trailers generally have high-mounted identification lights, and would always present a larger surface to reflect light from the approaching vehicle's headlamps. The results of this analysis show that the highest proportion of rear-end collisions occurs to vehicles with flatbed trailers, traveling on divided roads at night. The lowest proportion is for vans traveling on undivided roads during the day.

The results of the analysis performed by Carsten et al. suggest that there are conspicuity differences between van and flat-bed trailers (most evident from the rear). The data must be interpreted with some caution, however, because of the physical differences between the two trailer types; there is a large amount of exposed sheet metal on the back of a van trailer along with the additional lighting.

Observations suggest that most van trailers, even when reasonably clean, present a poor target at night. A large part of the problem is that the great mass of the trailer is well above the mounting height of car headlamps. As a result, it receives relatively little illumination from low beams. For vehicles using high beams, the illuminated surface of the trailer can make a significant difference. In terms of lighting, the major difference between van and flat-bed trailers is that the cluster of three identification lamps is typically mounted at the top of the unit in van trailers. In addition, many van trailers show corner marker lights at the top. The high-mounted lights may assist in seeing the truck over a hillcrest (although the stopping sight distance rule should allow adequate maneuver room even if a flat-bed trailer is stopped over a hillcrest), and in estimating distance and rate of closure. Nevertheless, it is hard to see how the configuration of the lighting, and the sometimes addition of two corner marker lights on van trailers, could make a significant difference in conspicuity for the variety of situations encountered.

The most ambitious and carefully controlled study was conducted by Burger et al. (1985), and involved a total of about 4,000 trailers, half of which were equipped with 2-inch wide, red and white reflective tape along the lower edge on the sides and outlining the rear. Relevant collisions were monitored for nearly two years. In that period the trailers accumulated over 106 million miles of exposure, about two thirds of which was at night. The findings were that non-relevant collisions were about the same for the two groups, but relevant collisions were lower for the group of trailers with the reflective treatments. Interestingly, there was a reduction both night and day, 21.2 and 16.3 percent, respectively. Subsequent reanalysis of the nighttime data reduced that figure to about 15 percent, which was still statistically significant.

The other category of research on truck conspicuity has employed criteria other than collisions. One of these was by Green et al. (1979). The report contains three sections, a collision analysis, a review of the literature on the subject of conspicuity, and the description of a study of the effect of various conspicuity treatments on subject eye movements. In the study, three treatments using white retroreflective tape in various widths and configurations were compared with a control condition on an unlighted trailer. It was noted that the distance from the trailer at which subjects began to fixate it increased with the amount of retroreflective material employed.

In Germany studies have been reported on systems to improve conspicuity to the side (Schmidt-Clausen et al., 1987) and rear (Schmidt-Clausen and Kurth, 1987). These investigations include measurements of luminance densities both in the field and in the laboratory. Subjective scaling techniques were used to select the specific treatments finally recommended.

The Japan Transportation and Science Committee, Nighttime Traffic Safety Committee (undated) reported on the effectiveness of various truck rear marking systems using retroreflective or fluorescent materials. Their effectiveness was evaluated by means of a survey of about 2,000 truck drivers. The results indicate that the responding truck drivers felt that the addition of the materials was a significant benefit in making the vehicles more visible. An analysis of collision involvement is planned, but the results are apparently not yet available.

Reid (1977) described an evaluation of the distance at which various types of truck rear markings could be identified at night. The independent variables included glare, type of beam (i.e., British or European), height, and orientation of the markings. Only four observers participated, three of whom were in their 50s. Among the findings were that markings made with High Intensity (type III) materials were so bright as to obscure the chevron markings and impair recognition under no-glare conditions. However, they were better than the less reflective materials under glare conditions.

In sum, the evidence clearly suggests that under present FMVSS 108 requirements large trucks exhibit insufficient conspicuity, and that a variety of means might be employed to effect a reduction in the frequency and seriousness of conspicuity-related crashes.

Based on these previous findings, this research effort has been focused within practical bounds and a limited scope of work, in order to refine the information available on optimal conspicuity marking systems. Specifically, the following assumptions were used:

- Upgraded markings would consist of passive retroreflective treatments.

  - Use of passive markings would address situations involving parked vehicles, unlit vehicles, electrical failures, etc.

- The allowed markings would be a minimum of two inches in width.

  - Two inches was found to be a width that could be accommodated by most trailer types.

- A standard message set (i.e., colors, pattern, configuration) would be adopted.

  - A standardized message set was felt to be important to maximize effectiveness.

- The colors of materials would be limited to only red and white.

  - This color combination was selected because of the established value of the color red as a hazard and the good visibility of the combination in both daytime and nighttime environments.

- Only nighttime visibility would be considered.

  - Based on earlier research, the nighttime benefits of enhanced conspicuity alone are sufficient to justify the additional materials. Daytime benefits would simply be an added bonus.

- Only the enhancement of trailers would be considered.

  - While single-unit trucks make up a substantial proportion of the heavy truck population, they were not included because of their minimal exposure to situations typically associated with conspicuity related crashes and their relatively low frequency of involvement in such crashes.

Introduction

This report describes a number of investigations that were carried out to develop the best possible marking system within the constraints listed, and to establish the parameters of the system. These studies are grouped under several headings. Chapter 1 describes the data analyses that were used to examine the potential benefits of enhancing large truck conspicuity. Chapter 2 deals with the issue of treatment pattern, and describes studies that seek to determine whether there is any merit to having a pattern, and what the pattern should be. Chapter 3 is concerned with the question of maximum and minimum reflectivity values for the materials used in the marking systems. Chapter 4 addresses the issues of treatment width and the possible masking of stop and turn signals by the proposed conspicuity treatments. Chapter 5 describes two surveys: one carried out to evaluate the effects of environmental dirt, the other to obtain an estimate of the life expectancy of retroreflective materials used as markings on trucks. Chapter 6 offers recommendations for treatment specifications, with consideration given to a number of variables that would affect performance in the real world. In addition, in the Appendix of the report there is a brief chapter on the performance characteristics of retroreflectors, which may assist persons having limited familiarity with such materials in understanding the studies and recommendations contained herein. Also in the Appendix is a section discussing the issue of cost-benefits in conspicuity enhancements.

DATA ANALYSES

Previous studies of the effect of enhanced conspicuity on collision involvement have contributed towards an understanding of the truck conspicuity problem, but they are lacking in some important details. In an effort to better define the relationship between the parameters of interest, several analyses of available accident data were carried out as part of this study. These analyses focused on factors such as roadway classification, area type (i.e., urban vs. rural), ambient illumination, collision configuration, accident severity, and trailer body style, and they permitted an estimation of the magnitude of conspicuity-related crashes as well as the development of distributions for some of their characteristics. An analysis of truck travel data was also conducted in order to understand the conditions to which the conspicuity-enhancing treatments would be exposed and to assess the conditions where such improvements might be most beneficial. The travel data also allowed the calculation of accident rates associated with the parameters that define conspicuity-related accidents. Accident rates provide an objective means of comparing the relative risk among different types of trucks under varying operating conditions.

The accident data analyses were conducted on several computerized files. These included NASS (National Accident Sampling System), GES (General Estimates System), the CARDfile (Crash Avoidance Research Datafile), the Michigan State Police accident file, and UMTRI's database of large trucks involved in fatal accidents. The exposure data came from two surveys of large truck travel conducted by UMTRI, one on the national level and the other for the state of Michigan.

Potential Conspicuity-Related Involvements

The first task explored the relationship between conspicuity-related crashes involving a large truck and such factors as collision type, vehicle actions, relation to intersection, and time of day. This set of analyses was conducted on the UMTRI versions of the 1985 through 1988 Michigan State Police motor vehicle accident files. An analysis file was built from these four years of data which contains all tractor-semitrailers involved in accidents that met our initial criteria for conspicuity-related crashes (Table 1.1). In previous research, Vector Enterprises defined conspicuity-related accidents as multi-vehicle crashes where the truck was struck in the side or the rear. From the outset, we limited our cases to two-vehicle crashes because of the difficulty involved in analyzing the circumstances of an accident involving more than two vehicles. The cases were further restricted to trucks with rear damage when the two vehicles were traveling in the same direction, and trucks with side damage when the two vehicles were approaching at an angle or from opposite directions. All of the cases were confined to those where the other involved vehicle suffered front-area damage.

Additionally, those cases taking place at a driveway access that involved rear- or side-damaged trucks and front-damaged other vehicles were included in the file.

Table 1.1 - Criteria Used to Build Analysis File for Potential Conspicuity-Related Accidents

- Michigan 1985-1988
- Two-vehicle accidents
- Tractor-semitrailer involved
- Trucks with rear or side damage
- Other involved vehicles with front damage
- Rear-end cases restricted to those with two vehicles traveling in same direction or occurring at driveway access
- Side impacts restricted to those with two vehicles approaching at an angle or from opposite directions or at driveway access

It should be noted that cases were included in our analysis file based on the area of damage to the vehicles and not according to which vehicle actually hit the other one. This is because the Michigan data do not include a variable that distinguishes "struck" from "striking" vehicles. This distinction may sometimes be inferred by considering the area of damage and movements of the vehicles involved in an accident. It will be noted later that for some of the cases included in our initial file, it is highly probable that the truck was the actual striking vehicle.

Table 1.2 shows the number of cases in the analysis file by year and indicates the proportion they represent out of all two-vehicle accidents occurring in Michigan from 1985-1988 in which a tractor-semitrailer was involved. This proportion remains relatively stable from year to year at about one-quarter of all the two-vehicle tractor-semitrailer accidents. It should be emphasized that the cases included in our file are those defined by the parameters that we considered most likely to pertain to conspicuity-related crashes, but they do not necessarily include all collisions in which conspicuity was a factor. In addition, a few of the cases in the analysis file most likely involve the truck as the striking vehicle and therefore are not related to the conspicuity of the truck.

TABLE 1.2- Potential Conspicuity-Related Two-Vehicle Accidents Involving a Tractor-Semitrailer as a Proportion of All Two-Vehicle Tractor-Semitrailer Accidents Michigan 1985–1988

	YEAR				
	1985	1986	1987	1988	TOTAL
Number of Conspicuity-Related Accidents	1,231	1,317	1,648	1,780	5,976
Number of Two-Vehicle Tractor-Semitrailer Accidents	4,821	5,205	6,497	6,746	23,269
Proportion of Conspicuity-Related out of all Two-Vehicle Accidents	25.5%	25.3%	25.4%	26.4%	25.7%

NOTE: The large increase in the total number of accidents between 1986 and 1987 reflects a change in coding on the Michigan PAR. Prior to 1987 many singles were incorrectly coded as bobtails when the truck-tractor box on the form was marked and the number of trailers mistakenly left blank.

Involvements by Configuration, Relation to Intersection, and Light Condition

The cases in the conspicuity analysis file were classified according to the actions of the vehicles involved in order to facilitate an understanding of the circumstances pertaining to these accidents. Prior to this breakdown, the cases were subdivided according to three parameters: configuration type (rear-end or side impact), relation to intersection (intersection, non-intersection, or driveway), and time of day (day, night, or unknown). All references to "night" pertain to accidents occurring under both unlit and artificially lit conditions and include the dawn and dusk periods as well.

The breakdown of the cases in the analysis file according to these three factors is shown in Table 1.3. The 11 cases in the file for which time of day was unknown are not included in this table. A series of pie graphs has also been prepared to illustrate the composition of the analysis dataset. Figure 1.1 at right indicates that the cases in the analysis file are predominantly rear-ends as opposed to side impacts. Figure 1.2 illustrates the breakdown according to relation to intersection. The accidents are evenly divided between intersections and non-intersections, at about 40 percent each, with the

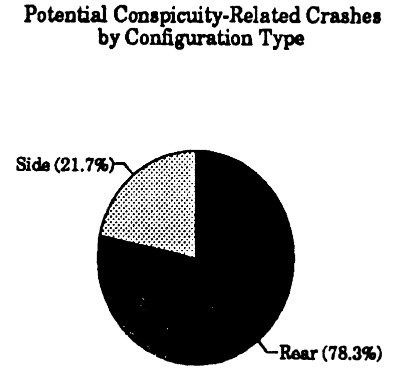


FIGURE 1.1

TABLE 1.3–Potential Conspicuity-Related Accidents by Configuration, Relation to Intersection, and Time of Day Michigan 1985–1988

Configuration	DAYTIME ONLY			
	Intersection	Non-Intersection	Driveway	TOTAL
Rear	1,446 33.1%	1,533 35.0%	489 11.2%	3,468 79.3%
Side	479 10.9	90 2.1	338 7.7	907 20.7
TOTAL	1,925 44.0%	1,623 37.1%	827 18.9%	4,375 100.0%
Configuration	NIGHTTIME ONLY			
	Intersection	Non-Intersection	Driveway	TOTAL
Rear	322 20.3%	715 45.0%	164 10.3%	1,201 75.5%
Side	177 11.1	60 3.8	152 9.6	389 24.5
TOTAL	499 31.4%	775 48.7%	316 19.9%	1,590 100.0%
Configuration/ Time of Day	DAY AND NIGHT			
	Intersection	Non-Intersection	Driveway	TOTAL
Rear/Day	1,446 24.2%	1,533 25.7%	489 8.2%	3,468 58.1%
Rear/Night	322 5.4	715 12.0	164 2.7	1,201 20.1
Side/Day	479 8.0	90 1.5	338 5.7	907 15.2
Side/Night	177 3.0	60 1.0	152 2.5	389 6.5
TOTAL	2,424 40.6%	2,398 40.2%	1,143 19.2%	5,965 100.0%

NOTE: This table is based on all two-vehicle accidents involving a tractor-semitrailer with rear or side damage and another vehicle with front damage.

All percentages shown are total percents for the given block of the table.

remainder occurring at driveway accesses. The third figure indicates that about 27 percent of the accidents occurred at night and the rest in the daytime.

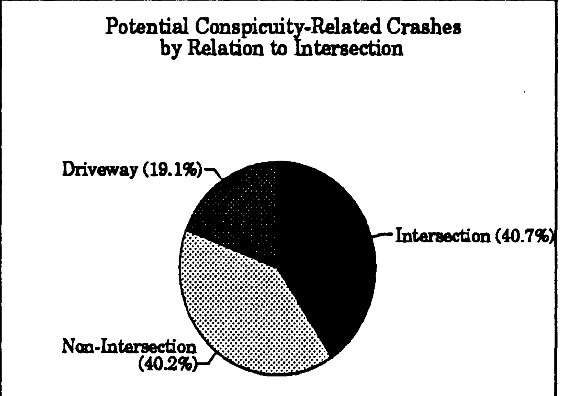

Potential Conspicuity-Related Crashes
by Relation to Intersection

FIGURE 1.2

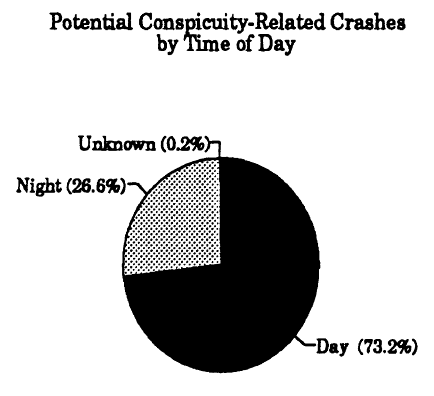

Potential Conspicuity-Related Crashes
by Time of Day

FIGURE 1.3

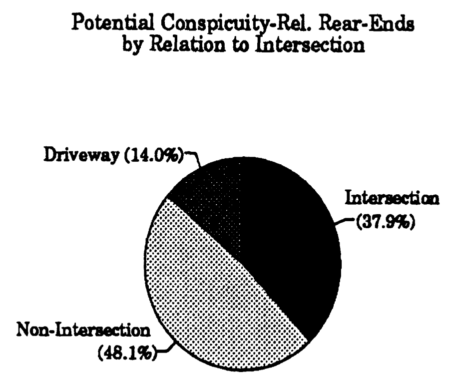

Potential Conspicuity-Rel. Rear-Ends
by Relation to Intersection

FIGURE 1.4

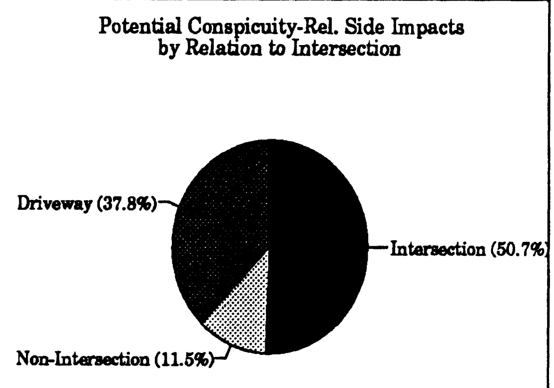

Potential Conspicuity-Rel. Side Impacts
by Relation to Intersection

FIGURE 1.5

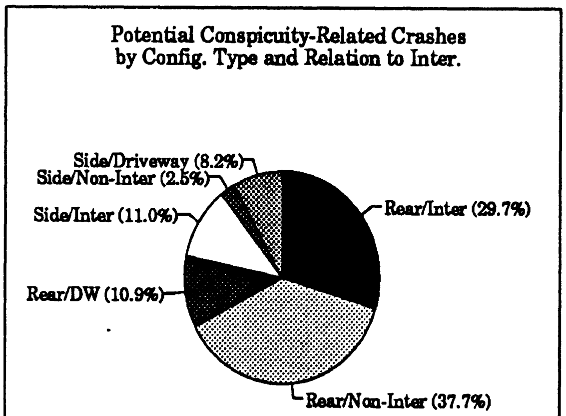

Potential Conspicuity-Related Crashes
by Config. Type and Relation to Inter.

FIGURE 1.6

Figures 1.4 and 1.5 compare rear-end accidents versus side impacts according to relation to intersection. Not surprisingly, the side impact crashes occur proportionately much less at non-intersections compared to the rear-ends. The side impacts are characterized by a higher percentage of intersection crashes than the rear-ends, and the driveway involvements represent a much larger share of the side impacts than of the rear-ends. The information in Figures 1.4 and 1.5 is combined in Figure 1.6 at left in order to illustrate the overall share of the cases in the analysis file that each of these six categories of accidents represents.

Figures 1.7-1.10 add light condition at the time of the crash to the comparisons. Figures 1.7 and 1.8 indicate that the proportion of rear versus side impacts shows little change from day to night, although the percentage of side-impacts is slightly higher at night than during the day. The relation to intersection distribution varies more between day and night (Figures 1.9 and 1.10), with intersection crashes representing a larger share during the day than at night and non-intersection crashes comprising a higher percentage of the nighttime than the daytime collisions.

Conspicuity-Related Daytime Crashes by Configuration Type

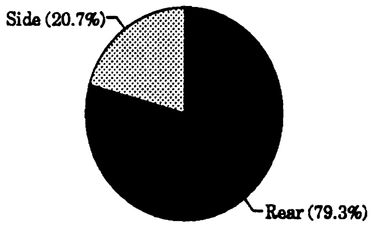


FIGURE 1.7

Conspicuity-Related Nighttime Crashes by Configuration Type

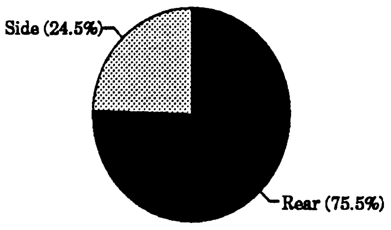


FIGURE 1.8

Conspicuity-Related Daytime Crashes by Relation to Intersection

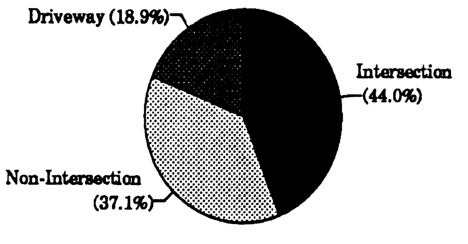


FIGURE 1.9

Conspicuity-Related Nighttime Crashes by Relation to Intersection

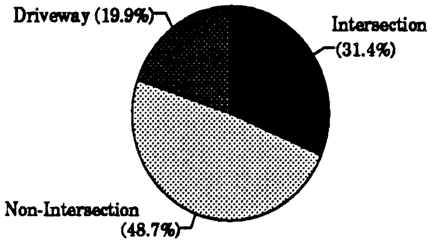


FIGURE 1.10

Figures 1.11-1.14 consider all three parameters simultaneously. The difference in the proportions of intersection versus non-intersection crashes between day and night previously noted for rear-ends and side impacts combined holds true when these two collision types are considered individually. The increase in non-intersection and decrease in intersection crashes from day to night is slightly more pronounced for the rear-end collisions than the side impacts, however.

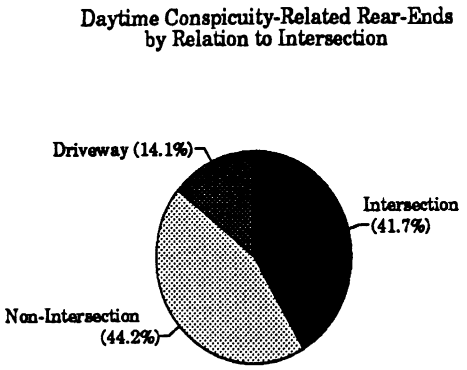

Daytime Conspicuity-Related Rear-Ends by Relation to Intersection

FIGURE 1.11

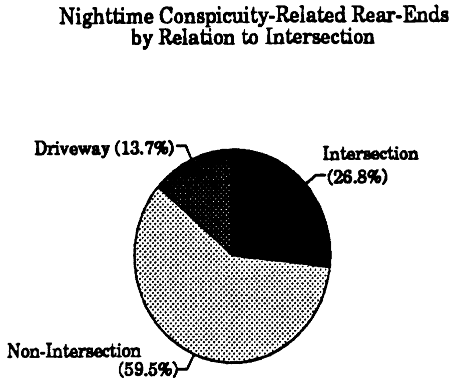

Nighttime Conspicuity-Related Rear-Ends by Relation to Intersection

FIGURE 1.12

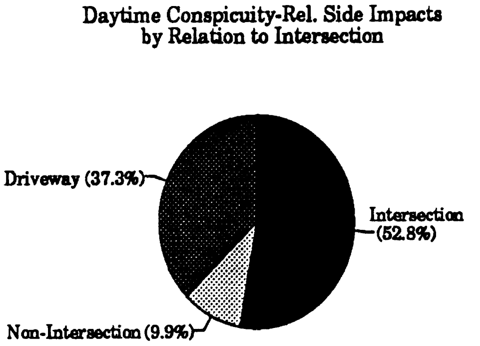

Daytime Conspicuity-Rel. Side Impacts by Relation to Intersection

FIGURE 1.13

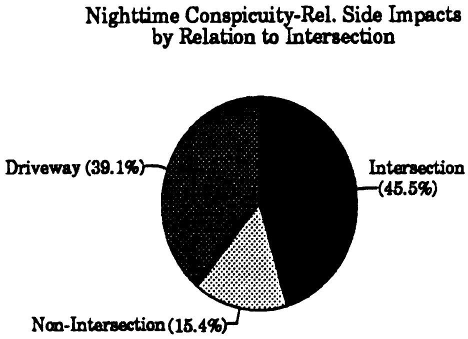

Nighttime Conspicuity-Rel. Side Impacts by Relation to Intersection

FIGURE 1.14

Finally, Figures 1.15 and 1.16 break the cases into the same six categories shown in Figure 1.6, but further split into day versus night. The distribution of the accident categories is similar between day and night, except for the rear-ends at intersections and not at intersections. These two categories represent approximately equal shares of the daytime crashes, but the rear-ends at non-intersections are 2.2 times as common as the intersection rear-ends at night.

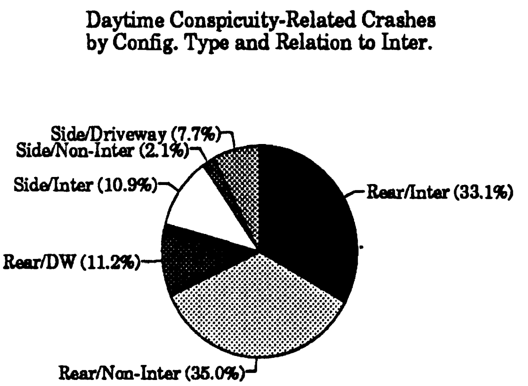

Daytime Conspicuity-Related Crashes by Config. Type and Relation to Inter.

FIGURE 1.15

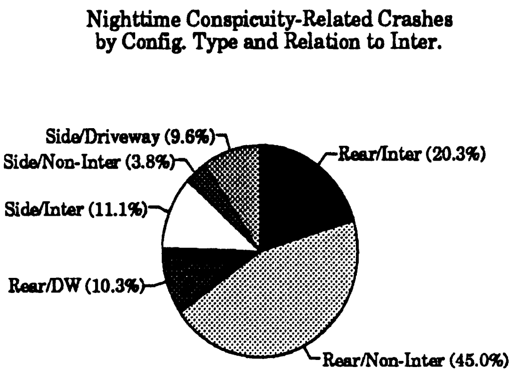

Nighttime Conspicuity-Related Crashes by Config. Type and Relation to Inter.

FIGURE 1.16

Vehicle Actions

In Tables 1.4-1.9, the accidents in the analysis file are categorized according to the particular actions of the vehicles involved. A separate table has been used for each of the six categories defined by the combination of rear-end versus side impact crossed by intersection, non-intersection, and driveway. Each of these categories has been considered separately because the possible vehicle actions differ among the categories. Driveway collisions are treated separately from crashes at intersections because the element of surprise is more likely to apply to driveways than intersections, and this should be considered when attempting to define conspicuity-related accidents. Tables 1.4-1.9 also split the cases into daytime versus nighttime crashes.

The relative sizes of the major categories, as shown in Figure 1.6, should be kept in mind when examining Tables 1.4-1.9. For example, as indicated in Table 1.3 and in the pie graph series, rear-ends make up a much larger share of the cases in the file than do side impacts, and daytime crashes are much more numerous than nighttime collisions. Thus Table 1.8, which shows the vehicle action breakdown for side impacts at non-intersections, accounts for only 2.5 percent of the accidents overall, while Table 1.4, rear-ends at intersections, describes accidents comprising nearly 30 percent of the file. In the six tables, "truck" and "car" are used as shorthand to refer to "tractor-semitrailer" and "other involved vehicle" respectively.

Rear-End Collisions at Intersections - Distributions for rear-end involvements at intersections are shown in Table 1.4 according to light condition and the movements of the tractor-semitrailer and the other involved vehicle. This entire class of accidents represents about 30 percent of the cases in the analysis file. The most unexpected finding revealed by the table is that 27.5 percent of the cases involved the truck backing into the other vehicle. Truck backing accidents comprised 30 percent of the daytime collisions and 15 percent of the nighttime collisions. Although not shown in the table, in 71 percent of the truck backing cases the other vehicle was stopped, while in just 27 percent of these cases was the other vehicle actually moving, usually straight ahead. Thus, it seems clear that most of the truck backing accidents should not be considered conspicuity related. (Note, however, that research described later in this report demonstrates that enhanced conspicuity does provide motion cues. Such cues may allow approaching vehicles to detect backing trucks sooner, allowing more time for braking or avoidance maneuvers.)

Leaving aside the truck backing cases, the most common scenarios for the rear-end intersection collisions were truck turning right, car proceeding straight (13.6 percent); truck stopped, car proceeding straight (13.3 percent); and both vehicles proceeding straight (8.0 percent). The latter two scenarios were more

TABLE 1.4- Tractor-Semitrailer Rear-Ends at Intersections by Light Condition
Michigan 1985–1988

Vehicle Actions	Light Condition					
	Day		Night		TOTAL	
	Number	Percent	Number	Percent	Number	Percent
Both straight	88	6.1%	54	16.8%	142	8.0%
Truck stopped, car straight	175	12.1	59	18.3	235	13.3
Truck right, car straight	201	13.9	40	12.4	241	13.6
Truck left, car straight	55	3.8	23	7.1	79	4.5
Both right	108	7.5	15	4.7	123	6.9
Both left	71	4.9	9	2.8	80	4.5
Car changing lanes/passing, truck straight, turning, or stopped	80	5.5	15	4.7	95	5.4
Car avoiding other vehicle, truck straight, turning, or stopped	16	1.1	8	2.5	24	1.4
Truck avoiding other vehicle, car straight	5	0.3	0	0.0	6	0.3
Truck backing	439	30.4	48	14.9	488	27.5
Truck right, car stopped	58	4.0	19	5.9	77	4.3
Truck left, car stopped	15	1.0	1	0.3	16	0.9
Truck changing lanes/passing, car straight, turning, or stopped	30	2.1	5	1.6	35	2.0
Other	105	7.3	26	8.1	132	7.4
TOTAL	1,446	100.0%	322	100.0%	1,773	100.0%

NOTE: Cases include all two-vehicle accidents occurring at an intersection where both vehicles were moving in the same direction. In each case, the tractor-semitrailer was damaged in the rear and the other vehicle suffered front damage.

common at night than during the day, as were cases of the truck turning left and the car moving straight. In contrast, accidents involving both vehicles turning right or both turning left were more common in the daytime than at night.

Rear-End Collisions at Non-Intersections - Table 1.5 shows distributions for rear-end collisions not taking place at intersections or driveways. This is the most common group in the analysis file, with 38 percent of the cases. Again there is a surprisingly high percentage of truck backing cases, 19.8 percent of the total, with the vast majority of these occurring during the daytime. In the truck backing collisions, the car was stopped 63 percent of the time and making some movement, usually proceeding straight, 36 percent of the time. Once again it seems clear that most of the truck backing cases were not related to the conspicuity of the truck, although a minority may have been.

There is a narrower range of vehicle actions at non-intersections compared to intersections, and this is reflected in Table 1.5. Leaving aside the truck backing cases, the most common daytime collisions were both vehicles moving straight (23.1 percent) and truck stopped, car straight (19.9 percent). These were the two most common nighttime collision scenarios as well, but the case of both vehicles moving straight was much more common at night, representing 53.7 percent of the cases.

Rear-End Collisions at Driveways - Distributions for rear-end collisions at driveways are shown in Table 1.6. Cases of the truck either backing into or out of a driveway represent about 28 percent of the total, but in only 40 percent of these was the other vehicle stopped. Thus, the conspicuity of the truck may have been a factor in a majority of the truck backing accidents occurring at driveways. The most common situation among the driveway rear-end collisions was the truck being struck from the rear while turning into a driveway. These cases represented about 41 percent of the total. Usually the other vehicle was moving straight at the time of the accident, while in a minority of cases it was changing lanes or passing. Trucks were more often struck from behind while turning right rather than turning left.

Side-Impact Collisions at Intersections - Moving now to side-impact collisions, Table 1.7 presents distributions for those taking place at intersections. This category of accidents represents about half of all potential conspicuity-related side impacts and 11 percent of all cases in the analysis file. The most common scenario among these accidents was both vehicles moving straight, with nearly 38 percent of the total. Another significant group was the truck turning left and the other vehicle proceeding straight, at 14.3 percent. Both of these groups were slightly more common at night than during the day.

TABLE 1.5- Tractor-Semitrailer Rear-Ends, Not at Intersections or Driveways, by Light Condition Michigan 1985–1988

Vehicle Actions	Light Condition					
	Day		Night		TOTAL	
	Number	Percent	Number	Percent	Number	Percent
Both straight	354	23.1%	384	53.7%	739	32.8%
Truck stopped, car straight	305	19.9	138	19.3	445	19.8
Car changing lanes/passing, truck straight or stopped	105	6.8	52	7.3	157	7.0
Car avoiding other vehicle, truck straight, stopped, or changing lanes/passing	54	3.5	25	3.5	79	3.5
Truck avoiding other vehicle, car straight or changing lanes/passing	20	1.3	4	0.6	24	1.1
Truck backing	426	27.8	19	2.7	445	19.8
Truck changing lanes/passing, car straight or stopped	92	6.0	48	6.7	140	6.2
Both changing lanes/passing	13	0.8	3	0.4	16	0.7
Other	164	10.7	42	5.9	206	9.2
TOTAL	1,533	100.0%	715	100.0%	2,251	100.0%

NOTE: Cases include all two-vehicle accidents not occurring at an intersection or a driveway, where both vehicles were moving in the same direction. In each case, the tractor-semitrailer was damaged in the rear and the other vehicle suffered front damage.

TABLE 1.6- Tractor-Semitrailer Rear-Ends at Driveways by Light Condition Michigan 1985–1988

Vehicle Actions	Light Condition					
	Day		Night		TOTAL	
	Number	Percent	Number	Percent	Number	Percent
Truck right into driveway, car straight	106	21.7%	32	19.5%	138	21.1%
Truck left into driveway, car straight	60	12.3	32	19.5	92	14.1
Truck right into driveway, car changing lanes/passing	23	4.7	5	3.0	28	4.3
Truck left into driveway, car changing lanes/passing	6	1.2	2	1.2	8	1.2
Truck right out of driveway, car straight	9	1.8	7	4.3	16	2.5
Truck left out of driveway, car straight	25	5.1	19	11.6	44	6.7
Truck stopped, car straight	8	1.6	5	3.0	13	2.0
Truck turning into or out of driveway, car avoiding other vehicle	17	3.5	8	4.9	25	3.8
Truck backing into driveway	106	21.7	13	7.9	119	18.2
Truck backing out of driveway	48	9.8	17	10.4	65	10.0
Car turning out of driveway, truck straight or stopped	19	3.9	3	1.8	22	3.4
Entering driveway, both straight, or both right, or both left	11	2.2	1	0.6	12	1.8
Leaving driveway, both straight, or both right, or both left	13	2.7	4	2.4	17	2.6
Other	38	7.8	16	9.8	54	8.3
TOTAL	489	100.0%	164	100.0%	653	100.0%

NOTE: Cases include all two-vehicle accidents occurring at a driveway access where the tractor-semitrailer was damaged in the rear and the other vehicle suffered front damage.

TABLE 1.7– Tractor-Semitrailer Side Impacts at Intersections by Light Condition Michigan 1985–1988

Vehicle Actions	Light Condition					
	Day		Night		TOTAL	
	Number	Percent	Number	Percent	Number	Percent
ANGLE						
Both straight	176	36.7%	71	40.1%	248	37.7%
Truck right, car straight	9	1.9	4	2.3	13	2.0
Truck left, car straight	64	13.4	30	16.9	94	14.3
Car right, truck straight	18	3.8	5	2.8	23	3.5
Car left, truck straight	20	4.2	11	6.2	31	4.7
Truck turning, car stopped	76	15.9	7	4.0	83	12.6
Car straight or turning, truck stopped	12	2.5	5	2.8	17	2.6
OPPOSITE DIRECTIONS						
Truck left, car straight	37	7.7	10	5.6	47	7.1
Car left, truck straight	6	1.3	1	0.6	7	1.1
Both straight	6	1.3	7	4.0	13	2.0
ANGLE OR OPPOSITE DIRECTIONS						
Both turning	13	2.7	5	2.8	18	2.7
Truck avoiding other vehicle, car straight or turning	13	2.7	3	1.7	16	2.4
Car avoiding other vehicle, truck straight or turning	9	1.9	4	2.3	13	2.0
Other	20	4.2	14	7.9	35	5.3
TOTAL	479	100.0%	177	100.0%	658	100.0%

NOTE: Cases include all two-vehicle accidents occurring at an intersection where the two vehicles were approaching either at an angle or from opposite directions. In each case, the tractor-semitrailer was damaged on one side and the other vehicle suffered front damage.

Side-Impact Collisions at Non-Intersections - Non-intersection side impacts (Table 1.8) represent only 2.5 percent of the cases in the analysis file. This group of accidents could be considered a miscellaneous category. About one-quarter of them took place at junctions like ramps or crossovers, 14 percent occurred in the vicinity of intersections, and the location of the rest, while not at intersections or driveways, was indeterminable. The most common vehicle actions, representing 53 percent of the cases, were both vehicles proceeding straight.

Side-Impact Collisions at Driveways - Side-impact collisions at driveway accesses (Table 1.9) show some similarity with rear-end driveway collisions in terms of vehicle actions. As with the rear-ends, the most common situation in the driveway side impacts was the other vehicle striking a truck turning into a driveway, with 43 percent of the cases. Again, the truck was usually making a right turn and the other vehicle was usually proceeding straight, although sometimes changing lanes or passing. Trucks backing into or out of driveways accounted for only 6 percent of the daytime cases, but one-third of the nighttime cases.

TABLE 1.8- Tractor-Semitrailer Side Impacts, Not at Intersections or Driveways, by Light Condition
Michigan 1985–1988

Vehicle Actions	Light Condition					
	Day		Night		TOTAL	
	Number	Percent	Number	Percent	Number	Percent
Truck stopped, car straight	4	4.4%	11	18.3%	15	10.0%
Both straight	53	58.9	26	43.3	79	52.7
Car changing lanes/passing, truck straight	6	6.7	3	5.0	9	6.0
Ramp or crossover situation, truck turning	5	5.6	5	8.3	10	6.7
Ramp or crossover situation, car turning	7	7.8	0	0.0	7	4.7
Truck avoiding other vehicle, car straight	3	3.3	7	11.7	10	6.7
Car avoiding other vehicle, truck straight	4	4.4	1	1.7	5	3.3
Other	8	8.9	7	11.7	15	10.0
TOTAL	90	100.0%	60	100.0%	150	100.0%

NOTE: Cases include all two-vehicle accidents not occurring at an intersection or a driveway, where the vehicles were approaching from opposite directions or at an angle. In each case, the tractor-semitrailer was damaged on one side and the other vehicle suffered front damage.

TABLE 1.9- Tractor-Semitrailer Side Impacts at Driveways by Light Condition
Michigan 1985–1988

Vehicle Actions	Light Condition					
	Day		Night		TOTAL	
	Number	Percent	Number	Percent	Number	Percent
Truck right into driveway, car straight	101	29.9%	20	13.2%	121	24.6%
Truck left into driveway, car straight	23	6.8	6	3.9	29	5.9
Truck right into driveway, car changing lanes/passing	36	10.7	5	3.3	41	8.4
Truck left into driveway, car changing lanes/passing	16	4.7	4	2.6	20	4.1
Car turning into driveway, truck straight or changing lanes/passing	17	5.0	2	1.3	19	3.9
Entering driveway, both right or both left	6	1.8	3	2.0	9	1.8
Truck backing into driveway	14	4.1	36	23.7	51	10.4
Truck right out of driveway, car straight	4	1.2	5	3.3	9	1.8
Truck left out of driveway, car straight	22	6.5	19	12.5	41	8.4
Car turning out of driveway, truck straight or changing lanes/passing	21	6.2	4	2.6	25	5.1
Exiting driveway, both right	7	2.1	1	0.7	8	1.6
Truck backing out of driveway	6	1.8	15	9.9	21	4.3
Car avoiding other vehicle, truck turning in or out of driveway	8	2.4	4	2.6	12	2.4
One vehicle exiting driveway, both straight, or one starting up/one straight	25	7.4	17	11.2	42	8.6
Other	32	9.5	11	7.2	43	8.8
TOTAL	338	100.0%	152	100.0%	491	100.0%

NOTE: Cases include all two-vehicle accidents occurring at a driveway access where the tractor-semitrailer was damaged on one side and the other vehicle suffered front damage.

Factors Associated With Conspicuity-Related Accidents

In the last section, a group of tractor-semitrailer involvements that were potentially related to truck conspicuity was defined. The composition of that group of accidents was examined with respect to accident type, light condition, relation to intersection, and vehicle movements. In this section, the same group of accidents will be compared with a group of all types of two-vehicle accidents involving a tractor-semitrailer. Once again data from the 1985-1988 Michigan State Police files will be used, with the potentially conspicuity-related group of accidents defined as in the last section. The other group consists of all two-vehicle accidents involving a tractor-semitrailer from those four years of Michigan data.

Distributions of Associated Factors

Figure 1.17 compares light condition at the time of the accident between the potentially conspicuity-related involvements and the group of all two-vehicle tractor-semitrailer collisions. The distributions are similar, but dark conditions are more common among the conspicuity group and daytime is more common among the general two-vehicle accidents. Lit and unlit dark conditions combined account for 23.4 percent of the conspicuity group and only 18.4 percent of the other group. This is not a tremendous difference, but it does support the idea that a lack of conspicuity was a factor in the first group of accidents.

FIGURE 1.17
Light Condition

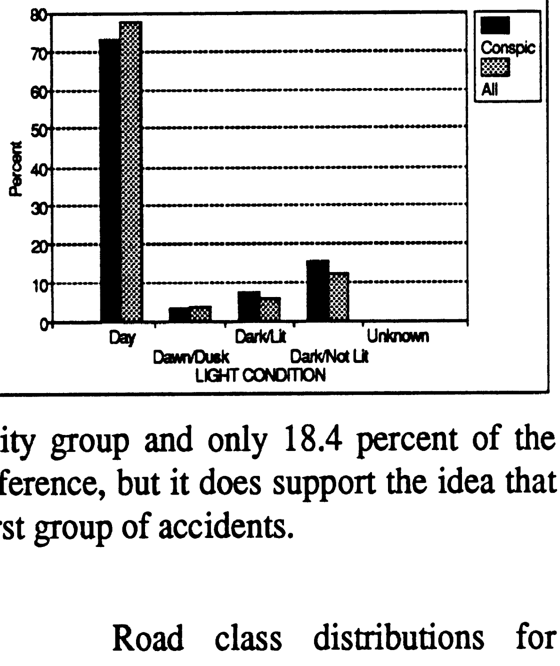
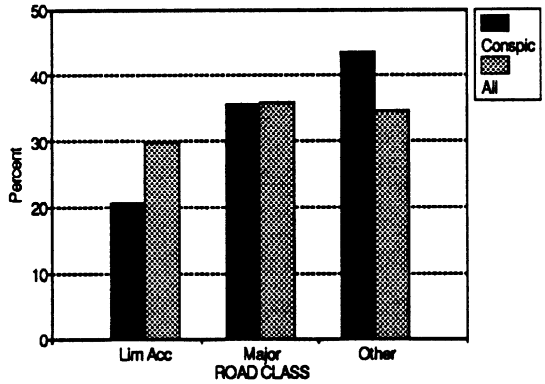


FIGURE 1.18
Road Class



Road class distributions for accidents under all light conditions are shown in Figure 1.18. The three classes of roads considered are limited access routes, major arteries, and all other roads. Less than 21 percent of the conspicuity-related involvements took place on limited access roads, compared to nearly 30 percent of the other group. In contrast, 44 percent of the conspicuity involvements occurred on "other" roads, compared to 34 percent of the other group. Although not pictured here, the road class distributions for daytime and nighttime involvements are quite similar to the overall pattern in that the "other" roads are over-represented among the conspicuity group and the limited access routes are over-represented among the general two-vehicle group. It is possible that factors pertaining to the road geometry and roadway environment of the "other" roads, such as poorer lighting conditions at night and shorter sight-distances, lead to reduced conspicuity of the trucks on these roads in comparison to limited access roads.

FIGURE 1.19
Road Surface–Daytime

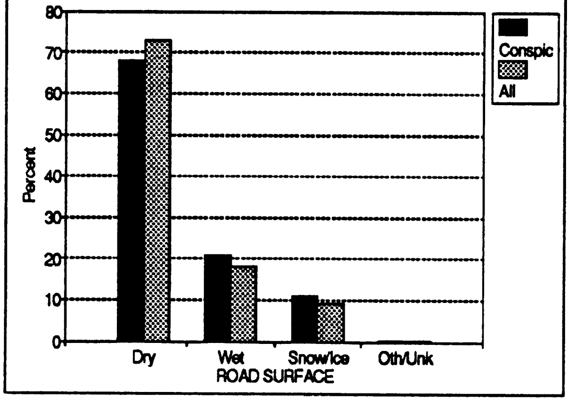


FIGURE 1.20
Road Surface–Nighttime

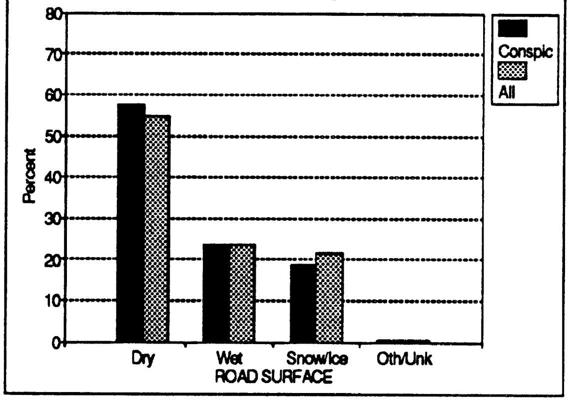
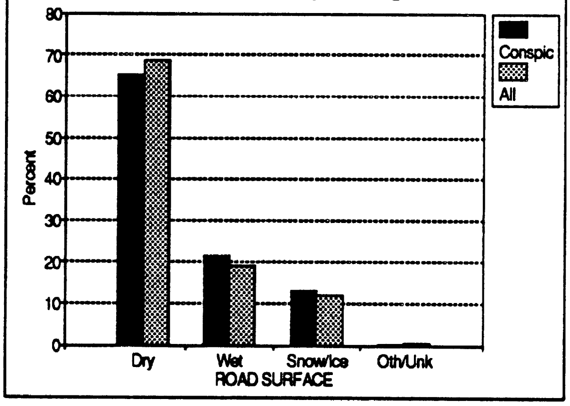


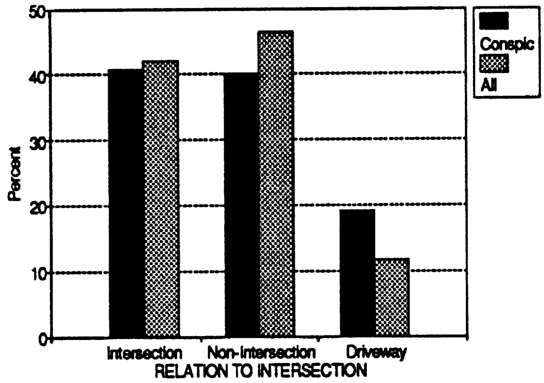
FIGURE 1.21
Road Surface–Day and Night



Figures 1.19-1.21 show distributions for road surface condition for daytime, nighttime, and all involvements. While there is not a great deal of variation between the distributions of conspicuity-related and all two-vehicle collisions in any of the three graphs, there are some interesting differences with respect to light condition. Among daytime accidents (Figure 1.19), a higher proportion of the general group occurred on dry roads, while higher proportions of the conspicuity group occurred on wet roads and on snowy or icy roads. In contrast, under dark conditions (Figure 1.20) relatively more of the conspicuity accidents occurred on dry roads, while relatively more of the general accidents took place on snowy or icy roads. The distributions for accidents under all light conditions (Figure 1.21) are similar to those under daylight conditions, since daylight collisions are more prevalent than nighttime accidents. In general, the three figures suggest that some of the accidents in the conspicuity-related group that took place in the daytime may have been related to poor road conditions and an inability to stop in addition to or instead of reduced conspicuity of the truck. On the other hand, the relatively higher proportion of dry road involvements at night for the conspicuity group strengthens the idea that an inability to perceive the truck was a major factor in the accident.

Distributions were also prepared for weather condition at the time of the accident. Although not presented here, the patterns are very similar to those shown in the road surface condition figures. During the daytime, rain and snow were more common among the conspicuity group than among the other accidents, while at night, clear conditions were more common for the conspicuity accidents than for the two-vehicle accidents in general.

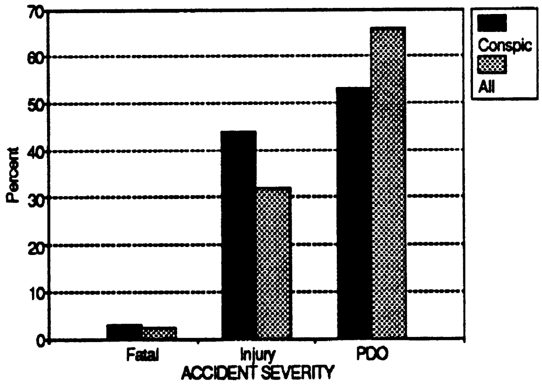
FIGURE 1.22
Relation to Intersection



In Figure 1.22 the two groups of accidents are compared according to relation to intersection. Accidents under all light conditions are represented, since the overall pattern showed little difference between daytime and nighttime collisions. Intersection accidents have about the same representation between the two groups, 41 percent among the conspicuity group and 42 percent among the general accidents. Non-intersection accidents were more common among all two-vehicle accidents, 47 percent compared to 40 percent, while driveway accidents were more common among the conspicuity group, 19 percent to 12 percent.

The next factor considered was accident severity. Although not pictured, the severity distributions for the two groups of accidents were essentially identical for collisions occurring during the daytime. At night, however, as shown in Figure 1.23, the conspicuity-related accidents appear to be more severe than two-vehicle accidents in general. Over 47 percent of the conspicuity accidents resulted in at least one fatality or injury, compared to just 34 percent of the general group. This difference in severity should be considered as part of any assessment of countermeasures related to enhancing the conspicuity of trucks.

FIGURE 1.23
Accident Severity–Nighttime



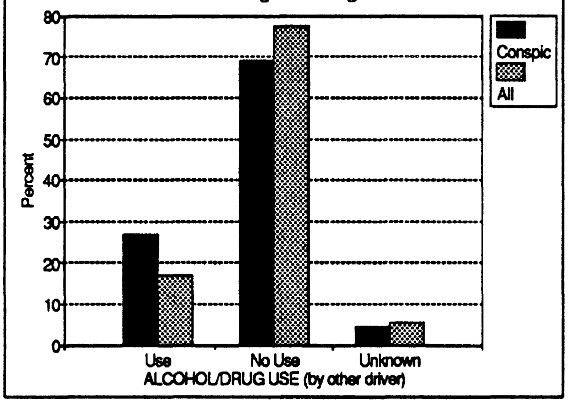


FIGURE 1.24
Alcohol/Drug Use--Nighttime

Alcohol or drug use by the non-truck driver was the next factor considered. Incidence of alcohol use during the daytime was very low and there was little difference between the distributions of conspicuity-related and all two-vehicle accidents. The nighttime distributions are shown in Figure 1.24. Alcohol/drug use among drivers of the other involved vehicles was more common in the conspicuity group (27 percent) than the other group (17 percent). This might suggest that trucks with reduced conspicuity are a particular hazard for alcohol-involved drivers of other vehicles.

Conclusions

Comparisons between two-vehicle tractor-semitrailer accidents thought to be conspicuity related and two-vehicle tractor-semitrailer accidents in general lend additional insight into the nature of the former group. The potentially conspicuity-related accidents tend to occur more at night and on "other" road classes compared to two-vehicle accidents in general. The nighttime conspicuity accidents tend to be more severe and have a higher incidence of alcohol involvement than nighttime two-vehicle accidents overall. During the daytime, poor road surface conditions may play a role in conspicuity-related accidents. At this point it is difficult to determine the relative importance of various associated factors or to estimate any interactions with reduced truck conspicuity that might increase the risk of accident.

Accident Risk and Trailer Body Style

The next stage of analysis concerned the involvement of tractor-semitrailers in fatal accidents, focusing on trailer body style, road class, land use (rural/urban), and time of day. The accident data for this analysis came from UMTRI's TIFA (Trucks Involved in Fatal Accidents) file. The TIFA file includes information produced by an ongoing survey concerning all medium and heavy trucks involved in fatal accidents in the continental United States. At the time of analysis, the file was complete for seven years, 1980 through 1986, and contained approximately 35,000 records.

While TIFA data may be used to produce frequencies of fatal accidents, a measure of exposure, in this case travel, is needed to calculate the rate of fatal accidents per mile. UMTRI conducted the National Truck Trip Information Survey (NTTIS) from 1985 to 1987, interviewing truck owners about the actual use of their trucks. The data in this file may be used to produce estimates of the annual mileage logged by particular types of trucks. By combining NTTIS with TIFA data, the *relative* risk of fatal accident involvement according to truck configuration and travel conditions may be calculated. Knowledge of the relative risk will assist in the assessment of any possible benefits that may derive from truck-marking systems.

Travel Data

Tables 1.10-1.12 present national annual mileage estimates, in millions of miles, for tractor-semitrailers according to trailer body style. Each of these tables is based on NTTIS data, and the mileage figures represent the total miles logged by all singles hauling a particular type of trailer. Table 1.10 contrasts travel on limited access routes with travel on all other road types. The relative mileage accounted for by each trailer type varies somewhat according to the type of road. For example, vans accumulate about 62 percent of the total limited access mileage but only 40 percent of the mileage on other roads.

TABLE 1.10
Annual Travel of Tractor-Semitrailers
by Trailer Body Style and Road Type
NTTIS File

Trailer Type	Millions of Vehicle Miles Traveled					
	Limited Access	Column Percent	Other Roads	Column Percent	TOTAL	Column Percent
Van	11,971	61.73	5,559	40.21	17,530	52.77
Flatbed	2,889	14.90	1,797	13.00	4,685	14.11
Tank	1,548	7.99	1,229	8.89	2,778	8.36
Auto Carrier	274	1.41	202	1.46	475	1.43
Dump	762	3.93	1,667	12.06	2,430	7.31
Other	1,948	10.05	3,371	24.38	5,319	16.01
TOTAL	19,393	100.00	13,824	100.00	33,217	100.00

Table 1.11 presents similar figures, this time splitting the data by trailer type and land use (rural/urban). While all of the trailer types examined log more miles in rural areas than urban areas, a few differences exist in the proportion of overall travel according to land use. Vans account for 50 percent of the rural miles but 59 percent of the urban miles, while the "other" trailer type category declines from 19 percent of the rural mileage to 10 percent of the urban mileage. The remaining trailer types show little variation in their shares of rural versus urban travel.

TABLE 1.11
Annual Travel of Tractor-Semitrailers
by Trailer Body Style and Land Use
NTTIS File

Trailer Type	Millions of Vehicle Miles Traveled					
	Rural	Column Percent	Urban	Column Percent	TOTAL	Column Percent
Van	11,225	49.68	6,305	59.37	17,530	52.77
Flatbed	3,235	14.32	1,450	13.66	4,685	14.11
Tank	1,870	8.27	908	8.55	2,778	8.36
Auto Carrier	292	1.29	184	1.73	475	1.43
Dump	1,704	7.54	726	6.83	2,430	7.31
Other	4,271	18.90	1,047	9.86	5,319	16.01
TOTAL	22,597	100.00	10,620	100.00	33,217	100.00

Travel by time of day is considered in Table 1.12. In this table, and elsewhere in this section, "day" refers to any time between 6 a.m. and 9 p.m., while "night" indicates the hours from 9 p.m. to 6 a.m. All of the configurations considered put on far more miles during the daytime hours than at nighttime, but their relative share of the mileage varies somewhat according to the time of day. Vans account for much more of the total nighttime mileage (67 percent) than the daytime mileage (50 percent).

TABLE 1.12
Annual Travel of Tractor-Semitrailers
by Trailer Body Style and Time of Day
NTTIS File

Trailer Type	Millions of Vehicle Miles Traveled					
	Day	Column Percent	Night	Column Percent	TOTAL	Column Percent
Van	13,366	49.52	4,164	66.90	17,530	52.77
Flatbed	3,928	14.55	758	12.17	4,685	14.11
Tank	2,295	8.50	483	7.75	2,778	8.36
Auto Carrier	432	1.60	43	0.69	475	1.43
Dump	2,243	8.31	187	3.00	2,430	7.31
Other	4,728	17.52	590	9.49	5,319	16.01
TOTAL	26,992	100.00	6,225	100.00	33,217	100.00

Relative Risk of Fatal Accident Involvement

In Tables 1.13 through 1.16, the seven years of TIFA data have been averaged together and combined with the NTTIS travel figures in order to produce estimates of the relative risk of fatal accident involvement for singles according to trailer body style. Each of these tables compares both the relative risk (between different trailer types) of being involved in any type of fatal accident with the relative risk of involvement in a fatal accident where the tractor-semi is struck in a rear-end or angle collision. The latter group serves as a roughly-defined category of cases where the accident may have been related to the conspicuity of the truck. This group is termed "conspicuity-related fatal involvements" in this set of tables, but the label is intended as a short-hand notation for fatal accidents where the truck is struck in a rear-end or angle crash, rather than as a definite indication that conspicuity played a role in the accident.

Six different trailer body styles are considered in Table 1.13, with the total annual mileage of each, according to the NTTIS file, listed in the second column. The next column lists the average annual number of fatal involvements of singles hauling each of the trailer types. These figures were derived from the seven years of TIFA data. The rates of fatal involvements per vehicle mile traveled were then calculated from these two sets of numbers, although to save space these figures are not presented in this table. The rate for each trailer type was then divided by the overall rate for all singles in order to obtain the relative risk figures listed in the fourth column of Table 1.13. These figures provide a direct means of comparison among the different trailer types. A relative risk factor greater than one indicates that the particular trailer type has a greater rate of involvement in fatal accidents than singles in general. Conversely, a relative risk factor less than one represents a lower rate of involvement.

TABLE 1.13
Relative Risk of Fatal Accident Involvement
for Tractor-Semitrailers by Trailer Body Style
NTTIS and 1980–86 TIFA Files

Trailer Type	10^6 VMT	All Fatal Involvements	Relative Risk	Conspicuity-Related Fatal Involvements	Relative Risk
Van	18,520	1,489	0.88	287	0.81
Flatbed	4,947	704	1.56	187	1.99
Tank	2,904	335	1.26	66	1.19
Auto Carrier	468	33	0.77	7	0.83
Dump	2,501	173	0.76	30	0.62
Other	5,440	447	0.90	85	0.82
TOTAL	34,779	3,181	1.00	662	1.00

NOTE: The fatal involvement figures are annual averages from the seven years of TIFA data.

Based on the NTTIS and TIFA data, flatbeds have the highest relative risk of fatal involvements (1.56) of the trailer styles considered and auto carriers (0.77) and dumps (0.76) the lowest (Table 1.13). The fatal involvements were also subset into those where the truck was struck in the side or the rear, and the average annual occurrences of these are listed in the "conspicuity-related" column of Table

1.13. The relative risks of involvement in a "conspicuity-related" fatal accident are listed in the final column of the table. Flatbeds again have the highest risk of involvement (1.99) and dumps the lowest (0.62).

A more interesting comparison can be made across the two relative risk columns of Table 1.13. For instance, while vans have a lower than average relative risk of involvement in all fatals (0.88), they have an even lower relative risk of involvement in "conspicuity-related" fatals (0.81). Assuming that the shape of the trailer is related to its degree of conspicuity, the lower relative risk of vans for "conspicuity-related" fatals is not surprising. In fact, vans, tanks, and dumps, which all present a large surface area to the observer, each have lower "conspicuity-related" relative risk factors than overall relative risk factors. On the other hand, flatbeds and auto carriers, which present a sketchy outline, both have higher relative risks of "conspicuity-related" involvements than overall involvements.

Tables 1.14, 1.15, and 1.16 present relative risks for all fatal involvements and "conspicuity-related" fatal involvements according to road type, land use, and time of day respectively. Only vans, flatbeds, and tanks are specifically considered in these tables, with all other trailer body styles represented under "other," because of the small sample sizes in the dump and auto carrier categories when the data are so finely divided. The three tables split travel into six classes: limited access roads, other roads, rural areas, urban areas, daytime, and nighttime. For each of these divisions, flatbeds have a higher relative risk factor of involvement in a "conspicuity-related" accident than in fatal crashes in general. Conversely, vans have a slightly lower relative risk factor for "conspicuity-related" fatals than all fatals in each of the six travel categories, and the same is true for tanks, except in the category of urban travel.

TABLE 1.14
Relative Risk of Fatal Accident Involvement for Tractor-Semitrailers by Trailer Body Style and Road Type
NTTIS and 1980–86 TIFA Files

	LIMITED ACCESS			OTHER ROADS		
Trailer Type	10^6 VMT	Rel. Risk All Fatals	Relative Risk Conspic. Fatals	10^6 VMT	Rel. Risk All Fatals	Relative Risk Conspic. Fatals
Van	11,971	0.99	0.85	5,559	1.03	0.99
Flatbed	2,889	1.42	1.96	1,797	1.73	2.14
Tank	1,548	0.94	0.81	1,229	1.31	1.27
Other	2,984	0.68	0.78	5,240	0.65	0.55
TOTAL	19,393	1.00	1.00	13,824	1.00	1.00

TABLE 1.15
Relative Risk of Fatal Accident Involvement for Tractor-Semitrailers by Trailer Body Style and Land Use
NTTIS and 1980–86 TIFA Files

Trailer Type	RURAL			URBAN		
	10^6 VMT	Rel. Risk All Fatals	Relative Risk Conspic. Fatals	10^6 VMT	Rel. Risk All Fatals	Relative Risk Conspic. Fatals
Van	11,225	0.89	0.81	6,305	0.90	0.82
Flatbed	3,235	1.59	2.01	1,450	1.50	2.00
Tank	1,870	1.30	1.21	908	1.16	1.17
Other	6,267	0.80	0.76	1,956	0.88	0.76
TOTAL	22,597	1.00	1.00	10,620	1.00	1.00

TABLE 1.16
Relative Risk of Fatal Accident Involvement for Tractor-Semitrailers by Trailer Body Style and Time of Day
NTTIS and 1980–86 TIFA Files

Trailer Type	DAY			NIGHT		
	10^6 VMT	Rel. Risk All Fatals	Relative Risk Conspic. Fatals	10^6 VMT	Rel. Risk All Fatals	Relative Risk Conspic. Fatals
Van	13,366	0.86	0.83	4,164	0.81	0.69
Flatbed	3,928	1.53	1.83	758	1.80	2.48
Tank	2,295	1.20	1.13	483	1.43	1.33
Other	7,403	0.90	0.82	820	0.97	1.03
TOTAL	26,992	1.00	1.00	6,225	1.00	1.00

In order to more specifically define travel conditions, road type, land use, and time of day were considered simultaneously to produce the eight different travel categories used in Tables 1.17 through 1.21. The total number of fatal involvements, by trailer body style, from the seven years of TIFA data are given in Table 1.17 and similar figures for "conspicuity-related" fatals are listed in Table 1.18. The annual estimated travel of each trailer type across the eight travel categories is presented in Table 1.19. Finally, Table 1.20 indicates the relative risk of fatal accident involvement in each of the travel categories, and Table 1.21 does the same for "conspicuity-related" fatals.

TABLE 1.17
Fatal Involvements of Tractor-Semitrailers by Trailer Body Style and Travel Category
Seven-Year Totals
1980–86 TIFA Files

Travel Category	Trailer Body Style				
	Van	Flatbed	Tank	Other	TOTAL
LimRurDay	1,114	384	115	195	1,808
LimRurNite	1,196	413	122	151	1,882
LimUrbDay	819	305	124	212	1,460
LimUrbNite	665	206	107	88	1,066
OthRurDay	2,946	1,964	994	2,541	8,445
OthRurNite	1,663	805	453	611	3,532
OthUrbDay	1,299	541	233	614	2,687
OthUrbNite	639	254	166	123	1,182
TOTAL	10,341	4,872	2,314	4,535	22,062

NOTE: The labels in the left column have the following meanings:
LimRurDay = Limited Access, Rural, Day
LimRurNite = Limited Access, Rural, Night
LimUrbDay = Limited Access, Urban, Day
LimUrbNite = Limited Access, Urban, Night
OthRurDay = Other Roads, Rural, Day
OthRurNite = Other Roads, Rural, Night
OthUrbDay = Other Roads, Urban, Day
OthUrbNite = Other Roads, Urban, Night

TABLE 1.18
Conspicuity-Related Fatal Involvements of Tractor-Semitrailers by Trailer Body Style and Travel Category
Seven-Year Totals
1980–86 TIFA Files

Travel Category	Trailer Body Style				
	Van	Flatbed	Tank	Other	TOTAL
LimRurDay	158	74	19	46	297
LimRurNite	237	149	22	44	452
LimUrbDay	135	67	19	38	259
LimUrbNite	156	94	25	31	306
OthRurDay	452	362	150	367	1,331
OthRurNite	312	239	95	150	796
OthUrbDay	269	149	49	110	577
OthUrbNite	266	155	76	59	556
TOTAL	1,985	1,289	455	845	4,574

TABLE 1.19
Annual Travel (Millions of Miles) of Tractor-Semitrailers by Trailer Body Style and Travel Category
NTTIS File

Travel Category	Trailer Body Style									
	Van		Flatbed		Tank		Other		TOTAL	
	Miles	Pct.	Miles	Pct.	Miles	Pct.	Miles	Pct.	Miles	Pct.
LimRurDay	5,702	58.94	1,505	15.56	740	7.65	1,727	17.85	9,674	100.00
LimRurNite	2,220	70.60	417	13.27	215	6.85	292	9.28	3,144	100.00
LimUrbDay	3,051	58.63	790	15.19	486	9.34	877	16.85	5,203	100.00
LimUrbNite	999	72.85	176	12.85	107	7.83	89	6.47	1,371	100.00
OthRurDay	2,594	30.71	1,187	14.06	790	9.35	3,876	45.89	8,447	100.00
OthRurNite	710	53.24	125	9.41	125	9.37	373	27.98	1,333	100.00
OthUrbDay	2,020	55.06	445	12.14	280	7.62	924	25.19	3,668	100.00
OthUrbNite	236	62.59	39	10.29	35	9.31	67	17.81	377	100.00
TOTAL	17,530	52.78	4,685	14.11	2,778	8.36	8,224	24.76	33,217	100.00

TABLE 1.20
Relative Risk of Fatal Accident Involvements for Tractor-Semitrailers by Trailer Body Style and Travel Category
NTTIS and 1980–86 TIFA Files

Travel Category	Trailer Body Style				
	Van	Flatbed	Tank	Other	TOTAL
LimRurDay	1.05	1.36	0.83	0.60	1.00
LimRurNite	0.90	1.65	0.95	0.86	1.00
LimUrbDay	0.96	1.38	0.91	0.86	1.00
LimUrbNite	0.86	1.50	1.28	1.28	1.00
OthRurDay	1.14	1.65	1.26	0.66	1.00
OthRurNite	0.88	2.42	1.37	0.62	1.00
OthUrbDay	0.88	1.66	1.14	0.91	1.00
OthUrbNite	0.86	2.09	1.51	0.58	1.00
ALL	0.89	1.57	1.25	0.83	1.00

TABLE 1.21
Relative Risk of Conspicuity-Related
Fatal Accident Involvements for Tractor-Semitrailers
by Trailer Body Style and Travel Category
NTTIS and 1980–86 TIFA Files

Travel Category	Trailer Body Style				
	Van	Flatbed	Tank	Other	TOTAL
LimRurDay	0.90	1.60	0.84	0.87	1.00
LimRurNite	0.74	2.48	0.71	1.05	1.00
LimUrbDay	0.89	1.70	0.79	0.87	1.00
LimUrbNite	0.70	2.39	1.04	1.57	1.00
OthRurDay	1.11	1.94	1.21	0.60	1.00
OthRurNite	0.74	3.19	1.27	0.67	1.00
OthUrbDay	0.85	2.13	1.11	0.76	1.00
OthUrbNite	0.76	2.71	1.47	0.60	1.00
ALL	0.82	2.00	1.19	0.75	1.00

The patterns observed earlier continue to hold for the eight travel categories used in Tables 1.20 and 1.21. In each instance, flatbeds have a higher relative risk factor for "conspicuity-related" fatals than for fatals in general, while the opposite is true of vans. Tanks show the same pattern as vans, except in the category of limited access/rural/daytime travel.

Conclusions

The analysis of the NTTIS and TIFA files corroborates the idea that the shape of the trailer body is related to its degree of conspicuity. A comparison between fatal accidents potentially related to the conspicuity of the truck versus all fatal accidents has shown that singles hauling trailers with a large surface area, like vans and tanks, have a lower risk of involvement in conspicuity-related crashes than do singles hauling other types of trailers, particularly flatbeds. Furthermore, this generalization holds for virtually every travel condition tested under a scheme that took into account road type, land use, and time of day.

Large Truck Accident Experience by Severity

The previous section concerned relative risk of fatal accident involvement for tractor-semitrailers with different trailer body styles. The results indicated that vans, tanks, and dumps have a lower relative risk of involvement in fatal accidents where the truck is struck in a rear-end or angle crash than they do for fatal accidents in general. Conversely, flatbeds and auto carriers have higher relative risk factors for involvement in these types of accidents than for fatal accidents overall. While these findings are consistent with the idea that the size and shape of the trailer are related to the degree of conspicuity of the truck, the data are based solely on fatal involvements, which represent a very small proportion of all truck accidents. Ideally it would be desirable to have similar estimations of relative risk of involvement in injury and property damage only (PDO) accidents. Unfortunately, there is currently no database concerning the involvement of large trucks in non-fatal accidents that contains reliable, nationally representative, detailed information, such as that provided by the TIFA file for trucks in fatal accidents.

Injury and PDO Accidents

While there are no data available to assess the relative risk of involvement in non-fatal accidents according to trailer body style, it is possible to determine whether the general relationships between travel conditions and involvement in a fatal accident hold for other accident severities. NHTSA's NASS (National Accident Sampling System) database is suitable for this purpose since it provides national coverage of accidents of all severities. One limitation of NASS, however, is that its national estimates are more reliable for the more common types of accidents, such as those involving passenger cars. The smaller sample sizes and larger sampling weights associated with less frequent events, like large truck accidents, limit the accuracy of national estimates concerning these events. An attempt was made to partially compensate for these problems by combining three years of NASS data, 1984 through 1986, for the present analysis. The NASS data were used to produce national estimates of tractor-semitrailer involvements in injury and PDO accidents, and the NTTIS file was used for travel estimates so that rates of involvement per mile could be calculated.

As a comparative source of information, the Michigan State Police motor vehicle accident file was also used to examine truck involvements in non-fatal accidents. The Michigan file has the advantage of being a census database, but it cannot be assumed to represent the national large truck accident experience. To calculate travel estimates to be used with the Michigan accident file, the Michigan Truck Trip Information Survey (MTTIS) database was used. This file is based on a survey conducted by UMTRI concerning the travel of Michigan-registered medium and heavy trucks within the state of Michigan. Since the Michigan State Police accident file does not indicate the state of registration of trucks, data from this file were supplemented by data on the state of registration of involved trucks. The Michigan data discussed in this section concern only Michigan-registered tractor-semitrailers and their travel and accident experience within the state. The accident and travel data are based on the period from May 1987 to May 1988.

Involvement Rates for Different Severities

Table 1.22 presents the rates of involvement in fatal accidents for tractor-semitrailers based on data from the TIFA and NTTIS files. Because TIFA is a national census database and because both of these files are geared exclusively towards large trucks, we consider the rates listed in the table to be reliable. From left to right the columns of Table 1.22 list the travel category, millions of vehicle miles traveled, average annual number of fatal involvements, and number of fatals per hundred million vehicle miles traveled. In terms of road type, limited access roads have a much lower rate of fatal involvements than other types of roads, by a factor of about 3.5. The land use split is less dramatic, with rural areas having a slightly higher rate than urban areas. Finally, the daytime (6 a.m. to 9 p.m.) rate for fatal accidents is less than half the nighttime (9 p.m. to 6 a.m.) rate. These three travel factors were also combined to produce the eight-way split listed in Table 1.22. The rates vary widely according to travel condition, ranging from 2.77 for rural limited access roads during the day to 46.61 for other road types in urban areas at night.

TABLE 1.22
Fatal Involvement Rates by Travel Category
for all Tractor-Semitrailers
NTTIS and 1980–86 TIFA Files

Travel Category	10^6 VMT	Fatals (Annual Average)	Fatals/10^8 VMT
Limited Access	19,397	929	4.79
Other Roads	13,830	2,360	17.07
Rural	22,601	2,327	10.30
Urban	10,627	962	9.05
Day	27,003	2,147	7.95
Night	6,225	1,142	18.35
TOTAL	33,228	3,289	9.90
LimRurDay	9,678	268	2.77
LimRurNite	3,144	280	8.90
LimUrbDay	5,205	221	4.24
LimUrbNite	1,371	160	11.69
OthRurDay	8,447	1,253	14.84
OthRurNite	1,333	526	39.50
OthUrbDay	3,674	405	11.03
OthUrbNite	377	176	46.61

Similar rates were produced for injury and PDO involvements using NASS for the accident data and again using NTTIS for the travel estimates. For both injury accidents and PDOs, the limited access roads have lower rates of involvement than do the other road types (Table 1.23). This pattern is similar to that shown by the fatal rates in Table 1.22. The NASS land use patterns differ from the TIFA pattern, however. Whereas the fatal rate was slightly higher in rural areas than urban ones (Table 1.22), the rate in urban areas is higher than the rural rate for injury accidents and especially for PDOs (Table 1.23). The time of day patterns are also contrary to those shown by the fatal accidents, which have a much higher nighttime than daytime rate. For the injury accidents, the nighttime rate is just slightly higher than the daytime rate, while for PDOs daytime is much higher than nighttime (Table 1.23).

TABLE 1.23
NASS Injury and PDO Involvement Rates by Travel Category
for all Tractor-Semitrailers
NTTIS and 1984-86 NASS Files

Travel Category	10^6 VMT	NASS Injuries (Ann. Avg.)	NASS PDOs (Ann. Avg.)	Injuries/ 10^8 VMT	PDOs/ 10^8 VMT
Limited Access	19,397	22,447	34,420	115.72	177.45
Other Roads	13,830	32,391	100,398	234.20	725.93
Rural	22,601	23,493	44,473	103.95	189.30
Urban	10,627	31,344	90,346	294.95	850.15
Day	27,003	44,276	123,774	163.96	458.37
Night	6,225	10,562	11,045	169.68	177.44
TOTAL	33,228	54,838	134,819	165.04	405.74
LimRurDay	9,678	4,500	10,444	46.50	107.92
LimRurNite	3,144	4,468	5,099	142.13	162.19
LimUrbDay	5,205	11,901	17,309	228.67	332.58
LimUrbNite	1,371	1,577	1,568	114.99	114.36
OthRurDay	8,447	12,138	26,757	143.70	316.77
OthRurNite	1,333	2,387	2,173	179.13	163.07
OthUrbDay	3,674	15,736	69,264	428.29	1,885.13
OthUrbNite	377	2,130	2,204	565.32	585.15

The Michigan State Police and MTTIS data were used to derive the rates shown in Table 1.24. In the data that were available to us, fatal and injury accidents were combined, and these are shown as "casualty" accidents in the table. In general the Michigan casualty and PDO rates show patterns similar to the TIFA fatal rates. The limited access roads have lower rates than the other road types, the urban rates are somewhat lower than the rural rates, and, for the casualty involvements, the nighttime rate is higher than daytime. The only major difference from the TIFA rates is with the Michigan PDOs, where the daytime rate is higher than the nighttime rate.

TABLE 1.24
Injury and PDO Involvement Rates by Travel Category
for all Tractor-Semitrailers Registered in Michigan
and Traveling in Michigan
MTTIS and Michigan State Police Files

Travel Category	10^6 VMT	Michigan Casualties	Michigan PDOs	Casualties/ 10^8 VMT	PDOs/ 10^8 VMT
Limited Access	454	381	1,105	84.01	243.66
Other Roads	310	772	2,921	249.42	943.72
Rural	426	775	2,383	182.04	559.74
Urban	337	378	1,643	112.07	487.10
Day	662	946	3,567	142.98	539.11
Night	101	207	459	204.18	452.75
TOTAL	763	1,153	4,026	151.11	527.63
LimRurDay	204	188	580	91.96	283.72
LimRurNite	42	63	137	150.18	326.58
LimUrbDay	177	107	348	60.37	196.33
LimUrbNite	30	23	40	76.97	133.87
OthRurDay	160	441	1,478	274.90	921.33
OthRurNite	19	83	188	438.46	993.13
OthUrbDay	120	210	1,161	175.66	971.14
OthUrbNite	11	38	94	357.82	885.12

Relative risk factors were calculated for each of the five accident groups: TIFA, NASS injury accidents, NASS PDOs, Michigan casualty accidents, and Michigan PDOs (Table 1.25). For each set of data, the involvement rate for each travel category was divided by the overall group rate. This allows for a direct assessment of the relative risk posed by each of the travel conditions. Road type clearly shows the most consistent pattern between the different datasets and their corresponding different severities. In each of the five cases, the relative risk of involvement on non-limited access roads is two to four times the relative risk on limited access roads.

TABLE 1.25
Relative Risks of Involvement in Accidents by Severity and Travel Category for Tractor-Semitrailers
NTTIS, MTTIS, 1980-86 TIFA, and 1984-86 NASS

Travel Category	RELATIVE RISKS				
	Fatal (TIFA)	Injury (NASS)	PDO (NASS)	Casualty (Michigan)	PDO (Michigan)
Limited Access	0.48	0.70	0.44	0.56	0.46
Other Roads	1.72	1.42	1.79	1.65	1.79
Rural	1.04	0.63	0.47	1.20	1.06
Urban	0.91	1.79	2.10	0.74	0.92
Day	0.80	0.99	1.13	0.95	1.02
Night	1.85	1.03	0.44	1.35	0.86
TOTAL	1.00	1.00	1.00	1.00	1.00
LimRurDay	0.28	0.28	0.27	0.61	0.54
LimRurNite	0.90	0.86	0.40	0.99	0.62
LimUrbDay	0.43	1.39	0.82	0.40	0.37
LimUrbNite	1.18	0.70	0.28	0.51	0.25
OthRurDay	1.50	0.87	0.78	1.82	1.75
OthRurNite	3.99	1.09	0.40	2.90	1.88
OthUrbDay	1.11	2.60	4.65	1.16	1.84
OthUrbNite	4.71	3.43	1.44	2.37	1.68

The land use rate pattern is more confusing (Table 1.25). The risk factors for both casualty and PDO accidents in Michigan are similar to TIFA, with rural areas slightly over-represented compared to urban areas. However, for NASS injuries, the urban relative risk factor is 2.8 times the rural risk factor, and for NASS PDOs, the urban factor is 4.5 times the rural factor. While for both the NASS and the Michigan data urban involvements account for a greater share of the PDO accidents than of the injury accidents, there remains a significant difference between NASS and Michigan in that rural accidents are over-represented for Michigan and urban accidents are over-represented for NASS.

Table 1.25 also presents the relative risk factors according to time of day. Here there is some consistency between the NASS and Michigan rates, both of which differ from TIFA. The TIFA fatal rates indicate that nighttime involvements are over-represented compared to daytime involvements. For both the NASS injury and Michigan casualty data, nighttime is slightly over-represented, but not to the same extent as in the fatal rates. The pattern reverses for PDO accidents in both the NASS and Michigan data, with daytime occurrences over-involved compared to nighttime.

Conclusions

Some tentative conclusions can be put forth on the basis of the analyses of the TIFA, NASS, and Michigan files. One is that truck travel is much safer on limited access routes than on other types of roads, and this holds for all accident severities. The proportion of limited access mileage approaches 60 percent of the total mileage of tractor-semitrailers, according to both the NTTIS and MTTIS files. Yet despite more travel on limited access roads, more truck accidents take place on other road types. This produces relative risk factors that are consistently lower for limited access routes than for other road types no matter which set of data or accident severity is examined.

Unlike the road type pattern, the effect of daytime/nighttime appears to differ according to accident severity. Fatal truck accidents have a higher rate of occurrence at night than during the day. Based on the NASS and Michigan data, injury accidents also have a higher nighttime rate, but it is not as severe as for fatal accidents. For PDOs, however, both the NASS and Michigan data indicate that the relative risk is lower at night than during the day. This difference according to accident severity could be a matter of traffic density. PDO accidents commonly occur in situations where traffic is heavy but moving at relatively low speeds. This is more often the case during the daytime than at night.

Based on the analyses conducted, it is difficult to say whether the rural/urban rate patterns have any connection with accident severity. The main differences observed were among the different databases, not between the accident severities, so that the Michigan rates were similar to the TIFA rates, and NASS had a reverse pattern. Several hypotheses can be imagined that would account for this difference. One might be a bias inherent in the NASS sampling procedure so that the primary sampling units used are not representative of truck accidents. This could lead to over-estimates of the number of truck accidents taking place in urban areas, which would yield the higher urban rates for NASS. Another explanation might involve an under-reporting of truck accidents in the Detroit area. This would lead to low frequencies of urban accidents in the Michigan data and the corresponding low urban rates. A third possibility is that some real difference exists between Michigan and the nation in terms of the rural/urban split of truck accidents. The present data offer no means of selecting one of these scenarios over the others, and the real difference could be due to a combination of these factors or to some entirely different explanation. The ambiguity of the data underscores the need for a national truck database of non-fatal accidents.

Rear-End Versus Side Impact Collisions and Risk

An analysis presented in a previous section concerned the risk of potential conspicuity-related fatal accidents, considering rear-end and side impact collisions together. In this section fatal rear-end and side impact crashes are treated separately in order to compare risk between the two. In the previous analysis, accident rates per mile of travel were calculated for tractor-semitrailers with different trailer body styles under various operating conditions. Rates per mile could again be calculated here, but since it is only the two different collision types in which we are interested, both groups would have the same denominator, annual miles logged by tractor-semitrailers. Therefore, simple frequencies will indicate the likelihood of a tractor-semitrailer experiencing a conspicuity-related fatal rear-end collision compared to a conspicuity-related fatal side impact collision.

Defining the Data

Once again seven years of TIFA data (1980 through 1986) were used for the analyses, with the scope restricted to tractor-semitrailers. Two subsets were defined from the data. They both consisted of accidents that were potentially related to the conspicuity of the truck. The first included involvements where the truck was struck in a rear-end collision, with the initial impact on the rear or undercarriage of the truck. The second group comprised involvements where the truck was struck in an angle collision, with the initial impact on the sides or undercarriage of the truck. As a shorthand notation, the first group will be referred to as C-R (conspicuity-related) rear-ends and the second as C-R side impacts. It should be stressed that the conspicuity of the truck was only a possible, not definite, factor in the occurrence of these accidents.

In the seven years of data examined, a total of 23,240 tractor-semitrailers were involved in fatal accidents. Out of these, 3,711 or 16 percent fell into one of the two conspicuity-related groups. The rear-end collisions outnumbered the side impacts by 2,134 to 1,577, a ratio of about 1.35 to 1.

Time of Day Comparisons

The different categories of fatal involvements were compared according to the time of occurrence. Figure 1.25 illustrates the distribution of time of occurrence in one-hour blocks for the C-R rear-ends, C-R side impacts, and all the TIFA singles involvements. The numbers on the x-axis indicate the start of the hour, so the tick marked "2" on the a.m. side represents the hour from 2:00 to 2:59

a.m. In Figure 1.26, the rear-ends and side impacts have been combined into all conspicuity-related accidents. For every hour of the day between 6 p.m. and 7 a.m., there were higher proportions of occurrences of conspicuity-related accidents than fatal involvements in general (Figure 1.26). As Figure 1.25 indicates, the conspicuity-related pattern is driven by the rear-end collisions but generally holds for the side impacts as well.

FIGURE 1.25
Rear-ends, Side Impacts and TIFA by Time of Day

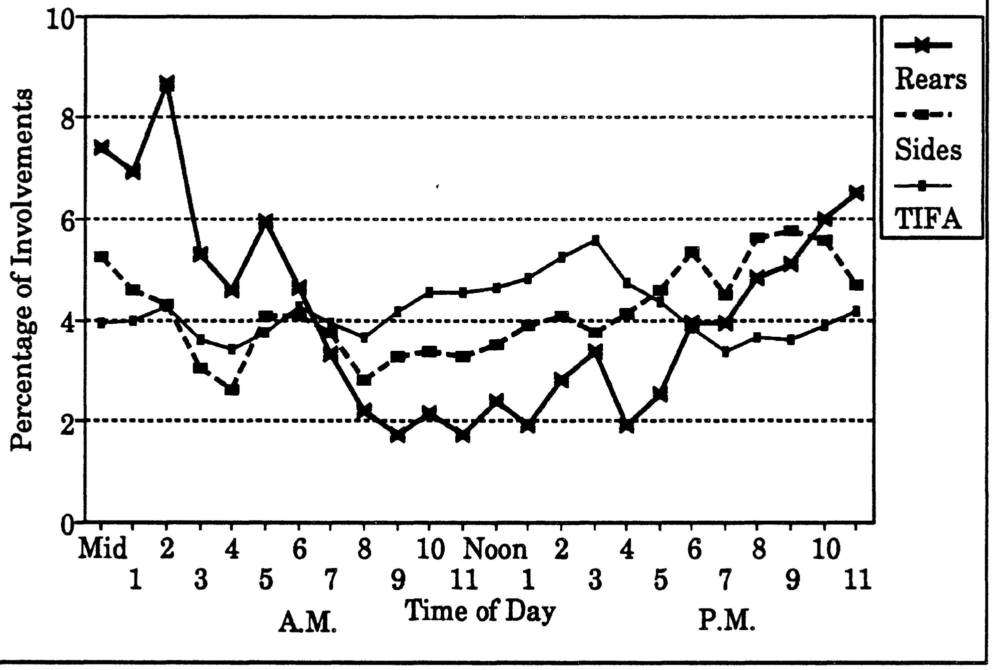
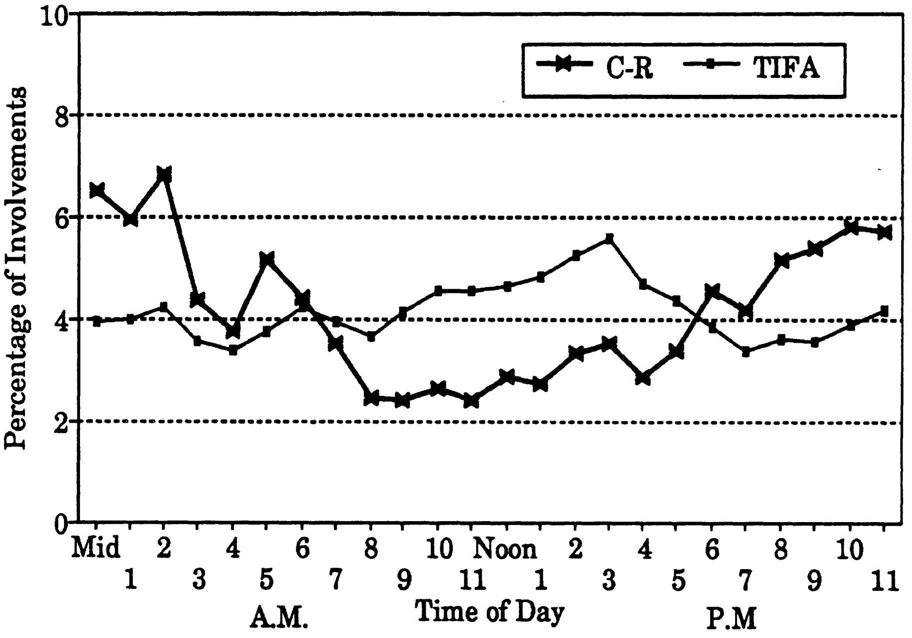


FIGURE 1.26
Conspicuity-Related v. TIFA Accidents by Time of Day



The hours of the day have been combined into two 12-hour periods in Table 1.26. Again the clear difference in time of occurrence between the conspicuity-related accidents and all the fatal involvements is apparent. Over 63 percent of the C-R crashes took place between 6 p.m. and 6 a.m. compared to only 46 percent of all fatal accidents. For C-R rear-ends, the proportion is even higher, at 69 percent.

TABLE 1.26
Time of Day of Accident
Conspicuity-Related v. All TIFA Singles

Time of Day	C-R Rear-Ends		C-R Side Impacts		All C-R Crashes		All TIFA Singles	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
6 a.m. - 6 p.m.	656	30.74	700	44.39	1,356	36.54	12,632	54.35
6 p.m. - 6 a.m.	1,477	69.21	877	55.61	2,354	63.43	10,587	45.56
Unknown	1	0.05	0	0.00	1	0.03	21	0.09
TOTAL	2,134	100.00	1,577	100.00	3,711	100.00	23,240	100.00

Light Condition Comparisons

The contrast among the different groups of fatal accidents is seen again in the light condition distributions illustrated in Table 1.27 and Figures 1.27 and 1.28. Close to 70 percent of the C-R rear-ends occurred under dark/unlit or dark/lit conditions. A majority of the C-R side impacts also took place in the dark, with 54 percent. Fatal singles involvements overall were more likely to occur under daylight conditions, however, with 53 percent taking place in daylight and

43 percent when dark. The preponderance of C-R accidents at night, especially compared to fatal involvements in general, strengthens the idea that these accidents were in fact related to the conspicuity of the truck.

While C-R rear-ends were found to be more common than C-R side impacts in the TIFA file, Table 1.27 indicates that during daylight conditions, side impacts were slightly more numerous than rear-end collisions. This is perhaps related to the opportunity for the accidents to occur. While rear-end collisions commonly occur at both intersections and non-intersections, angle collisions are typically restricted to intersection situations. Since traffic density at most intersection locations peaks during the daytime, this likely contributes to the higher proportion of side impacts (compared to rear-ends) during the daylight hours.

TABLE 1.27
Light Condition of Accident
Conspicuity-Related v. All TIFA Singles

Light Condition	C-R Rear-Ends		C-R Side Impacts		All C-R Crashes		All TIFA Singles	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Daylight	580	27.18	652	41.34	1,232	33.20	12,226	52.61
Dark	1,466	68.70	855	54.22	2,321	62.54	10,074	43.35
Dawn/Dusk	87	4.08	70	4.44	157	4.23	926	3.98
Unknown	1	0.05	0	0.00	1	0.03	14	0.06
TOTAL	2,134	100.00	1,577	100.00	3,711	100.00	23,240	100.00

FIGURE 1.27
Rear-ends, Side Impacts, and TIFA
by Light Condition

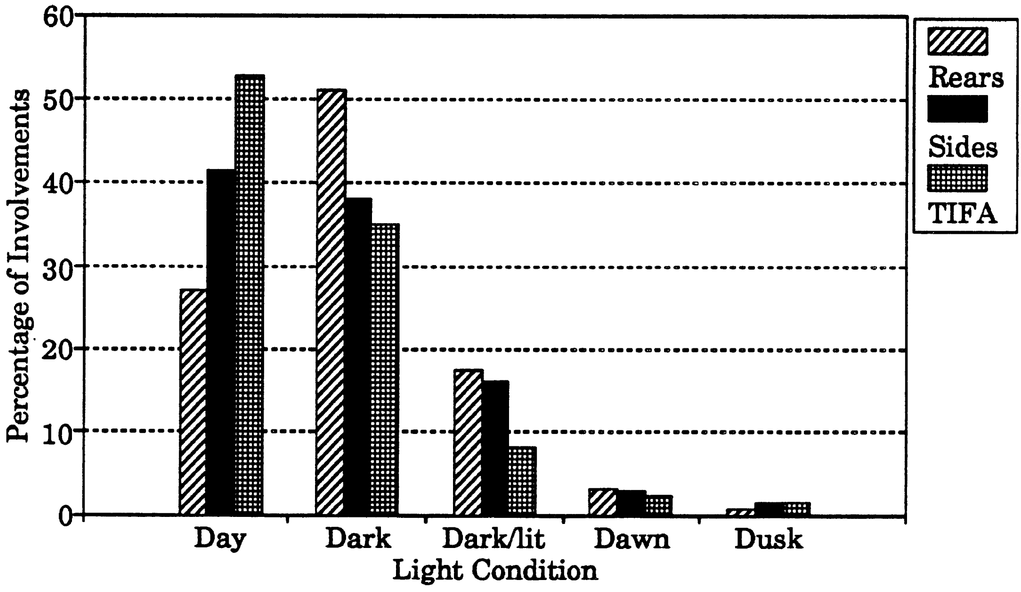
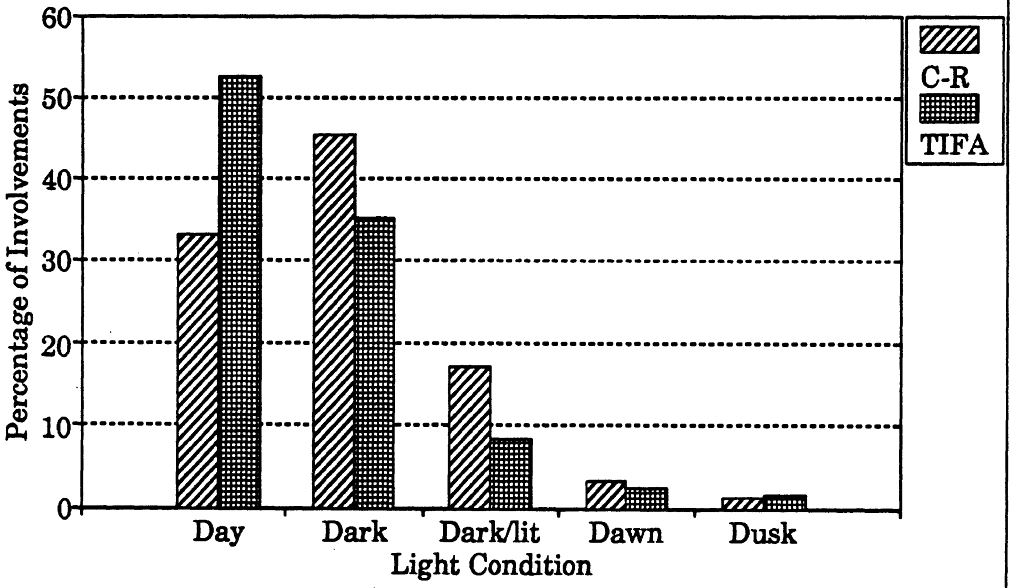


FIGURE 1.28
Conspicuity-Related v. TIFA Accidents
by Light Condition



Trailer Body Style

In Table 1.28, the distributions of the different groups of fatal accidents are presented according to trailer body style. While van and flatbed trailers follow the typical pattern of having significantly more C-R rear-end than C-R side impact involvements, the tanker trailers experienced approximately equal numbers of both kinds of collisions. A more interesting observation from the table concerns the representation of the different trailer body styles in each of the accident groups. While flatbeds accounted for 21 percent of all fatal singles involvements, they accounted for almost 29 percent of the C-R accidents and 31 percent of the C-R rear-end collisions. On the other hand, tractors hauling van trailers made up 45 percent of all fatal involvements but only 41 percent of the C-R crashes and only 39 percent of the C-R rear-end collisions. This pattern is consistent with previous analyses we have conducted concerning trailer body style and fits the expectation that flatbed trailers would tend to be more inconspicuous than van trailers.

TABLE 1.28
Trailer Body Style
Conspicuity-Related v. All TIFA Singles

Trailer Body Style	C-R Rear-Ends		C-R Side Impacts		All C-R Crashes		All TIFA Singles	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Van	838	39.27	674	42.74	1,512	40.74	10,422	44.85
Flatbed	658	30.83	405	25.68	1,063	28.64	4,931	21.22
Tank	176	8.25	174	11.03	350	9.43	2,343	10.08
Other	361	16.92	264	16.74	625	16.84	4,573	19.68
Unknown	101	4.73	60	3.80	161	4.34	971	4.18
TOTAL	2,134	100.00	1,577	100.00	3,711	100.00	23,240	100.00

Conclusions

In summary, the analyses of the TIFA file indicate that among potentially conspicuity-related fatal collisions involving tractor-semitrailers, rear-end crashes are somewhat more common than side impact collisions. Likewise, the risk of involvement in the rear-end class of accidents is greater than the risk of involvement in the side impact group. At nighttime, the rear-end crashes are even more common than the side impacts, but under daylight conditions there are slightly more side impacts than rear-ends. Both types of conspicuity-related accidents had a higher proportion of nighttime occurrence than did fatal singles involvements overall. Finally, differences were observed with respect to trailer body style, with flatbed trailers over-represented among conspicuity-related accidents and vans under-represented.

Summary

A series of analyses was conducted in an attempt to characterize conspicuity-related large truck accidents and the factors associated with them. Since the data came from computerized files, it was virtually impossible to determine with certainty whether the inconspicuous nature of one vehicle played a role in any given crash. This kind of a decision could be made more confidently through review of accident reports, but even then it is a difficult determination to make since accidents frequently involve a complicated series of events and involve several different factors. Therefore, the strategy employed was to eliminate crashes where the conspicuity of the trailer almost certainly did *not* contribute to the accident, such as sideswipes or trucks striking another vehicle. In this way subsets were defined where the conspicuity of the truck plausibly played a role in the accident.

In considering how to treat trailers to enhance their conspicuity, several factors must be weighed. One is the collision configuration of conspicuity-related accidents. This includes the actions of the involved vehicles and whether the accident is a rear-end or side impact collision. Another concerns the accident environment, in terms of lighting, road class, and relation to intersection. The benefit of the conspicuity treatment may be realized more under certain circumstances than others. Prevalence of conspicuity-related accidents should be estimated to determine the maximum number of accidents that could be prevented. Rates of occurrence are also important in order to determine if there is differential opportunity for accident reduction. The severity and property damage costs of conspicuity accidents must be considered and balanced by the costs of implementing conspicuity-enhancing measures. In addition, differences among the trucks themselves, particularly in terms of trailer body style, must be evaluated.

In terms of prevalence, four years of Michigan data suggested that 26 percent of all accidents involving a tractor-semitrailer and one other vehicle were related to the conspicuity of the truck. TIFA data indicated that 16 percent of *all* fatal accidents involving a tractor-semitrailer (including single-vehicle accidents) were conspicuity related. Among conspicuity-related accidents, fatal data showed 57.5 percent to be rear-ends and 42.5 percent to be side impacts, while Michigan data of all severities showed rear-ends to outnumber side impacts by 78 percent to 22 percent.

With respect to accident severity, four years of Michigan data showed conspicuity-related accidents to be more severe than two-vehicle accidents in general at night. Over 47 percent of the conspicuity accidents resulted in casualty, compared to only 34 percent of the general group. No difference was observed between the two groups during the daytime. In comparing conspicuity-related rear-end to side impact collisions, two national databases showed rear-ends to be more severe, but the data suffer from small sample size. Michigan data suggest side impacts are more severe, but the data are not nationally representative, and the low reporting threshold in Michigan might be increasing the proportion of low damage rear-end accidents compared to reported accidents nationally. These differences also help explain the different proportions of rear-ends and side impacts in Michigan data compared to TIFA data.

The issue of costs associated with conspicuity-related accidents was not addressed in this chapter, but a brief discussion is presented in Appendix C at the end of this report. In terms of property damage costs, no databases were found that would permit cost estimates of side-impact, conspicuity-related collisions. Office of Motor Carrier (OMC) data were used to estimate costs of conspicuity-related, rear-end accidents for different severity levels. The average estimate derived from OMC cannot be directly used in a cost-benefit analysis because of the high reporting threshold of accidents to OMC. However, casualty accidents reported to OMC, which are not affected by reporting threshold, approach $11,000 in average property damage costs. Because a substantial proportion of conspicuity-related rear-ends result in casualty, this suggests a much higher average cost of all conspicuity rear-ends than the $3,200 reported by Vector Enterprises. This in turn indicates that the savings in property damage costs alone realized from preventing a portion of these crashes might easily offset the costs of treating the trailers.

Conspicuity-related accidents were compared to all two-vehicle accidents between a tractor-semitrailer and another vehicle using Michigan data. Conspicuity-related accidents differed from general two-vehicle accidents in that they occurred more often at night, took place more frequently on "other" roads (non-limited access and non-major artery), and occurred more at driveways. At night, conspicuity-related accidents were found to more often involve other drivers who had been drinking. Daytime conspicuity accidents more frequently involved poor roadway surfaces than did general accidents, but nighttime conspicuity accidents took place more often on dry roads. These statements suggest a complex relationship between truck conspicuity and other factors. Some factors like darkness inherently contribute to the lack of conspicuity of the truck. Others, like roadway geometry and environment, may interact with low conspicuity to increase the chance of an accident. For example, "other" roads have been shown to be less safe than limited access routes and major arteries for all types of accidents. But the fact that "other" roads are especially over-represented among conspicuity-related accidents suggests an interaction between road class and conspicuity in increasing the chance of that type of accident.

Given what we know about some of the factors associated with conspicuity-related accidents, it is important to consider travel distributions of different types of tractor-semitrailers. Compared to singles of all trailer bodies, vans travel proportionately more on limited access roads, while dumps and "others" travel relatively more on non-limited access roads. On the other hand, vans travel relatively more at night, while "others" log proportionately more miles during the day. Comparing fatal rates among the different trailer body styles, the relative risk factors for vans, tanks, and dumps are lower for conspicuity-related accidents than for fatal accidents in general. Conversely, flatbeds and auto carriers have higher risk factors for conspicuity-related accidents than for fatal accidents overall. Both the shape of the trailers and the travel patterns associated with the different trailer body styles probably contribute to these differences.

In thinking about the benefit of markings on trailers, one needs to take into account the configuration of conspicuity-related accidents. The angle from which another vehicle approaches a truck is one factor in determining how well the other motorist will be able to perceive trailer markings. Distributions of vehicle actions were shown to vary according to collision configuration, light condition, and relation to intersection. However, there were some broad similarities. About 59 percent of all nighttime conspicuity-related non-driveway accidents in Michigan involved a tractor-semitrailer that was either moving straight or stopped and another vehicle that was moving straight. This is a straightforward set of vehicle movements that would probably be amenable to enhanced conspicuity of the trailer. On the other hand, for accidents occurring at driveways, 59 percent of the rear-ends involved the truck turning into or out of a driveway as did 39 percent of the side impacts. During turning maneuvers one face of the trailer may not be directly ahead of the motorist, so conspicuity-related accidents taking place at driveways may not benefit as much from enhanced trailers.

2 THE VALUE OF PATTERN AND CONFIGURATION OF MATERIALS ON THE MARKED VEHICLE

INTRODUCTION

One of the principal issues to be addressed in this program of research was whether the proposed conspicuity-enhancing treatment should be in the form of a pattern of some kind and, if so, what that pattern should be. A second, equally important issue concerned the arrangement or configuration of materials on the vehicle. Specifically, would a strip of reflective material along the vehicle's frame rail be adequate, or should reflective material outline the vehicle where possible.

Several investigations exploring these issues were conducted in an earlier NHTSA contract concerning truck conspicuity (Ziedman et al., 1981). Their findings indicated that a solid white bar gave the best recognition performance. Nevertheless, an alternating red/white bar was recommended over the solid white for three reasons: (1) it was felt that the solid white bar might be too bright a stimulus under some operating conditions; (2) a conspicuity marking should have a distinctive pattern; (3) a color contrast effect is required for daytime conspicuity. The final recommendation was for a pattern in which 12 inches of red was alternated with 8 inches of white. They also recommended that the vehicle be fully outlined with reflective material, primarily to aid in estimates of distance and closing speed.

In the present study, the above issues were further explored. With regard to the first item above, it should be noted that a study of discomfort glare associated with retroreflective materials, described in detail in Chapter 3, "Treatment Values," indicated that current materials did not present a glare problem. The issues of distinctive markings and color contrast, however, do have merit. The use of a distinctive marking should be a significant aid in identifying an object as a truck, while the use of high contrast colors should improve daytime truck conspicuity.

The research to be described in this chapter sought to further expand the work of Ziedman et al. by conducting further investigations of the above issues.

STUDY 1: SUBJECTIVE EVALUATION OF VARIOUS PATTERNS

The purpose of this study was to screen a large number of possible patterns to select one or more that subjects felt were most effective as markers for hazards such as large trucks.

Method

Independent variables

The patterns evaluated in the study were constructed using retroreflective sheeting material attached to pieces of hardboard 1/8 inch thick, 4 inches wide, and 7 feet long.

Patterns. NHTSA and UMTRI agreed at the outset that the patterns investigated should be limited to combinations of red and white, 4 and 2 inches in width. Within these constraints, nine combinations of red and white patterns were prepared in both 4- and 2-inch widths. One of these patterns was all red, while another was all white. The other seven were combinations of red and white as follows:

Red Dimension (inches)	White Dimension (inches)
3	12
6	12
8	12
12	12
12	8
12	6
12	3

Type of material. Stimuli were made using two grades of retroreflective material: enclosed lens (type II) and prismatic sheeting. The SIAs of the two materials differed by a factor of about eight, with the type II white typically measuring about 120 cd/lux/m^2, and the prismatic white typically measuring about 1,000 cd/lux/m^2.

In addition to the stimulus materials listed above, four other test strips were made using the 12-inch red and 8-inch white combination. There were two of these in each material, two in each width. The only difference was that the points where the red and white joined were cut at a 45° angle (creating a herringbone pattern). It was thought that this pattern might make a more effective hazard display. The four samples were used in a preliminary investigation to determine the distance at which the bevel elements could be distinguished. Based on these observations, a pattern using a 45° element cannot be reliably distinguished from one using a 90° element at a distance beyond 250-300 feet, using low-beam headlamps in a dark environment. Hence, no further work was done with the panels using the 45° elements.

Viewing distance. Subjects viewed the displayed patterns at two distances, 500 and 1,000 feet.

Dependent variable

A paired-comparison approach was used. Subjects viewed pairs of the patterns displayed one above the other, about one foot apart. They were asked to judge which one of each pair was more effective as the indication of a hazard. They did so by circling the notation "top" or "bottom" on their scoresheet.

Procedure

The study was carried out on a private road in a dark, rural area. The pattern display was set up on one shoulder of the road. It was serviced by four individuals, two who placed the pattern strips on the display, and two who restored strips from previous trials and secured those required for the next trial.

Ten subjects were run at a time. They were seated in two cars parked on the shoulders of the test road. The car parked on the shoulder opposite that occupied by the display was turned somewhat so that its headlamps were directed toward the display. The cars were set up at one distance (either 500 or 1,000 feet from the display), and then moved to the other distance at the halfway point in the study. A total of 20 subjects participated in the study.

In the subject instructions (see Appendix B) emphasis was placed on selecting the pattern that was best for marking a hazard such as a large truck. Other criteria, such as visibility (which might give an advantage to patterns using more white) were not to be considered.

A complete pair comparison was presented for each combination of material type and width. Thus, the subjects viewed 36 pairs of the 4-inch type II, another 36 pairs of the 2-inch type II, etc., for a total of 144 pairs at each distance. Four different presentation sequences were used, repeated at each distance. Subjects were given brief (about five seconds) views of each pair and noted their preference on scoresheets while the display was being changed. The entire test took about two hours.

Results

The overall results of this test are shown in Tables 2.1 and 2.2. These matrices show the percentage of times each configuration in the left column was judged a more effective indication of a hazard than the configurations listed in the rows to the right. For each configuration listed there are four cells to accommodate the two widths (2 and 4 inches) and two viewing distances (500 and 1,000 feet). For example, with the prismatic material, the white 2-inch configuration was preferred over the red 2-inch configuration 35 percent of the time at 500 feet and 30 percent of the time at 1,000 feet.

Tables 2.3 and 2.4 present a simplified version of the results. Table 2.3 is for the prismatic material. Each cell here is a mean of the four cells for each configuration compared in Table 2.1. The format, however, is the same, except that the order of the configurations has been changed to correspond to the subjects' expressed preferences. Thus, 12R-12W was preferred over all other configurations by the percentages shown in each cell. Similarly, 12R-8W was preferred over all other configurations (excepting 12R-12W) by the percentages shown in each cell, etc.

The data for the prismatic material as shown in Table 2.3 are very consistent. The subjects preferred configurations with red and white equal, or with more red than white. They thought the white bar was the least effective of the treatments shown.

Table 2.4 is for the type II material. The subjects commented, and the data confirmed, that they could not readily distinguish the different patterns in this material at 1,000 feet. Therefore, the cell entries in Table 2.4 are the means of only the 500-foot judgments.

TABLE 2.1

Percent of Times Configuration in Left Column Were Judged More Effective as Indicators of a Hazard Than Configurations in Rows to Right. Prismatic Material.

		All Red	All Red	12R-12W	12R-12W	12R-8W	12R-8W	12R-6W	12R-6W	12R-3W	12R-3W	8R-12W	8R-12W	6R-12W	6R-12W	3R-12W	3R-12W
		500	1000	500	1000	500	1000	500	1000	500	1000	500	1000	500	1000	500	1000
All White	2	35	30	20	35	15	25	35	55	20	75	30	60	40	60	50	35
	4	20	25	15	25	5	20	20	30	30	40	50	50	35	45	40	40
All Red	2			40	60	35	60	60	70	45	70	35	70	60	65	60	65
	4			30	45	50	30	40	30	35	55	45	80	55	75	75	60
12R-12W	2					55	75	65	50	55	50	85	55	95	70	90	55
	4					50	40	50	60	65	65	85	85	95	80	100	85
12R-8W	2							55	50	70	55	60	50	80	70	95	60
	4							55	70	60	60	90	80	80	85	95	85
12R-6W	2									75	70	65	60	75	50	80	50
	4									50	55	80	80	85	75	85	80
12R-3W	2											45	45	50	65	85	45
	4											60	50	70	45	85	55
8R-12W	2													80	75	95	65
	4													85	55	90	55
6R-12W	2															85	45
	4															80	55

TABLE 2.2

Percant of Times Configurations in Left Column Were Judged More Effective as Indicators of a Hazard Than Configurations in Rows to Right. Type II Material.

		All Red 500	All Red 1000	12R-12W 500	12R-12W 1000	12R-8W 500	12R-8W 1000	12R-6W 500	12R-6W 1000	12R-3W 500	12R-3W 1000	8R-12W 500	8R-12W 1000	6R-12W 500	6R-12W 1000	3R-12W 500	3R-12W 1000
All White	2	45	60	20	40	15	45	30	60	40	65	5	35	5	30	40	30
	4	50	65	20	55	20	50	20	30	45	30	10	20	10	10	15	25
All Red	2			35	35	30	45	30	35	20	35	35	40	20	40	50	60
	4			25	60	35	60	10	30	15	45	45	25	40	30	45	40
12R-12W	2					60	75	90	85	90	70	75	35	60	75	90	65
	4					70	75	25	15	50	55	50	30	60	25	70	55
12R-8W	2							85	50	100	40	50	50	40	45	65	40
	4							30	25	80	65	45	40	40	20	65	45
12R-6W	2									90	65	20	35	40	30	35	40
	4									70	65	45	50	30	50	90	70
12R-3W	2											10	65	25	30	40	35
	4											25	30	50	40	55	55
8R-12W	2													90	50	85	55
	4													45	65	95	70
6R-12W	2															80	70
	4															90	65

Table 2.3
Percent of Times Configuration in Left Column Were Judged More Effective as Indicators of a Hazard Than Configurations in Rows to Right. Prismatic Material. Average of Both Widths, 500-Foot Distance Only

	8R-12W	6R-12W	12R-8W	12R-6W	3R-12W	12R-3W	RED	WHITE
12R-12W	55	56	59	56	78	85	83	76
8R-12W		58	61	56	70	79	84	84
6R-12W			63	50	71	71	74	65
12R-8W				54	50	58	68	59
12R-6W					57	64	65	73
3R-12W						74	76	53
12R-3W							66	55
RED								59

TABLE 2.4
Percent of Times Configurations in Left Column Were Judged More Effective as Indicators of a Hazard Than Configurations in Rows to Right. Type II Material, Average of Both Widths, 500-Foot Distance Only

	8R-12W	6R-12W	12R-8W	12R-6W	3R-12W	12R-3W	RED	WHITE
12R-12W	63	60	65	58	80	70	70	80
8R-12W		68	53	67	90	83	60	93
6R-12W			60	65	70	63	70	93
12R-8W				58	65	90	68	83
12R-6W					63	80	80	75
3R-12W						53	53	73
12R-3W							83	58
RED								53

In some respects the results given in the two tables are the same. For example, the 12R-12W configuration was preferred over all others, and white was rated least effective. However, the 12R-8W configuration, which was rated second best with the prismatic material, was rated fourth best in this material, with the 8R-12W and 6R-12W rated better. There are other changes in rankings as well.

There is no obvious reason for the differences in ratings associated with the different materials. Due to their superior photometric performance, the prismatic configurations looked much brighter, and the red appeared more saturated. By contrast, the type II configurations appeared weak and unsaturated. It may be that the subjects preferred more white when presented with a treatment having lower overall brightness.

The results of this investigation do make it clear that subjects prefer a pattern as a means of marking a potential hazard like a large truck. Within the range of colors and patterns investigated, the expressed preference is for a marker using equal amounts of red and white. The 12R-8W pattern recommended by Ziedman et al. is a close second to the 12R-12W, when using materials of maximum photometric performance. When using less bright materials, other combinations seem to be preferred. Presumably the same would be true if the brightness of the material were reduced due to dirt or aging.

STUDY 2: FIELD EVALUATION

Introduction

The first study described in this chapter yielded information about which combinations of red and white retroreflective materials were judged most effective as hazard markers. It is reasonable to ask whether the subjective judgments obtained in that investigation would correlate very well with data obtained under actual driving conditions from subjects who were not aware of the true purpose of the study. To answer this question two additional investigations were conducted. The first of these used new, clean reflective materials. The second study examined the effects dirt and/or aging might have on reflective materials by "degrading" the stimuli used in the first study.

Method

Subjects in this study drove a car on dark, rural roads with instructions to look for "potential hazards." When they saw something that they thought fit that description they were to press a button (which started a distance counter) and describe to the experimenter what they thought it was. At five points during the drive they encountered panels with various hazard warning treatments. The identification distance and description obtained from each of these was of primary interest in the study.

Independent Variable

Five warning configurations were prepared for this study. They were presented on strips of 1/2 inch plywood, 6 inches high and 7 feet long. The strips were first painted a uniform gray, with a reflectivity of about 12 percent. Type II (enclosed lens) retroreflective material was then attached in strips 2 inches wide. Red and white colors were used. The SIA was approximately 30 for the red and 110 for the white. The five treatments were:

1. Continuous white bar.
2. Continuous red and white bar (12 inches red to 8 inches white)
3. Broken white bar (8 inches white followed by a 12-inch blank)
4. Broken red and white bar (12 inches of red, 8 inches of white, followed by a 20-inch blank)
5. "Standard" treatment (two 2-inch diameter prismatic reflectors, one at each end of the panel)

In treatment 5 the usual acrylic reflectors were simulated by a red prismatic sheeting material having an SIA of approximately 300.

The "degraded" stimuli were prepared by taping strips of neutral density film over the reflective material on the five treatments. This reduced their effective SIA by about 80 percent.

Dependent Variable

The dependent variable was the distance at which the subject identified each stimulus configuration as a "potential hazard." The subject's assessment of the nature of the hazard was also noted. Of interest here was how likely the subject was to associate the treatment with a vehicle.

Equipment

The test vehicle was a full-size station wagon, which had been especially equipped for lighting work. Its headlamps were controlled by equipment that permitted their operating voltage to be maintained within 0.03 volt. The car was also equipped with a counter system that worked off the left front wheel, producing four counts (1.72 feet each) per revolution. A bar was placed across the roof of the vehicle, mounting two 4-inch diameter truck turn signal lamps, showing yellow to the front and red to the rear. The purpose of these lamps was to facilitate identification of the test car by the experimenters who presented the hazard markers.

Subjects

A total of 31 subjects participated in the first test. Of these 18 were young (i.e., 18-40), and 13 were older (i.e., 65+). An additional 20 subjects participated in the second test, using the degraded stimuli. All of these were younger individuals. All subjects were licensed drivers who were paid for their time while engaged in the study.

Test Course

Since other vehicles, either preceding or oncoming, would reduce the conspicuity of the hazard markers, it was important that the test be conducted on roads where there was little traffic. In addition, the experimenters who placed the hazard targets needed a car to move from point to point on the course, and that vehicle had to be parked safely and out of the view of the subject. Finally, the target positions had to be selected so that the subject had a clear view for a minimum of 2,000 feet. A driving course was selected near the Institute and involved two-lane rural roads that met the necessary criteria.

Procedure

Subjects were run individually. Each reported at an assigned time, signed a consent form, and was seated in the driver's position of the test vehicle. The instructions were then read to them (see Appendix B). Subjects were told that this was a study designed to determine what people regarded as potential hazards while driving. A "potential hazard" was defined as a condition that may cause them to have to alter speed or direction. Examples given were pedestrians, parked vehicles, and holes or debris in the road. Traffic control devices and vehicles going in the same or opposite direction were excluded as potential hazards for purposes of this study. No mention was made of the markers placed by the experimenters.

The study was run on unlighted, two-lane roads in a rural area. The subjects drove at speeds ranging from 30 to about 45 mph. Many subjects responded only to the stimuli placed there by the experimenters. Others responded to a variety of objects, including the occasional pedestrian, animal, or crossing car, over which the experimenters had no control. With rare exceptions responses to other stimuli did not conflict with the stimuli to which it was desired that they respond.

The stimulus materials were handled by experimenters working out of another vehicle, which was always kept hidden from the subject. When the test car was seen coming the stimulus board was held up about waist high, positioned so that it covered approximately half the lane used by the subject. When the test car approached within about 200 feet the board was withdrawn.

The five stimuli appeared at three different positions in the course. The points at which they appeared twice were passed three times by the subject, thus reducing expectancy. The five stimuli were rotated through the positions in the course on a systematic basis. The route covered about 15 miles, and the test took about 45 minutes to complete, including preliminaries such as reading the instructions.

Results

The results will be described in terms of identification distances and hazard identifications by the subjects. Hazard identifications were classified at four levels for purposes of analysis. These were:

0 = nonthreatening (e.g., reflectors on mail box posts or at driveway entrances), don't know, or no response.

1 = marginal (e.g., bicycle, pedestrian)
2 = road barricades, railroad crossing
3 = vehicle

The results of the first study are given in Table 2.5. For each of the five treatment conditions the table shows the mean identification distance and the percent of identifications that were level 2 or 3. Statistical analysis shows that the continuous white bar was identified at a significantly greater distance ($p < 0.05$) than any of the other treatments. The difference in identification distance between the broken white bar and the broken red and white bar is also significant ($p < 0.05$). The difference between the continuous red and white bar and the broken white bar is not significant ($p > 0.05$). The "standard" treatment was identified at a significantly shorter distance, i.e., took the longest to identify ($p < 0.01$) than any of the other treatments.

It appears from Table 2.5 that the continuous white bar treatment has the advantage in terms of identification distance. Using the same criterion, the broken white bar is about equal to the continuous red and white bar, and appears better than the broken red and white bar. However, the red and white treatments were more likely to be identified as a level 2 or 3 hazard than the all-white or "standard" treatments.

TABLE 2.5
Results of Hazard Identification Study

Number	Configuration	Mean Identification Distance (feet)	% Classified as Level 2 or 3
1	Continuous White Bar	1011	70
2	Continuous Red and White Bar	822	83
3	Broken White Bar	876	63
4	Broken Red and White Bar	787	87
5	"Standard" Treatment	640	70

The results of the second study, using the degraded stimuli, are shown in Table 2.6. The visibility distance data are generally similar to those shown in Table 2.5. Given the lower SIA values of the stimuli employed in this study, this may appear surprising. Actually, it is attributable to the fact that only young subjects participated in the second study, while about 40 percent of the sample in the first study were older individuals. The statistical analysis shows that the distances associated with the "standard" treatment were significantly shorter ($p < 0.05$) than those of any other treatment. The other differences were short of statistical significance in this test (i.e., $p > 0.05$). Unlike the first study, the results of the second study show no evidence of a difference in the probability of being classified as a class 2 or 3 hazard as a function of the pattern employed.

TABLE 2.6

Results of Hazard Identification Study Using Degraded Stimuli

Number	Configuration	Mean Identification Distance (feet)	% Classified as Level 2 or 3
1	Continuous White Bar	985	90
2	Continuous Red and White Bar	902	82
3	Broken White Bar	800	84
4	Broken Red and White Bar	781	78
5	"Standard" Treatment	565	78

Discussion

It seems clear that attributes of a treatment that make it more likely to be identified as a hazard are of greater importance than the distance at which it is seen. The latter characteristic can be controlled by using more material or a material having greater retroreflective efficiency. The finding of the first field study, that the red and white patterns had a higher probability of being associated with something likely to call for an evasive response, is support for the findings of the preceding paired-comparison study, indicating the desirability of employing a pattern in the conspicuity treatment. This finding was not replicated in the second experiment, however, suggesting that identification of the stimuli was sensitive to display brightness, or simply represents differences between the two groups of subjects.

STUDY 3: LABORATORY EVALUATION OF THE VALUE OF PATTERN

Given the inconsistent findings of the hazard identification investigations just described, it was decided to conduct one further study. This was carried out in a laboratory, using photographic stimuli of a relatively large number of configurations.

Method

Independent variable

The independent variable was hazard situation. A total of 22 such situations were developed for use in this investigation. They fell in four categories as described below:

Pedestrian. The pedestrian was dressed in dark clothing and stood in the center of the lane, facing the camera. Two distances were employed. At the further distance the legs of the pedestrian could barely be distinguished in the photograph. At the closer distance the entire body could be seen, although not clearly. Another photograph at the closer distance was included as well, at a higher level of illumination (actually a longer exposure). In two additional photographs the pedestrian was wearing a partial and a fully reflective vest.

Automobile. An ordinary automobile was shown in three positions. In two of them the car was on the left, facing right, as though waiting to turn into the road. All that could be seen were the headlights on the left, a patch of illuminated foliage on the right, and a streak of illumination across the road surface. There were two of these photographs, at 300 and 500 feet. There were also two photographs of the front of the car (no lights) facing toward the camera directly ahead, simulating approaching a car parked on the wrong side of the road. One of these was taken at 300 feet, another at 500 feet. Finally, there was one photograph of the rear of the car (no lights) at 500 feet.

Truck treatments with reflex reflectors. A total of six treatments were shown using round, red, reflex reflectors. These displays are shown schematically in Figure 2.1. All of these were photographed at 500 feet.

Truck treatments with reflective tape. A total of six treatments were shown using retroreflective tape in either red and white or all white. These displays are shown schematically in Figure 2.2. All of these were photographed at 500 feet as well.

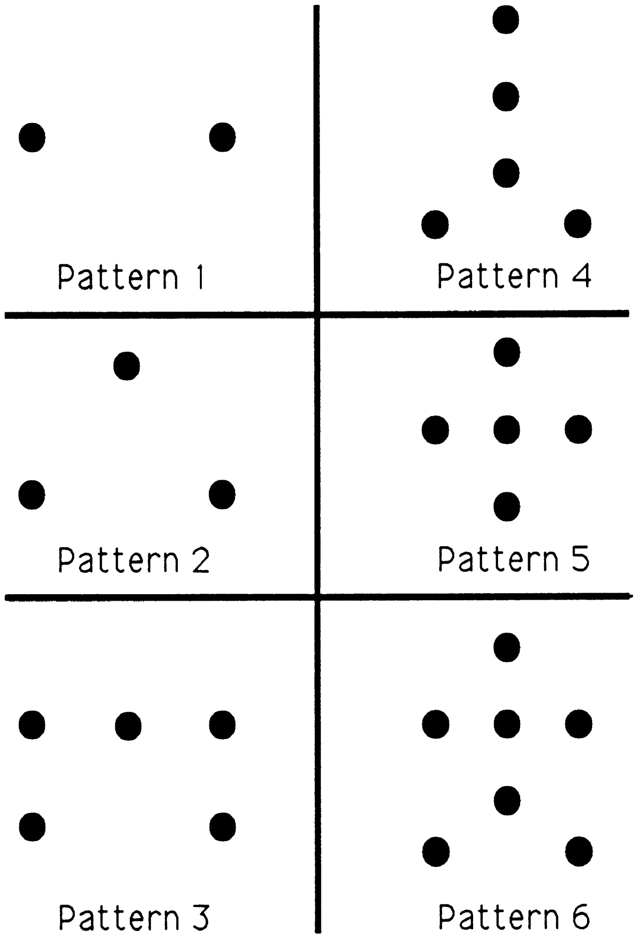
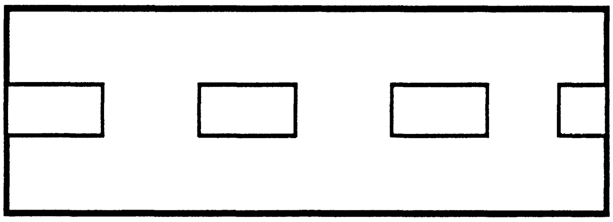
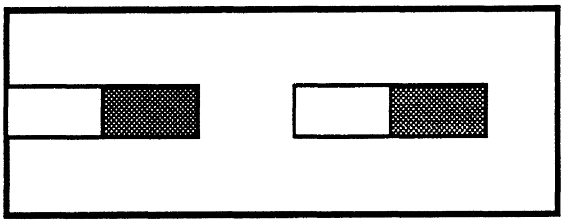


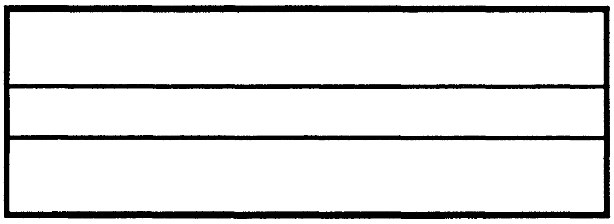
Figure 2.1. Treatment configurations using round reflex reflectors.



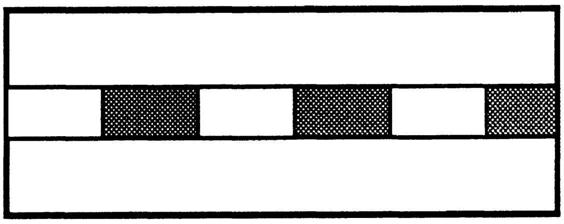
Reflective Treatment 1



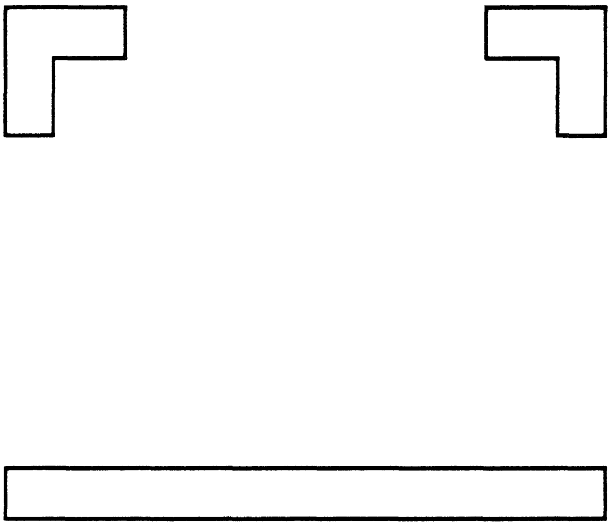
Reflective Treatment 3



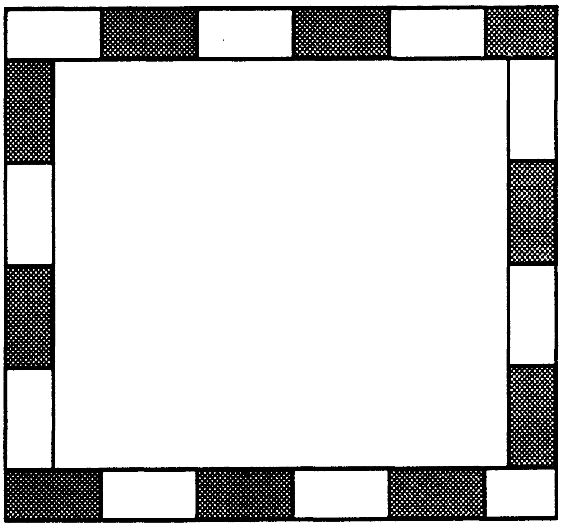
Reflective Treatment 2



Reflective Treatment 4



Reflective Treatment 5



Reflective Treatment 6

Figure 2.2. Treatment configurations using reflective tape.

Dependent Variable

When subjects viewed the photographs they were asked three questions: 1. Did you see anything unusual? 2. What do you think you saw? 3. If you were the driver, what would you do?

Development of test stimuli. The truck markings were created full-scale by attaching the reflective material to pieces of plywood. In the field these were assembled into the desired patterns and placed on a stand at the appropriate height while the photographs were taken.

The photographs were in the form of 35mm color slides, and were taken at night on a dark, two-lane road in a rural area. The camera was placed on a tripod in front of the car, between the headlamps. As a first step a number of photographs were taken of one configuration at a number of f stops and exposure durations to determine the combination that gave the most realistic results. When the test stimuli were photographed three shots were made of each at different exposure durations bracketing the one selected in the first test. The photograph that appeared most realistic was selected for the test. Two photographs in which no stimuli were present were included as well.

Subjects

A total of 22 subjects participated in this test. All were licensed drivers. Their ages ranged from 19 to 75.

Procedure

The test was set up in a small laboratory. The scenes were projected on a screen at one end of the room, about 12 feet from the subjects. The size of the stimuli were adjusted to be the same as if they were viewed at the appropriate distances in the field.

Subjects were run two at a time. They were brought into the laboratory, and seated on either side of the projector. The instructions were read to them (see Appendix B). Each scene was presented for approximately three seconds. When it was switched off the subjects were to write down their answers to the three questions listed earlier on a sheet of paper. A small flashlight was supplied each subject for that purpose.

Results

For the purpose of analysis, responses to questions 2 and 3 listed earlier were categorized as follows:

Question 2: What do you think you saw?
  0 = nothing, don't know, anything non-threatening
  1 = marginal, e.g., fences, bicycles
  2 = barricades, railroad crossing
  3 = vehicle, or person where appropriate

Question 3: If you were the driver, what would you do?
  0 = nothing
  1 = nothing, but be ready if the need arises
  2 = slow down, prepare to stop if necessary
  3 = slow down greatly, or stop, or turn around

The results of the investigation are summarized in Table 2.7. The table shows, for each treatment investigated, the percent that were correctly identified (i.e., level 3) as well as the percent that were correctly identified or identified as a significant hazard (i.e. levels 2 + 3). Also shown are the percent of responses indicating an action at level 3, at levels 2 + 3, and at levels 1 + 2 + 3.

Much of the data in Table 2.7 seems in line with what would be expected. The no-treatment conditions were correctly identified almost all the time, and the indicated responses were appropriate. The results for the dark-clad pedestrian also make sense. The more visible he was the more likely a correct identification would result, coupled with an appropriate response. An exception seems to occur in the case of the reflective vests. However, these turned out to be poor photographs, with the vest appearing as an ill-defined blob. Thus, the decline in correct identifications is understandable. Given that it was identified as a level 2 or 3 hazard 80-90 percent of the time, the fact that 30-40 percent of the action responses were "do nothing" is surprising.

Table 2.7
Results of Laboratory Hazard Identification Test

Type of Treatment	Level within Type	Question 2,Identification			Question 3,Action	
		% Correctly Identified	% Correctly at Level 2or3	% Respond at Level 3	% Respond at Level 2or3	% Respond at Level 1+2+3
No Treatment	1	100	100	0	0	0
	2	91	91	0	0	5
Pedestrian	Furthest	14	23	18	18	41
	Closest	41	55	55	55	55
	High Illuminance	59	91	86	86	91
	Outline Vest	41	91	32	50	59
	Full Vest	32	82	5	50	68
Automobile	Turning 500'	5	68	32	36	64
	Turning 300'	18	59	86	86	86
	Front 500'	9	55	50	50	50
	Front 300'	46	91	86	91	91
	Rear 500'	14	59	96	96	96
Reflex Reflector from Figure 2.1	1	23	50	5	96	96
	2	23	82	32	41	45
	3	10	76	59	64	73
	4	14	82	23	23	32
	5	14	86	23	46	55
	6	23	96	36	55	59
Reflective Tape from Figure 2.2	1	41	86	18	59	59
	2	41	86	32	64	64
	3	46	91	73	77	82
	4	41	86	36	68	73
	5	9	91	36	46	69
	6	5	68	32	36	64

With the exception of the rear view, the results for the automobile are generally what were expected. The relatively poor identifications of the rear are balanced by the high levels of actions indicated.

The results with the reflex reflectors are particularly interesting. At best these treatments elicited an identification as a vehicle only about one time in four, although, with the exception of treatment 1 (the "standard" treatment) there was a good probability of being identified as a level 2 or 3 hazard. In terms of elected actions, only one subject indicated a level 3 response to the standard treatment, but all but one indicated a level 2 or 3 response. The other treatments using reflex reflectors seemed to elicit more uncertainty concerning action, perhaps because they were nonstandard. In a number of cases the percentage of cautionary or stronger actions indicated is considerably less than the percentage of identifications as a level 2 or 3 hazard.

With the exception of the outline treatments, the results with the reflective tape were generally better than with the reflex reflectors. There was a much better chance that it would be identified as a vehicle, and the probability of eliciting a level 1 or stronger action was more consistent and generally higher.

The full outline treatments were unlikely to be identified as a vehicle, although they had a good likelihood of being identified as at least a level 2 hazard. Surprisingly, the red/white outline was poorer in this respect than the all-white. In terms of eliciting at least a level 1 action, they compared well with the other tape treatments.

Discussion

The results of this investigation provide no evidence to support the use of a red-white pattern over an all-white treatment. There is some suggestion that that which is familiar (i.e., the rear of the car and the two reflex reflector treatments) will elicit high levels of cautionary actions, even though the identifications associated with them seem relatively poor. In the end, it is the actions that count. This is an argument for standardization of treatment. If drivers are presented with a condition that they have come to associate with a particular type of hazard they will react in a way that should reduce the likelihood of a collision.

STUDY 4: THE EFFECT OF TRAILER MARKINGS ON THE PERCEPTION OF MOTION IN DEPTH

Introduction

The marking systems being investigated are designed primarily to enhance the detectability of the vehicles (trailers) on which they are placed. Approaching drivers, however, must not only become aware that an object is in their path, they must also obtain other information about the object. Specifically, information about the dynamic relationships between the two vehicles could be vital in determining whether evasive action is necessary. This is particularly important, for example, if the lead vehicle is moving a great deal slower than the overtaking vehicle.

Research carried out by Vector (Ziedman et al., 1981) considered the possible value of different marking systems as aids to the detection of relative movement. Their results indicate that markings are a significant factor in the detection of relative movement. They found that such movement was more readily detected when the vehicle was outlined, identifying a two-dimensional surface, than with markings just along the frame rail. The research to be described in this section of the report was intended to follow up on the Vector work.

Method

This study was carried out in a laboratory. The treatments of interest were presented to the subjects on a computer-driven CRT screen. Measures were taken of the time required for subjects to correctly identify the "direction" of movement of the display (i.e., whether it was getting larger or smaller).

Independent Variables

Treatments. The four treatments used in the investigation are illustrated in Figure 2.3. They were intended to represent the markings that could appear on the rear of a trailer. The markings included a full and a partial outline, along with two possible frame-rail treatments of a solid and a broken bar. The horizontal dimension on each of these displays prior to any size change was 0.9 inch. The height of the two-dimensional displays was also 0.9 inch. At the 9-foot viewing distance employed, 0.9 inch is 0.48°, which is approximately equal to the angle subtended by the rear of a truck at 1,000 feet.

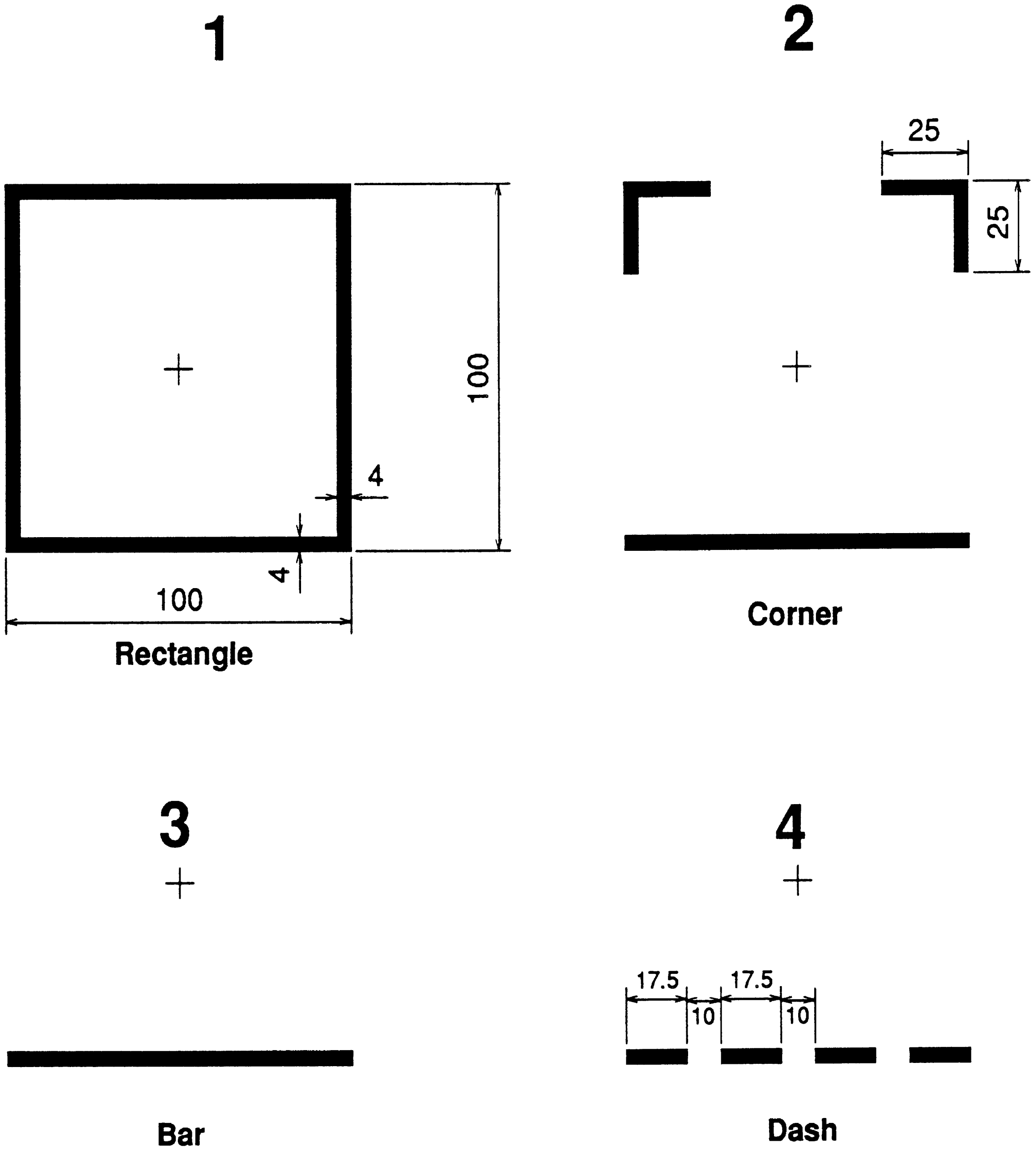


Figure 2.3. Displays used in motion-detection study.

Direction. Relative motion of the rear of a truck was simulated by having the displayed figures grow larger (i.e., approaching) or smaller (i.e., moving away). The total change in either direction was 0.7 inch, accomplished in five seconds. At the viewing distance employed this worked out to a rate of 0.074°/second, equivalent to a closing speed of about 90 mph at a separation distance of 1,000 feet.

Replications. Each subject viewed a total of eight replications of each of the test conditions.

Dependent Variable

Time was measured from the onset of simulated movement of the displayed figures until the subject responded by pressing a button.

Procedure

Subjects were run individually. They were brought into the laboratory and seated at a table. Their seated position was adjusted to bring their eyes 9 feet from the screen on which the stimuli were displayed. The instructions were then read to them (see Appendix B), and any questions answered.

The stimuli were displayed on a CRT, with black against a white background. When the image first appeared it was stationary. After a period of time (randomly variable from 3 to 10 seconds) it began to change size. As soon as the direction of movement could be discerned the subject pressed either an up or down arrow key on a computer keyboard in front of them (up for growing larger, down for growing smaller). Time between the initiation of movement and the button press was measured and stored in the computer. Errors (i.e., pressing the wrong direction key) were disregarded in the scoring. A note appeared on the screen, however, advising the subject that the wrong key had been pressed.

Trials were run in blocks of 16, constituting two replications of each condition. The order of presentation of the stimuli was changed for each block. Subjects were given one block for practice, then four more blocks in which times were recorded. A short break was taken between blocks 3 and 4. With time for instructions, the study required less than 30 minutes to complete.

Results

The mean response times to the four treatment configurations are given in Table 2.8. The results appear to fall into two categories, with the response times for the two-dimensional treatments (1 and 2) being shorter than the response times for the one-dimensional treatments. Table 2.9 lists the mean response times associated with the two directions of stimulus movement. Finally, Table 2.10 lists the mean response times associated with the eight replications.

Table 2.8
Mean Response Times (in seconds) as a
Function of Treatment Configuration

Treatment Configuration		Mean Response Time
Number	**Description**	
1	Full outline	0.80
2	Partial Outline	0.83
3	Solid Bar	0.90
4	Broken Bar	0.94

Table 2.9
Mean Response Times (in seconds) as a
Function of Movement Direction

Direction	Mean Response Time
Coming (Growing Larger)	0.88
Going (Growing Smaller)	0.86

Table 2.10
Mean Response Times (in seconds)
Recorded for Replications

Replication Number	Mean Response Time
1	0.92
2	0.93
3	0.84
4	0.84
5	0.82
6	0.83
7	0.88
8	0.88

An analysis of variance was conducted on a log transformation of the response time data. The results of this analysis showed that there were significant differences among treatments ($p < 0.01$) and among replications ($p < 0.05$), but not between directions ($p > 0.05$). Post hoc tests (Student-Newman-Keuls) showed that treatments 1 and 2 did not differ significantly ($p > 0.05$), nor did treatments 3 and 4. Treatments 1 and 2 did, however, yield significantly shorter response times than did treatments 3 and 4 ($p < 0.05$). The analysis also showed only one difference among the replications at the 0.05 level, that being between replications 2 and 5.

Discussion

The results of this study support the findings reported by Ziedman et al. in that displays representing a two-dimensional surface work better when judging relative speed than do one-dimensional displays. Thus, there would appear to be a basis for a marking system approximating the partial outline treatment used in this investigation. It should be noted, however, that while the results clearly indicate that there is an advantage in using a two-dimensional configuration of tape in judging closing speed, it is not clear if, and to what extent, such treatments would reduce crashes. Furthermore, two-dimensional configurations of reflective materials such as those used in this study can only be implemented on trailers that have a suitable structure available for mounting, such as a tanker or van.

STUDY 5: JUDGMENTS OF SEPARATION DISTANCE AS A FUNCTION OF TREATMENT

Introduction

In the previous laboratory study it was found that subjects could more readily detect movement toward or away from them when the object was fully or partially outlined than when it was marked with a horizontal bar. The purpose of this study was to determine whether the same would hold true of judgments of changes in separation distance.

Three studies were carried out to investigate this question. Two of them were conducted in the field, using retroreflective targets in either full or half scale. Changes in target size were accomplished by moving the targets closer to or further from the subjects. There were problems with extraneous cues in these studies, which may have been a factor in the findings of no differences. The laboratory study to be described was undertaken to solve the problem of extraneous cues.

Method

Independent Variables

Treatments. The independent variable was treatment configuration. The same four stimulus configurations were used as in the laboratory study of movement detection (see Figure 2.3). As in the case of the movement study, the stimuli were displayed on a computer screen.

Viewing distance. The reference stimulus was scaled to a viewing distance of 300 feet. Test stimuli were displayed 5, 10, and 15 percent larger or smaller than the reference stimulus.

Dependent Variable

Subjects were asked on each trial to judge whether the test stimulus was smaller or larger than the reference stimulus.

Subjects

Twelve subjects participated in the study. They were of various ages, 22 to 75. Half were male, half female. Age and sex were not independent variables in the study.

Procedure

The subjects were run individually. They reported to the Institute at the assigned time and signed consent forms. The instructions were read to them (see Appendix B). Six practice trials were given before data collection started.

On each trial the reference stimulus was displayed for three seconds, then removed. Four seconds later the test stimulus was displayed for three seconds. When it was removed the subject indicated to the experimenter whether he/she felt the test stimulus was larger or smaller than the reference stimulus. Where the subjects were uncertain of a response they were required to guess.

The subjects viewed four replications of each condition, a total of 24 trials for each stimulus, or 96 trials for the entire study. With time for instructions and practice the study required about 45 minutes to complete.

Results

The results of this investigation are shown in Figure 2.4. The figure shows percent correct identifications of the direction of the size change of the test stimulus as a function of stimulus configuration. Where there are differences of any size between the configurations only the dash bar has a lower probability of correct identification.

Discussion

The results of the laboratory study still suggested there was little if any difference in responses to the four stimulus configurations, although the broken bar stimulus appeared to present more problems for subjects than did any of the other configurations. It is difficult to explain why the broken bar configuration would be worse than the solid bar, and why the differences would exist only when it was shown larger than the reference stimulus. A conservative interpretation of these findings suggests that any differences among these treatments in terms of judging distance changes are very small and may be nonexistent.

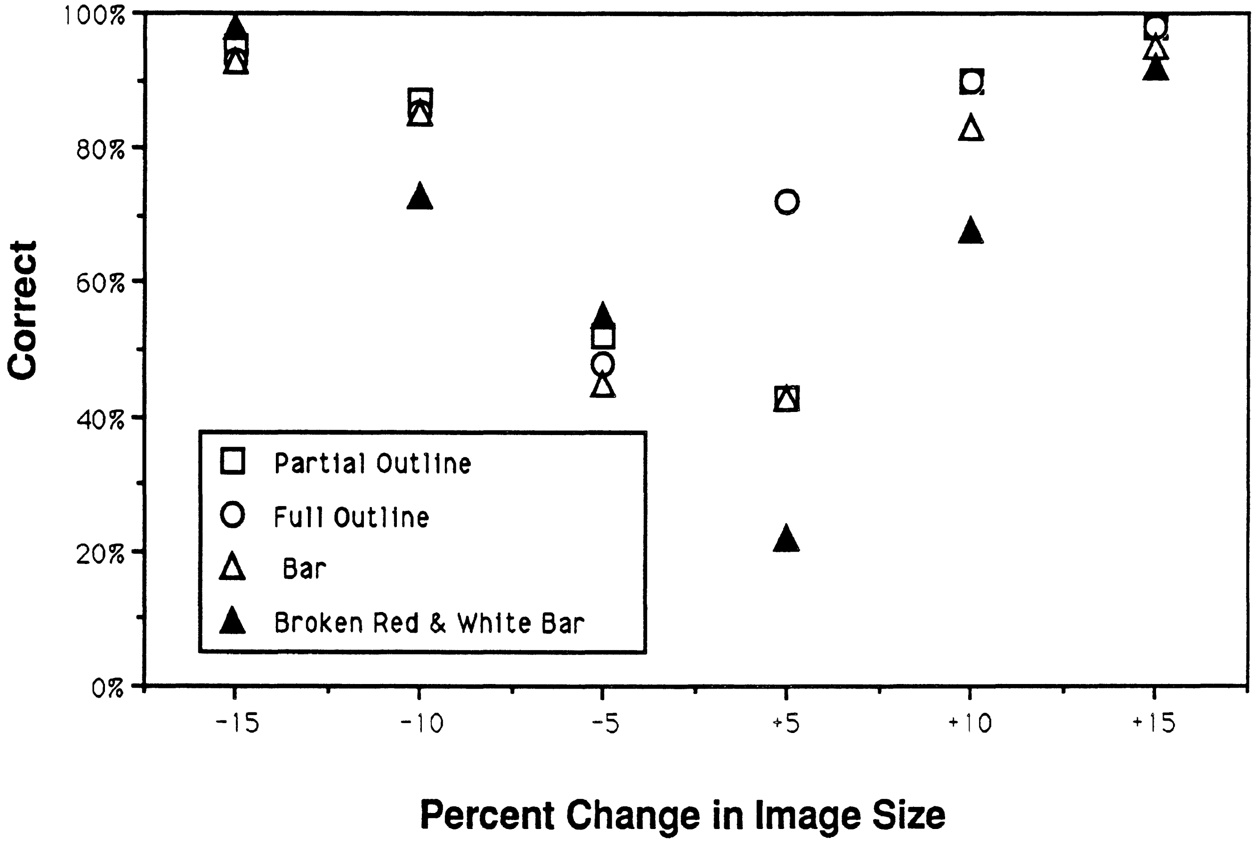


Figure 2.4. Percent correct as a function of stimulus type and percent change in image size.

STUDY 6: PROBLEMS IN MARKING ALL TYPES OF TRAILERS

The primary focus of this research program has been on the enhancement of conspicuity for what most individuals regard as "traditional" trailers, i.e., vans and flat-beds. There are, however, a great variety of trailer configurations, including tankers and car carriers, that are relatively common. When considering a marking system employing retroreflective tape, some of these configurations are particularly difficult to accommodate.

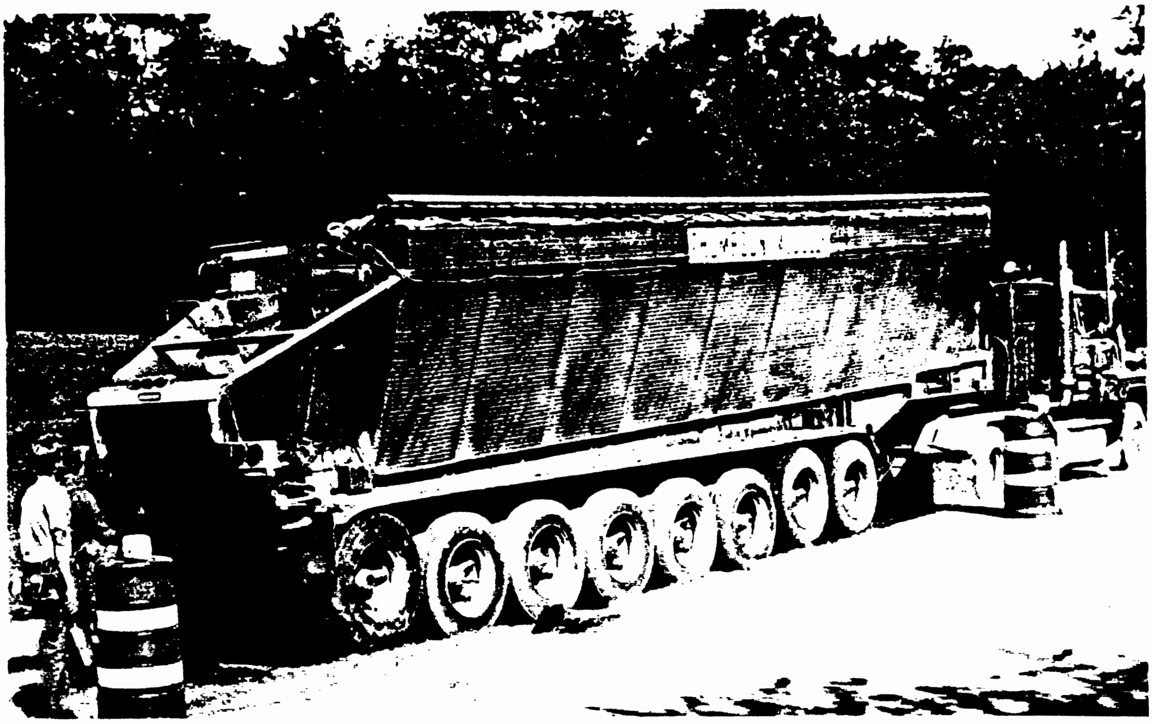
Figure 2.5 shows eight photographs of trailers that illustrate some of the variety of configurations that must be considered. For some configurations, such as the pole trailer, there is virtually nothing to which tape can be attached. For other configurations, such as the carriers, there are no continuous surfaces allowing the entire length to be marked. For tankers, the use of the only available vertical surfaces would result in the reflective material being unusually high relative to other types of trailers.

There is no easy solution to the problems presented by different trailer configurations. In some cases manufacturers may be able to provide suitable mounting surfaces when confronted with the necessity of doing so based on a revised FMVSS 108. In other cases it will probably be necessary to make do with whatever can be accomplished using available surfaces. Some trailers may present an insolvable problem in terms of using tape. For these configurations, the Government may wish to require additional and/or higher output marker lights.

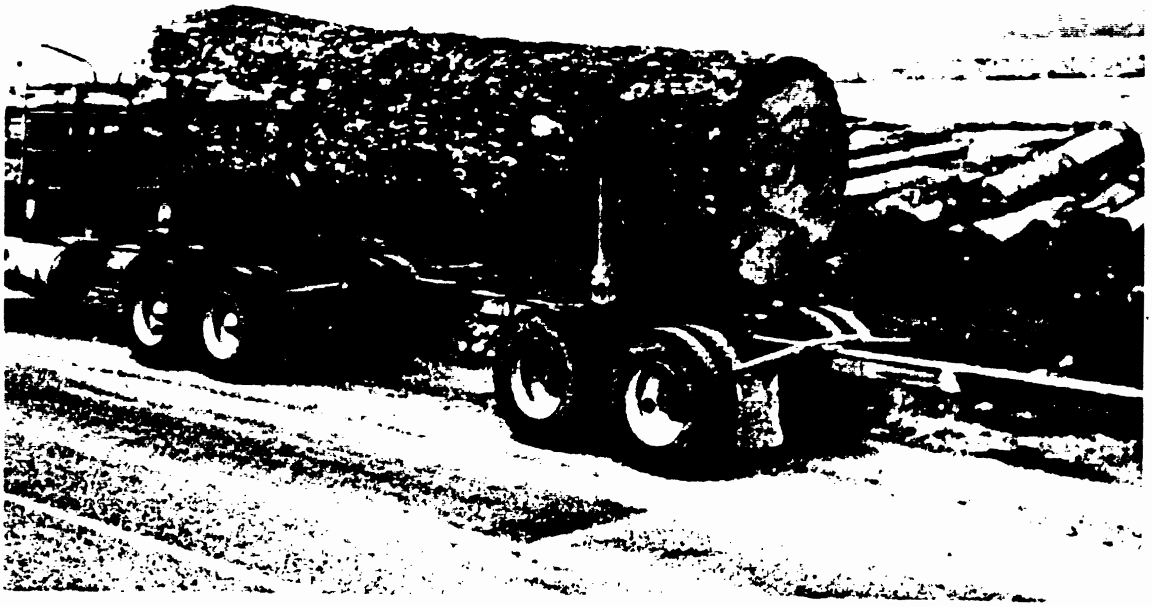
Roll-off Unit

Tanker

Figure 2.5. Examples of different trailer configurations.

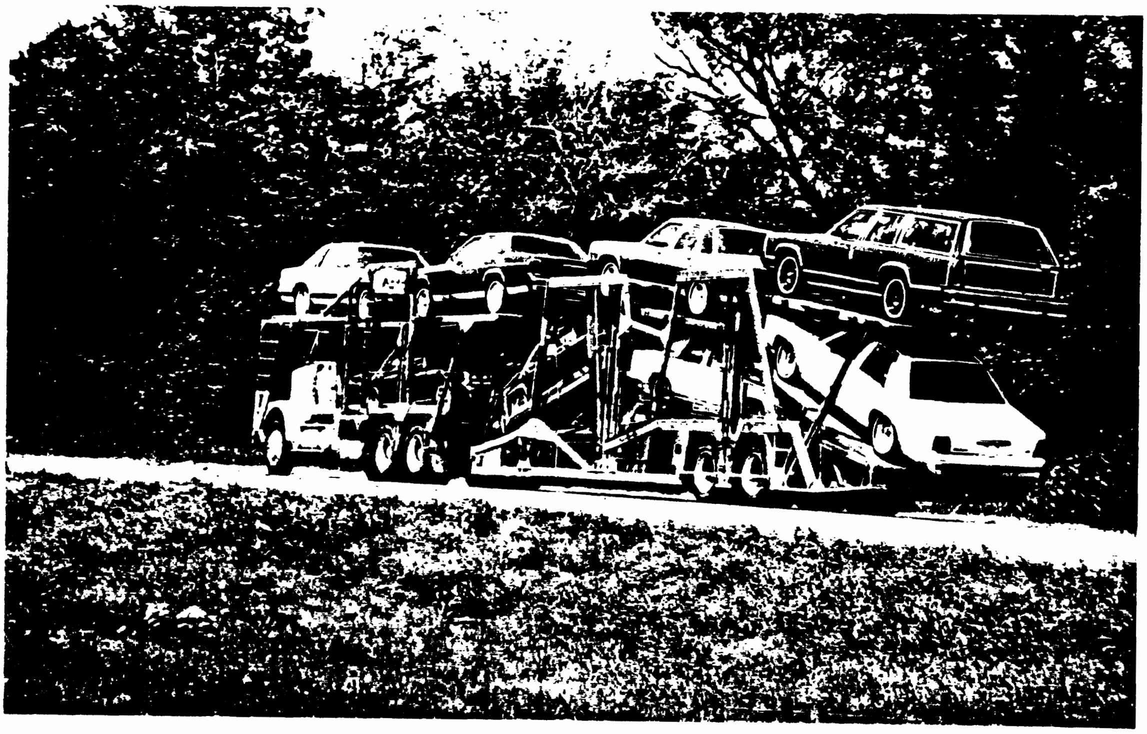


Asphalt Trailer

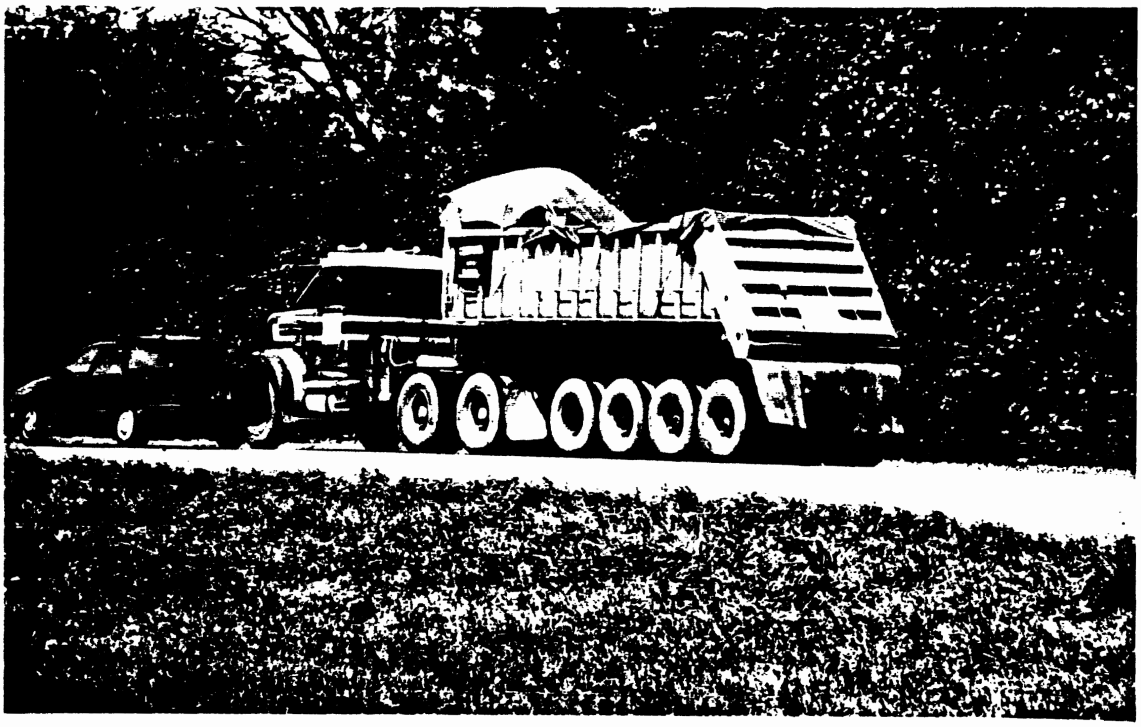


Pole Trailer

Figure 2.5 Examples of different trailer configurations. (cont.)

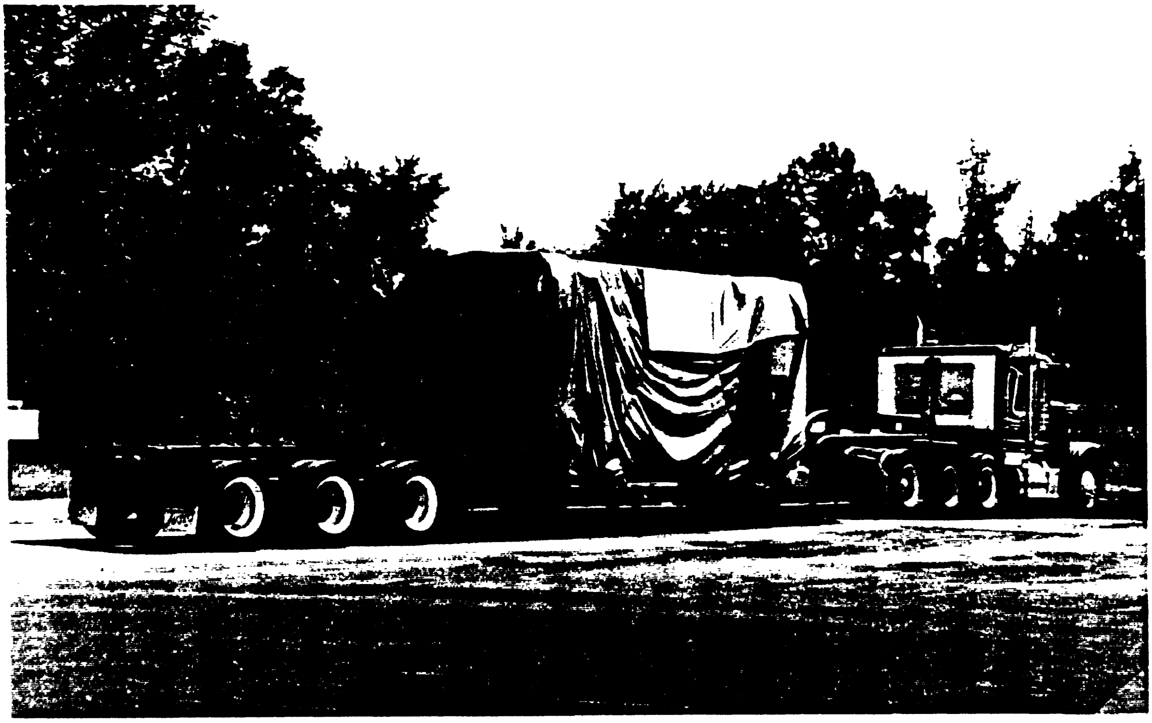


Car Carrier



Dump Trailer

Figure 2.5. Examples of different trailer configurations. (cont.)



Low Boy Trailer

Bulk Carrier

Figure 2.5. Examples of different trailer configurations. (cont.)

3 TREATMENT VALUES

One of the principal aims of this program was to develop data that would support recommendations for minimum and, if appropriate, maximum reflectivity values for retroreflective materials used in conspicuity-enhancing treatments. The two investigations carried out for that purpose are described in this chapter of the report. The question of maximum reflectivity values will be dealt with first.

MAXIMUM REFLECTIVITY VALUES

Introduction

To maximize the nighttime attention-getting characteristics of retroreflective treatments it is necessary that they be as bright as possible. "Bright as possible" is limited by two factors. One of these is technology, i.e., how efficient can retroreflective materials be made? The second factor is a concern for protecting other roadway users from excessive glare.

Bright sources in the visual field can reduce visibility, a phenomenon commonly referred to as disability glare. In the context of this study the concern is with obscuring brake and turn signals. This issue is dealt with in Chapter 4 of this report. Bright sources can also cause discomfort. Because drivers may sometimes be exposed to glare from conspicuity treatments on trucks for protracted periods of time (e.g., when following a truck in a situation where passing is not possible), discomfort glare is a significant concern.

Unlike disability glare, which can be objectively measured, discomfort glare is a subjective phenomenon. Its measurement typically requires the use of a rating scale of some type to produce quantitative data. In the context of automotive lighting the rating scale most often employed to assess discomfort is that first described by deBoer (1973). This is a 9-point scale, one version of which follows:

1 Unbearable
2
3 Disturbing
4

5 Just Acceptable
6
7 Satisfactory
8
9 Just Noticeable

The scale was originally published in Dutch, and various translations of the descriptors associated with the odd numbers have appeared. Recent work has made it clear that the scale has problems (Gellatly and Weintraub, 1990). One of these problems arises from the fact that the scale associates small numbers with intense stimuli, which is the opposite of conventional use.

It is desirable that a rating scale produce data that are at least on an interval scale, so that routine arithmetical and statistical operations can be performed. It is not known whether appropriate measures were taken to produce an interval scale in the original Dutch version of the scale. Apparently no efforts have been made to do so with any of the English versions. The work of Gellatly and Weintraub referenced earlier makes it clear that the adjectives listed above do not lie on an interval scale, particularly "satisfactory" and "just acceptable." In fact, their data suggest the order of those two may be reversed. The fact that apparently reasonable data have been obtained with the scale in spite of this problem (e.g., Schmidt-Clausen and Bindels, 1974; Olson and Sivak, 1983) indicates that the numbers and not the adjectives are the primary factor guiding the subjects' judgments. Therefore, this problem, although undesirable, may not be particularly serious.

Other research has shown that judgments of glare discomfort are task dependent to a significant degree (Sivak et al., 1989). That is, if the glare is perceived as producing a significant loss of visibility it will be judged more uncomfortable than it would otherwise. As one example, these results suggest that if delineation was in such poor condition that glare rendered it difficult or impossible to see, the glare would be rated more uncomfortable than if the delineation was in good condition and remained visible in the presence of glare.

In sum, the subjective scaling of discomfort is difficult to accomplish, and the best available instrument, the deBoer scale, has some significant problems. Because it is the best available instrument, the deBoer scale was used in the investigation reported here. The reader, in interpreting the results, should be cognizant of the limitations of the method employed.

Since discomfort glare is an important criterion in the design of automotive headlamps, there has been considerable work in that context. The most important and comprehensive is that of Schmidt-Clausen and Bindels (1974). Certain of the parameters investigated by Schmidt-Clausen and Bindels have been replicated by Olson and Sivak (1983) under both laboratory and field conditions. There appear to be differences between Europeans and Americans in such judgments (Sivak, Olson, and Zeltner, 1988). Europeans seem to judge the same stimuli more uncomfortable than do Americans (perhaps due to the less glaring headlamp design used in Europe). Other than that, the data have been shown to be generally consistent. A sample of laboratory results is shown in Figure 3.1.

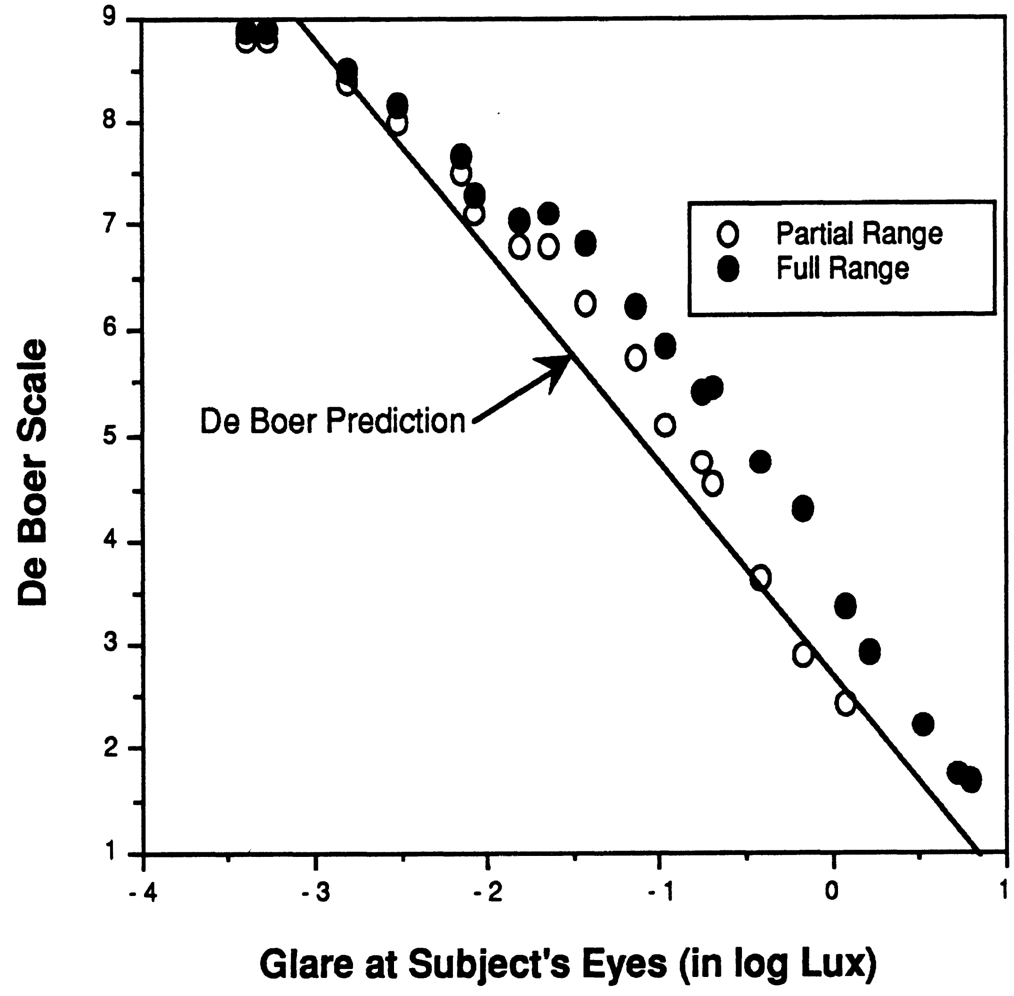


Figure 3.1. Results of laboratory discomfort glare evaluation. From: Olson and Sivak, 1983

In setting the upper limits of material SIA, three separate investigations were carried out. The first of these was a basic study of the effects of source width and luminance on judgments of glare discomfort. The second study examined the effects of exposure duration. As a final step, measurements were made of the luminance of a retroreflective surface, employing a variety of vehicles and viewing distances. These data were used as a basis for calculations of glare delivered to the eyes of the driver. Each of these investigations will be described in this section of the report.

Discomfort as a Function of Source Width and Luminance

The purpose of this study was to obtain basic data on discomfort glare as a function of the width and luminance of the stimulus source. A laboratory study was carried out using a methodology similar to that employed in the other laboratory investigations of discomfort glare referenced earlier.

Independent variables

Stimulus height. The stimulus materials were 8.5 inches wide, and were attached to cards that were 8.5 inches wide and 8 inches high. For this configuration the stimuli always presented a horizontal angle of 2.03° at the viewing distance of 20 feet. The height of the stimulus materials varied in six steps from 8 inches to 0.25 inch. The heights employed and their vertical angular sizes are given in Table 3.1.

TABLE 3.1
Heights and Angular Size of Stimuli Used in Glare Discomfort Study

Height (inches)	Angular Size (degrees)
8	1.91
4	0.95
2	0.48
1	0.24
1/2	0.12
1/4	0.06

Treatment Values

A simulated headlamp was also employed as part of the stimulus array. This was done primarily to provide a glare stimulus range approximating that encountered in night driving. Failure to do so could lead to a significant bias due to the "range effect." The range effect in glare discomfort research was first noted by Lulla and Bennett (1981), who found that the rated discomfort of a particular glare level depended on the range of glare stimuli within which it was contained. In nighttime driving glare ranges downward from that provided by an encounter with high beams on a two-lane road. The upper end of this range was provided by a 35mm projector. This "headlamp" projector had an opening of one inch. At the 20-foot viewing distance used that resulted in an angular size of 0.24°.

Stimulus intensity. Five luminance levels were selected for the retroreflective strips used as stimuli; levels that were separated by approximately one log unit. There were small differences (a few percent, maximum) from one strip to another at the same level of illumination from the source projector, due to inherent variability in the retroreflective material. These were judged too small to be of consequence. Table 3.2 lists the five luminance levels employed.

TABLE 3.2
Luminance of Retroreflectance Material at Different Intensity Levels

Projector Setting Number	Luminance (cd/m^2)
1	18,800
2	1,640
3	170
4	21.6
5	4.6

Illumination at the subject's eyes varied depending on the luminance of the stimulus strip and its width. Table 3.3 lists the various glare levels (in lux) as a function of source intensity and treatment height. Glare from the headlamp projector is included as well.

TABLE 3.3
Relationship Between Projector Settings, Stimulus Height, and Glare at the Subject's Eyes (in lux)

Projector Setting Number	Simulated Headlamp	Retroreflective Treatment Height (inches)					
		8	4	2	1	0.5	0.25
1	15.2	15.2	7.6	3.8	1.9	0.95	0.475
2	1.49	1.26	0.63	0.31	0.16	0.078	0.039
3	0.152	0.13	0.065	0.033	0.016	0.008	0.004
4	0.019	0.016	0.008	0.004	0.002	0.001	0.0005
5	0.0042	0.0035	0.0017	0.0009	0.0004	0.0002	0.0001

Dependent Variable

The dependent variable was discomfort ratings, using the deBoer scale, obtained for each of the test conditions.

Subjects

Twenty individuals participated in this study. Their ages ranged from 22 to 75. All were healthy, licensed drivers who had participated in other investigations at the Institute. Half were male, half were female. Age and sex, however, were not treated as independent variables in the analysis.

Equipment

Figure 3.2 is a schematic of the laboratory arrangement. As noted earlier, the retroreflective stimulus strips were attached to cards. The area not occupied by the reflective material was covered by black velveteen, as was the stimulus card holder. The stimulus cards were illuminated by a 35mm slide projector, situated directly in front of the subject. This projector was fitted with an internal aperture that kept the total illuminated area to a circle one foot in diameter at the stimulus plane. The beam from this projector was reflected from a mirror directly below the subject's eyes. This was necessary to keep the observation angle as small as possible. Neutral density filters were used in the slide tray to obtain the desired illumination levels.

A second projector constituted the "headlamp" source. It was located behind the stimulus card holder. A hole was made in the card holder for the beam from this projector. The hole was covered when a stimulus card was in place. Neutral density filters in the slide tray of this projector provided the different glare levels. Both projectors were fitted with electronic shutters to control the stimulus exposure interval (set at one second).

The subject was seated about 22 feet from a wall, which was painted a uniform gray. The wall was illuminated to an average level of 1 cd/m^2. The range of luminances measured on the wall was from 1.2 to 0.8 cd/m^2. This adaptation luminance was selected based on recent research (Olson et al., 1990) indicating that it is the proper level of adaptation of a driver using low beams on a dark road.

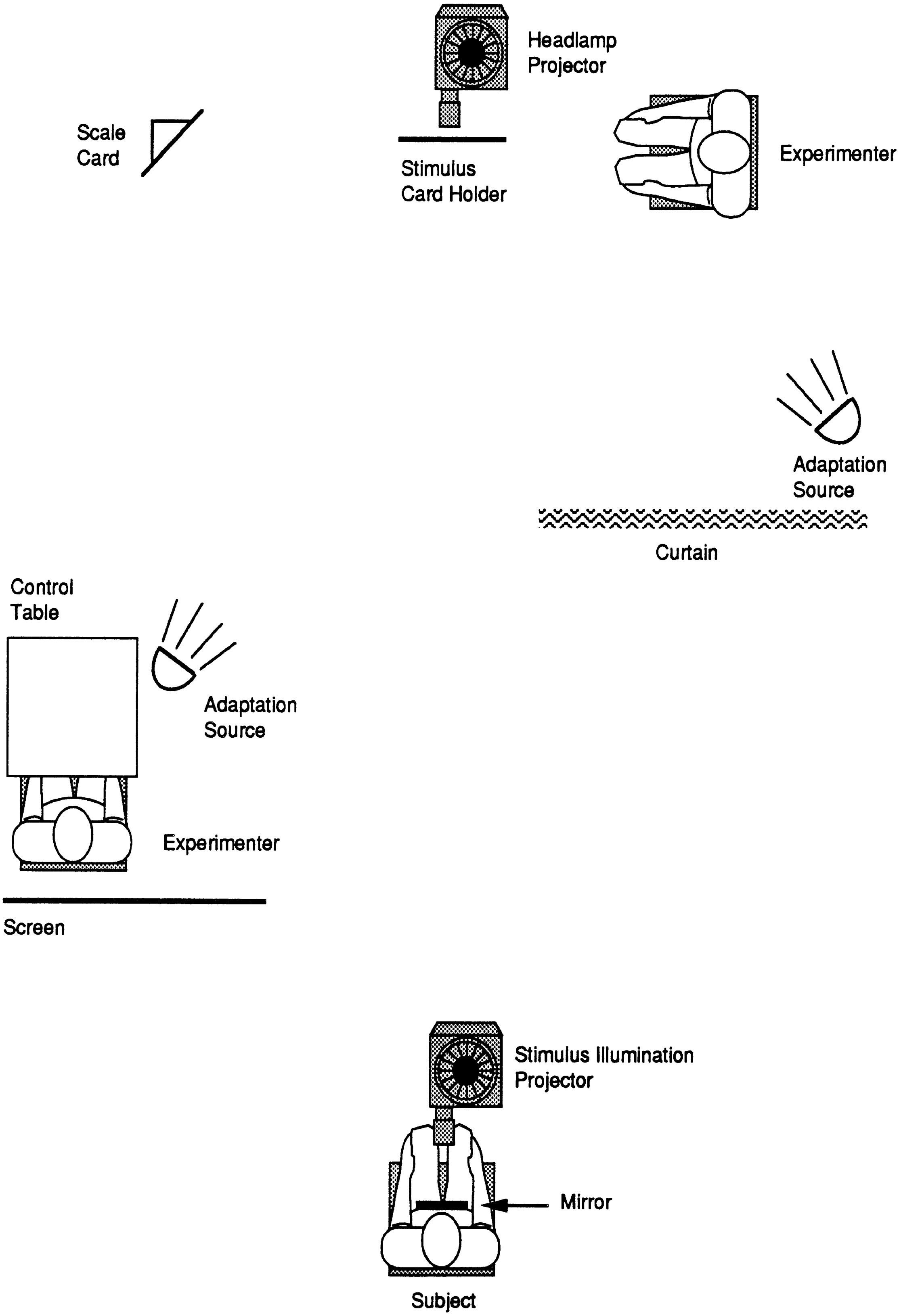


Figure 3.2. Schematic of test set up for glare discomfort study.

Luminance of the wall was controlled by two lamps ("adaptation sources"). These also provided illumination for a large card on which the deBoer scale was printed. This card was placed off to the left of the subject, where it could be easily seen.

Two experimenters were required. One removed and replaced the stimulus cards between trials. He was screened from the subject by means of a curtain. The second experimenter adjusted the settings on the two projectors, triggered the projector shutters, and recorded the subject's response. He was screened from the subject's view by a panel.

Procedure

Subjects were run individually. They were seated at a table and told to rest their chin in a cup. The vertical position of the cup was adjusted so that the subject had a clear view of the largest reflective strip (the 8-inch strip), but nothing below it. With this dimension set, the subject's seated height was adjusted until it felt comfortable. The laboratory lights were extinguished (except for those controlling adaptation), the instructions were read, and any questions answered. Ten minutes were allowed for the subject to adjust to the level of illumination. During this interval practice trials were given to ensure that the subject understood the instructions and was using the scale properly. The subject was then given five replications of each condition (five luminance levels, seven sources), a total of 175 trials. These were administered in a randomized sequence and thus, were different for each subject. With time for a short break at the halfway point, data collection took about 45 minutes.

Results

The principal results of this investigation are given in Figure 3.3. This figure shows the relationship between illuminance at the subject's eyes and the discomfort rating. Seven sets of data are shown, representing the six stimulus widths plus the "headlamp" projector.

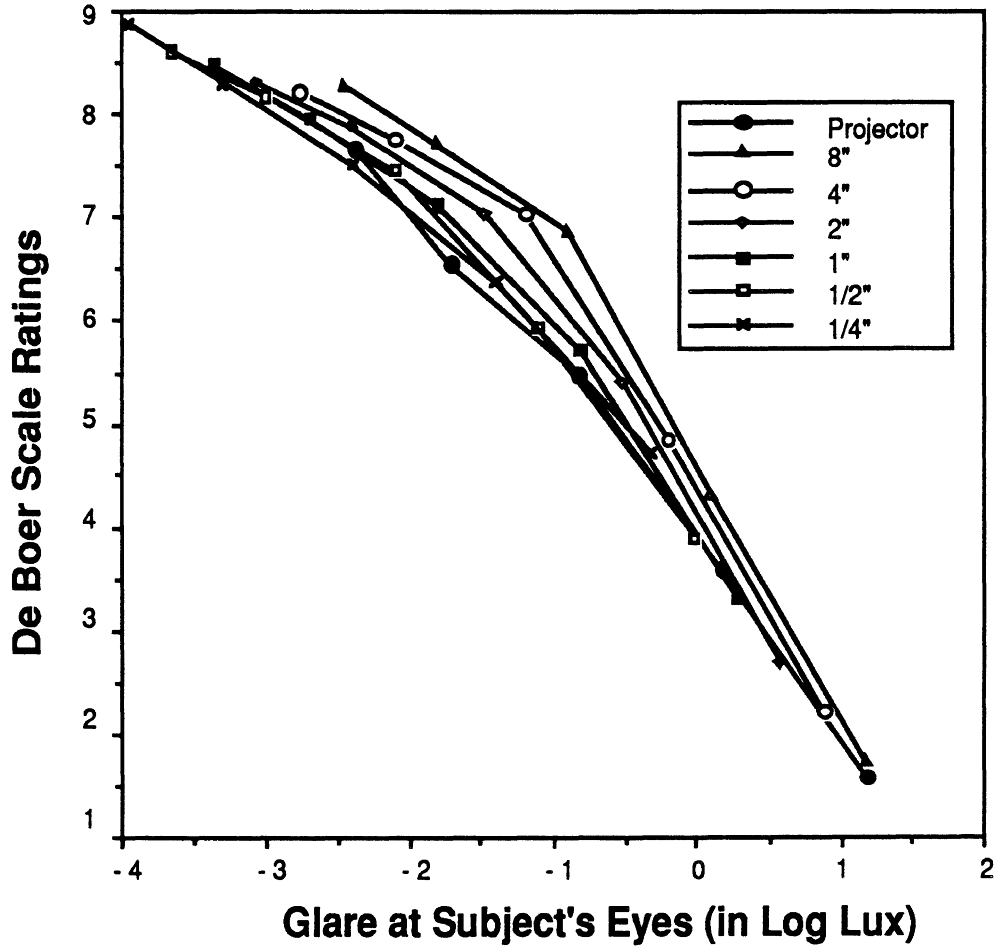


Figure 3.3. deBoer ratings as a function of intensity and stimulus size.

Two main points should be made concerning these results. First, the data for the headlamp projector closely approximate those reported elsewhere (see Figure 3.1), particularly at the high end. Glare levels at the low end from the projector are rated more uncomfortable than in other studies. This represents the range effect mentioned earlier. Because several of the reflective stimuli delivered less glare to the eye at the lower levels than did the projector, they had the effect of expanding the range of glare at the lower end. As a consequence, subjects rated the lower levels from the projector more uncomfortable than they otherwise would have.

Second, for materials subtending a vertical angle of 0.48° or more, judgments were clearly influenced by the luminance of the material as well as by illuminance at the eye. Wider materials were judged more comfortable than narrower materials at the same glare levels. This effect is most noticeable in mid range.

While interesting, the findings relating to material width are of no practical consequence. The two-inch stripe set as the standard for purposes of this project would subtend 0.095° at a distance as short as 100 feet. A treatment would have to be 40 inches wide to subtend the same angle at 100 feet as the widest stimulus used in this study. For the use contemplated for these data, it is appropriate to take the data from the narrowest stimuli as a guide for setting maximum SIA.

To establish maximum glare using deBoer data requires making several assumptions. As a start, it is reasonable to use deBoer 5 (just acceptable) as an indicator of the maximum level. Referencing Figure 3.3, this suggests a value of 0.2 lux. In considering this, however, it would be well to bear in mind that there is considerable scatter in the data. Figure 3.4 is a normal probability distribution of judgments of 5 for the various stimuli. At the 95th percentile these judgments range from -2 to -3 log lux, i.e., from 0.01 to 0.001 lux. The lower value is appropriate for the narrower treatments. To the extent practical, it would be desirable to keep glare levels in this range, and to view the value of 0.2 lux as an upper limit.

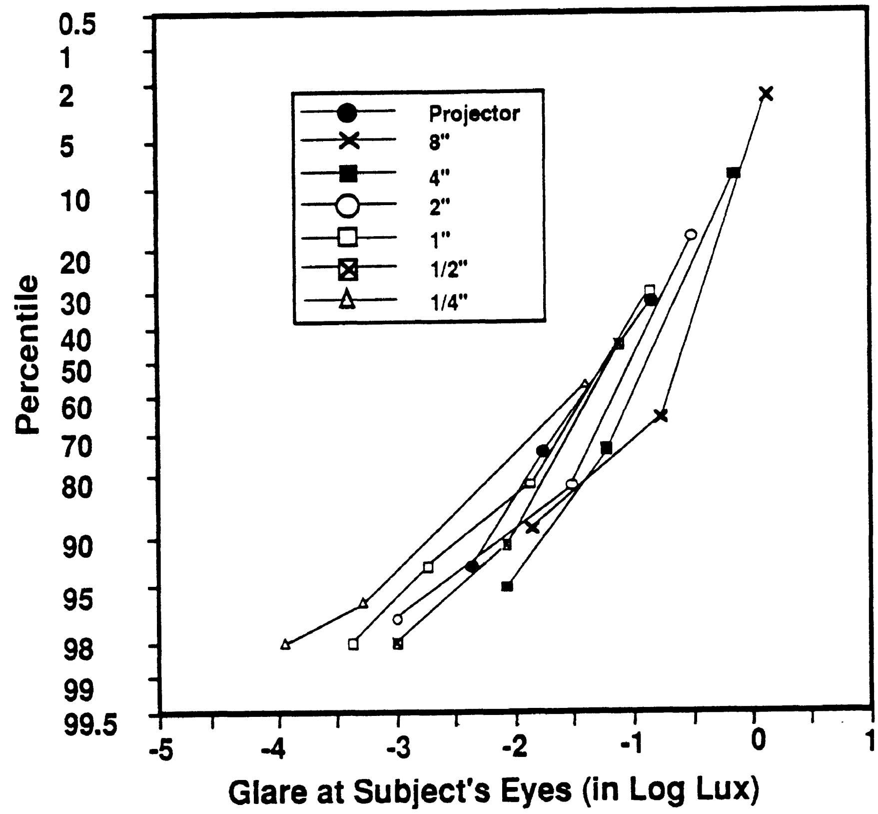


Figure 3.4. Normal probability plot of judgement of "5" as a function of stimulus intensity and size.

Discomfort as a Function of Glare Duration

The next step in this program was to assess whether the duration of exposure to glare affected perceived discomfort.

The authors are aware of only one study that has examined the effect of glare duration in a driving setting (Olson and Sivak, 1981). This was done to evaluate the effects of duration of glare received from rearview mirrors. It was done in the field, and used two glare durations, ten seconds and three minutes. The results indicated that the longer duration was judged about one deBoer unit more uncomfortable than the short duration. This study was run at relatively high levels of glare, however. The lowest glare level used was 0.73 lux, and the maximum was 70 lux. In addition, trying to maintain reasonably accurate control over these levels while operating two cars over public roads presented formidable difficulties. The results, however, are consistent with the expectation that perceived discomfort increases with length of exposure.

The focus of the current investigation is on glare levels that are generally lower than those used in the referenced study. It is reasonable to ask whether there would be as great a change in perceived discomfort at those levels. To address this issue a separate investigation was carried out. This was a laboratory study, using the same general approach as the first study in this series.

Independent Variables

Stimulus intensity. Three levels of stimulus intensity were employed. These were 1.0, 0.1, and 0.01 lux, measured at the subject's eyes.

Exposure duration. Three levels of duration were employed. These were 2 seconds, 1 minute, and 5 minutes.

Dependent Variable

The dependent variable was deBoer discomfort ratings obtained for each of the test conditions.

Treatment Values

Subjects

Twenty individuals participated in this study. Their ages ranged from 22 to 75. Most of them had taken part in the first discomfort glare study as well. All were healthy, licensed drivers. Half were male, half were female. As in the first investigation, age and sex were not treated as independent variables.

Equipment

The physical arrangement differed from that used in the first study in two ways. First, glare was provided by the projector only. No reflective material was used. Second, a simple driving simulator was used, the output of which was displayed on a 21-inch television screen, 20 feet in front of the subject. The glare projector was placed on top of the television. The subject was seated in a car body, and controlled the simulator by means of a steering wheel. A large copy of the rating scale was placed off to the subject's right about 45^o and illuminated to a level such that it could be easily read. The wall behind the simulator display was illuminated to an average level of 1.0 cd/m^2, as in the first study.

Procedure

Subjects were run individually. They were seated in the car body, the laboratory lights were extinguished (except for those controlling dark adaptation), and the instructions were read to them. They were then given a brief practice period on the simulator so that they could become used to its operation. Dark adaptation occurred during this interval. Data collection then started. The subject was required to operate the simulator and was periodically exposed to glare from the projector. When the glare was removed he/she made a rating using the deBoer scale. Three replications of each stimulus condition were provided in a random order different for each subject. Typically, about 70 minutes were required to complete the test.

Results

The results of this investigation are illustrated in Figure 3.5. This figure shows the deBoer rating as a function of glare intensity and duration. Although the differences that appear in the figure are not statistically significant, they do conform to expectations in that the brief exposure was rated somewhat more comfortable than the longer exposures. These data suggest that longer exposures may change the rating about half a deBoer unit. Referring to Figure 3.3, this would reduce the recommended maximum glare from 0.2 to 0.1 lux.

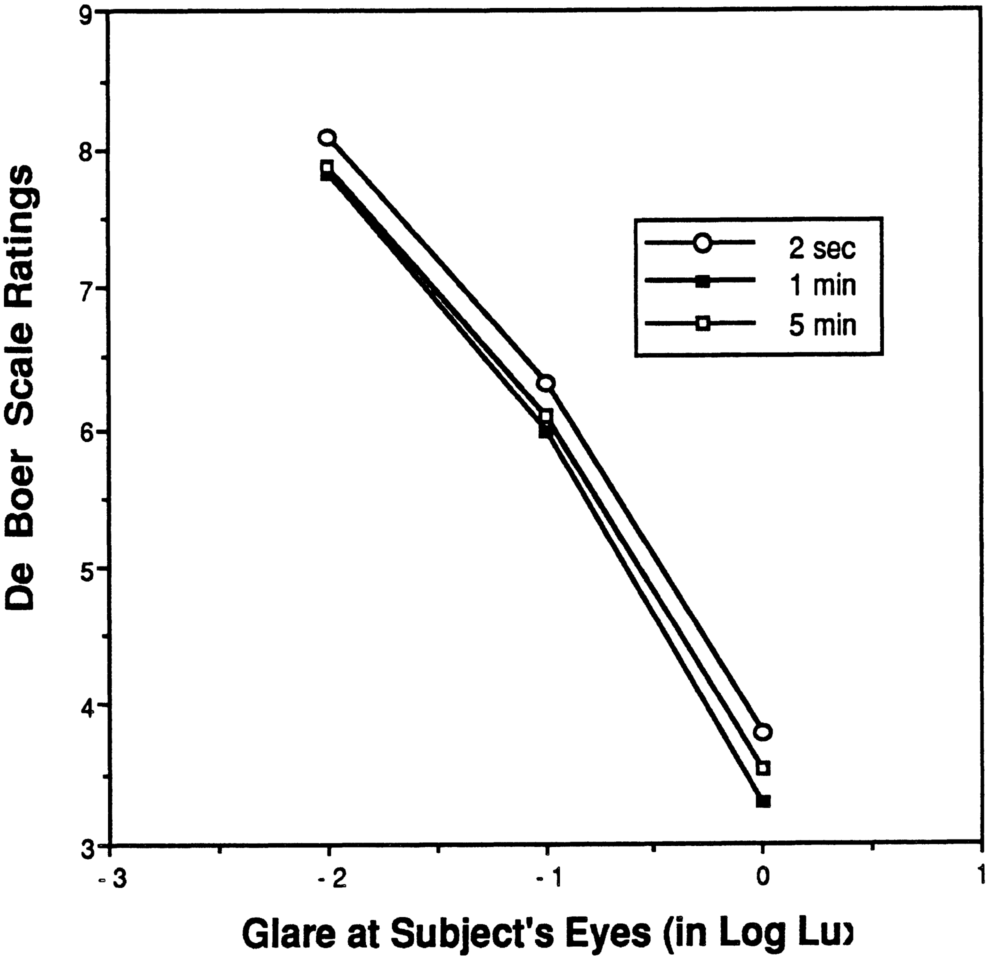


Figure 3.5. deBoer ratings as a function of glare intensity and duration.

Field Luminance and Glare Measures

Introduction

The data to this point have concerned glare in terms of illumination at the eye. The problem now is in translating those data into retroreflective material specifications.

Treatment Values

The most common specification for retroreflective material of the type that would be employed as markings on large vehicles is SIA (specific intensity per unit area), given in candelas/lux/m^2 or candelas/ft-c/ft^2. (Readers not familiar with the specifications of retroreflective materials may find it helpful to read the chapter entitled "An Introduction to Retroreflective Materials" in Appendix A of this report.) The purpose of this section is to establish a maximum SIA, based on the findings of the two laboratory studies just described.

As a first step, field measurements were made of the luminance of a piece of retroreflective material illuminated at a range of distances by the low beam headlamps of three different vehicles. The three vehicles were a cabover tractor, a late-model minivan and a full-size station wagon. These vehicles were selected to represent the range of observation angles that might be found in vehicles on the road today. Table 3.4 gives the key dimensions of each vehicle. Because it is a major factor in determining observation angle, the most important dimension for purposes of this test was the mean eye-to-headlamp distance. It turned out to be much the same for the minivan and station wagon, but the tractor was about twice as large. Calculated observation angles for the three vehicles at four observation distances are given in Table 3.5. It should be noted that the observation angle is affected by target location as well as vehicle dimensions. The angles shown in Table 3.5 assume a target straight ahead, as was true in this test.

TABLE 3.4
Key Dimensions of Vehicles Used for Field Luminance Measurements

Vehicle	Headlight Mounting Height	Driver Eye Height	Horizontal Separation Between Headlamps	Horizontal Distance: Driver to Left Headlamp	Mean Eye to Headlamp Distance
Tractor	41.5	99	80	9	74.5
Minivan	28.5	54	49	10	36.8
Station Wagon	30.0	48	63	13	37.6

TABLE 3.5
Representative Observation Angles for the Three Vehicles Used in the Field Luminance Measurements

	Observation Distances (feet)			
Vehicle	1000	750	500	250
Tractor	0.36°	0.47°	0.71°	1.42°
Minivan	0.18°	0.23°	0.35°	0.70°
Station Wagon	0.18°	0.24°	0.36°	0.72°

Procedure

A schematic of the test arrangement is provided in Figure 3.6. A panel of retroreflective material was placed at one end of the test facility, and it was viewed from the measurement vehicle. A glare car was placed in the lane next to the retroreflective panel, facing toward the measurement vehicle. Measures were made of the glare provided by its low and high beams at each distance in each of the measurement vehicles.

The retroreflector used in this study was a 30-inch square panel of prismatic material in yellow. Its SIA (at 0.2° and -4°) was averaged 600. It was supported on a stand so that its center was about 5 feet above the ground. Measurements were taken with each of the three vehicles at 1,000, 800, 600, 500, 400, 300, 200, and 100 feet from the reflective surface.

At each distance and in each vehicle measurements were made of the luminance of the retroreflective panel (in cd/m^2), the illuminance reaching it (in lux), and illuminance at the eye of the driver (also in lux) from the low and high beams of the glare car. In addition, lux readings were taken at the driver's eye with and without the measurement vehicle's low beam lamps on. The latter reading was taken only at the 1,000-foot distance. These will be referred to as "ambient" readings.

The test was run as follows: The vehicles were positioned as shown in Figure 3.6, with the measurement vehicle 1,000 feet from

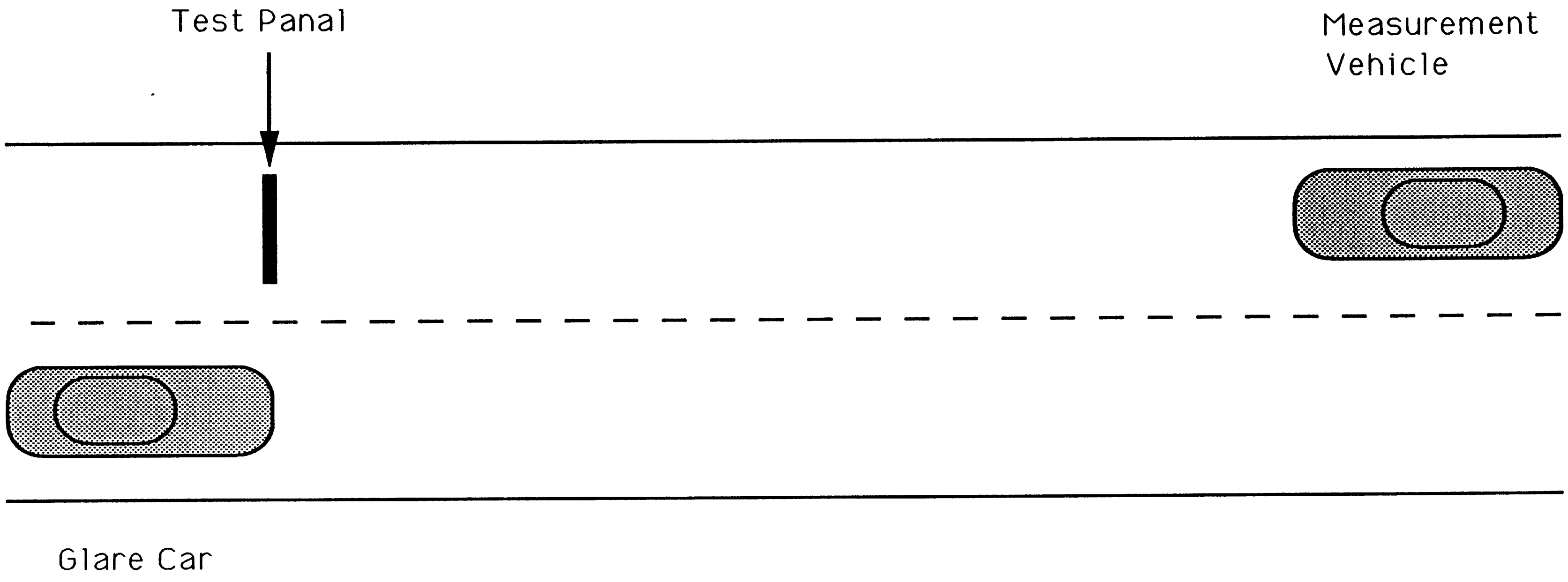


Figure 3.6 Schematic of arrangement for field measurements.

the test panel. Ambient readings were taken by holding a lux meter directly in front of the driver's eyes, first with the headlamps off and then with the low beams on. Then, using a model 1980A Spectra-Pritchard photometer, a luminance reading was taken of the retroreflective panel, using the largest aperture that would fit inside the image of the panel. A lux reading at the panel was then taken and reported to the experimenters in the measurement vehicle by radio. As a final step lux readings were taken at the driver's eye with the low and high beams of the glare car illuminated. The measurement vehicle was then moved forward to the next indicated point and the process repeated.

The test was carried out on a private road in a dark, rural area. There were no significant sources of illumination on or near the facility. The lamps of all four of the vehicles involved were checked for aim before the test.

Results

The results of the field measurements are given in Table 3.6. There is an unexplained anomaly in the ambient low beam measurements at 800 feet, otherwise the data appear reasonable and consistent. Note that the illumination at the target provided by the headlamps of the tractor was about half that provided by the other two vehicles. This factor, combined with the larger observation angle on the tractor, accounts for the much lower target luminance values listed.

It is interesting to note the glare levels generated by ordinary headlamps under these conditions. The recommended maximum glare from conspicuity-enhancing treatments, based on the laboratory studies described earlier, was 0.1 lux. Even at a separation of 1,000 feet, the glare from the low beams in this case averaged about 0.1 lux. It rose to much higher levels at shorter separations, although the sensation of discomfort would not be linearly related to the lux, since the glare angle was increasing at the same time.

TABLE 3.6
Results of Field Measurements

				Distance [ft]							
				1000	800	600	500	400	300	200	100
Tractor	1	Ambient (Sky)	Lx	0.02							
	2	Ambient (Low Beam)	Lx	0.05	0.09	0.05	0.06	0.06	0.07	0.10	0.07
	3	Target Luminance	cd / m**2	1.5	1.7	1.7	1.6	1.4	1.1	1.1	1.3
	4	Target Illuminance	Lx	0.07	0.06	0.08	0.09	0.11	0.15	0.29	1.0
	5	Glare (Low Beam)	Lx	0.13	0.16	0.18	0.21	0.25	0.31	0.42	0.73
	6	Glare (High Beam)	Lx	0.88	1.4	2.2	2.8	3.5	4.6	4.3	2.2
	7	Headlamp Intensity	cd	6,503	3,567	2,676	2,090	1,635	1,254	1,078	929
Minivan	1	Ambient (Sky)	Lx	0.01							
	2	Ambient (Low Beam)	Lx	0.05	0.11	0.07	0.08	0.09	0.09	0.09	0.10
	3	Target Luminance	cd / m**2	27	25	34	37	41	35	22	14
	4	Target Illuminance	Lx	0.13	0.12	0.17	0.22	0.29	0.43	0.83	2.7
	5	Glare (Low Beam)	Lx	0.12	0.19	0.17	0.21	0.25	0.33	0.48	0.82
	6	Glare (High Beam)	Lx	0.63	0.91	1.5	2.1	2.6	3.7	5.2	5.3
	7	Headlamp Intensity	cd	12,077	7,135	5,685	5,110	4,311	3,595	3,084	2,508
Station Wagon	1	Ambient (Sky)	Lx	0.01							
	2	Ambient (Low Beam)	Lx	0.04	0.08	0.05	0.05	0.06	0.06	0.06	0.07
	3	Target Luminance	cd / m**2	59	24	41	51	46	39	29	12
	4	Target Illuminance	Lx	0.17	0.11	0.15	0.25	0.29	0.40	1.0	1.8
	5	Glare (Low Beam)	Lx	0.08	0.14	0.15	0.18	0.23	0.31	0.52	1.0
	6	Glare (High Beam)	Lx	0.58	0.94	1.5	2.0	2.8	3.9	5.7	7.2
	7	Headlamp Intensity	cd	15,793	6,540	5,017	5,806	4,311	3,344	3,716	1,672

The ambient low beam lux measures reported in Table 6 show that the glare measured at the driver's eyes increased by 0.03 to 0.05 lux as the vehicle moved in from 1,000 feet. At least part of this change should be attributable to illumination from the test panel. A more accurate assessment of the contribution of the panel can be had by using the following equation:

$$I = LA/D^2$$

Where:

I = illuminance at the eye of the observer in ft-c
L = average luminance of the surface in ft-L
A = luminous area in ft^2
D = observation distance in feet

Using this equation and the data on panel luminance in Table 3.6, the data in Table 3.7 were calculated. These results indicate that the maximum glare from the test panel occurred in the case of the minivan and station wagon at a distance of 100 feet, and averaged 0.008 lux. Even allowing for the fact that the tractor's headlamps were operating at much lower intensity than those with which the cars were equipped the calculated glare would be less than 0.002 lux, due to the large observation angle. These calculations do not take into account attenuation from the windshield. In the case of a typical passenger car, the windshield would reduce illumination at the driver's eye by 20-30 percent, depending on whether or not the glass is heat-absorbing.

Recommendations

The recommendations in this section are based on two primary assumptions: first, the use of a headlamp beam pattern similar to that in use in the US today; second, the use of low rather than high beams.

There have been no major changes to the low-beam pattern in use in this country for many years. If changes are made in the future that result in a reduction in illumination above horizontal this will affect the relationship between SIA and detection distance discussed in the next section of this chapter.

TABLE 3.7
Calculated Glare (in lux) from Panel Used in Field Measurements

Vehicle	Observation Distance (feet)							
	1000	800	600	500	400	300	200	100
Tractor	0.00001	0.00002	0.00003	0.00004	0.00005	0.00008	0.00017	0.00081
Minivan	0.00017	0.00024	0.00059	0.00092	0.0016	0.0024	0.034	0.0088
Station Wagon	0.00037	0.00023	0.00071	0.0013	0.0018	0.0027	0.0045	0.0075

Low beams are assumed in this analysis for two reasons. First, if a driver is discomforted by a display viewed with high beams, he/she has the option of dimming to low beam. Second, low beams should be used in the presence of another vehicle.

The results of the field measurements indicate that the maximum glare occurred at the shortest observation distance (100 feet). For the minivan and station wagon used in the test the observation angle at that distance was about 1.8°. At an observation angle of 1.8° the SIA of the material used on the test panel was about 6. Since this material yielded a glare level about one-tenth of the maximum suggested by the laboratory results, the material would have had to have an SIA of 60 at an observation angle of 1.8° to generate glare at a potentially troublesome level. The same effect, of course, could be achieved by increasing the area of the panel by a factor of ten.

For convenience sake, the recommended maximum material specification will be given in terms of a specific area, one square foot. Technically, giving the performance for a specific area changes the units to SI from SIA. Since the area of the test panel was 6.25 square feet, a panel one foot square would require an SI of 375 (60 X 6.25) to generate the same lux level. Thus, the recommended maximum SI is 375 cd/ft-cd (or cd/lux) at an observation angle of 1.8°.

To illustrate what this means in practical terms, consider the following examples (all of which are given for the same observation angle of 1.8°):

1. Two-inch wide treatment across the width of the rear of a trailer: This adds up to 1.33 square feet of material, assuming an eight-foot stripe. The maximum SIA is 375/1.33, or 281.

2. Two-foot wide treatment across six feet of the total trailer width in the rear: This gives a total of 12 square feet of material. The maximum SIA is 375/12, or 30.

3. Two-inch wide treatment the length of a 50-foot trailer: This gives a total of 8.33 square feet of material. The maximum SIA is 375/8.33, or 45. In practice, since the maximum glare occurs at relatively short viewing distances, only a portion of the 50-foot length of material would be maximally illuminated. Consequently, the actual glare at the driver's eye would be substantially less than assumed in the calculation.

These examples hold for material placed as low as possible on the trailer. If additional material were added at higher points, for example if the entire trailer were outlined as suggested in the Vector report, glare would increase, but not in proportion to the square feet of material added. This is because much of the additional material would be very high relative to the typical mounting height of headlamps and would receive correspondingly less illumination.

As a practical matter, the results of this analysis make it clear that there are no retroreflective materials presently available that are capable of generating glare approaching levels of concern in terms of driver discomfort when used in a reasonable treatment. One would have to use about 50 square feet of the brightest material on the market today to generate that level of glare. Certainly the treatments of concern to the present effort will not produce glare at a level that will result in an unacceptable level of discomfort.

MINIMUM REFLECTIVITY VALUES

Introduction

One of the fundamental concerns of this program was to set realistic minimum SIA values for retroreflective material used to enhance the nighttime conspicuity of large vehicles. Doing this required four separate steps. The first of these involved a field study that related material SIA and treatment configurations to detection distance. Because of space limitations at the test facility, the output of the headlights on the test car had to be reduced by filters to ensure that treatments would not be seen at the maximum available distance. The second step then was a small-scale study to develop data to correct for the effect of the headlamp filters.

Treatment Values

With the filter correction accomplished the third step was to prepare cumulative probability distributions for each SIA level and note the 85th percentile level. These were then corrected for subject expectancy in the fourth step and the results plotted. This yielded a relationship between SIA and 85th percentile detection distance required for establishing a minimum reflectivity value.

These data must then be modified by consideration of factors such as the effects of dirt, orientation, and operating environment to arrive at realistic minimums. That process will be described in Chapter 6, "Recommendations."

Method

This was a field study in which subjects rode in a car being driven toward test displays. Two displays were employed. At one end of the track both side and rear treatments of interest were displayed on a 40-foot trailer. At the other end of the track the treatments used in the hazard identification study were displayed, together with some variations of interest. Space limitations on the facility available made it necessary to use neutral density filters over the test vehicle's headlamps. Otherwise many of the treatments would have been seen from one end of the track to the other and no meaningful differences would have been recorded.

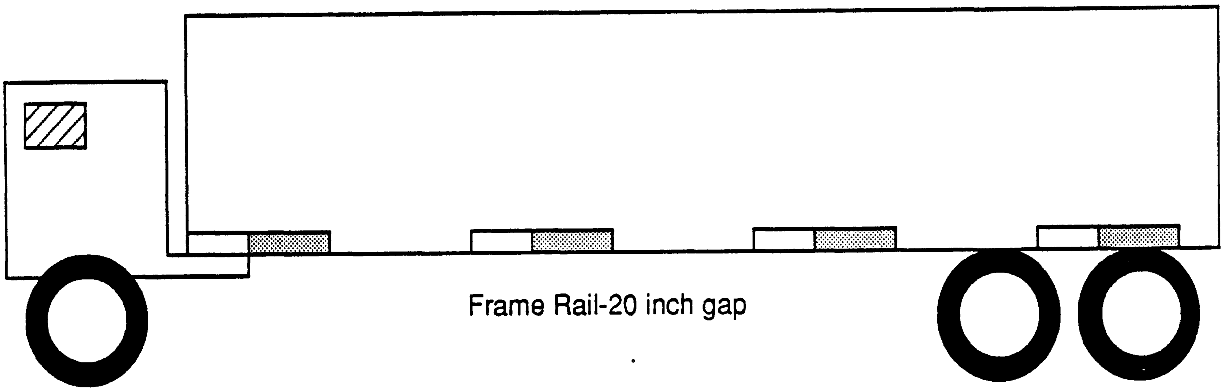
<u>Independent Variables</u>

<u>Treatments on the trailer.</u> A total of nine treatments were displayed on the trailer. With the exceptions noted all used type II (enclosed lens) retroreflective sheeting, 2 inches wide, in a red and white pattern (12 inches red and 8 inches white). The SIA averaged about 100 and 25 for the white and red areas, respectively. The factory-equipped reflex reflectors on the trailer were covered with tape during the test. The treatments were (see schematics in Figure 3.7):

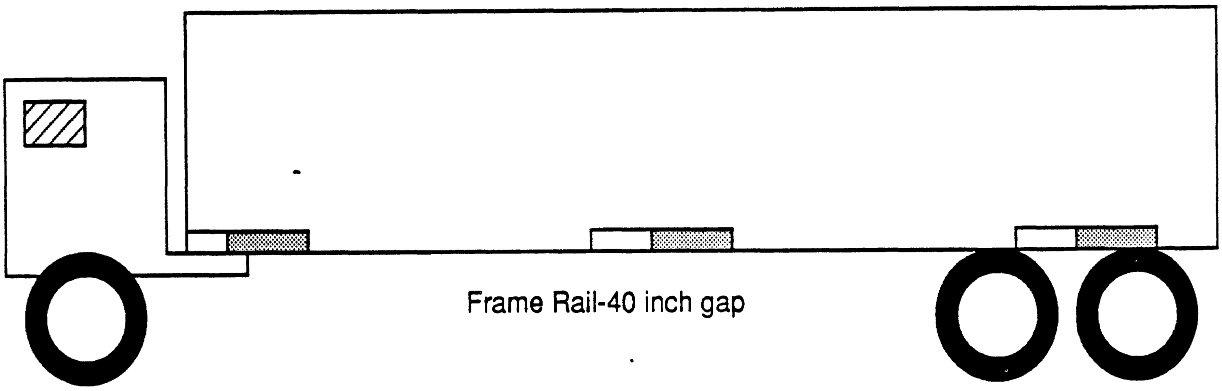
1. Frame rail treatment. A 40-foot strip along the lower part of the trailer.

2. Frame rail treatment, encapsulated lens (Type III) material. This treatment was identical to number 1, except that the SIA of the white and red areas averaged about 315 and 70, respectively.

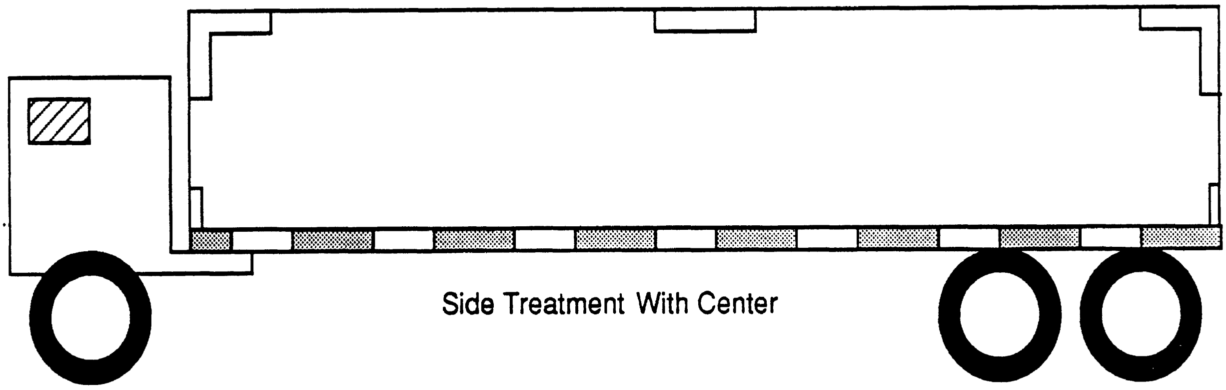
Treatment Values



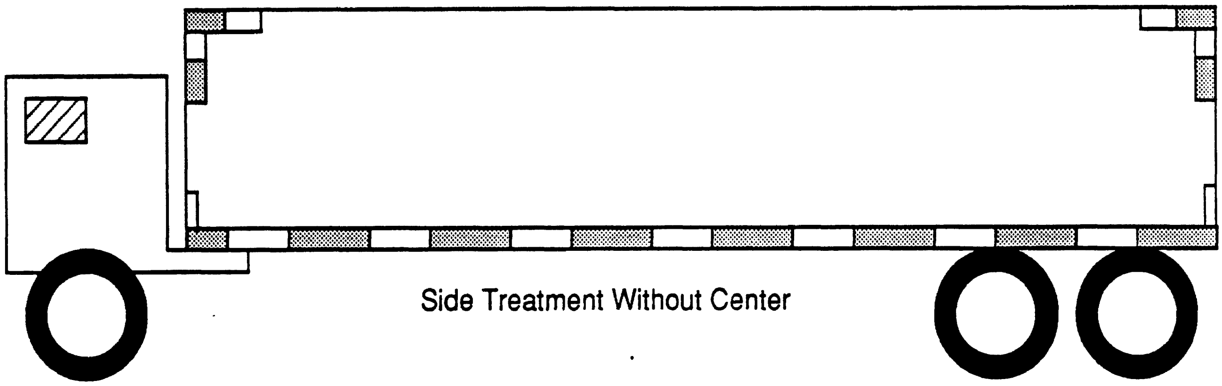
Frame Rail-20 inch gap



Frame Rail-40 inch gap



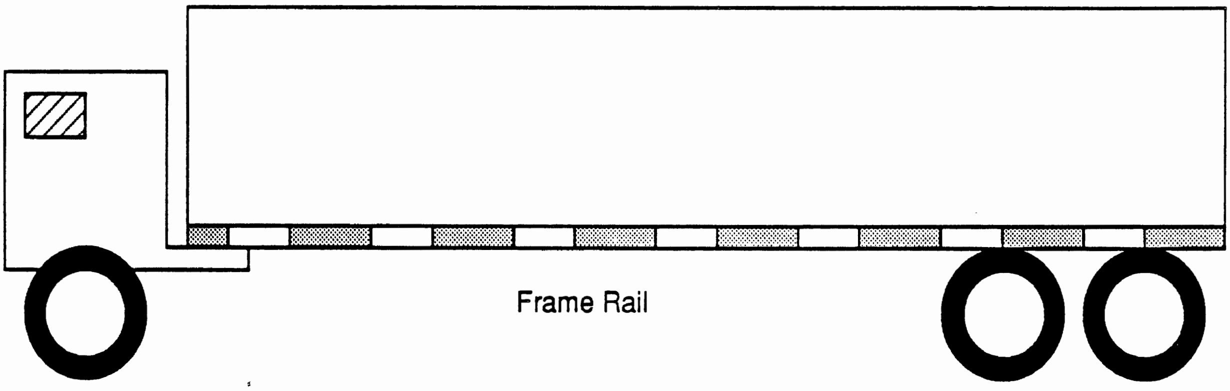
Side Treatment With Center



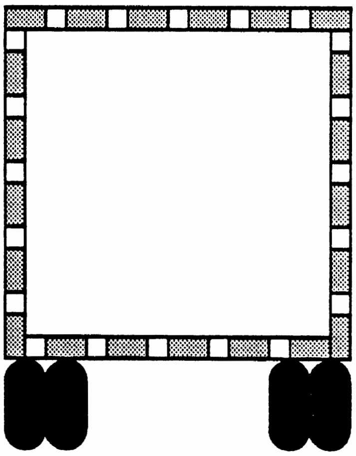
Side Treatment Without Center

Figure 3.7 Schematic representation of treatments on test trailer.

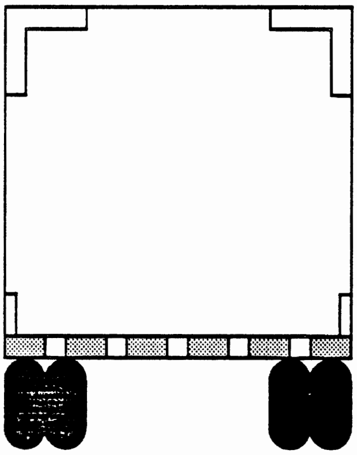
Treatment Values



Frame Rail



Rear-full outline



Rear-partial outline

Figure 3.7 (continued)

3. Frame rail treatment, prismatic material. This treatment was also identical to number 1, except that the SIA of the white and red areas averaged about 1000 and 300, respectively.

4. Frame rail treatment with 20-inch gaps. This treatment was identical to number 1, except that alternate sections of the 12-8 pattern were covered to simulate the effect of using only half as much material.

5. Frame rail treatment with 40-inch gaps. This treatment was also identical to number 1, except that for every section of the 12-8 pattern that was exposed, the next two sections were covered.

6. Side treatment with center marking. Frame rail treatment as in number 1, supplemented by a 12-inch upward extension at each bottom corner, plus a right-angle marker at each top corner extending 12 inches in each direction, plus a 3-foot long bar in the center along the top of the trailer. All the supplements were in white.

7. Side treatment without center marking. Identical to number 6 except the top center marker was eliminated, and the two top corner markers and the bottom upward extensions were increased to 18 inches in each direction, and used a red and white pattern.

8. Rear, full outline. This was displayed in the center of the trailer, using four of the strips from treatment 1 to make a square outline 8 feet on a side.

9. Rear, partial outline. This treatment used the 8-foot bottom treatment, as in number 8, but only the right-angle corner markers at the top, as in number 6.

Stand treatments. Since it was necessary to return the test vehicle and subjects to the far end of the track at the start of each trial with the trailer, there was an opportunity to collect additional data. It was decided that this period would be used to gather additional information on the visibility gains associated with increased levels of material SIA, and to evaluate a treatment employing acrylic reflex reflectors. These treatments were placed on a stand on the right shoulder at the other end of the track from the trailer. They included the five treatments from the hazard identification study described in Chapter 2, along with three other treatments of interest. Each of these displays was 7 feet long and, with one exception to be noted, 2 inches wide. The average SIA values of the treatments from the hazard identification study were 110 and 30 for the white and red respectively. The specific displayed treatments were:

1. Solid white bar.

2. "Standard" treatment, consisting of two 2-inch diameter reflectors made using a prismatic sheeting having an SIA of 300.

3. Broken red and white bar. Twenty inches of red and white pattern (12 inches red and 8 inches white), followed by a 20-inch blank.

4. Broken white bar. Eight inches of white material followed by a twelve-inch blank every 20 inches.

5. Solid red-and-white bar. Continuous 12-8 red-and-white pattern repeated for 7-foot length of the treatment.

6. Same as number 5, using encapsulated lens (type III) material having an average SIA of 315 and 70 for the white and red areas, respectively.

7. Same as number 5, using a prismatic material having an average SIA of 1000 and 300 for the white and red areas respectively.

8. Same as number 5, using reflex reflector strips. As supplied by the manufacturer these strips had an effective area 1 inch wide and 17 inches long. For purposes of this study the strips were cut to be 12 and 8 inches long for the red and white, respectively, so they would exactly match the patterns created using reflective tape. The width stayed at 1 inch, half that of the other treatments.

Treatment Values

Subject age. Two groups of subjects participated in the study. One group consisted of ten persons in the age range of 20-40. The second group consisted of eight persons 65 years and older. Half were male, half were female, although sex was not an independent variable.

Dependent Variable

The dependent variable was the distance from the display at which the subject indicated he/she could see it.

Equipment

The car in which the subjects rode was the same one used in other visibility studies described in this report. Its characteristics have been described in detail in Chapter 2. For purposes of this test the car was equipped with filters over the headlamps that reduced their output to 2.5 percent of total output.

The material used on the trailer was attached to pieces of 1/2-inch plywood, 6 inches wide and 8 feet long. The plywood was first painted a 12 percent gray before the material was attached to it. Hooks were fastened at appropriate points around the side of the trailer to support the plywood strips. To make the 40-foot display, five pieces of plywood were hung end to end on the side of the trailer. Other pieces were hung along the top as required to make the various configurations.

Test Facility

The study was carried out on a service road at an airport. The road is approximately 2,500 feet long, flat and straight. It is paved with asphalt, and consists of two 12-foot lanes with gravel shoulders. The road is in a very dark area.

Procedure

Subjects were run in groups of three. An experimenter drove the car while the subjects were seated one in front on the right side and two in the back. Each subject was provided with a box on which were a number of push buttons. To start the study the test car with the subjects in it was driven to the end of the track furthest from the trailer. This was done without the headlamp filters in place. On the way down the experimenter pointed out the display at the far end of the track to the subjects. Once turned around and facing the trailer the experimenter read the instructions (see Appendix B). Basically the subjects were told to press any one of the buttons on the box when they could see the display they were approaching. Without the filters in place the display could be seen from the start position. Questions were answered at this point, the filters were installed, and two practice runs given before the test proper started.

Two replications of each configuration were run. The display was changed for each trial. The order of presentation was established to simplify the process of changing configurations for the individuals responsible for that chore. There were two such orders. Half the subjects saw one order, half the other.

The subjects were driven toward the trailer at a speed of 30 mph. When each subject detected the display he/she pressed a button, starting a counter on a box next to the driver. When the car reached the end of the road the experimenter put the counters in hold, turned the car around, stopped, wrote the numbers on a sheet of paper, reset the counters, and started the run toward the other display. In the meantime the display on the trailer was being changed. The process for setting up the display at the end of the track opposite the trailer was the same, except that, after writing down the results of the run, the driver got out and changed the display. He then reentered the car and drove toward the trailer again. This process was repeated for the eighteen round trips necessary to complete the test. The study required about 75 minutes for each group of subjects.

Results

The results of this portion of the study are summarized in Table 3.8. This table presents the mean detection distances recorded, with headlamp filters in place, for each test configuration by each subject group, as well as the total for both groups. These data were subject to ANOVA, the results of which showed that both the age and treatment effects were significant ($p < 0.01$). Post hoc tests (Student-Newman-Keuls) were conducted on the treatment effects. These results will be described together with the visibility distance data.

For most treatments displayed on the trailer, the relative measured visibility distances seem reasonable. That is, increasing

TABLE 3.8
Mean Distances Recorded in Detection Distance Study

	Configuration	Young Subjects Distance(ft)	Young Subjects S.D.	Older Subjects Distance(ft)	Older Subjects S.D.	Total Distance(ft)	Total S.D.
Trailer	1. Frame Rail	829	217	602	160	728	223
	2. Frame Rail (Encapsulated Lens Material)	1112	256	864	219	1002	268
	3. Frame Rail (Cube Corner Material)	1656	497	1218	379	1461	494
	4. Frame Rail (20 inch Gaps)	754	198	485	177	634	231
	5. Frame Rail (40 inch Gaps)	694	199	435	129	579	213
	6. Side Treatment with Center	883	186	690	202	797	214
	7. Side Treatment without Center	811	242	664	265	746	260
	8. Rear Full Outline	685	182	492	185	599	205
	9. Rear Partial Outline	701	193	475	171	601	214
Stand	1. Solid White Bar	904	300	577	174	758	298
	2. "Standard" Treatment	435	231	190	190	326	244
	3. Broken Red-White Bar	663	201	440	146	564	209
	4. Broken White Bar	691	191	491	189	602	213
	5. Solid Red-White Bar	804	258	550	133	691	245
	6. Solid Red-White Bar (Encapsulated Lens Material)	1160	333	823	225	1011	333
	7. Solid Red-White Bar (Cube Corner Material)	1539	474	1067	324	1329	473
	8. Solid Red-White Bar (Reflex Reflector)	1167	309	794	231	1001	332

Note: Distances measured with filters over headlamps.

the material SIA (comparing treatments 1, 2, and 3) increased visibility distance. All of these differences were found to be significant ($p < 0.05$). Treatments 1 and 3 represent an approximately tenfold difference in SIA. The measured mean visibility distances differed by about 100 percent. This is the same visibility distance improvement found when comparing the same materials in a study of highway sign conspicuity (Olson, 1988). Reducing the amount of material by 50 percent (comparing treatments 1, 4) reduced measured visibility distance about 10 percent. Reducing the material to one-third of a full treatment (treatment 5) reduced measured visibility distance about another 10 percent. Neither of these differences was significant ($p > 0.05$), however.

Neither of the two side treatments providing partial outlines (treatments 6 and 7) resulted in a significant improvement in detection distance over the frame rail treatment alone ($p > 0.05$). The possible value of these configurations as an aid in assessing distance and/or closing speed is addressed in Chapter 2 of this report.

The two rear treatments (treatments 8 and 9) differ by only 1 foot in mean measured visibility distance, and obviously do not differ statistically ($p > 0.05$). Given the considerably greater amount of material employed in treatment 7, this was surprising.

The relative visibility distances of the first five treatments on the stand correspond approximately to those recorded for the same treatments in the hazard identification study. The distances measured for the solid red and white (treatment 5) do not differ significantly ($p > 0.05$) from those measured for the broken red and white (treatment 3), the broken white (treatment 4), and the solid white (treatment 1). As in the case with the treatments on the trailer, a tenfold increase in SIA (comparing treatments 5 and 7) produced an approximate doubling of visibility distance. The reflex reflector (treatment 8) was detected at a mean distance almost exactly the same as that using the encapsulated lens material (treatment 6). The difference in measured visibility distance is not significant ($p > 0.05$). This suggests that the reflex reflector has an equivalent SIA double that of the encapsulated lens material (since the reflex reflector display was only half the width), or 630 and 140 for the white and red areas, respectively.

Treatment Values

FILTER CORRECTION STUDY

The primary purpose of this investigation was to develop a correction for the data collected in the minimum reflectivity study. This was done by measuring visibility distance on a limited number of reflective treatments with and without the headlamp filters in place. The test treatments were positioned at the same end of the track as occupied by the stand treatments in the first study, and used two of the same stimuli.

In the first part of this investigation data were collected on the relative performance of linear reflex reflectors so that they could be included in the specifications. The treatments could also be created using round reflex reflectors of the type commonly employed as markers on trucks. To evaluate this approach a sample treatment was made up using round reflex reflectors, and its visibility was evaluated relative to treatments using sheeting materials having different SIA values. These treatments were placed at the other end of the track in the position previously occupied by the trailer.

Independent Variables

Two treatments from among those used on the stand in the initial investigation were employed. These were the broken white and broken red and white displays (treatments 3 and 4 on the stand in the first study). They were viewed with and without filters over the headlamps.

Four treatments were used on the display at the end of the track where the trailer had been located. These consisted of three 7-foot by 2-inch strips of reflective sheeting, such as had been used in other displays, and a treatment made using round reflex reflectors. Three levels of SIA were used in the sheeting treatments, i.e., types II, III and prismatic materials, the same as treatments 1, 2, and 3 employed on the trailer in the first study. Each of these used a 12-8 red-white pattern.

The reflex reflectors were Grote 4002s. These were circular and had an effective diameter of 2.25 inches. There was a blank spot in the middle of each reflector that was 0.5 inch in diameter. The reflectors were placed on the board using three red followed by two white in a 20-inch space to equal the 12-8 red-white sheeting pattern. With this approach the average distance between the effective areas of the reflectors was 1.75 inches.

Procedure

The procedure was basically the same as employed in the first study. An experimenter drove the test car. Three subjects were run at one time, one seated in the right front, the other two in the rear. The instructions (see Appendix B) required them to look for the display and press a button when they could detect it. This action started a counter, which was stopped by the experimenter when the display was passed. The displays were changed for each trial, but always remained in the same place.

Half the runs toward the stand treatments were made with the filters in place, half without. All runs toward the display which included the reflex reflectors were made using the filters.

Five subjects participated in the study. Sixteen round trips were scheduled, giving a total of four measures for each condition. With time for instructions and one practice run, the test took about one hour.

Results

Table 3.9 gives the results for the filter-no filter comparison. Averaged across both treatments, the displays were seen at 4.3 times greater distance without the filters over the headlamps. This is the factor that was applied to the results of the first investigation to correct for the effect of the filter.

Table 3.9
Mean Detection Distances (in feet) as a Function of
Treatment and Filter Condition

	Filter Condition	
Treatment	**Filters**	**No Filters**
Broken White	268	1261
Broken Red and White	277	1084
Mean	273	1173

Figure 3.8 is a plot showing mean visibility distance as a function of weighted average SIA of the materials employed (i.e., the average of the SIA of the white and red areas, allowing for the different amounts of each). The mean visibility distance of the display using round reflex reflectors was 650 feet. Thus its performance is equal to a display using 2-inch-wide tape having a weighted average SIA of 250. The performance of the display using the reflex reflectors was appreciably better than the Type III material with a weighted average SIA of 170, but significantly less than the prismatic sheeting with a weighted average SIA of 580.

The equivalent SIA noted for the round reflex reflector treatment is specific to the units and the configuration tested. No effort was made to sample the products of other manufacturers. All other factors being equal, changing the size of the units or their spacing would affect the amount of light returned to the observer and, therefore, the visibility distance.

Implications

The main purpose of this investigation was to develop data that could be used to establish minimum SIAs for reflective treatments. Thus, it was necessary to convert the results into a form that would be useful to that end.

What was desired was determining a value of SIA that represented the minimum that would allow detection at a safe distance by the majority of drivers under realistic conditions. This requires consideration of a number of variables. The issues will be discussed in some detail in Chapter 6, "Recommendations." The analysis presented here represents a first step only.

Figures 3.9, 3.10, and 3.11 are percentile plots of the detection distances measured with type II, type III, and prismatic materials, respectively. The data have been corrected for the effect of the headlamp filters and represent the performance anticipated from a baseline configuration such as treatments 1, 2, and 3 in the minimum reflectivity values study described earlier.

As a next step it would be useful to prepare a plot showing detection distance as a function of SIA. A relatively high percentile value should be used for this purpose, to ensure that a large fraction of the driving population is included. In this case the 85th percentile

Treatment Values

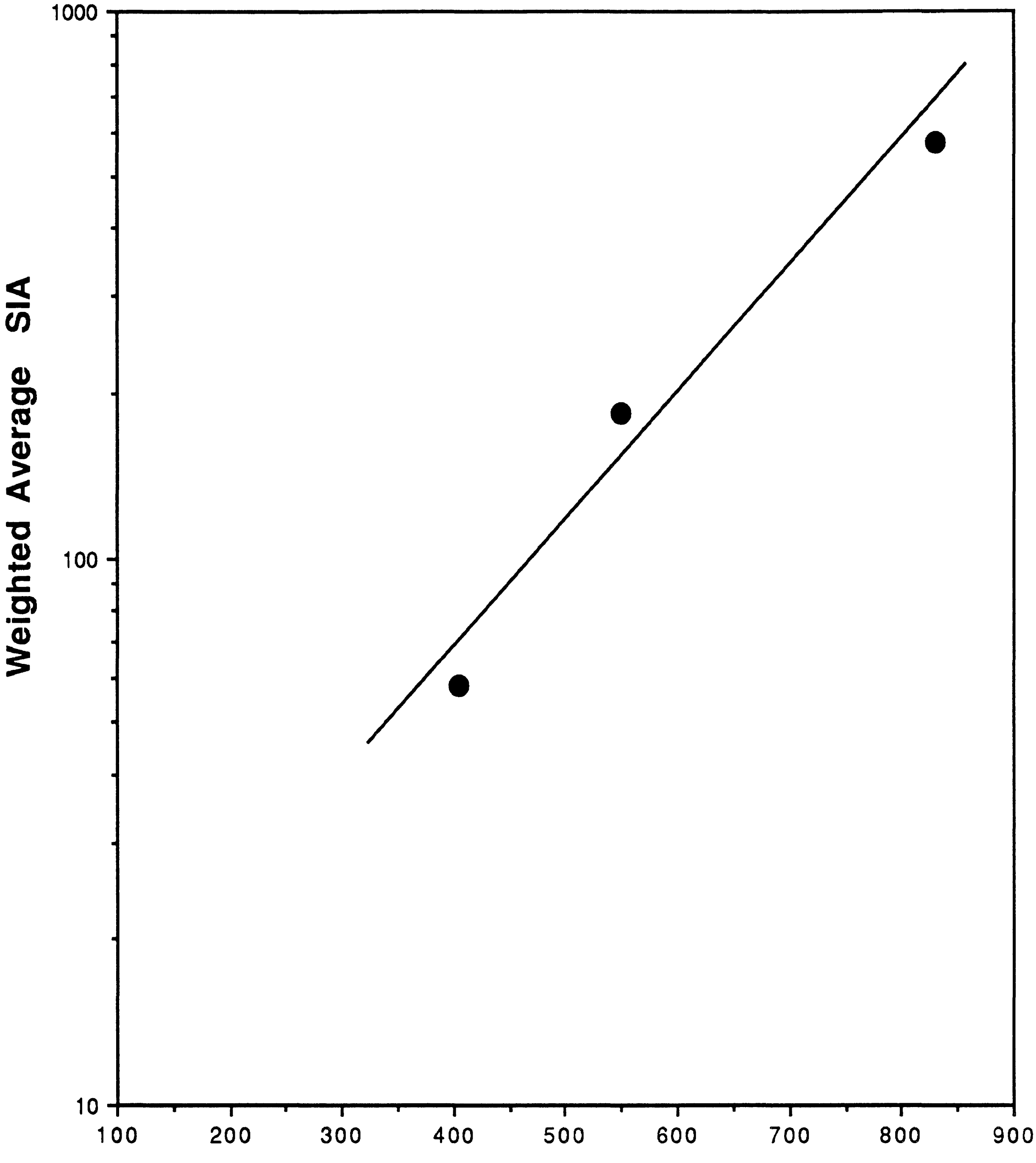


Figure 3.8. Relationship between SIA and visibility distance.

was used to establish detection distances. Figure 3.12 is a plot of 85th percentile detection distance as a function of weighted average SIA for three materials. The line on the right side of the figure, labeled "alerted data," is derived from Figures 3.9 through 3.11. These detection distances range from 1,900 to 3,700 feet for the type II and the prismatic materials, respectively. These data, obviously, apply to test conditions in which the subjects knew what they were looking for, and about where it was located. It would be expected that their performance would generally exceed that of individuals who did not have that knowledge. An appropriate correction for this state of awareness, based on the data of Roper and Howard (1938), is to reduce the visibility distances by 50 percent. This results in the second line in the figure, labeled "corrected for expectancy." Now the visibility distances range from 900 to 1,800 feet. This information forms the foundation for the recommendations to be derived from this program.

Treatment Values

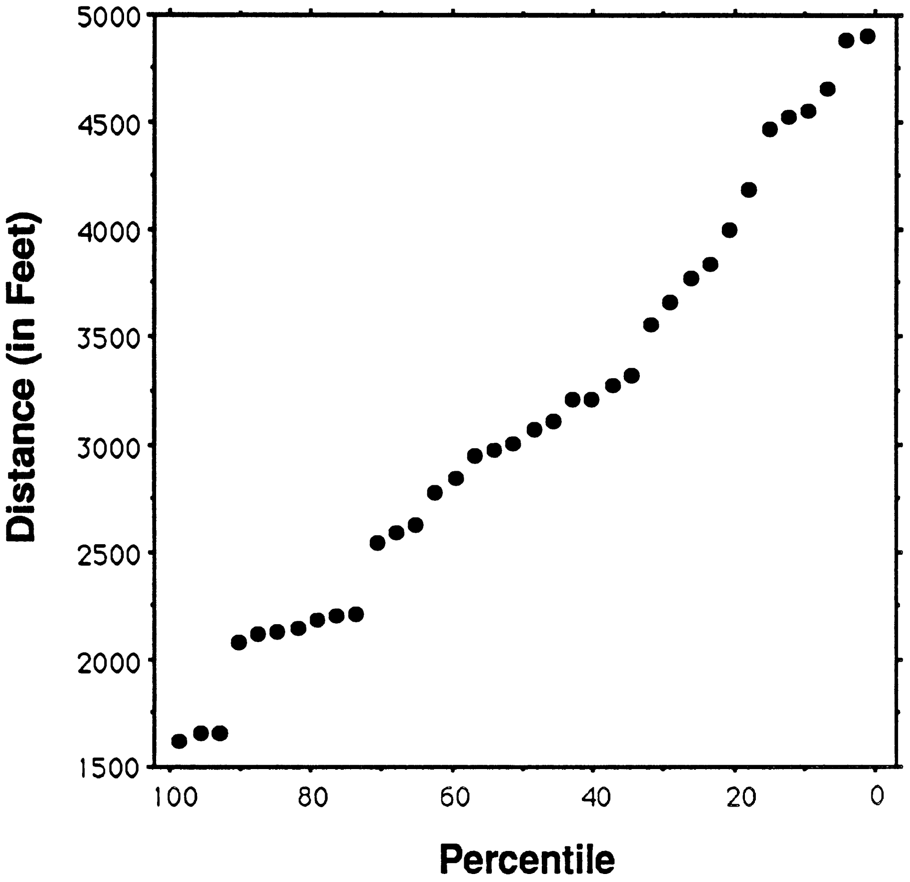


Figure 3.9 Percentile Plot of Detection Distances Measured Using Treatment with Type II Reflective Material.

Treatment Values

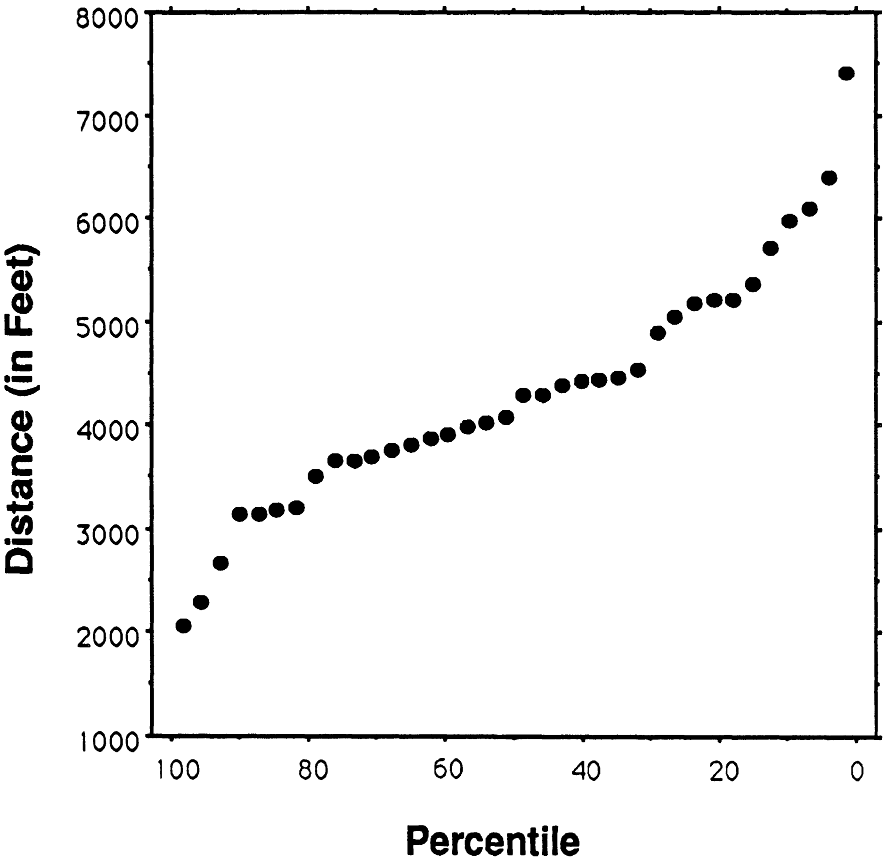


Figure 3.10 Percentile Plot of Detection Distances Measured Using Treatment with Type III Reflective Material.

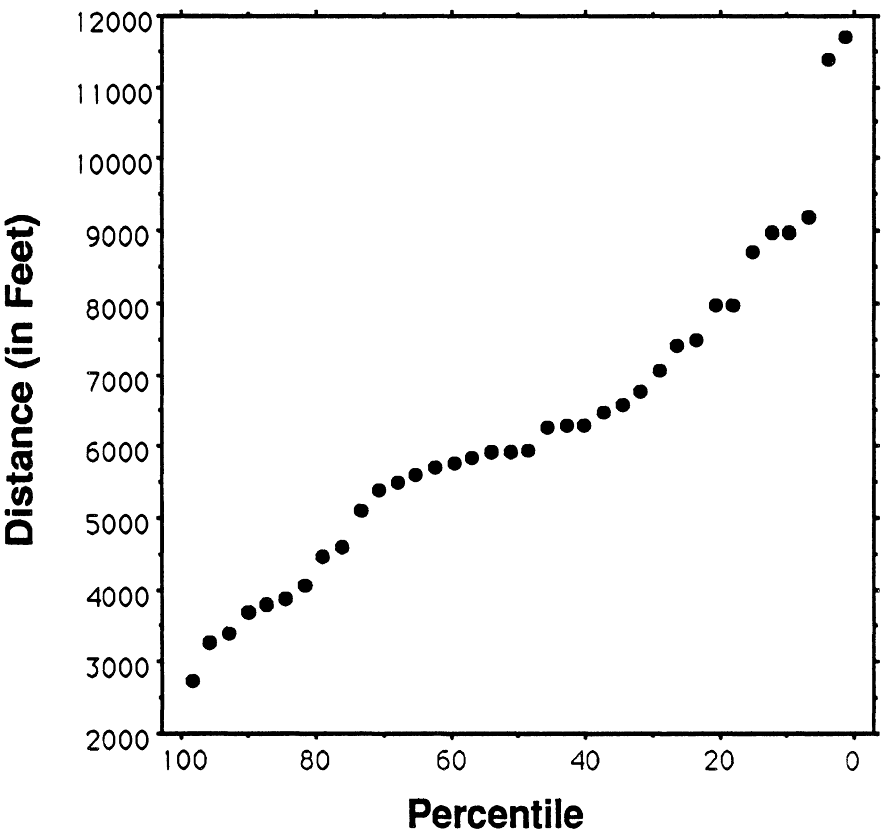


Figure 3.11 Percentile Plot of Detection Distances Measured Using Treatment with Prismatic Reflective Material.

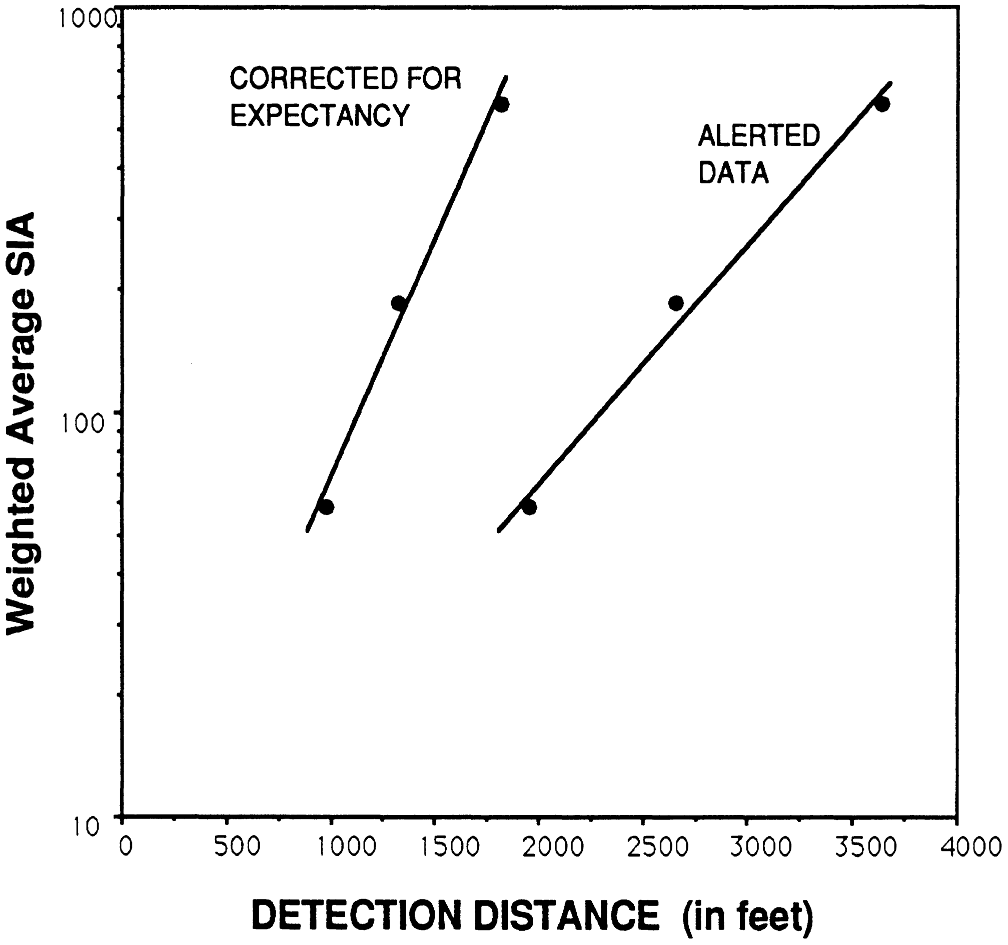


Figure 3.12. Plot of 85th percentile detection distances as a function of material SIA.

4 TREATMENT CHARACTERISTICS

This section of the report describes two investigations that were carried out to address the following questions:

1. What effect does changing treatment width have on visibility distance?

2. How close to stop and turn signal lamps can reflective material be placed without reducing their conspicuity?

THE RELATIONSHIP BETWEEN MATERIAL WIDTH, SIA, AND DETECTION DISTANCE

Introduction

Proposals concerning the use of retroreflective markings on large vehicles have considered different widths. For example, current recommendations from the SAE suggest a minimum width of 1.5 inches. The recommendations of the Vector study (Ziedman et al., 1981) were for 4 inches, although their field study results are based on treatments using 2-inch width. Some trucks on the road have barricade-design treatments on the rear that appear to be 12 to 24 inches wide.

It seems evident that the conspicuity of a treatment would be affected by its width, as well as material SIA. This was recognized during the performance of the NHTSA contract on truck conspicuity by Vector Enterprises. A study was carried out as part of that contract (Ziedman and Mulholland, 1982) to investigate this relationship. This investigation was carried out statically, at a simulated viewing distance of 233 feet. Subjects were asked to adjust the luminance of one treatment until it was as conspicuous as another next to it.

Figure 4.1 shows the relationship between treatment width and luminance to achieve equal conspicuity, based on the results of the Ziedman and Mulholland investigation. The data suggest that width matters very little for treatments more than 4 inches wide. On the

the other hand, the luminance of a one-inch treatment must be about double that of a two-inch treatment to achieve equal conspicuity.

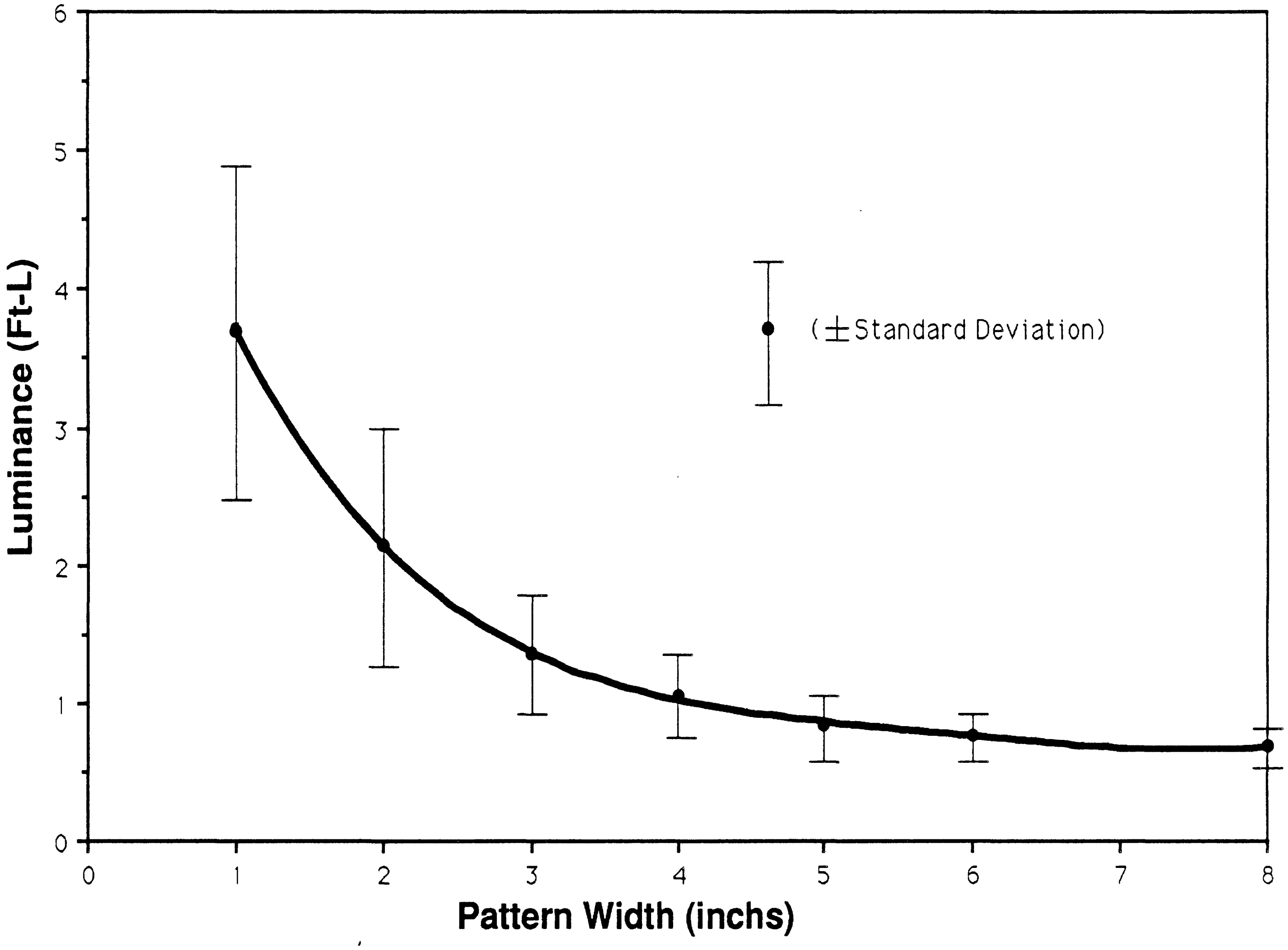


Figure 4.1 Treatment conspicuity as a function of material width.
From: Ziedman-Mulholland, 1982.

The fact that the test was static, and run at only one viewing distance raises some concerns. The angular width of the treatments at 233 feet ranged from 0.02° to 0.16°. One question about the data arises from the fact that the perception of the brightness of a surface is affected by whether it is seen as a point or area source. With a point source the perception of brightness is based on the total amount of light returned; with an area source the perception of brightness is based on the luminance per unit area. As an example, if two white cards of different size are viewed close up they will appear equally bright. If everything remains the same, but the observer is moved far enough away so that both cards become point sources, the larger card will appear brighter because it reflects more light. The angular sizes used by Ziedman and Mulholland spanned from what should clearly be point sources to marginal area sources. The results are consistent with what would be expected from mixing point and area sources.

Given this concern, the question now becomes how relevant these data are to detecting treatments under real-world operating conditions. To address this issue another study was conducted, using a detection-distance criterion.

Method

Independent Variables

Material SIA. Three levels of material SIA were used, as provided by prismatic, encapsulated-lens (type III), and enclosed-lens (type II) sheeting. All the materials were white. The average SIA of the three materials (at 0.2° and -4°) was 1,000, 290, and 120, respectively.

Material Width. There were four levels of the width variable: 2, 4, 8, and 16 inches.

Dependent Variable

The dependent variable was the distance from the treatment at which it was detected by the observers.

Treatment Characteristics

Equipment

The reflective treatments were attached to plywood panels seven feet long. These were placed horizontally on stands four feet from the ground. Subjects were presented with the stimuli while riding in a station wagon which was equipped with distance measuring equipment, subject response recording equipment, and a voltage control system for lighting, as described earlier. The headlamps used in the test were large rectangular, non-halogen sealed beams.

The test was conducted on a road located on the property of a large airport. The road is newly constructed, paved with asphalt, flat and straight, and 2,600 feet long. There are two 12-foot lanes, with grass and gravel shoulders. The area surrounding the test site is very dark.

During pilot testing it became apparent that many of the stimulus materials could be seen from one end of the track to the other. To remedy this problem various alternatives were tried. Finally, the test was run using only one headlamp, reduced to about 20 percent of normal output by means of a neutral density filter. This was the minimum level of illumination at which subjects felt comfortable operating the test car at the required speed. As will be seen shortly, however, even this modification did not completely solve the problem.

Stimulus materials were located on the right shoulder at either end of the facility. They were in the care of experimenters whose responsibility it was to have the proper display in place for each run. The materials were moved from one end of the facility to the other for alternate groups of subjects to balance out whatever location effects may have been present.

Subjects

A total of 16 subjects completed the test. A mix of older and younger subjects participated, ranging in age from 24 to 75. Ten were female, six were male. Neither sex nor age were independent variables in this study.

Procedure

Subjects were run in groups of three. They reported to the Institute and were transported to the test site. One was selected to drive, the others rode in the front seat. Each was given a box having a silent push button on it. The subjects were told that the study was in the context of markings on large vehicles. They were instructed to press the button when they could detect the markings located on their right at each end of the road (see subject instructions in Appendix B). Two practice runs were given, one in each direction. Any questions were answered and the test started.

On each run the driver accelerated to the recommended speed of 35 mph and drove in the right lane toward the far end of the track. When the treatment was detected each subject pressed his/her response button. These actions started digital counters (one for each subject), which were stopped by the experimenter in the back seat as the treatment was passed.

The levels of the independent variables made a total of 12 stimuli. Each was viewed by each subject three times in a random order, making a total of 36 runs. With time for instructions and practice trials, the test was typically completed in 60-70 minutes.

Results

Although the headlamp illumination from the test vehicle was reduced to the maximum extent deemed feasible, it was apparent that many of the subjects could detect the 8- and 16-inch prismatic and the 16-inch encapsulated treatments at the maximum distance available (2,600 feet). Some subjects could detect the 8-inch encapsulated lens treatments, and a few subjects could detect the 16-inch enclosed lens treatments at the maximum distance as well. The result was a "ceiling effect," which is apparent in the data shown in Figure 4.2.

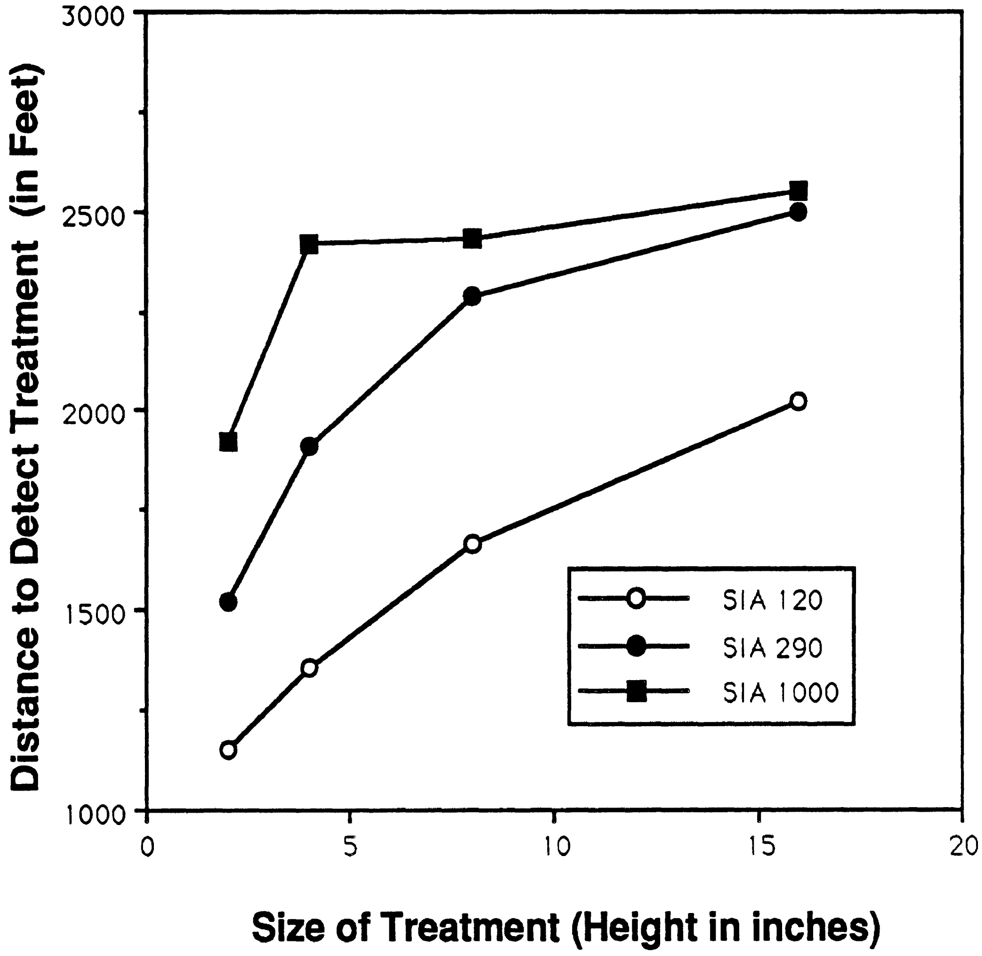


Figure 4.2 Detection distance as a function of type and width of reflective material employed.

Despite the ceiling effect, the data are generally consistent with a hypothesis that detection distance was a function of the total light returned from the treatment. This can be seen by comparing materials of different widths, taking into account the differences in SIA. For example, the encapsulated-lens material had an SIA 2.4 times greater than the enclosed-lens material. Thus, a 2-inch strip of encapsulated-lens sheeting will return about the same amount of light as a 5-inch strip of enclosed-lens sheeting. In these data the 2-inch encapsulated-lens strip was equal to a 6-inch enclosed-lens strip. Similarly, the prismatic material had an SIA 8.3 times greater than the enclosed-lens material. Thus, a two-inch prismatic strip will return about the same amount of light as a 17-inch enclosed-lens strip. In these data the 2-inch prismatic strip was equal to a 14-inch enclosed-lens strip.

Discussion

There is certainly variability in the data, but it seems clear that the subjects were responding as though all the treatments were point sources. This is not surprising, even the 16-inch strip subtends only 0.04° at 2,000 feet. This is equivalent to the 2-inch strip in the data from Ziedman and Mulholland, a size at which subjects were behaving as though the treatments were point sources.

In sum, at distances of concern in truck conspicuity, the effectiveness of markings is a straightforward function of material SIA and treatment width. If 4 inches is taken as a "standard" width for example, a 1.5-inch treatment would have to have an SIA 2.7 times higher to have comparable performance. For all practical purposes, this is equivalent to stepping up one grade of material. Thus, if type II material was deemed satisfactory in 4-inch width, type III material would be required for a 1.5-inch width treatment.

THE EFFECT OF CONSPICUITY-ENHANCING MATERIALS ON THE PERCEPTION OF STOP AND TURN SIGNALS

Introduction

Since the application of conspicuity-enhancing materials will likely take place in areas of a trailer where active lighting systems operate, it is important to examine the implications of placing these materials in close proximity to such lighting. In particular, the presence and function of brake and turn signal indications should not be masked by the enhancement materials. Clearly, the placement of high-efficiency reflective surfaces near such signals will likely reduce their contrast and, possibly, their effectiveness. If the response time to stop and turn signals is increased by the addition of conspicuity-enhancing materials the result could be a net loss in terms of overall safety.

The recommendations of the Vector study of truck conspicuity (Ziedman et al., 1981) included keeping reflective materials 6 inches or more away from stop and turn signals. It is not clear what this recommendation is based on. Given the potential importance of this question, and the absence of research to provide guidance, a study was carried out to determine how close reflective materials could be placed to signal lamps without interfering with their effectiveness.

Method

Independent variables

Distance from the signal. Four levels, 1, 2, 4, and 6 inches between the bottom edge of the treatment and the top edge of the signal lamp. Control data were also taken with no reflective material present.

Material SIA. Three levels, provided by enclosed-lens (type II), encapsulated-lens (type III), and prismatic sheeting. The approximate SIAs were as follows:

	RED	WHITE
Type II	30	120
Type III	100	300
Prismatic	300	1000

Under the conditions of the test these materials produced luminance levels (in cd/m^2) as follows:

	RED	WHITE
Type II	18	60
Type III	59	150
Prismatic	150	527

Signal color. Both stop and turn signals were presented. Turn signals stimuli included both yellow and red signals.

Treatment width. Two levels, 2 and 4 inches. Most data were taken with the 2-inch material. Two distances from the signal (1 and 2 inches) were run with the 4-inch width using type II material.

Treatment Characteristics

Color next to the signal. Two levels, red or white next to the signal. Most data were taken with red next to the signal. A limited amount of data were taken with white next to the signal, using two SIA levels (type II and III material), positioned 2 inches from the signal.

Ambient illumination. The study was run under daytime conditions, and at night with illumination provided by the low-beam headlamps of the vehicle in which the subjects were seated. SIA was not a variable in the daytime study.

Dependent variable

Time was measured from the onset of the stop or turn signal until the subject responded by pressing a button.

Subjects

Twelve subjects participated in the daytime study, eleven in the nighttime study. These were licensed drivers whose ages ranged from 21 to 75.

Equipment

A plywood panel, 4 feet wide and 3 feet high served as the background for the lights and conspicuity displays. The panel was supported on legs so that its lower edge was 3 feet above the ground. The entire structure was painted a uniform gray of 12 percent reflectivity. A 4-inch-diameter red lamp using a two-filament bulb was used to present the stop and red turn signals. A yellow lamp of the same size with a single filament bulb was used to present the yellow turn signals. The lamps were positioned at the lower left-hand corner of the background panel (as viewed by the subjects), with a center-to-center separation of seven inches. The presence filament of the red lamp was continuously on during the night portions of the study.

The retroreflective material was attached to strips of hardboard, 1/8th inch thick, 4 feet wide and 4 inches high. Two feet of red material was attached on one end and 2 feet of white on the other. These strips could be adjusted up or down in 1 inch increments.

Treatment Characteristics

The intent was to establish a worst-case scenario for the test, i.e., with the lamps producing minimum output and the reflective material producing maximum or near-maximum luminance. To accomplish this the voltage to the signal filament of each lamp was adjusted to yield outputs at the minimum established for such lamps (i.e., 80 cd for red and 120 cd for yellow, both at H-V). In addition, the separation distance between the car and the display was selected to achieve near-maximum luminance of the retroreflective material. Based on work done earlier in this project, and reported in Table 3.6, maximum luminance would be obtained at a separation of about 500 feet, with a rapid fall-off at distances of less than 300 feet. The separation selected for this study was 340 feet, which placed the vehicle at a distance where display luminance was near maximum, but a sudden brake application by a lead vehicle would be more of a potential problem than at 500 feet.

Procedure

Subjects were run three at a time. They were positioned in the front seat of a full-size station wagon. The vehicle had standard US-type low beams (halogen). Headlamp aim was checked before the study started. An experimenter was in the back seat of the vehicle. His responsibility was to read the instructions, monitor performance, operate the timers, and note the response times for each trial.

Subjects reported to the Institute, signed consent forms, and were seated in the test vehicle. The experimenter took his seat in the rear and read the instructions (see Appendix B). The subjects were told to look at a street lamp that was about 1,000 feet away and separated from the display by about 2°. When they could detect a signal from the board they were to press a button. The subjects were not asked to differentiate stop from turn signals. The concern was that the delay required to determine whether the lamp was flashing (at least in the case of the red lamp) could swamp differences in detection associated with the proximity of the reflective material.

The various material combinations were presented in a random order. There were a total of 15 such combinations at night, and eight during the day (due to SIA dropping out as a variable). A particular display was placed on the board and a number of response time trials run for the stop and each color of turn. Five replications were run during the day, and four at night. There would then be a short break while the display was changed. Individual trials were run at an average of about every twelve seconds. The interstimulus interval varied from about five to ten seconds.

Results

The results of the daytime study are summarized in Table 4.1. The table shows the response time for each treatment and signal type. Each entry in the table is the mean for twelve subjects and five replications. The data were subjected to a log transform and analyzed using an Analysis of Variance (ANOVA) model. The differences were found to be far short of statistical significance (p = 0.74, 0.92, and 0.63 for the stop, red and yellow turn, respectively).

Table 4.1
Mean Response Time Recorded to Signals
Under Daytime Conditions

Type of Treatment	Distance From Signal (inches)	Response Time (Second)		
		Stop	Red Turn	Yellow Turn
Blank (Control)	-	0.66	0.67	0.62
2" Wide Pattern Red Next To Signal	1	0.72	0.71	0.70
	2	0.63	0.68	0.67
	4	0.65	0.66	0.66
	6	0.69	0.69	0.62
4" Wide Pattern Red Next To Signal	1	0.67	0.68	0.69
	2	0.64	0.64	0.63
2" Wide Pattern White Next To Signal	2	0.66	0.67	0.65

Table 4.2 lists the results for the nighttime study. In this case each entry in the table is the mean for eleven subjects and four replications. These data were also subjected to a log transform and analyzed using an (ANOVA) model. The differences for the red and yellow turn signals were again found to be far short of statistical significance (p = 0.79 and 0.77, respectively). The differences for the stop signal, however, were significant at the 0.05 level. A post hoc analysis on the stop data (Student-Newman-Keuls) revealed that only the difference between the control condition and the type III

material with 4-inch spacing was significant ($p < 0.05$). This difference makes no sense intuitively, and given the lack of significance elsewhere in the data, it is probably fortuitous.

TABLE 4.2
Mean Response Time Recorded to Signals Under Nighttime Conditions

Type of Treatment	Material	Distance From Signal (inchs)	Response Time (Seconds)		
			Stop	Red Turn	Yellow Turn
Blank (Control)	-	-	0.60	0.65	0.63
2" Wide Pattern Red Next To Signal	Type 2	1	0.65	0.66	0.65
		2	0.68	0.69	0.62
		4	0.65	0.61	0.60
		6	0.68	0.65	0.61
	Type 3	2	0.67	0.70	0.63
		4	0.75	0.67	0.63
		6	0.65	0.66	0.63
	Prismatic	2	0.73	0.68	0.68
		4	0.69	0.69	0.69
		6	0.71	0.67	0.65
4" Wide Pattern Red Next To Signal	Type 2	1	0.66	0.69	0.69
		4	0.65	0.65	0.63
2" Wide Pattern White Next To Signal	Type 2	2	0.71	0.67	0.65
	Type 3	2	0.62	0.68	0.63

Discussion

The results of this investigation indicate that the placement of retroreflective material near a brake or turn signal has little or no effect on the conspicuity of the signal. While the daytime results were expected, the nighttime results were not. Given that a worst-case scenario was investigated (i.e., minimum output from the signals combined with near-maximum luminance of the retroreflective treatments), and given the appearance of the display to the investigators, the results were surprising.

The results are, however, relatively clean. There is a suggestion in the data that the brightest materials may have had some effect, since they consistently have the longest response times. Were the differences marginally nonsignificant it would have been worthwhile to collect additional data. With the p values found in the statistical analysis this was judged not to be a useful exercise.

THE EFFECT OF CONSPICUITY-ENHANCING MATERIALS ON THE IDENTIFICATION OF STOP SIGNALS

The investigation just described dealt with the effect of conspicuity-enhancing materials on driver perception-response time. There is another issue, however, that involves the effect of such treatments on the identification of stop signals. On most US-built vehicles "stop" is signaled by increasing the brightness of the presence lamps. For drivers who observe the onset of the signal there is no problem. For those who do not, identification of the state of braking requires the driver to base his/her judgment on the discrimination of a change in absolute brightness. Unfortunately, people do not generally do well with any form of absolute judgment. Research in the context of discriminating brake from presence signals makes it clear that a large brightness difference is required to ensure the reliable discrimination of brake from presence signals, even under ideal conditions (Sivak et al., 1986). Having bright surfaces near the signal source makes for a less-than-ideal condition, and may affect the discrimination of brake signals. This study was designed to investigate that possibility.

Method

Independent Variables

Signal intensity. Five levels of signal intensity were utilized,

Material SIA. Three levels of material SIA were employed, as provided by type II, type III, and prismatic retroreflective materials. The SIAs for the red areas were 24, 68, and 299 respectively. Those for the white areas were 119, 359, and 1189 respectively.

Material position. The strips of retroreflective material were placed at three distances from the signal source. The edge-to edge separations used were 1, 3, and 6 inches.

Dependent Variable

The dependent variable was the percent of times a given signal intensity was identified as "brake."

Equipment

Signals were presented by a truck brake lamp with a lens 4 inches in diameter. The lamp was mounted near the bottom of a panel 3 feet high and 4 feet wide, and supported 3 feet off the floor. The panel was covered with black velveteen to maximize contrast.

The retroreflective strips were 4 feet long and 4 inches wide. They were half red and half white. The red portion was always above the test lamp. The strips were illuminated by a 35mm slide projector placed just behind the subject at the level of his/her eyes to minimize the observation angle. The area illuminated was restricted to a rectangle measuring 2.5 feet wide and 3.0 feet high at the plane of the panel to which the lamp was attached. The subject's viewing distance was 35 feet.

Procedure

Subjects were run individually. They were brought into the laboratory, seated in a chair, and the projector used to illuminate the test strips adjusted to the proper height. The instructions were read to them (see Appendix B).

The subjects were given four opportunities to rate each combination of lamp intensity, material type, and spacing. They were given a 4-second exposure to the signal lamp. When it was extinguished they were to call out "brake" or "presence." These judgments were noted by one of the experimenters. While this was going on a second experimenter set up for the next trial. With time for instructions and some practice the entire test took less than an hour.

Results

The results of this investigation are given in Figures 4.3 through 4.5. Each of these figures shows, for a particular retroreflective material, the percent of times a given level of signal was called "brake" as a function of the separation between the signal lens and the retroreflective material. Although it is not large, there is some evidence of an interference effect from the placement of conspicuity-enhancing materials close to the signal source. This effect can be minimized by keeping the materials 6 or more inches from the signal. It is true that the effect is negligible or non-existent at signal levels in the range where brake signals are supposed to be. However, because of dirt, low voltage conditions, etc., signal intensities are sometimes below specifications.

Discussion

The results of these investigations provide some basis for a conservative recommendation that would maintain some spacing between the reflective material and signal sources. Tentatively, a minimum edge-to-edge separation of 6inches is recommended between treatment and signal source when using type III and prismatic materials. Since signal lamps are not always performing at even minimum levels, there would be some merit in keeping even type II reflective treatments separated from signal sources. Given the nature of the data, the choice of a specific recommendation for type II material is difficult, but a 3 inch edge-to-edge separation appears to be a reasonable minimum for this material.

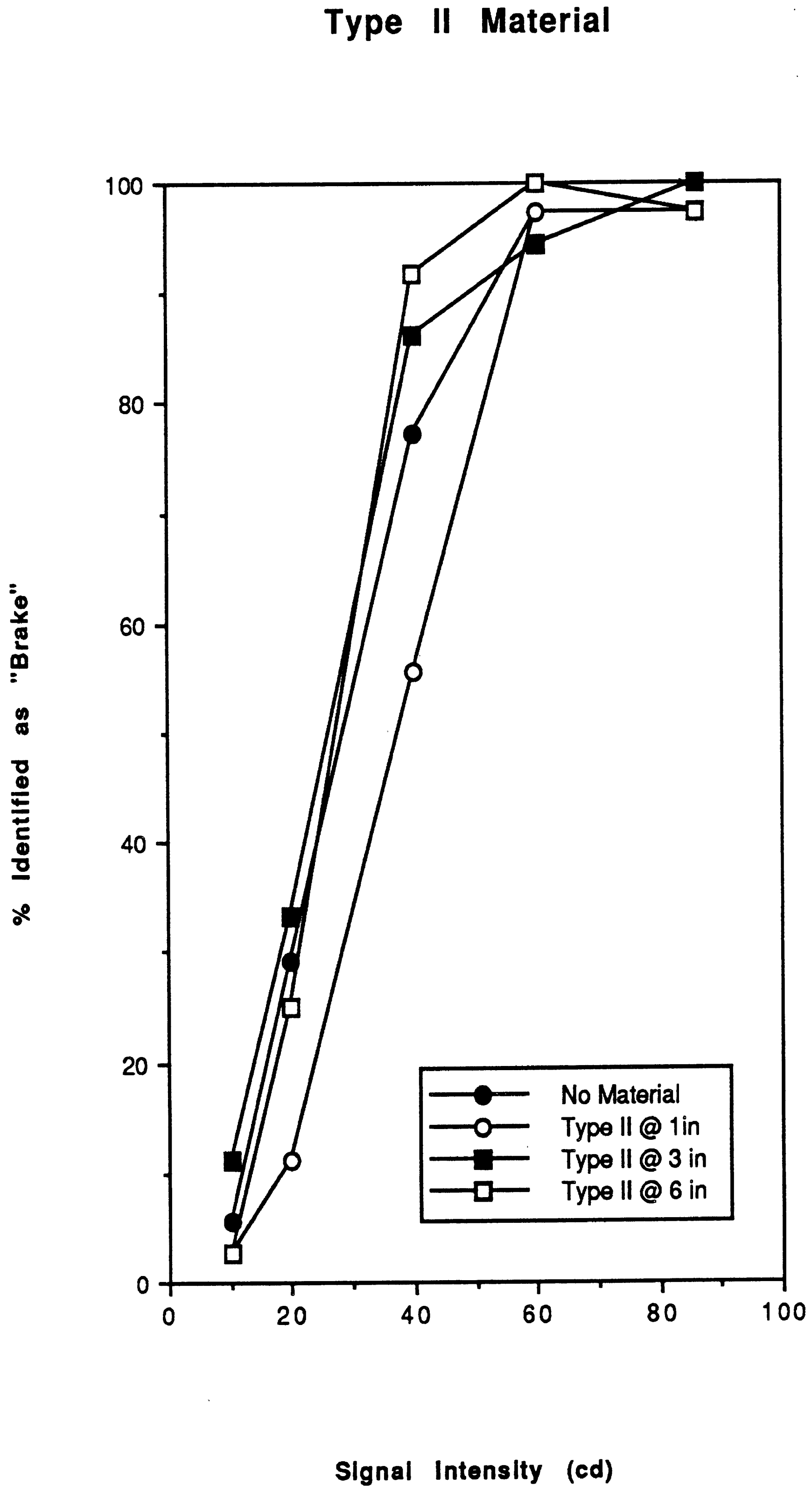


Figure 4.3. Percent of times a signal was called "brake" as a function of signal intensity and proximity of type II material.

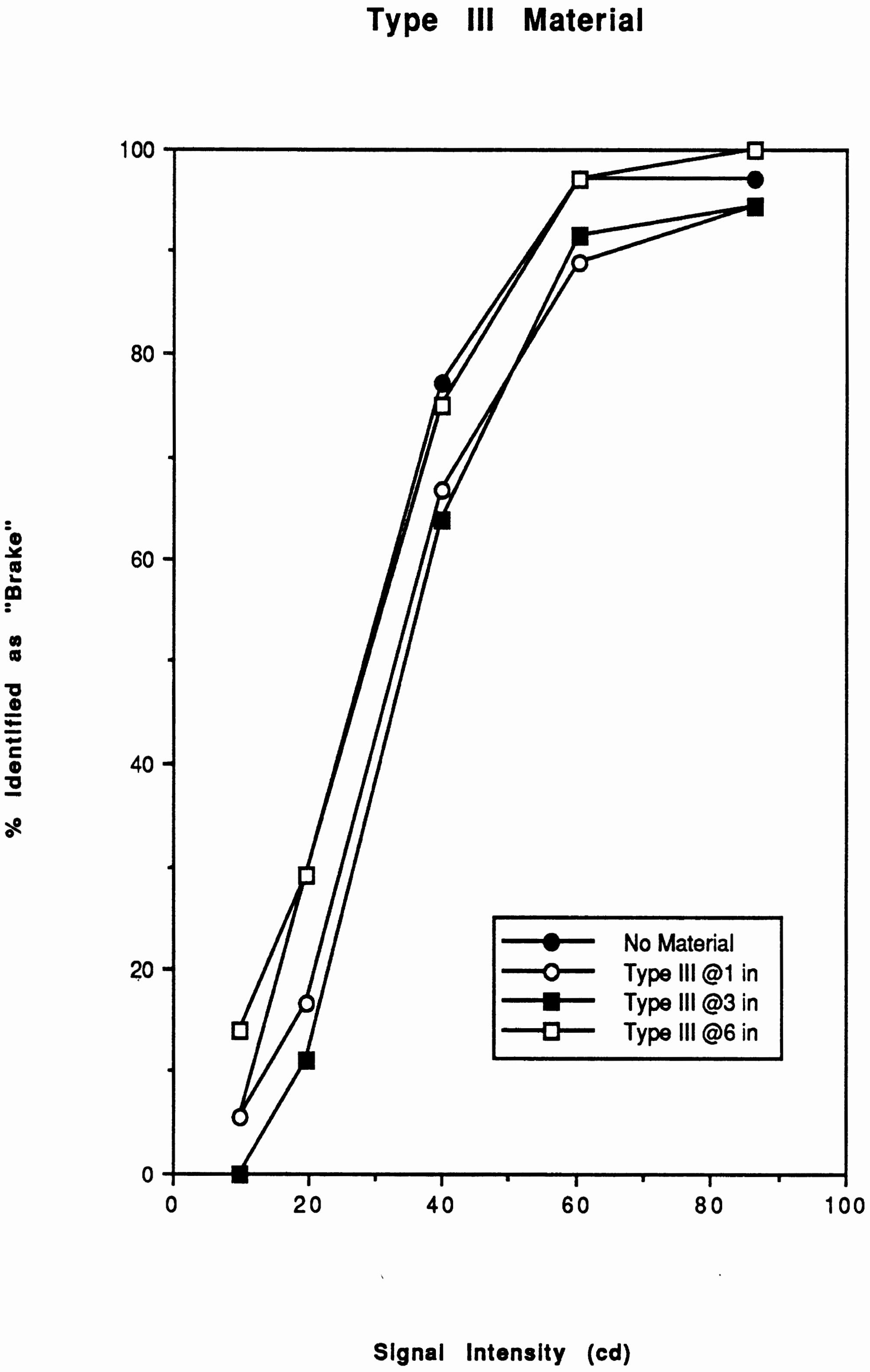


Figure 4.4. Percent of times a signal was called "brake" as a function of signal intensity and proximity of type III material.

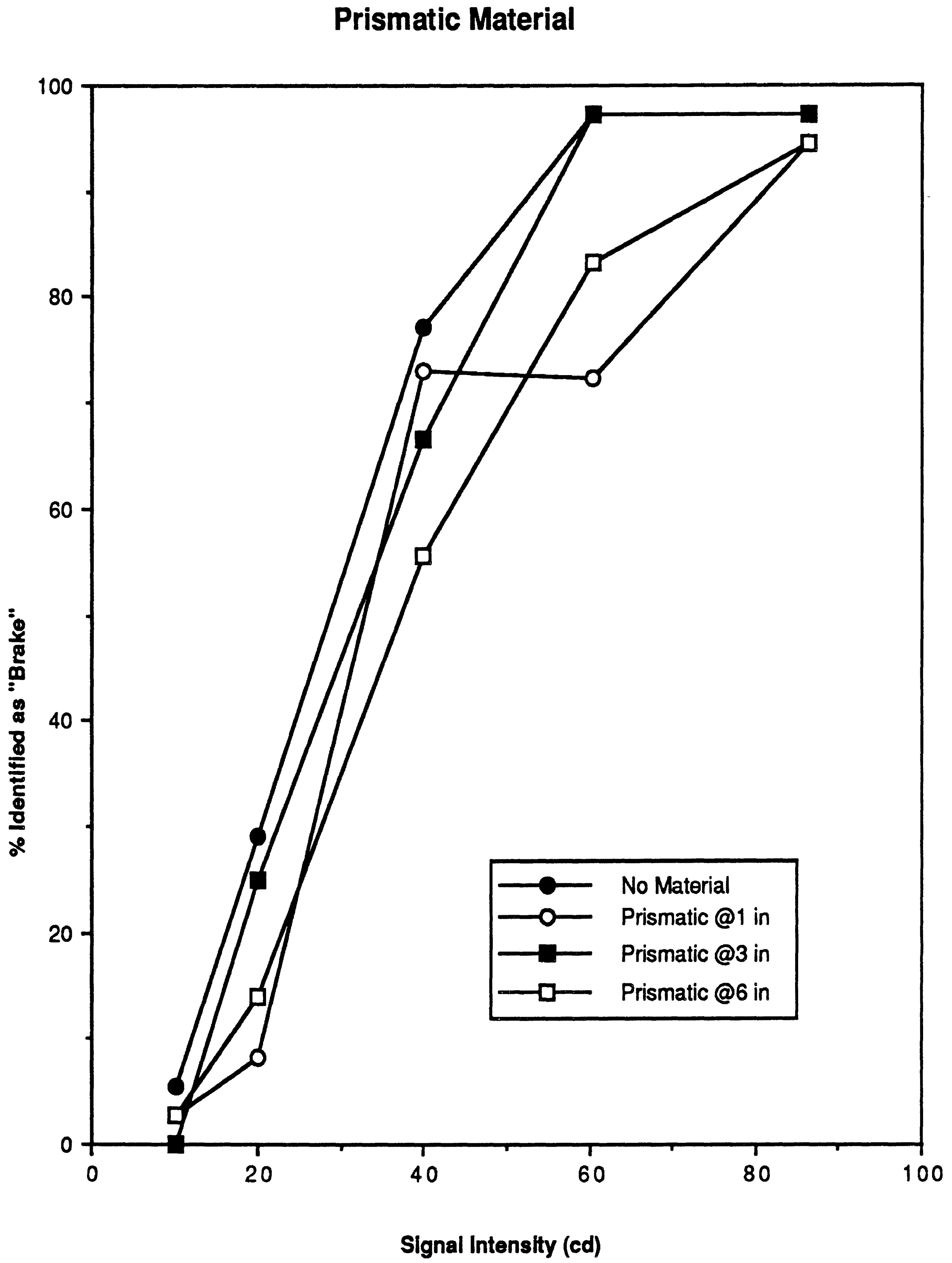


Figure 4.5. Percent of times a signal was called "brake" as a function of signal intensity and proximity of prismatic material.

5 ENVIRONMENTAL EFFECTS

One important attribute of reflective materials is how the performance of these materials changes over time. Given the harsh conditions to which these materials may be subjected, the environment can degrade their performance in two ways. First, the accumulation of dirt and grime can reduce the effective SIA of these materials. This effect is short-term and can be minimized through regular maintenance. Second, the materials may also lose reflective performance as they age, a relatively long-term problem. Although both of these effects are of considerable importance in understanding the limits of retroreflective materials as markers on trucks, there is very little information about either of them. This chapter describes research conducted in an effort to supply additional data about both the short- and long-term degradation of these materials.

STUDY 1: THE EFFECTS OF ENVIRONMENTAL DIRT ON THE PERFORMANCE OF RETROREFLECTIVE MATERIALS

Introduction

It is a fact that vehicles become dirty in use. Under certain weather conditions dirt accumulates very quickly. Clearly, dirt will diminish the performance of reflective devices. In attempting to set minimum specifications for the performance of retroreflective markings, it is important to take into account the effects of dirt under conditions of normal operation and maintenance.

There has apparently been only one published study of the effects of dirt on the performance of retroreflectors mounted on trucks (Ziedman et al., 1981). In this test a piece of reflective sheeting was attached to the rear bumper of a small truck, which was driven about 1,500 miles over a four-week period of clear weather, mostly on paved roads. There is no description of how often SIA readings were taken or by what method. On a basis of this test the authors conclude that a 30 percent reduction in reflected light would be appropriate due to the effects of dirt and dust.

The evaluation reported by Ziedman et al. is somewhat limited in terms of time and the weather conditions encountered. Given the potential importance of dirt as a factor in the performance of truck markings, a more comprehensive study was indicated. This section of the report describes such a study.

Method

With the cooperation of three trucking companies that maintain terminals in the Ann Arbor area, a sample of seventeen van-type semitrailers was made available for the test. All were returned to the local terminal often enough so that they would be accessible for photometric measurements on a regular basis. Maintenance practices of the companies varied from almost daily to infrequent washings.

Prismatic reflective material was supplied in 4-inch width. This material was cut into pieces 3 3/4 inches wide to match exactly the diameter of the barrel of the Advance Retro Technology (ART) Model 920 retroreflectometer used to make the SIA measurements. In this way the positioning of the retroreflectometer could be controlled with some precision, thus minimizing errors associated with reading different areas of the sample. The patches were attached to the trailers using a special backing material that would facilitate removal when the test was completed.

Material patches were attached in pairs. The intent was that one of each pair would provide the "as is" measurement; the other would be cleaned each time to provide a baseline measurement. Six pairs of the patches were attached to each trailer, two on each side and two on the rear. The side-mounted patches were attached as far forward and as far to the rear as practical. The rear-mounted patches were placed on each side, about 1 foot from the outside edge. All the patches were placed as low as possible, just above the frame rail. When taking readings the "clean" patch was first wiped with a damp cloth; the other patch was measured with whatever dirt or dust was in place at the time.

SIA measurements were made on each patch at the time of installation, and at about one-month intervals thereafter over a six-month period. Readings were then made about every two months for the duration of the project. Thus, the readings covered a one-year period in a climate offering a full mix of seasons.

Results

One group of trailers included in the study belonged to a food company. They were kept very clean. The other two groups of trailers were washed less frequently. In the presentations to follow the results for the first group (fleet 1) will be kept separate from those for the other two groups (fleets 2 and 3), to give some idea of what difference high levels of maintenance can achieve.

The results of the measurements will be presented in a series of figures similar to Figure 5.1. This figure is concerned with test patches located on the sides of the fleet 1 trailers. (These trailers were exchanged for new ones after the study had been under way for about eight months. Hence there is less data than for the other two fleets.) The vertical axis of the figure shows SIA values read with the retroreflectometer. The horizontal axis lists the months in which the measures were taken. Each entry shows the mean SIA measured and one standard deviation bars. In this, as in the figures that follow, an overall decline from new performance can be noted both in the means and the increased standard deviations.

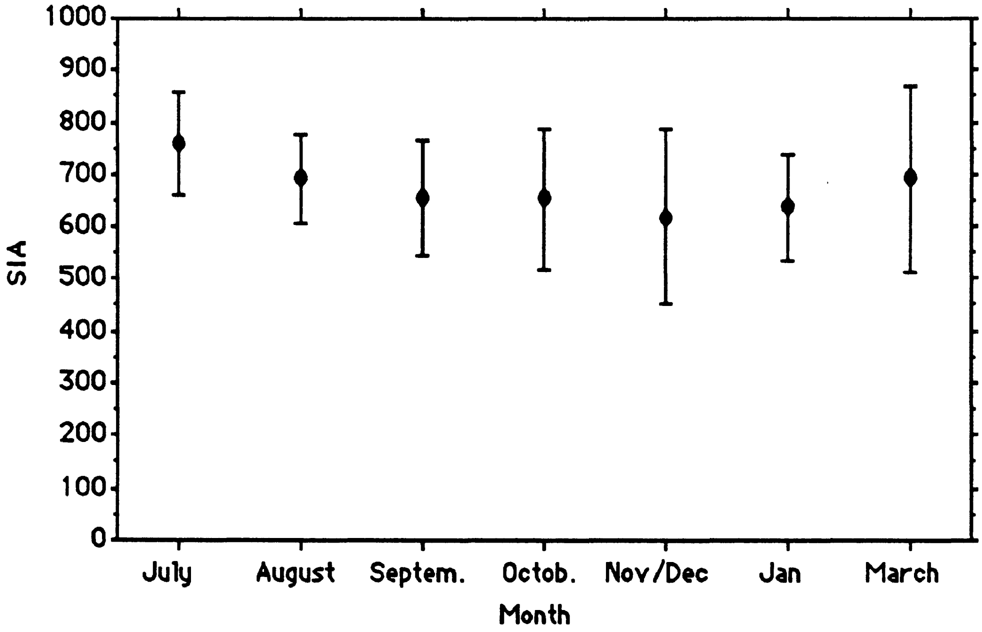


Figure 5.1. Means and one standard deviation ranges for SIA values measured on sides of fleet 1 trailers by measurement period.

Figure 5.2 shows the measurements on fleet 1 rears. It was expected that the rear markings would be more affected than the sides. Even on this fleet, with a high level of maintenance, there is a noticeably greater loss of reflective performance on the rear-mounted samples.

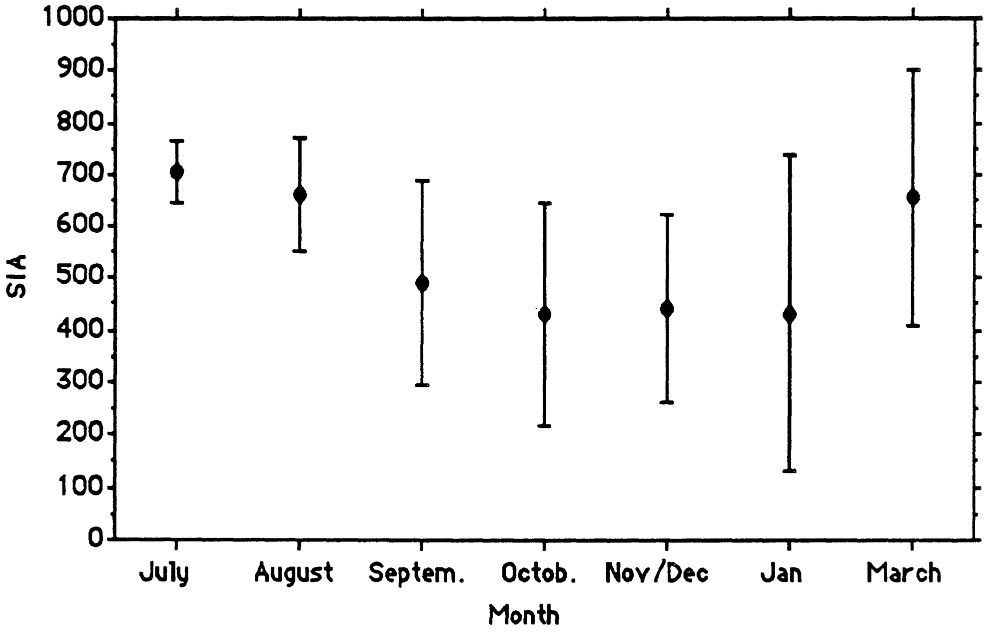


Figure 5.2. Means and one standard deviation ranges for SIA values measured on rears of fleet 1 trailers by measurement period.

Figures 5.3 and 5.4 show the results of the measurements on the sides and rears of the vehicles in fleets 2 and 3. The greater loss of reflectivity compared to fleet 1 is apparent, particularly in cold-weather months. Reduced performance is to be expected in this period, in snow-belt states at least, due to the increased incidence of wet roads and the use of deicing salt. Note also how the SIA values improve again in warmer weather, perhaps due to salt washing off the surfaces.

When the researchers came to the fleet 3 terminal for the final measurements they found that a crew was in the process of cleaning the trailers with portable power wash equipment. All of the trailers but one involved in the study had been cleaned already. (The final measurements on these trailers are not included in the analysis given in Figures 5.3 and 5.4.) The experimenters took measurements on the one remaining trailer, waited until it had been cleaned, and then took them again. The results showed a three to fivefold improvement in SIA after cleaning. This indicates that even truckers who do not have easy access to truck wash facilities can keep materials relatively clean using portable equipment.

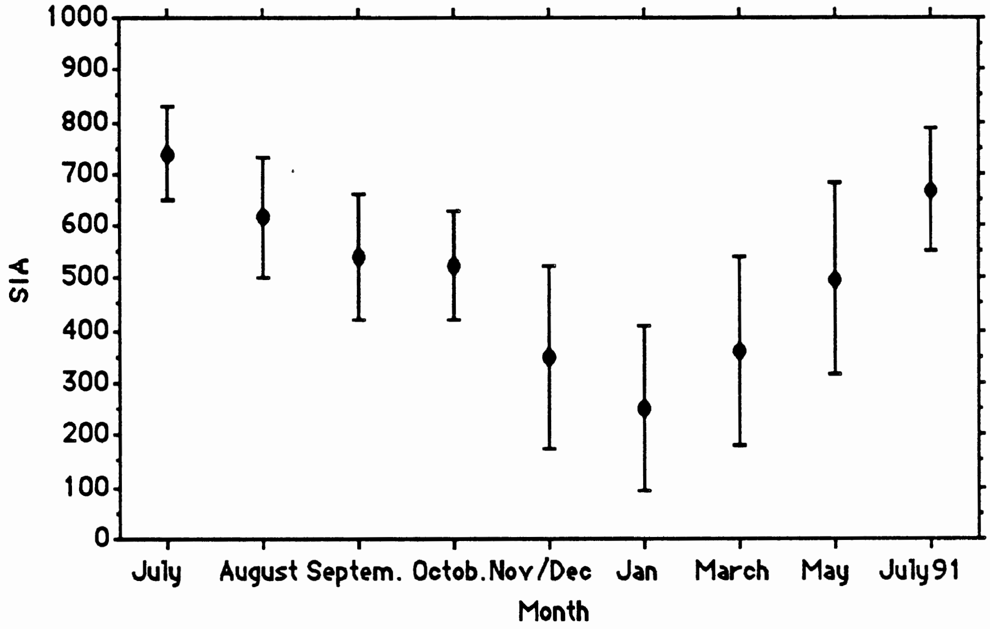


Figure 5.3. Means and one standard deviation ranges for SIA values measured on sides of fleets 2 and 3 trailers by measurement period.

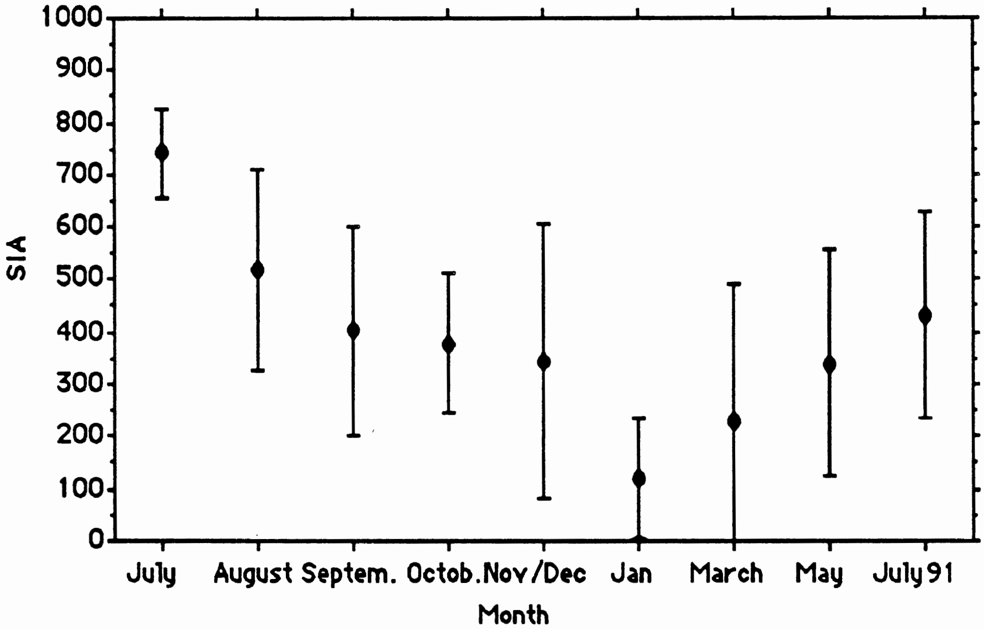


Figure 5.4. Means and one standard deviation ranges for SIA values measured on rears of fleets 2 and 3 trailers by measurement period.

The experimenters also noted a steady decline in the SIA of the control patches, which were cleaned with a damp cloth each time they were measured. This was a cause for concern, since it suggested a rather rapid degradation. When measurements had to be taken in the winter the manufacturer suggested using isopropyl alcohol to clean the patches. The SIA values promptly returned to nearly-new levels. Apparently a film had been deposited on the patches that was not being removed by water. This suggests that effective maintenance requires something more than simple rinsing with water.

For the purpose of preparing recommendations, a more useful way of looking at the data is in the form of percentile distributions. As in the case of the detection distance data discussed earlier, 85th percentile performance will be used as a reference. Figure 5.5 shows a percentile distribution of SIAs measured on the sides of fleet 1 trailers during the entire study period. The 85th percentile value is 540. The approximate average new SIA of the materials used in this test was about 750. On this basis an SIA of 540 represents a 28 percent loss in reflective performance.

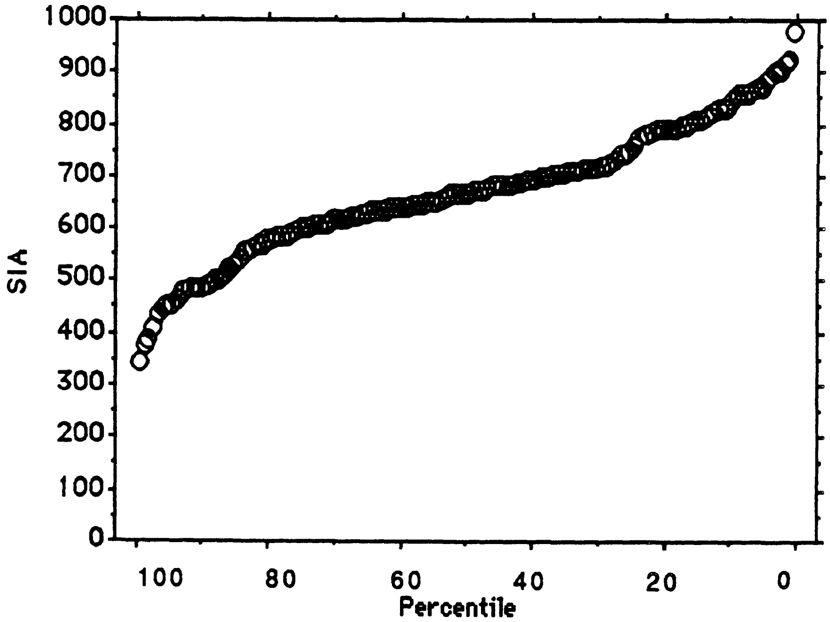


Figure 5.5. Percentile distribution of SIA values. Fleet 1 sides. All months.

Figure 5.6 is a percentile distribution of SIAs measured on the rears of fleet 1 trailers. In this case the 85th percentile SIA is 275, which represents a loss of about 60 percent in reflective performance.

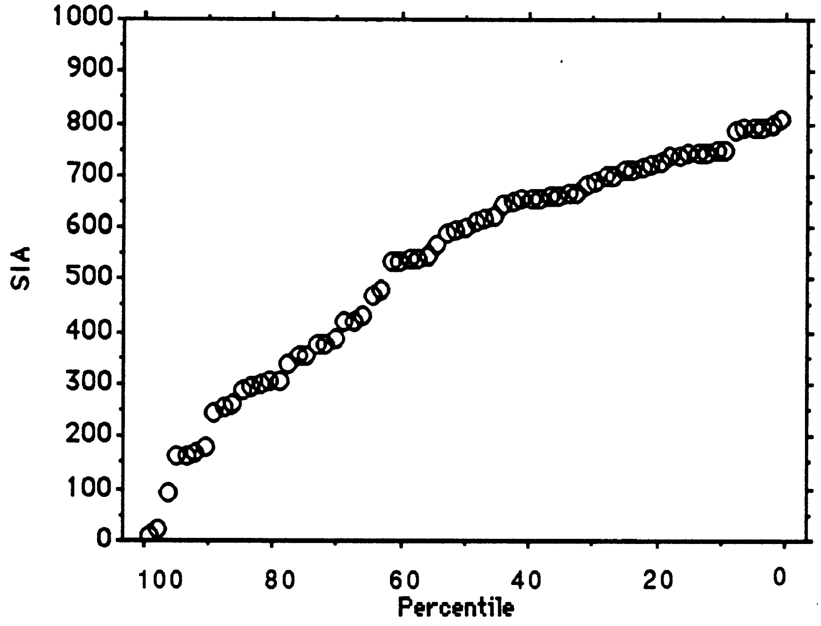


Figure 5.6. Percentile distribution of SIA values. Fleet 1 rears. All months.

Figures 5.7 and 5.8 are percentile distributions of SIA values for the sides and rears of fleet 1 measured during the cold-weather months only. The loss in reflective performance at the 85th percentile is somewhat greater in this sample; about 36 percent on the sides and about 70 percent on the rears.

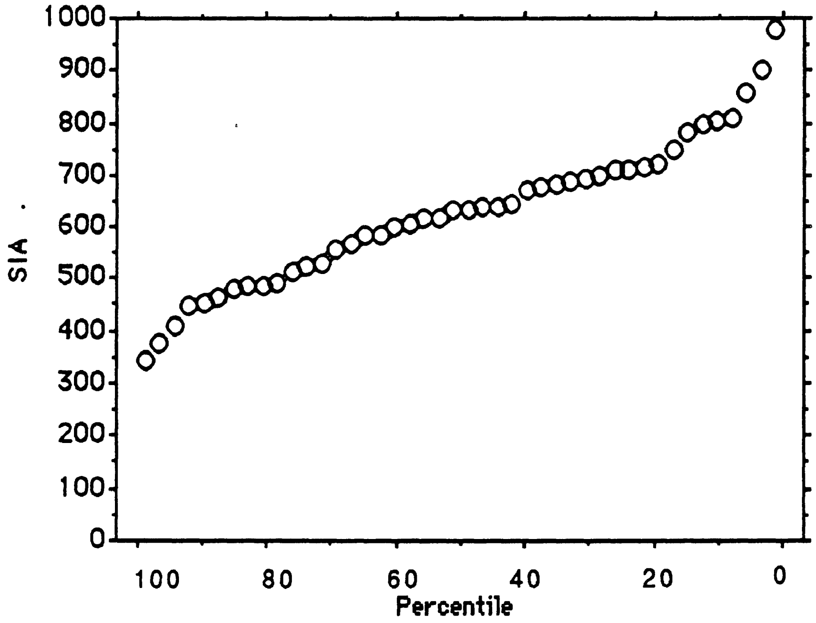


Figure 5.7. Percentile distribution of SIA values. Fleet 1 sides. Cold weather months.

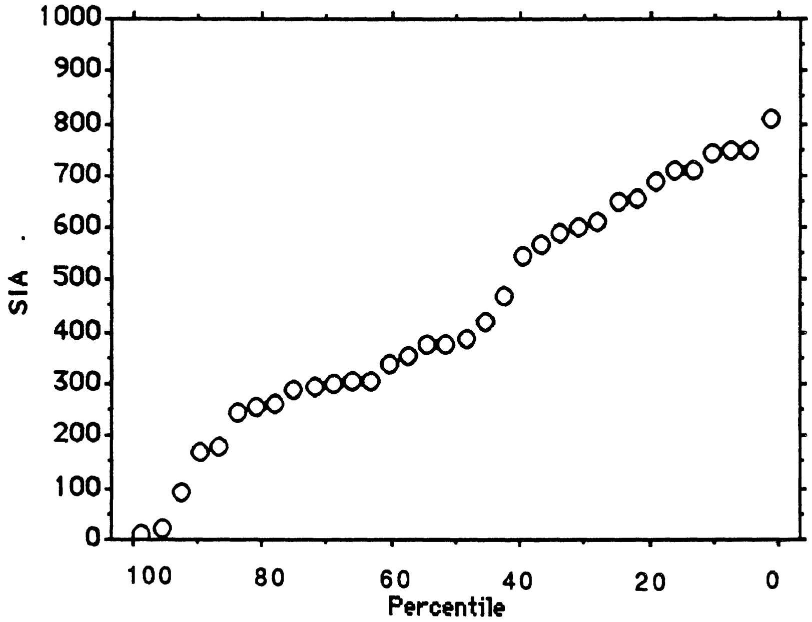


Figure 5.8. Percentile distribution of SIA values. Fleet 1 rears. Cold weather months.

Figures 5.9 and 5.10 are percentile distributions of SIA values for the sides and rears of fleets 2 and 3 during the entire study period. The loss in reflective performance at the 85th percentile is appreciably greater than in the case of fleet 1, about 70 percent on the sides and 90 percent on the rears.

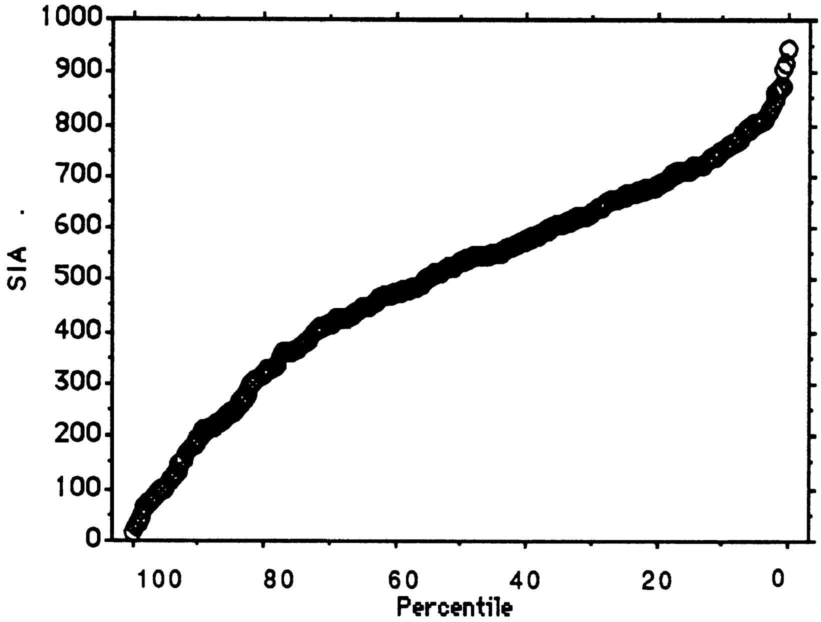


Figure 5.9. Percentile distribution of SIA values. Fleets 2 and 3 sides. All months.

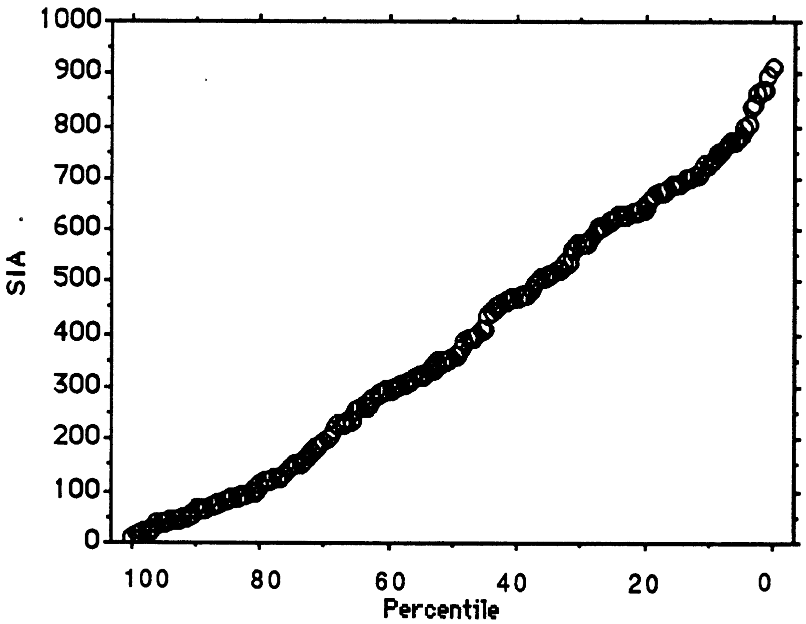


Figure 5.10. Percentile distribution of SIA values. Fleets 2 and 3 rears. All months.

Finally, Figures 5.11 and 5.12 are percentile distributions of SIA values for the sides and rears of fleets 2 and 3 during the cold-weather months only. The loss in reflective performance at the 85th percentile was about 85 percent on the sides and 95 percent on the rears.

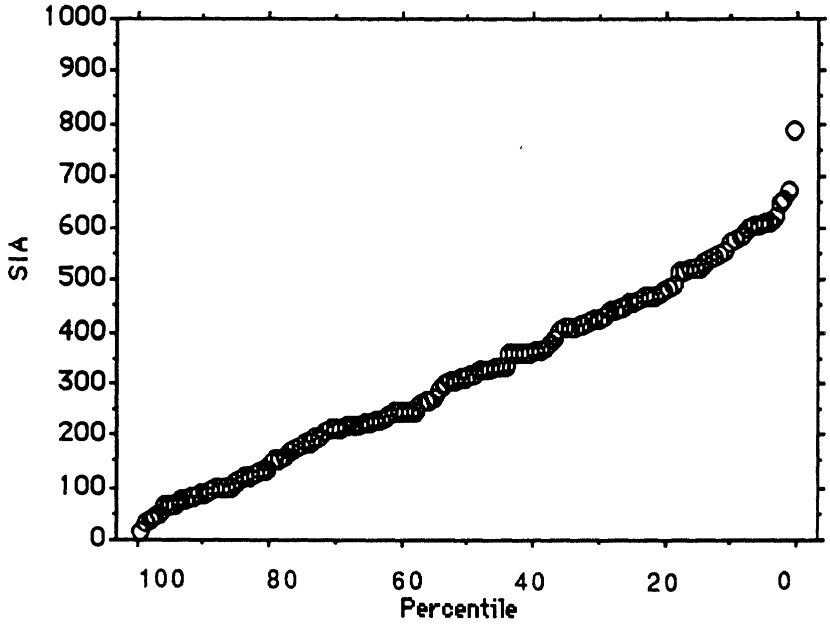


Figure 5.11. Percentile distribution of SIA values. Fleets 2 and 3 sides. Cold weather months.

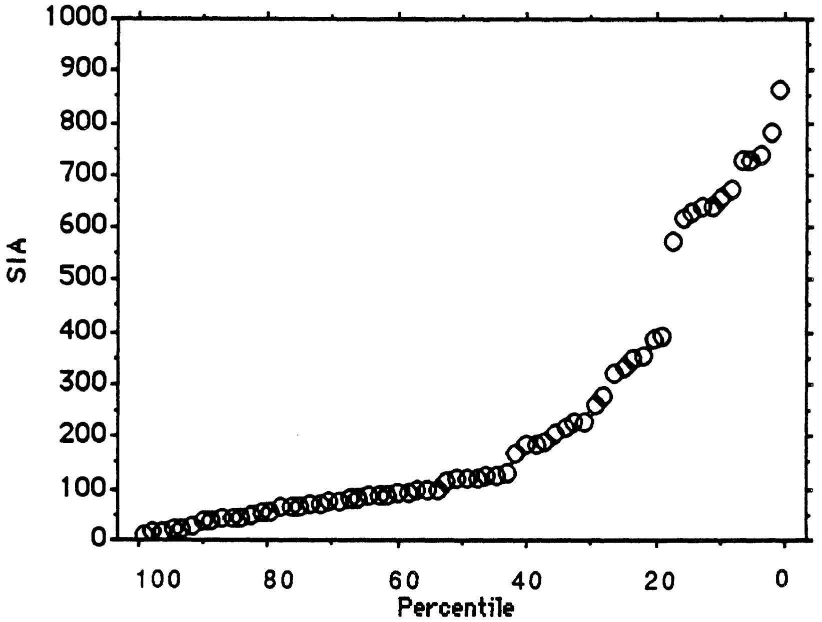


Figure 5.12. Percentile distribution of SIA values. Fleets 2 and 3 rears. Cold weather months.

Discussion

The results of this investigation show clearly that environmental dirt can be a very serious problem for retroreflective materials used to enhance the nighttime conspicuity of trucks. Unless the materials are kept clean, the anticipated improvements in visibility and associated reductions in collisions would be less than could otherwise be achieved. This problem is not an easy one to solve, particularly in view of how quickly these materials can become degraded in certain environments. Furthermore, appearances can be deceiving. SIAs one third or less of new values were regularly measured on trailers that did not appear to be very dirty. Even if the trucks are cleaned often, as in the case of fleet 1 in this investigation, the materials may function at well below new values much of the time, particularly those installed on the rear. Modifications to FMVSS 108 must therefore take these potential losses in effective SIA into account.

STUDY 2: THE DURABILITY OF CONSPICUITY-ENHANCING MATERIALS

Introduction

Considering the potential for the "aging" of retroreflective materials, it would be useful for the purchaser of these materials to have some idea of how long their SIA would remain above established minimum levels. Ideally, this period would equal the expected life of the vehicle. Where this is not the case, such information would allow the purchaser to know that the treatment would have to be refurbished after a certain number of years. In the absence of such information the burden of deciding when the treatment is no longer adequate falls on the owner/operator, or on the government agencies responsible for inspecting these treatments.

Unfortunately, there is no information available to guide a decision as to how much of an allowance should be made for material degradation due to aging. Long experience has made it clear that retroreflective sheeting materials used on highway signs do deteriorate with age. This is acknowledged in the guarantees that the manufacturers of such materials offer. One example, for type II materials, indicates that they are guaranteed to retain at least 50 percent of the minimum new SIA for a period of seven years.

The materials designed for use on trucks are not necessarily identical in construction to those designed for use on signs. Certainly the conditions to which they are exposed are not the same. Hence, their life expectancies are quite possibly different. Given the potential importance of aging effects on setting minimum standards and in guiding material replacement, it would be useful to have data on this subject. The research that follows was designed to address this issue.

Method

The approach elected was a simple one. The first step was to identify truck fleets that had used retroreflective materials on their vehicles for a number of years, either in the form of logos or supplementary markings. Measurements were then made of the SIA of these materials, classified by age. Lastly, comparisons were made between the measured SIAs and those typically associated with new materials.

There are at least three significant problems with this method. First, great variability in SIA readings is to be expected, so a relatively large sample must be employed. Second, there is some variability in the SIA of new materials, even when type and color are controlled. Ideally, the SIA values of new materials could be compared to those of the "aged" materials to arrive at an estimate of change. Since there was no way of knowing the new SIA value of each sample, a "representative new value" had to be used, adding to the variance in the results. Third, and perhaps most important, the materials sampled were of a type that has been in use for a number of years. Even if the data showed some indications of age-related performance changes, the degree to which they can be extrapolated to the newer materials now coming into use is unknown.

With the cooperation of a manufacturer of retroreflective products, a number of truck fleets were identified as relatively long-term users of such materials. Officials at each of these fleets were contacted to determine how the materials were used, where they were placed, how long they had been using these materials, how many trucks were in the fleet, whether they could provide age data, and whether they would be willing to allow test personnel access to the trucks to collect data. Cooperation was excellent, but several fleets were eliminated due to having too few older units, or no measurable white areas on the treatment. (Most of the treatments were in the form of logos. The printing process changes the SIA to an unknown degree. Therefore, measurements could be taken only on white areas.)

Three fleets were selected for the study. Fleet 1 belonged to a grocery chain. The material was in the form of a logo, and was mounted on the side of the trailer. There were adequate numbers of trailers up to ten years old in this fleet. Fleet 2 belonged to a manufacturer of office furniture. The material was used to supplement rear markings, and was mounted on the underride guard. As a matter of policy, the rears of trailers in this fleet were completely refurbished after five years. Thus, the age range of material in fleet 2 was more restricted than in fleet one. Fleet 3 belonged to a drug store chain. The material was in the form of a logo and was mounted on the side of the trailer. There was a smaller number of trailers in this fleet (a total of 46, compared to about 150 in each of the other fleets), but there was a higher percentage of older units. All three fleets washed their trailers every time they came in the terminal.

Two persons were involved in taking the measurements. They made an appointment with a fleet official on a mutually convenient day. At the appointed time they met with the official and started taking measurements. One person took the readings, using an Advance Retro Technology model 920 retroreflectometer. The second person noted the trailer number and wrote down the SIA values. The surfaces were wiped clean with a damp cloth before measurements were taken. The findings in the dirt survey concerning the effects of cleaning with alcohol suggest that had alcohol been used here higher SIA values may have been recorded.

The fleet operator supplied the date on which the trailer had been placed in service. This information was used to sort the SIA readings on the basis of age.

Results

The results are summarized in Figure 5.13. This figure shows the mean SIA for trailers in each age group for each fleet. According to the manufacturer, a representative new SIA for material of the type used would be 100.

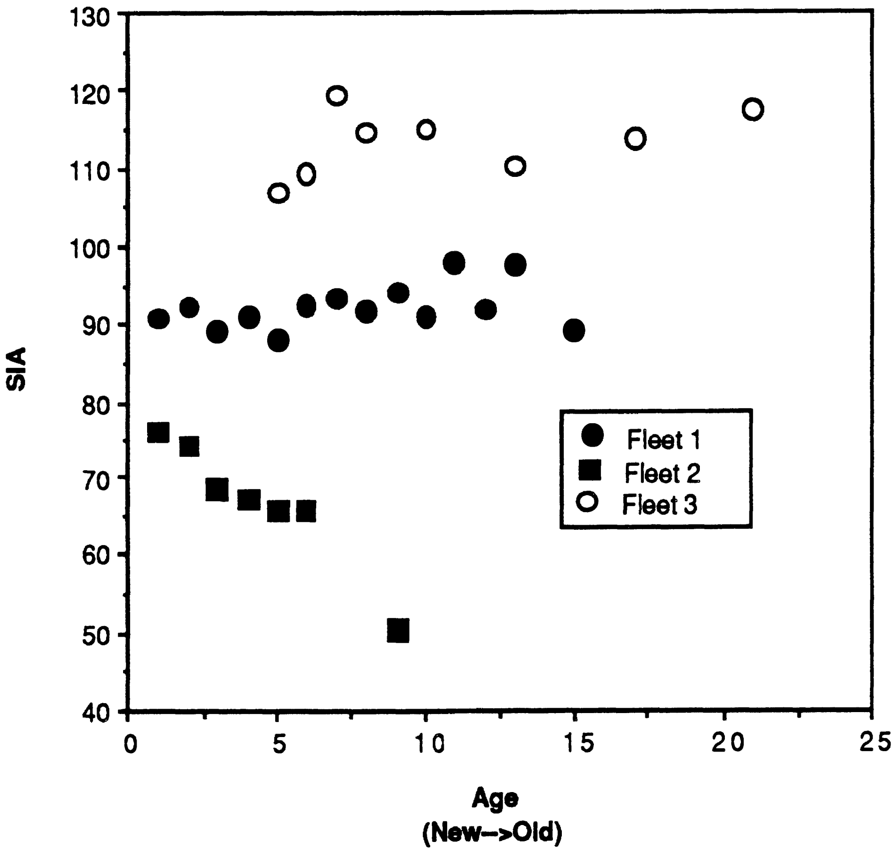


Figure 5.13. Mean SIA of retroreflective materials on three truck fleets classified by years of service.

There are differences between the results for the three fleets, both in terms of initial performance and losses in SIA with age. In the case of fleet 1, the mean SIAs are generally between 90 and 95, regardless of material age. In the case of fleet 2 it appears that something is causing an almost immediate loss in SIA of about 25 percent. In addition, there is some indication of further losses as the material ages. Fleet 3 is similar to fleet 1 in the absence of any indication of degradation. For some reason the SIA values average somewhat higher than fleet 1.

Discussion

The differences in material performance comparing the three fleets may be attributable to differences in location, methods of installation, maintenance, or other factors. According to the manufacturer, material used as logos is given a final top coating not used otherwise. This may account for at least some of the difference between fleet 2 and the other two. Clearly, there are some questions yet to be answered regarding the performance of retroreflective material in this type of environment.

Although the data are limited, they do suggest that material of the type included in this study holds up well when installed on a trailer. Indeed, if the data from fleets 1 and 3 are representative, it appears that such material would provide nearly new performance for more than ten years and quite possibly for the life of the trailer.

Environmental Effects

6 FINDINGS AND RECOMMENDATIONS

The preceding chapters of this report have described a number of investigations of variables having the potential to affect the performance of conspicuity-enhancing treatments. In this chapter the results of these studies were used as a basis for treatment recommendations. The chapter is divided into two parts. The first discusses a number of issues about which decisions must be made before the final treatment parameters can be established. The second lists the authors' recommendations and the rationale for them.

SYSTEM VARIABLES AND OPERATIONAL ASSUMPTIONS

There are a number of variables that can affect the performance of retroreflective material applied as markings on trailers. Decisions must be made concerning each of these before determining how best to specify acceptable performance goals for retroreflective marking systems. Each issue to be discussed here is described and a rationale developed for the recommended choice.

Minimum Detection Distance

The system parameters should be performance based, which requires establishing a minimum distance at which the marked object should be detected. In making recommendations, use was made of the policy on stopping sight distance formulated by the American Association of State Highway and Transportation Officials (AASHTO).

Stopping sight distance (SSD) is a criterion used in highway design in an effort to ensure that nothing about the roadway or its immediate environment will hide a hazard from an approaching driver until he/she is too close to stop. It considers the stopping characteristics of a loaded truck on wet pavement, a range of speeds, and a driver perception-response time of 2.5 seconds. (Other factors in SSD such as obstacle height and driver eye height are not relevant here.) Use of the SSD tables requires agreement on a "design speed." For purposes of the marking systems under consideration it was appropriate to assume a relatively high speed. The current national speed limit is 55 mph, although local jurisdictions have the option of increasing this to 65 on certain roads. It is clear from survey data (e.g. Olson, 1988), however, that approximately half of the vehicles on freeways are going faster than 65 mph. Accordingly, it would be reasonable to use a higher speed than 65 mph as a basis for the recommendations presented in this report. In the recommendations to follow 70 mph was used as the design basis. Using SSD values, at 70 mph the vehicle will travel 257 feet during the perception-response interval and 483 feet while braking, for a total of 740 feet. Thus, 740 feet is recommended as the minimum acceptable detection distance.

Selection of Performance Percentile

The variability of human performance is an acknowledged fact. Clearly, any standard designed to protect the public must take this variability into account and establish system parameters such that all, or nearly all, the relevant population will be accommodated. It is often not practical to include literally everybody due, for example, to cost considerations or the limitations of technology. In such cases standards should be based on the inclusion of a specified large percentage of the relevant population. The choice of percentile is somewhat arbitrary. In highway design it has been traditional to set standards to exclude no more than 15 percent of the relevant population. Hence, the 85th percentile was used as a performance criterion.

Operating Environment

The experimental data reported here were collected in the equivalent of a dark, rural environment. That is, there were few lights, signs, or other distractions. It is an environment that is ideal for detecting targets of the type employed. While a large percentage of the roadway mileage in the US probably fits this description, or comes close to it, a significant portion of the most heavily traveled mileage does not. Background clutter makes targets such as those employed in this test less conspicuous, and reduces mean detection distance. There is little data on the effect of surround clutter on the detection of retroreflective targets. One recent study (Olson, 1988), done in the context of small highway signs, found that about a tenfold increase in SIA was required to compensate for a background having a relatively high degree of clutter.

Many areas having high clutter also have fixed lighting, which helps to illuminate the marked vehicle. Lower speed limits are typical of such areas as well. While it is recognized that this is not universally true, on a system-wide basis it does reduce the effect of the loss of conspicuity due to background clutter. Given this fact, coupled with the lack of objective information on the crash experience of trucks as a function of environmental clutter, no corrections for this effect were made in the data presented here.

Population Age Mix

It is well known that changes in the eye, associated with aging, reduce visual capability in low-luminance environments. These effects can be seen in the data presented in Chapter 3, Treatment Values, as one example. It becomes an issue here because older drivers require more highly reflective materials than do young drivers to achieve particular performance levels. Materials may well be available to do the job, but generally at higher initial cost. The question of how to weight this factor when setting guidelines for the use of reflective material thus becomes important.

There has been some discussion of this question as concerns reflective materials used in signing. As one example, Awadallah (1987) argues that the weighting should consider the percentage of nighttime miles driven by older persons. He quotes information from a 1983 Personal Transportation survey conducted by the U.S. Department of Transportation indicating that persons 55 and older account for about ten percent of nighttime miles and fifteen percent of daytime miles.

Countering these statistics are trends that make it clear that the percentage of persons 55 and older is increasing rapidly (e.g., TRB Special Report 218, 1988). Further, these individuals are healthier, more active, have more experience with the automobile as a primary means of transportation, and have more disposable income than previous generations of older Americans. This suggests that the future will see an increase in the percentage of nighttime miles driven by older persons.

The sample of subjects who participated in the investigation relating treatment SIA to detection distance included a mix of older and younger individuals. Thus, the data in Figure 3.12 are offered as the best representation presently available of the relationship between the SIA of truck marking systems and detection distance for the population of Americans who drive at night.

Treatment Color

Trucks currently using retroreflective materials as markers employ a variety of colors. In some cases at least the colors seem to have been selected to blend with the color scheme on the trailer. A decision was made early in this effort to limit the investigation of color effects to red and white. This was done for a number of reasons.

- Red is a color that is commonly associated with danger.
- The combination of red and white is used as a hazard warning in other contexts (e.g., railroad crossing gates).
- The marking system should not only aid in detecting the vehicle, it should clearly identify it as a truck. This requires a system that is both unique and uniformly employed. The alternating red-white pattern recommended here is unlike that used for any other purpose. If used on all trucks it will eventually come to be recognized and associated with trucks, facilitating their identification when only the retroreflective treatment can be seen.
- The apparent brightness of a color depends to some extent on its saturation. The reds employed in retroreflective materials are highly saturated, appear brighter, and are detected at greater distances than would be suggested by their SIA. This effect was noted more for reds than for any other color in a field test of sign conspicuity (Olson, 1988).

Treatment Width

The research was carried out under the assumption that 2 inches would be established as the minimum width for sheeting materials employed as conspicuity-enhancing treatments. Data collected as part of this contract and reported in Chapter 4, Treatment Characteristics, show that if different treatment widths are employed the effect is the same as though the SIA were changed in direct proportion. For example, if a material having an SIA of 100 is being used, it would be equivalent to an SIA of 200 in 4-inch width and 75 in 1.5-inch width.

Material Aging

The typical service life of a trailer is estimated at 14 years. It would be desirable that retroreflective treatments provide adequate performance for at least that long. The limited data collected as part of this contract indicate that it is possible to use retroreflective materials in a trucking environment and suffer very little, if any, loss in performance for ten or more years. It would clearly be desirable to collect more data, particularly on the newer materials that will be required to meet any reasonable future standard. In establishing new performance regulations, it does not seem appropriate to ignore aging as a factor, because losses were noted on vehicles in one of the three fleets surveyed. Until more definitive data are available, it is recommended that performance loss due to aging be established at 80 percent retention over the fourteen-year period.

Effects of Dirt on the Treatment

It is clear from the data collected in this study that environmental dirt can have a major effect on the performance of reflective materials on vehicles. While the information presented here is far more comprehensive than anything else available, it is recognized that it is still limited. It gives some idea of what can happen when operating trucks under a variety of conditions, including winters that are probably close to the worst in the US from a point of view of adding layers of dirt and salt. Trucks that operate in more moderate climates would be less affected.

The most conservative approach would be to take data from the worst conditions measured in the survey. This would be 85th percentile data from the cold months for the trailers that were infrequently washed. Doing so, however, would mean assuming only 15 and 5 percent retention on the sides and rears, respectively, which would push SIA requirements beyond what can be achieved with current technology. As a compromise, it seems reasonable to require that marking materials be kept clean. Therefore, the cold-weather data from the trailers that were washed frequently were used as a basis for a standard. On this basis, retention is 64 and 30 percent on the sides and rears, respectively. Rounding the values for the sake of simplicity gives 60 and 30 percent retention.

Vehicle Orientation

"Orientation" refers to the angle that the marked surface forms relative to the path of the approaching vehicle. This is important because the performance of retroreflectors varies as a function of entrance angle, and orientation determines entrance angle. For example, if the marked surface of a trailer was oriented at 45° to an approaching vehicle, the luminance of its markings as perceived by the driver would generally be substantially less (depending on the material employed) than if the orientation were at 0° (i.e., perpendicular to the approaching vehicle).

In the real world of car-into-truck collisions the orientation of the struck trailer varies greatly. There are no data indicating the frequency with which various orientations are involved in collisions. While it would be unreasonable to assume a 0° orientation in all cases, trying to include very large angles would go beyond what is technically feasible in retroreflective materials at present, particularly when consideration must be given to other performance-degrading factors. An orientation angle of 45° has a certain logic in that it represents the maximum angle that could be encountered if the vehicle is approached from the rear and both rear and side markings are visible. Doing so, however, may make it impossible to meet minimum proposed regulations within the family of existing materials. As a reasonable compromise an orientation angle of 30° is recommended. This is an angle that is routinely measured and included in the performance specifications for retroreflective materials.

Proximity to Signal Sources and Other Markers

The research reported in Chapter 4, Treatment Characteristics, indicates that reflective material can influence the ability to identify stop signals and may affect their detection as well. To minimize this problem it is recommended that an edge-to-edge separation of not less than 6 inches be maintained between a retroreflective treatment and the signal source. There is no reason to be concerned with interference with marker lights on either the side or the rear of the vehicle.

Approach Geometry

"Approach geometry" refers to the path taken by the approaching vehicle before impacting the marked surface. The approach might be on a straight-flat section or may involve vertical and/or horizontal curves. In the latter case, not only is the effective orientation of the marked surface changed, but the headlights of the approaching vehicle may not be oriented to maximum advantage. For example, if the approach is around a curve to the driver's left the amount of illumination reaching the surface from the car's headlamps would be less than what it would be were the approach straight and flat. Due to a lack of information on this variable, no correction for it was included in the recommendations to follow.

RECOMMENDATIONS

Uniformity

It is recognized that there will be difficulties in applying the recommendations to all types of trailers due to the diversity of shapes, construction, etc. To the extent feasible, however, the recommended treatment should be used uniformly on all vehicles covered by any regulations. Uniformity will facilitate identification of the vehicle as a truck, which will reduce the likelihood of error and confusion on the part of drivers and reduce their perception-response time when faced with the necessity of avoiding a collision with a trailer.

Treatment Width

The investigations described in this report were carried out under the assumption that future regulations would be based on a minimum 2-inch treatment width. Wider widths should be allowed, however. Treatments of different widths will require an adjustment in recommended minimum SIA. There is no obvious criterion for a maximum width. Table 6.1, given later, lists minimum SIA values for widths up to 6 inches.

Pattern

An alternating red-white pattern should be used, with approximately equal amounts of each. First preference in the studies reported here was for a pattern with 12 inches of red followed by 12 inches of white. Twelve inches of red followed by 8 inches of white would also be acceptable. Minor variations around these numbers should have no effect on performance. Visibility can be improved by keeping the percentage of white relatively high. However, it should not exceed 50 percent of the total.

Configuration

There is evidence from the studies reported here that a treatment that outlines the vehicle will improve the identification of closing speeds. It is therefore recommended that an outline be required on the rear of trailers where the necessary mounting structure is available. There is no evidence that a full outline is required. A bar across the bottom and corner markers at the top will be adequate. There is no clear evidence concerning the use of a red/white pattern in the upper corner markers. It appears that these markers can be all white.

The work reported here provides no justification for full outlining of the sides of the trailer. If a driver detects and identifies the side of a trailer (which should be apparent from the length of the treatment) he/she can deduce that closing speed is equal to forward speed.

The results of the field visibility studies conducted as part of this research make it clear that gaps can be allowed in the pattern to save material costs. It is difficult to justify allowing gaps on the bottom bar in the rear, given the short distance involved. Gaps can be allowed in the side treatments. If gaps in the pattern are allowed they should take the form of one repeat of the red-white pattern followed by an untreated area of no more than equal length. A pattern in which the ratio of treated to untreated area was 1:2 was utilized in the field visibility studies. In the opinion of the experimenters it was substantially less effective than the full treatment and the one in which the ratio was 1:1. Therefore, a treatment in which the ratio of treated to untreated area exceeds 1:1 is not recommended. If gaps are accepted as the standard treatment it will be necessary to increase the minimum SIA to make up for the loss in detection distance. This will be discussed shortly under the heading of minimum SIA recommendations.

Figure 6.1 illustrates the proposed configuration and an optional configuration with gaps in the side treatment.

Proximity to Signal Sources and Other Markers

A minimum edge-to-edge separation of 6 inches should be maintained between reflective material and stop and turn signals. There is no need for a minimum separation requirement between such materials and marker lights.

Maximum SIA

The work described in Chapter 3, Treatment Values, was intended in part to set maximum SIA values to avoid unacceptable glare from the retroreflective treatment. In that study it was found that the maximum luminance readings were obtained at the shortest observation distance (100 feet). At this distance the observation angles were relatively large. Calculations determined that a recommended maximum SIA should be 60 at an observation angle of 1.8°. In general, the illumination delivered to the eye of the driver from any retroreflective treatment should not exceed 0.1 lux.

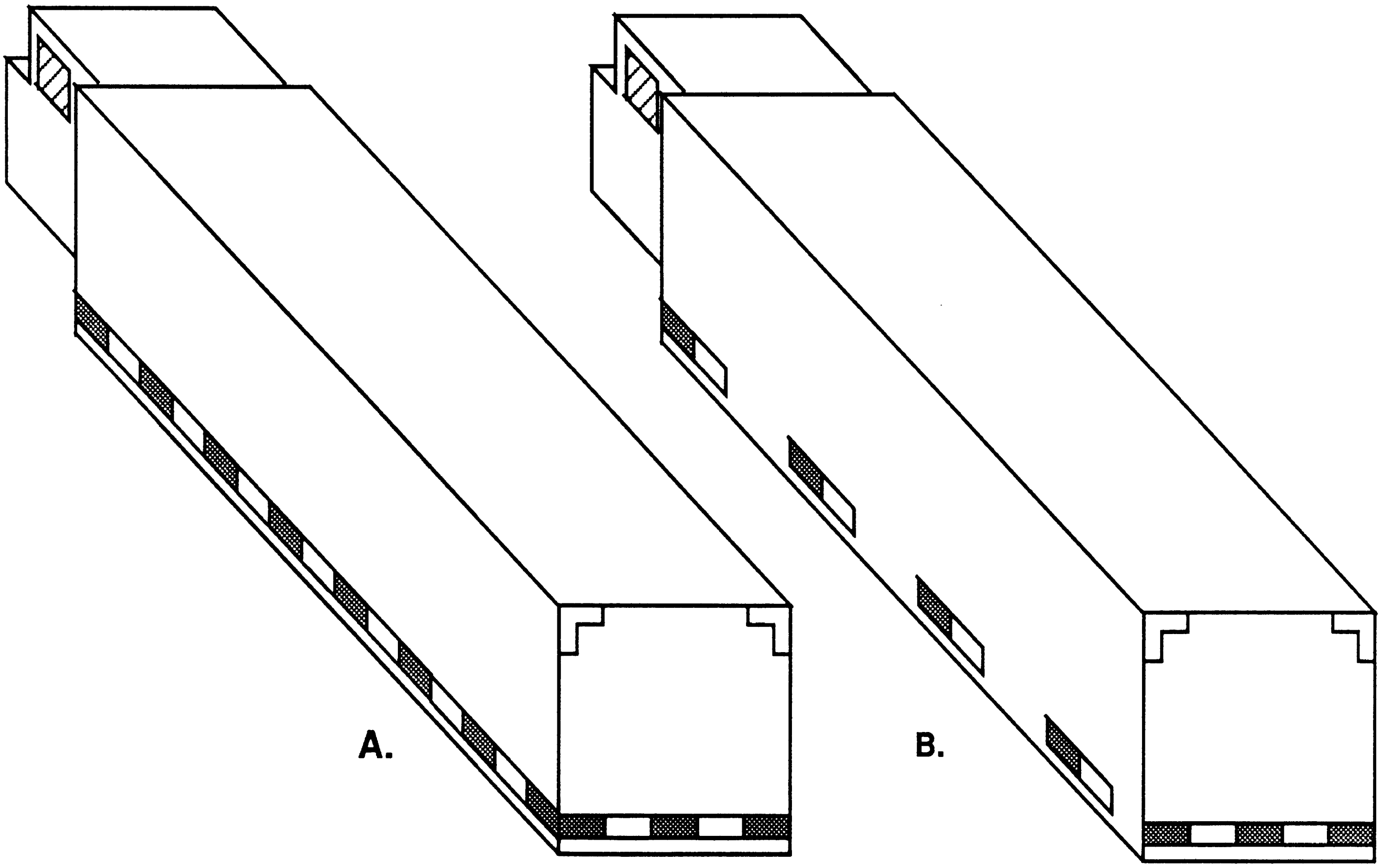


Figure 6.1. Recommended configuration of retroreflective materials (A), and optional treatment with gaps on sides (B).

Minimum SIA

Figure 6.2 is taken from Figure 3.12. It shows the relationship between the weighted average SIA of the retroreflective material used in the markings and detection distance at the 85th percentile. These data have been corrected for subject expectancy.

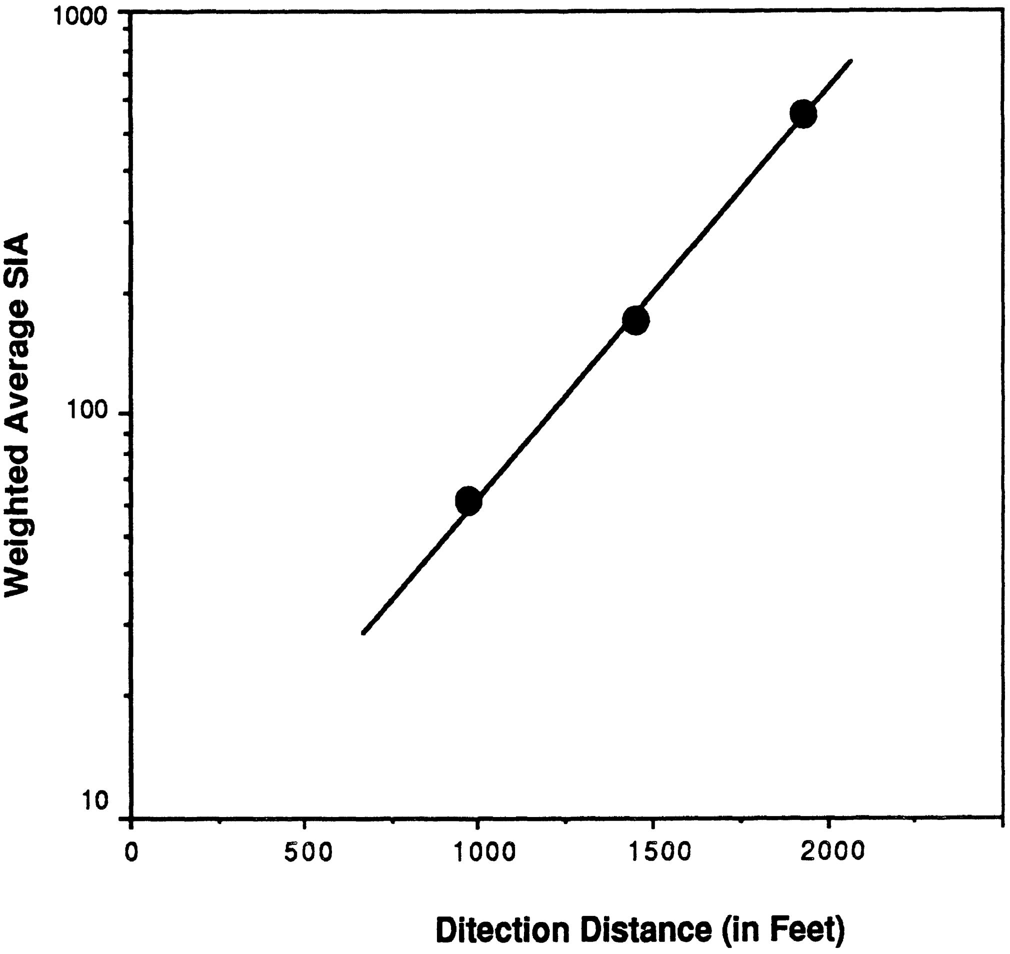


Figure 6.2. Plot of 85th percentile detection distances as a function of material SIA. From Figure 3.12, corrected for expectancy.

Using a detection distance of 740 feet as the minimum, Figure 6.2 indicates that a weighted average SIA of 35 would be required, substantially less than provided by type II material. This value must be upgraded, however, to allow for three effects, i.e., material degradation, dirt, and vehicle orientation.

It was recommended that a 20 percent loss be allowed for aging of the material over a period of ten years. This increases the minimum SIA to 42 from 35. The results of the surveys reported here indicate that it would be appropriate to assume that material installed on the sides of the trailer would be performing at 60 percent of clean values, material installed on the rear at 30 percent On that basis material on the sides of trailers should have a minimum weighted average SIA of 70, that on the rear should have a minimum weighted average SIA of 140. Assuming that red has 25 percent the SIA of white, and the use of a 12-8 red-white treatment, these values work out to SIAs of 127 and 32 for the white and red, respectively, when installed on the sides. Under the same assumptions the minimum SIAs are 254 and 64 for the white and red respectively when installed on the rear. To account for the effects of trailer orientation these specifications should be based on an entrance angle of 30°.

Table 6.1 summarizes the minimum SIA recommendations. Most of the values given are straightforward tradeoffs between area and SIA, based on work described in Chapter 4, Treatment Characteristics. A width of 1.5 inches is included mainly as a guide for retrofitting. In the case of a 2-inch treatment with gaps, the work described in Chapter 3, Treatment Values, indicates a 10 percent loss in detection distance is to be expected when compared to a treatment with no gaps. From Figure 6.2 it was determined that a 25 percent increase in SIA was required to make up for the loss in detection distance.

Table 6.1
Recommended Minimum Weighted Average
SIAs for Various Treatments
Observation Angle: 0.2 Degrees
Entrance Angle: 30 Degrees

SIDES				
		Weighted Average SIA	Typical SIA for 8" White and 11" Red Blocks	
		White/Red Pattern	White Blocks	Red Blocks
Standard	2 inch	70	125	30
	1.5 inch	88	157	38
	4 inch	35	63	15
	6 inch	23	41	10
	2 inch with gaps	88	157	38
REAR				
Standard	2 inch	140	250	60
	1.5 inch	176	314	76
	4 inch	70	125	30
	6 inch	46	82	20

Assumes red SIA is 25 percent of white. Relative SIAs for different colors vary.

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APPENDIX A

An Introduction to Retroreflective Materials

AN INTRODUCTION TO RETROREFLECTIVE MATERIALS

This report deals with the use of retroreflective materials as a means of improving the nighttime conspicuity of large vehicles. Some knowledge of how retroreflective materials work and the terminology used in describing their performance is necessary in understanding the issues addressed, the results obtained, and the recommendations offered. This chapter has been prepared to provide an introduction to the subject area for individuals who would find such information helpful.

When a beam of light encounters a surface some of the light is absorbed and the rest is reflected. If wavelengths are absorbed selectively, the perception is that the surface is colored. Other properties of the surface determine how the light is reflected. For example, a surface with a rough texture, such as ordinary writing paper, will cause light to be scattered in all directions. This is known as a diffuse reflector. On the other hand, a beam of light that encounters a smooth surface, such as a mirror, will be reflected with minimal scatter, and at an angle equal to but opposite the angle at which it enters. This is known as a specular reflector.

A retroreflector is an optical system having special, and very useful properties. It is a bit like a specular reflector in that most of a beam of light impinging on it will be reflected with minimal scatter. Unlike a specular reflector, the angle of the reflected light is substantially the same as the entering beam. In other words, a retroreflector returns light back toward the source, regardless of the orientation of the reflective surface relative to the entering beam of light. (Although the amount of light returned to the source is affected by the orientation of the surface [called the "entrance angle"] a point that will be further explored shortly.)

Retroreflectors occur in nature, as in the eyes of some animals. It was found some years ago that glass spheres, made with material having the proper refractive index and backed with a specular surface, would behave like the eyes of these animals, appearing very bright in car headlights at night. Indeed, the first such devices were commonly called "cat's-eye reflectors." The value of such retroreflectors in traffic control at night was quickly recognized. They were used as pavement delineators (what are today commonly called raised pavement markers), and to highlight the letters on devices such as stop signs.

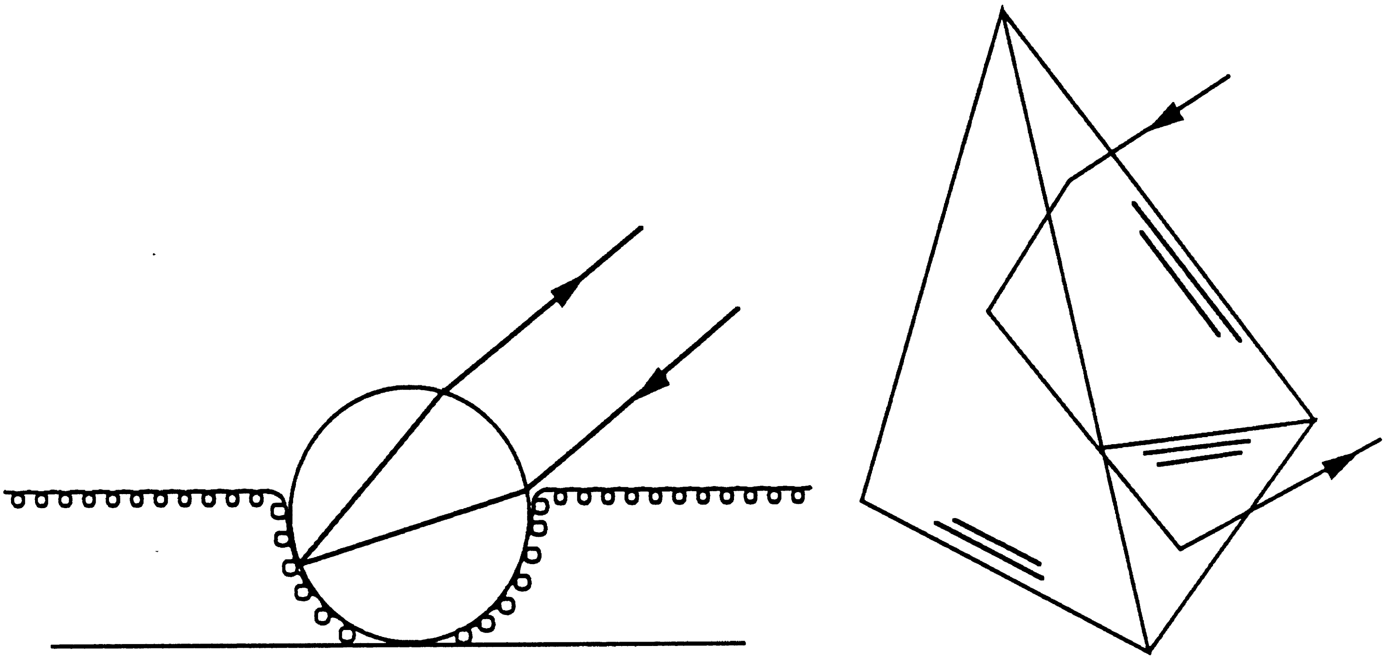
The first glass-bead retroreflectors were relatively large, typically about one inch in diameter. It was found perfectly practical to shrink them to microscopic size. They could then be spread over a suitable backing material, creating an area retroreflector. This eventually led to the sheeting materials in common use on signs and other markers today.

The discussion to this point has referred only to glass-bead products. There is another type of retroreflector in common use, using the cube-corner principle. Figure A.1 illustrates the two types of retroreflectors. In the glass bead device the entering ray of light is brought to a focus at or near the rear of the bead and reflected back on an approximately parallel path. (There must be some divergence from a true parallel path or nothing would reach the driver's eyes.) The cube-corner (prismatic) reflector consists of three surfaces oriented at 90° to each other. The entering ray of light is reflected from each of these surfaces and returned toward the source. Prismatic retroreflectors have been in common use for many years as markers on automobiles, trucks, bicycles and other vehicles, as well as for applications such as roadway delineators. Sheeting products incorporating this principle have recently become available. Such reflectors are more efficient than those using glass beads, and consequently appear brighter under identical viewing conditions.

Photometric Terminology

In this report certain basic photometric terms are used. These are defined as follows:

Luminance: The amount of light per unit area reflected from or emitted by a surface. "Brightness" is often used to refer to luminance. Brightness, however, is a subjective experience and is biased by a number of factors such as contrast and adaptation level. The usual units for measuring luminance are foot-Lamberts (ft-L) and candelas per square meter (cd/m^2). One foot-Lambert is the luminance that would be attained by a perfectly reflecting and diffusing surface located 1 foot from a source of one candela. A one-candela source can be roughly approximated by a candle such as one would find on a dinner table. Candelas per square meter is the metric equivalent of ft-L. One cd/m^2 is equal to 0.292 ft-L.



Spherical Element

Cube Corner Element

Figure A.1. Schematics of two types of retroreflective elements.

Illuminance: The areal density of light reaching a surface. The terms commonly used to describe illuminance are foot-candle and lux. One foot-candle is the amount of illumination reaching a surface 1 foot from a source of one candela. Lux is the metric equivalent of foot-candle. One lux is equal to 0.093 foot-candle.

Basic Terminology Used in Describing Retroreflectors

The performance of retroreflectors depends on the relationship between the reflector surface, light source, and light receptor (the eye or a light-measuring instrument of some kind). Some understand of this relationship, and the terms used to describe it, would be helpful.

Figure A.2 is a schematic intended to help understand the definitions to follow. The definitions are based on those given in the Federal Test Method Standard 370, March, 1977. The terminology contained in ASTM E-808 and CIE Publication 54 (1982) is also widely used in describing retroreflection. That terminology differs only slightly from the following.

1. Reference axis: The defined axis used to determine the entrance angle in photometric measurements and practical use. This axis passes through the reference center (0 in the figure).

2. Axis of incident light: The line between the reference center and the center of the exit aperture of the light source.

3. Observation axis: The line between the reference center and the center of the entrance aperture of the photoreceptor.

4. Entrance angle: The angle between the reference axis and the axis of incident light.

5. Viewing angle: The angle between the observation axis and the reference axis.

6. Observation angle: The angle between the axis of incident light and the observation axis.

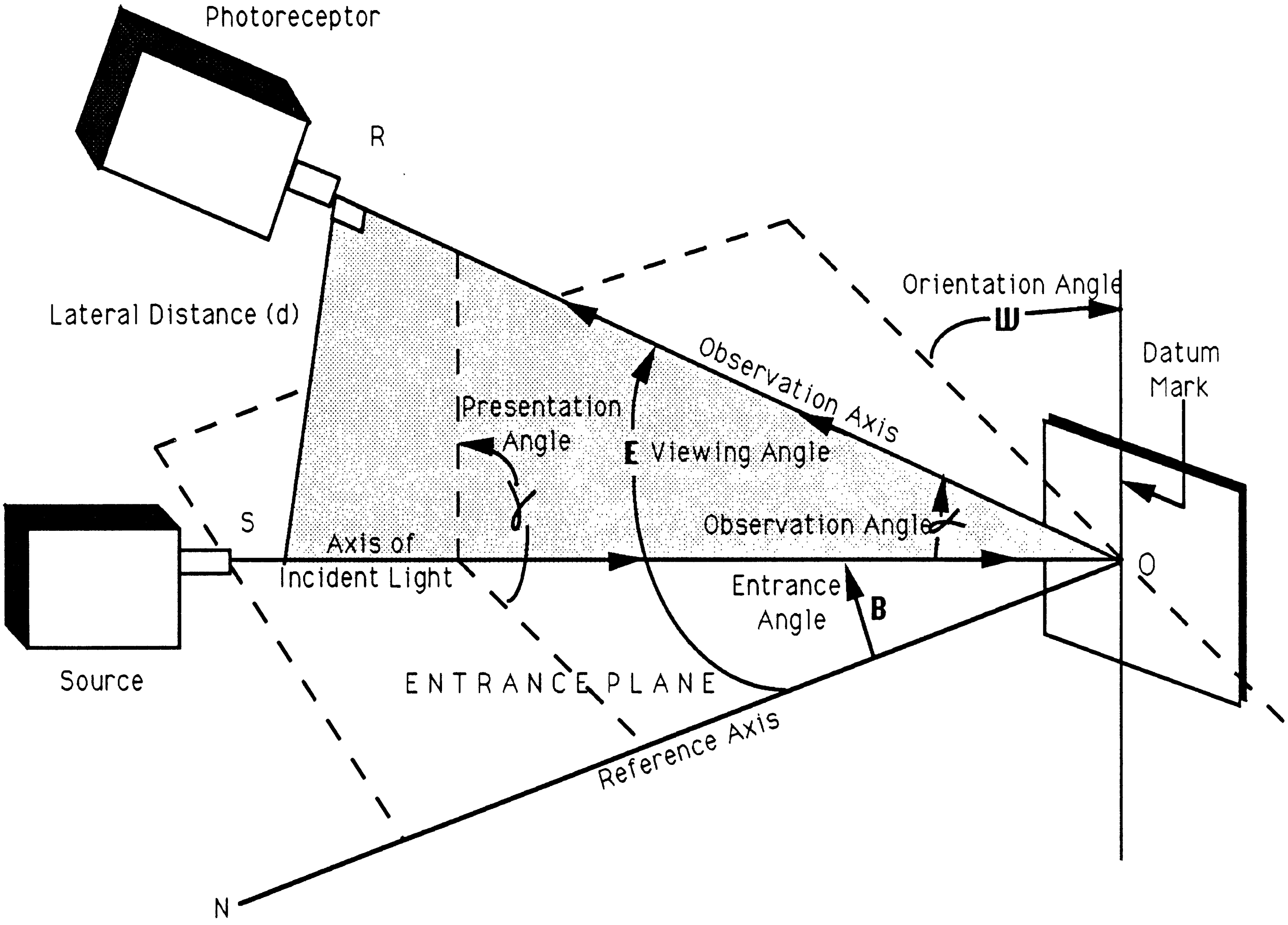


Figure A.2
Pictorial view with the presentation angle (γ) Illustrated at 90°
(A presentation angle of 0° is normally used).

7. Datum mark: The mark placed on the sample by the manufacturer that defines the initial (zero degree) orientation position, and from which the orientation angle is measured.

8. Orientation angle: The angle, when viewed from Point N, through which the sample may be rotated about the reference axis, from the initial zero degree orientation of the datum mark. The initial zero degree orientation angle may be defined relative to either the observation plane or the entrance plane.

9. Presentation angle. The dihedral angle between the entrance plane formed by the axis of incident light and the reference axis, and the observation plane formed by the axis of incident light and the observation axis. 0° is formed when the photoreceptor is placed in the plane formed by the axis of incident light and the reference axis, with the receptor on the same side of the source as the reference axis. A presentation angle of +90° is shown in the Figure.

For most practical purposes the key definitions are entrance and observation angle (items 4 and 6). The performance of a retroreflector is maximum when the entrance angle is at or close to 0°. Performance is reduced as the entrance angle is increased. The shape of this function depends on the optical characteristics of the material, and there are substantial differences from one material to another. For purposes of illustration, a fairly typical glass-bead retroreflector would have 60-70 percent of the retroreflectance at an entrance angle of 30° that it would at 0° (assuming an observation angle of 0.2°). At an entrance angle of 45° the retroreflectance might be only about 20-30 percent of what it would be at 0°.

The performance of a retroreflector is very sensitive to changes in observation angle. For one typical glass-bead product, if retroreflectance at 0.2° is taken as 100 percent (assuming an entrance angle of -4°), then retroreflectance at 0.33° would be about 75 percent, retroreflectance at 0.5° would be about 40 percent, and retroreflectance at 1.0° would be about 10 percent. To put this in perspective, the observation angle (averaged for both headlamps) for the driver of a typical automobile with the target close to the edge of the road would be about 0.2° at an observation distance of about 700 feet, and about 0.4° at 350 feet. In a large truck the observation angle would be about twice as large at the same distances.

Photometric Performance

The measurement of the performance of a retroreflector is an involved process, requiring careful preparation and precise positioning of light sources and measuring equipment. What is desired is a measure of the light returned from the retroreflective surface as a function of the amount of illumination reaching it. The usual metric for this purpose is SIA (specific intensity per unit area), given in units such as cd/ft-c/ft^2. The equivalent in metric units is cd/lux/m^2. As it happens, the numbers that result from the use of either equation are identical. For surfaces of fixed size (e.g., license plates) the area designation drops out, and the descriptor becomes simply SI (specific intensity), the units being cd/ft-c or cd/lux. In the case of SI the numbers that result from use of the two equations are not identical.

SIA is equivalent to the Coefficient of Retroreflection (symbol RA), as defined in ASTM E-809 and CIE Publication 54. SI is equivalent to the Coefficient of Retroreflected Luminous Intensity (symbol R), as defined in ASTM E-809 and CIE Publication 54.

Specifications for retroreflective materials typically appear in matrix form, giving the SIA for selected entrance and observation angles. An example is shown in Table A-1. This happens to be a Federal Specification for encapsulated lens (Type III) sheeting. Except for the SIA values themselves, it is similar to the format that would be used for other types of materials.

TABLE A-1
Minimum SIA Values for Type III Retroreflective Sheeting

Observation Angle (°)	Entrance Angle (°)	White	Yellow	Red	Orange	Green	Blue
0.2	-4	250	170	35	70	30	20
0.2	+30	140	90	19	40	17	11
0.5	-4	95	62	13	25	12	7.5
0.5	+30	55	36	7.8	15	6	4.4

The numbers in the table show minimum candelas out for each unit of illumination in (lux or ft-candles). For example, at an observation angle of 0.2° and for each lux of illumination impinging on each square meter of surface, the silver-white material will generate a minimum of 250 candelas at an entrance angle of -4°.

APPENDIX B

Subject Instructions Used in Various Investigations

SUBJECT INSTRUCTIONS - LAB DISCOMFORT GLARE STUDY

In the near future there is a good chance that large vehicles like trucks will be marked with areas of retroreflective material in an effort to improve their nighttime visibility. One concern is that the material must not be so bright that it causes unacceptable levels of glare to other drivers. The purpose of this study is to determine how bright would be too bright.

You have already seen that this study requires that you rest your chin in a cup to be sure that your eyes are in just the right position. All you have to do is look continuously at the X on the wall in front of you. About every 10 seconds or so you will experience a two-second exposure of glare from the box under the X. When the glare goes off call out a rating, using the scale to the left of the X. It is very important that you be looking at the X when the glare comes on, since your impression of glare depends on where it appears in your field of view. In particular, do not look directly at the glare source!!

Note that the scale goes from 1 to 9, with the odd numbers having descriptors such as unbearable, just acceptable, and so on. Decide which number best describes your reaction to the glare and call it out so that I can hear it. By the way, you can use the even as well as the odd numbers on the scale. Feel free to look at the scale while deciding what your rating is.

Most of the time the glare will come from pieces of reflective material, such as the one in place now. All the pieces will be white, but they will vary in width. On some trials glare will come from a small circular source in the center. Regardless of the type or size of the source, give us a rating of the discomfort you experienced. That's important. We're only interested in your impression of discomfort. For example, different size pieces of reflective material may appear equally bright, but one may seem more uncomfortable than the other. Base your response on the sensation of discomfort, not on apparent brightness.

We recognize that sitting with your chin in that rest is not the most comfortble way to pass the time of day. We'll give you a break about half way through the test. If you get still or tired at any time please let us know and we'll take a break.

Any questions?

SUBJECT INSTRUCTIONS - GLARE DURATION STUDY

The purpose of this study is to measure the effect that glare has on driver comfort while driving at night.

During the test you will be seated in this stimulator, as you are now. The display for the simulator is the television that you see in front of you. The object is to stay on the road that you will see displayed on the screen. I'll set up the simulator and give you some practice on it before the test starts.

Once we start, you will operate the simuator and I will periodically expose you to glare from the projector you see on top of the television. The intensity of the glare, and its duration, will vary from trial to trial. When the glare goes off each time please give me a rating of the discomfort you experienced, using the scale you can see through the right door of the car.

Note that the scale has nine points, five of which have descriptors such as "unbearable, just acceptable" and so on. Decide which number best describes your sensation of discomfort and call it out so I can hear it. Note please that your ratings can use the even as well as the odd numbers on the scale.

Please note that you should NEVER look directly at the glare source. Rather, keep your eyes focused on the television screen and on the road.

We realize that driving the simulator is not the most exciting way to pass the time of day. About half way through the test, we'll stop and give you a short break. If, however, at any time during the test you would like to take a break, let me know.

Do you have any questions?

SUBJECT INSTRUCTIONS

WIDTH-INTENSITY VISIBILITY DISTANCE STUDY

In the near future the Government may require that large trucks have additional markings on them to make them more visible at night. These markings will probably take the form of strips of reflective material across the rear and along the sides. The purpose of this study is to measure the distance at which such treatments can be seen as a function of the type of material used and its width.

This car will be driven up and down this road. At each end of the road a test panel will be located on the shoulder to your right. All you have to do is press a button on a box that I will give to you shortly when you see the test panel.

You can see one of the test panels in front of the car now. They will all be the same length and height above the ground, they will differ from trial to trial in their width and apparent brightness.

I am going to ask one of you to drive. Stay to the right of the center line and go about 35 mph. At each end of the track make a U-turn and start back in the other direction, unless I ask you to stop. Note that there is a stop sign in the center of the track; don't become so engrossed in the task that you run the sign.

One very important note: Please do nothing to let the others in the car know when you have responded. If you do it may influence their judgments.

We will start the test with one round trip for practice. Before we start do you have any questions?

SUBJECT INSTRUCTIONS: PAIR-COMPARISON STUDY

The Federal Government will shortly be requiring that large vehicles such as trucks have additional markings to make them more visible at night. These markings will consist of strips of reflective material. One issue is what pattern, if any, these strips should have. Tonight we are asking you to help us, and the Government, select a pattern for this purpose.

We will be showing you strips of reflective material in pairs, one over the other. An example can be seen ahead of the cars now. To help put you in the proper frame of mind for this study, imagine yourself driving at night. Ahead of you is a stopped truck, and the only means you have of knowing that is the reflective strip mounted on it. On each trial I'd like you to decide which pattern you think would be better for marking such a hazard, the one on top or the one on the bottom. When you've made that decision, circle the "Top" or the "Bottom" on your scoresheet.

Remember, we're looking for the pattern that best serves to mark a potentially deadly hazard. On each trial tell us which one you think best communicates to you the idea that "this is a hazardous object."

The patterns that you see tonight will all be some combination of red and white. You will see two different widths, and two levels of brightness. Please remember, the issue is what treatment best communicates the concept of "hazard," not what is most easily seen or any other criterion.

Before each trial we will call off a trial number over the radio. Look at the display, make your choice and note it on the score sheet we've given you. Then prepare for the next trial. The trials will come at short intervals, so you will have to decide between each pair quickly.

The study will be run at two distances, so at the halfway point we'll take a brief break while the two cars are moved.

Any questions?

INSTRUCTIONS: SPEED JUDGMENT STUDY

The purpose of this study is to determine how well people can judge whether another vehicle ahead of them is getting closer or further away.

On a computer screen you will see various figures representing the rear end of a truck. They will range from a horizontal bar to a square. When the figure first appears it will be stationary. After a time (which will vary from trial to trial) it will start to grow or become smaller, representing movement toward or away from you.

To respond, press the down arrow key in the lower right corner of the computer keyboard if you think the figure is approaching (i.e., getting larger), and the up arrow key if you think it is going away (i.e., getting smaller). Press the key as soon as you can once you are sure of the direction of movement. If you realize that you pressed the wrong key by mistake, press the correct key as quickly as possible. Keep your finger just above and between the keys between trials.

We'll start with a series of trials for practice. Do you have any questions?

SUBJECT INSTRUCTIONS

SIA-VISIBILITY DISTANCE STUDY

For a number of months now we have been working on a program intended to develop improved markings for large trucks. In the near future you may see the fruits of this research on the highway.

The purpose of this study is to measure the distance at which people can detect various types of treatments that might be employed to mark large trucks.

Ahead of us at the end of the road is a large tractor trailer. We will fit various types of reflective treatments on it, representing what might be done to the side and rear of a trailer. I will drive this car toward the trailer. All you have to do is push any one of the white buttons on the box that I gave you when you can see the trailer. When we reach the end of the road I will turn the car around, stop for a moment to write down the results of the run, and then drive back toward the other end. There is another display at that end, on your right. Again, press any button on the box when you can see it. At the other end I will once again turn the car around, stop to write down the results, change the display, and then drive back toward the other end.

We will make one round trip just for practice. That's all there is to it. Any questions?

SUBJECT INSTRUCTIONS

FILTER CORRECTION STUDY

The purpose of this study is to compare visibility distance with normal and filtered headlamps. The targets you will be looking for are reflective strips. One of them is ahead of the car now, on the right. As the car is driven along the road look for the target, which will always be in the same place. As soon as you can see it press any one of the white buttons on the box that I gave you earlier. That's all there is to it.

There is another target at the other end of the road, which you will see in a moment. Thus, you have to look for targets at both ends of the track. The targets never move and never change.

Some of you will see the targets sooner than others, which is just fine with me. I do ask that you do not make any comments when you see it that might tip off or put pressure on the others.

We're going to make one round trip for practice before we start. Any questions?

SUBJECT INSTRUCTIONS - HAZARD IDENTIFICATION STUDY

In attempting to understand driving strategy an important question is the identification of hazards. What do drivers consider to be hazards, how do they identify them, and at what distance can they be identified at night?

We are going to ask you to drive this car for about half an hour on roads just north of here. Keep a look out for what you consider to be potential hazards. When you spot one press any of the white buttons on the box on the seat next to you. Then tell me what you think it is.

A "potential hazard" is anything that may cause you to have to change speed or direction to avoid a conflict. Examples are pedestrians on the road, parked vehicles, large chuckholes or debris in the road, and vehicles that may pull in front of you from side roads. For purposes of this study potential hazards do not include such things as traffic lights, stop signs, routine warning signs for curves or crossroads, intersections with no traffic, and following or oncoming vehicles.

I'll tell you where to drive and the approximate speed. Remember when you see something that you think is a potential hazard, press one of the white buttons on the box next to you and tell me what you think it is.

Do you have any questions?

INSTRUCTIONS: DISABILITY GLARE STUDY

For some time now we have been conducting a series of studies aimed at setting specifications for using reflective material on large trucks to make them more visible at night. One of the issues is that treatments designed to make trucks more visible must not interfere with the visibility of stop and turn signals presented by that vehicle. This study is designed to look into that question.

You will remain seated in this car during the study. I have given each of you a push button. Ahead of you is a panel on which are mounted a red and a yellow lamp. In addition, we will place strips of reflective material on the panel at different distances from the lamps. All you have to do is press the button as soon as you notice that one of the lamps is on.

I don't want you to look directly at the lamps, however. Look at . . . between trials.

We'll be running a large number of trials in fairly rapid order. Every once in a while there will be a brief pause while the display on the board is changed, then we'll go back at it again. If you find yourself getting tired please say something and we'll take a break.

We'll start with a series of trials for practice. Do you have any questions?

SUBJECT INSTRUCTIONS

LABORATORY DISTANCE JUDGMENTS STUDY

This study is one of a series we have been conducting for the past year or more on the question of improving the marking of large trucks. One of the issues is whether the markings can make it easier for approaching drivers to determine speed and distance. This study is designed to tell us something about that.

What we are going to do is show you images of truck markings on a computer screen. You will see two identical images, one following the other, separated by a brief interval. The first image will be a reference. It will always be the same size. The second image will be slightly larger or smaller than the reference. All you have to do is tell us whether you think the second image is larger or smaller than the reference.

The sequence will be as follows: you will see the reference pattern for a few seconds, the screen will be blank for a few seconds, and then you will see the test pattern. When the screen goes blank again tell us whether you think the test pattern was larger or smaller than the reference. We'll then show the reference pattern again followed by another test pattern.

The differences between the reference and test patters will be small. Sometimes, maybe much of the time, you will not be sure whether the test pattern is larger or smaller. That's fine. We expect the task to be difficult. If you are not sure give us your best guess. Also, please don't spend a lot of time thinking about each situation. Your first impression is most likely to be accurate.

We're going to be showing you four different patterns in this study. The individual trials will come rather quickly, so we can get you out of here in an hour or less.

Any questions?

SUBJECT INSTRUCTIONS - STOP LAMP STUDY

The purpose of this study is to determine the level of brightness at which people will identify a red lamp as a brake signal. We are also interested in seeing whether bright surfaces near the lamp will change the judgment.

As you know, most cars signal a brake application by making the rear lamps brighter. An important question is how bright they have to be to reliably signal "brake" to all drivers. In addition, on trucks, reflective material may be mounted close to the lamps, and that might alter the level at which the signal will be seen as a brake.

Imagine yourself coming over the crest of a hill at night. Ahead of you is a vehicle. The question you have to answer is does the brightness of its rear lamps signal a brake application? In this study we'll use only a single lamp. It's attached to the panel you see at the other end of the room. Periodically the lamp will come on. When it does tell us whether you think it represents a tail or stop lamp.

The signals will be presented in fairly rapid order. Don't spend a lot of time thinking about each choice. Your first impression is what we want to hear.

Any questions?

APPENDIX C

Comments on Cost-Benefit Analysis for Conspicuity Enhancements

COMMENTS ON CONSPICUITY-RELATED ACCIDENT DATA AND PROPERTY DAMAGE COSTS

In an effort to clarify some of the issues associated with carrying out a cost benefit analysis in support of enhancing the conspicuity of large trucks, the original Vector Enterprises fleet field study data was reviewed and analyzed.

Estimating Truck Rear-End Collisions

There are currently no data that allow the estimated annual number of other-vehicle into truck rear-end crashes to be made with a high level of confidence. However, in order to make some approximation of the figure, computer runs were conducted on the 1986 NASS and 1988 GES databases to determine the number of rear-ends estimated by those two files. Both files were restricted to involvements of tractors pulling one or more trailers that were struck in the rear. For comparative purposes, the total number of tractor-trailer involvements (including both single- and multi-vehicle crashes) and the percentage of rear-ends out of the total were calculated.

Table C-1 shows the number of rear-ends, the total number of involvements, and the percentage of rear-ends for the NASS and GES data. The 1986 NASS file estimates 14,778 and the 1988 GES file estimates only 10,251 rear-ends. In terms of the total number of involvements, the 1986 NASS file yielded 200,430, while the GES figure was much lower at 133,225. The percentage that rear-ends comprise of the total number of involvements was 7.37 percent for NASS and 7.69 percent for GES.

TABLE C-1
NASS and GES Estimates of Tractor-Trailer Rear-End Crashes

Source	Sample Size	Rear-End Involvements	Total Involvements	Percent Rear-Ends
1986 NASS	336	14,778	200,430	7.37%
1988 GES	892	10,251	133,225	7.69%

It is difficult to determine which of the estimates of the total number of tractor-trailer rear-ends might be the most accurate. A problem common to the NASS and GES data files is that large trucks are sometimes misidentified in police accident reports, leading to false classifications in the computerized files. Furthermore, NASS and GES are probability-based samples, but the accuracy of their national estimates is frequently limited for large trucks because of small sample sizes (see Table C-1). It is therefore not surprising that these two databases have produced varying estimates of the annual number of tractor-trailer rear-end crashes.

Severity of Rear-End and Side Impact Collisions

Because there remains some ambiguity in the Vector fleet data concerning enhancing the conspicuity of trailers, further analyses of computerized files were conducted, focusing on the injury severity and property damage costs associated with rear-end and side impact crashes. Our objective was to determine whether these two types of collisions involving large trucks differ in their level of severity and/or the amount of property damage incurred. Our planned procedure was to obtain severity distributions for rear-ends and side impacts from several different databases and then to apply property damage cost estimates from the Office of Motor Carrier (OMC) datafile (MCS 50-T accident report forms) to these distributions. We successfully completed the first part of the process, but encountered major obstacles in the second part due to the structure of the OMC file.

Severity distributions were determined for three years of NASS data, 1984-1986; the 1988 GES file; and four years (1985-1988) of data from the state of Michigan automated police report files. The runs on the NASS and GES files included all tractors hauling any number of trailers, while the Michigan analysis was restricted to singles, or tractors hauling one trailer. The collision types considered were two-vehicle accidents where the truck was struck either in the rear or the side. Tables C-2 through C-4 compare the severity distributions between the rear-ends and side impacts for each of the three datasets.

The NASS data (Table C-2) indicate that rear-end crashes are associated with a slightly higher risk of casualties than side impacts. Property damage only crashes account for 47 percent of the rear-ends, compared with 53 percent of the side impacts. Conversely, non-fatal injuries comprise 48 percent of the rears and 43 percent of the sides. It should be noted, however, that even after combining three years of NASS data, the sample sizes upon which the national estimates are based are still not robust.

TABLE C-2
1984–1986 NASS
Severity Distribution of Rear-ends and Side Impacts

Accident Severity	Rear-Ends (N=117)		Side Impacts (N=127)	
	Weighted Freq.	Percent	Weighted Freq.	Percent
PDO	18,463	46.85%	29,713	52.98%
Injury	19,088	48.44	24,322	43.37
Fatal	21	0.05	72	0.13
Unknown Severity	1,837	4.66	1,972	3.52
Total	39,409	100.00%	56,079	100.00%

The results from the analysis of the 1988 GES file (Table C-3) are similar to those obtained from NASS. Once again the overall impression is that rear-ends are slightly more severe than side impacts. In this case the proportion of injury accidents is virtually identical between the two collision types, but fatal accidents are about 3 percentage points higher among the rear-ends than the side impacts, while PDOs (property damage only) are about 3 points lower. As with NASS, the sample sizes are small.

TABLE C-3
1988 GES
Severity Distribution of Rear-ends and Side Impacts

Accident Severity	Rear-Ends (N=86)		Side Impacts (N=113)	
	Weighted Freq.	Percent	Weighted Freq.	Percent
PDO	5,695	55.55%	7,856	58.31%
Injury	4,015	39.17	5,290	39.27
Fatal	541	5.28	326	2.42
Total	10,251	100.00%	13,472	100.00%

The analysis of four years of Michigan data produced different results (Table C-4). In this case the side impacts are clearly more severe. The proportion of both fatal and injury accidents is substantially higher among the side impacts, while PDOs account for a higher percentage of the rear-ends. The Michigan data come from a census file, and the four years of data have produced an adequate sample size. A possible reason behind the difference observed between the Michigan data and the national data might concern accident reporting thresholds. Michigan requires accidents to be reported if at least $200 worth of property damage is sustained. This is towards the low end among the states, many of which employ a tow-away threshold. It is conceivable that many low-speed car into truck rear-ends involve small amounts of property damage, meaning that a higher proportion of these low damage cases would be reported in Michigan than in the nation as a whole.

TABLE C-4
1985-1988 Michigan
Severity Distribution of Rear-ends and Side Impacts

Accident Severity	Rear-Ends		Side Impacts	
	Number	Percent	Number	Percent
PDO	3,547	75.84%	837	64.43%
Injury	1,089	23.28	428	32.95
Fatal	41	0.88	34	2.62
Total	4,677	100.00%	1,299	100.00%

The analysis of the severity distributions of rear-end and side impact crashes contained in three computerized files has not done much to resolve the question of which portions of trailers account for the most costly crashes. Analyses of two national databases suggested that rear-end crashes are slightly more severe than side impacts, while an analysis of Michigan data indicated that side impact collisions are more severe. Both national files have the problem of small sample sizes, while the Michigan data are not necessarily representative of the national accident experience.

Property Damage Costs of Rear-End and Side Impact Collisions

UMTRI maintains a computerized file of data from the Office of Motor Carrier's (OMC) MCS 50-T accident report form. This is probably the only national database containing information on property damage costs sustained in large truck accidents. We analyzed the 1986 OMC file in an attempt to calculate mean property damage costs for different levels of severity of rear-end and side impact collisions. The use of the OMC file necessarily reduces the focus of analysis from all tractor-trailer combinations to just interstate carriers. In addition, only those accidents resulting in a casualty or at least $4,200 in total property damage were required to be reported to OMC in 1986. The OMC file is very strong in terms of physical descriptions of trucks, and it contains adequate information concerning accident severity. However, it lacks several of the key variables needed to confidently identify the collision scenarios of interest for the conspicuity analysis. In particular, there are no variables describing the type of collision, the area of damage to the vehicles, or the role of the vehicles (striking versus struck).

The limitations of the OMC file are less severe for rear-end crashes than for side impacts. The file includes variables that describe the movement of each vehicle involved in a crash. One of the levels for these variables is "rear-end," which is used for the vehicle that strikes the rear of another vehicle. For this analysis, we looked at tractor-semitrailers that were coded as "decelerating," "stopped," "turning right," "turning left," or "moving straight" that were involved in a two-vehicle crash with the other vehicle coded as "rear-end." The truck movement codes selected are the ones that most likely correspond to conspicuity-related rear-end collisions. They account for 89 percent (885 out of 993) of the cases in the 1986 OMC file where the other vehicle is coded "rear-end." An additional 5 percent of those cases include "parked" trucks, which are excluded from this analysis.

We checked the validity of the vehicle movement codes by doing a run on UMTRI's 1980-1986 version of the Trucks Involved in Fatal Accidents (TIFA) database. This file combines FARS and OMC variables. Since FARS includes the standard variables used to identify collision types, we selected tractor-semitrailers and other vehicles with the OMC codes described above and examined the distribution of collision types and vehicle roles in the TIFA file. The expected result was trucks coded as "rear-end" for collision type and "struck" for vehicle role. In fact, 85 percent of the selected cases were coded this way. Therefore, we concluded that most of the cases in the OMC file with these vehicle movement codes are likely to be actual rear-end collisions. We do not claim to have selected all the rear-end cases contained in the OMC file, just those that we can identify with a relatively high degree of confidence.

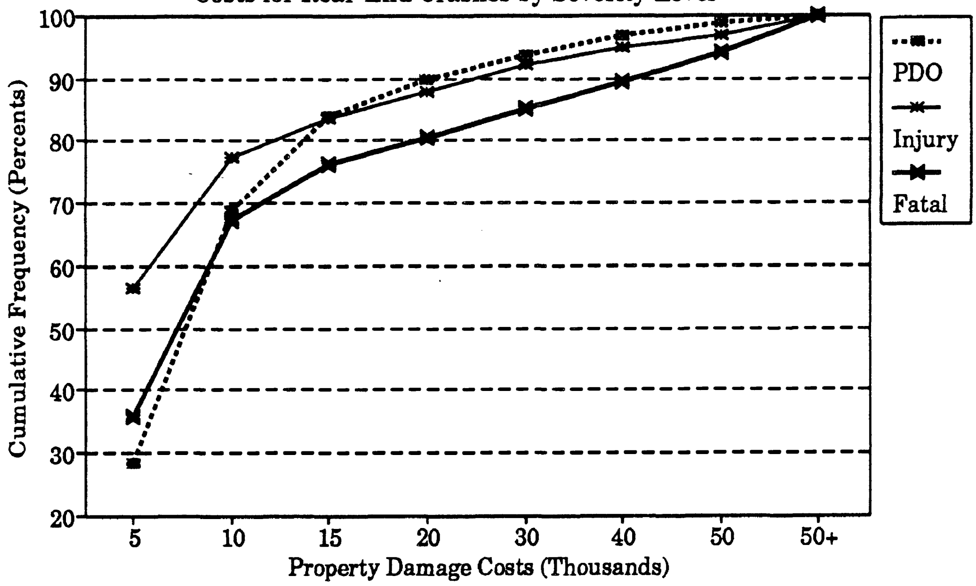
Table C-5 lists the mean property damage costs associated with the crashes that we identified as another vehicle rear-ending a tractor-semitrailer in the 1986 OMC file. Cases with unknown damage costs (about 10 percent of the total) were excluded from the analysis. The mean amount of damage was nearly $11,000 per crash. The OMC data indicate that PDO accidents are slightly more costly than non-fatal injury accidents, but this is probably attributable to the higher threshold for reporting PDOs. The OMC fatal crashes have the highest average cost of all at $16,350. As indicated by the standard deviations and maximum values in the table, however, there is a lot of variability in the amount of damage sustained within each of the severity levels.

TABLE C-5
1986 OMC
Property Damage Costs of Rear-Ends by Severity Level

Accident Severity	Accident-Level Property Damage Costs				
	Mean	Std. Dev.	Minimum	Maximum	N
PDO	$11,032	$10,212	$2,500	$60,000	158
Injury	10,278	16,049	0	120,000	573
Fatal	16,350	25,849	0	161,000	67
All	$10,937	$16,233	$0	$161,000	798

Cumulative frequency distributions for the property damage costs of these crashes are shown in Figure C-1. Differences among the three severity classes are very clear at the low end of the cost scale. While nearly 57 percent of the injury crashes result in damage of $5,000 of less, this is true of only 36 percent of the fatal crashes and just 28 percent of the PDO crashes. The difference between the PDOs and casualty crashes at this level is surely due to the reporting threshold difference. The effect of the reporting threshold difference diminishes at higher levels of cost. For example, about 84 percent of both PDOs and injury accidents result in $15,000 or less of damage. Beyond this level, the PDO cumulative frequency line is slightly higher than the injury line, reflecting the greater proportion of injury accidents at the top end of the property damage scale. The line for the fatal crashes lies significantly below the other two for most of the cost values on the graph, reflecting both the higher mean damage and the skewed distribution of fatal cases towards very high costs.

FIGURE C-1 - Cumulative Frequency Dists. of Property Damage Costs for Rear-End Crashes by Severity Level



Vector Enterprises reported an average savings of $3,200 in property damage costs for each crash prevented during their fleet study. While the average cost of the rear-end crashes in the OMC file is nearly $11,000, this figure is not directly comparable since PDO crashes were only required to be reported if there was $4,200 worth of damage. The inclusion of all PDO accidents would necessarily lower the average cost. The casualty accidents are not affected by such a bias, however, and their average property damage cost in OMC is also almost $11,000. For the OMC data, 80 percent of all truck rear-ends are casualty accidents. This is not representative of all truck accidents because of the reporting threshold, but in NASS, 51% of the accidents involved at least one casualty. If the 51 percent casualty accident proportion is accepted at an average cost of $11,000, then even if the remaining 49 percent of PDO crashes averaged only $1,000 worth of damage, the resulting total average would be about $6,100 per crash.

We had originally hoped to calculate similar property damage costs for side impact collisions in the OMC file. Unfortunately, this proved to be a virtually impossible task. None of the OMC vehicle movement codes are unique to angle collisions, and none of the other usual variables used to identify collision types are present in the file.

We again used the TIFA file to try to counteract these problems. First, we used TIFA variables to restrict the cases to two-vehicle angle collisions where a tractor-semitrailer was struck in the side. A crosstab of the OMC vehicle movement variables on these cases showed that 16 combinations of the variables accounted for nearly 80 percent of the cases. However, only 10.8 percent of all two-vehicle tractor-semitrailer crashes defined by these vehicle movement codes represented the collision type of interest, that is, the truck struck in the side in an angle crash. So, while we can identify the vehicle movement codes that most likely pertain to conspicuity-related side impact crashes, nearly 90 percent of the time these codes include other types of collisions, at least among fatal accidents. Therefore, any application of the OMC file's property damage cost values using these movement codes would include a vast majority of unwanted cases, thus nullifying the validity of the analysis.