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CONSPICUITY ON THE HIGHWAY: A Symposium Sponsored by the Committee on Visibility

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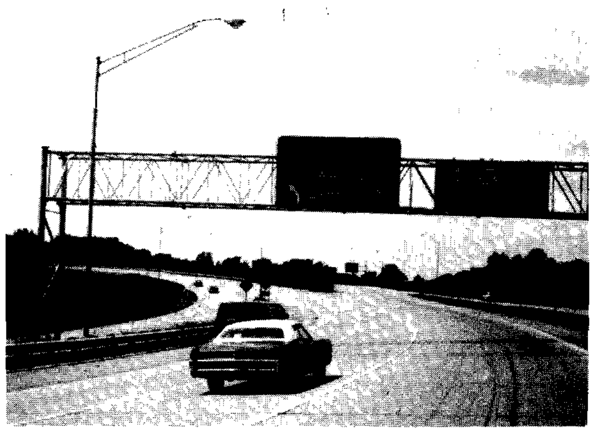

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FOREWORD

Albert Burg - Chairman, Symposium Planning Committee

The TRB Committee on Visibility has maintained a continuing effort to disseminate information on critical visibility topics to individuals responsible for providing motorists with a safer highway environment. Toward this end, since 1968 the Committee has sponsored six conferences and symposia, the most recent of which was the Symposium on Conspicuity on the Highway, held in St. Paul, Minnesota on June 24-26, 1980. This Circular presents most of the papers presented at that Symposium.

The purpose of the Symposium was to present state-of-the-art information on techniques, devices and principles that can be used to increase the highway user's ability to detect relevant objects in his environment, day or night. Ten papers were presented dealing with the principles of conspicuity and the conspicuity of vehicles, people and highway elements. Workshops were held at the close of the Symposium to summarize the information presented and the conclusions reached. Publication of this Circular makes available to a large number of interested professionals a summary of most of the ideas and concepts discussed at this meeting.

CONTENTS

PRACTICAL ASPECTS OF CONSPICUITY PRINCIPLES

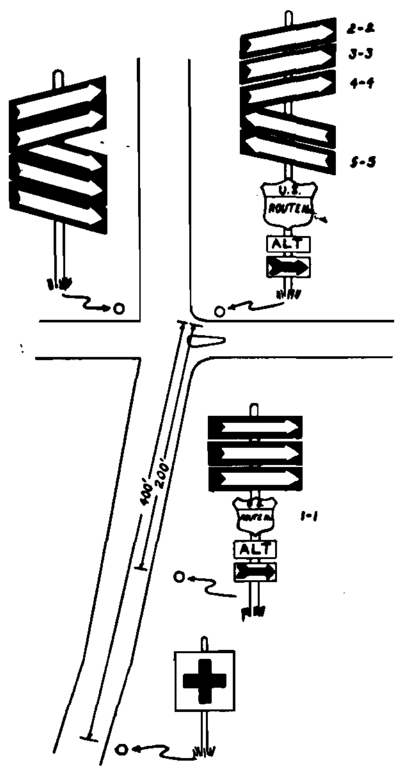
T. W. Forbes, Department of Psychology and Highway Traffic Safety Center, Michigan State University

My assignment is to furnish a brief general background for other more technical papers on the program. First, though, a bit of history and some definitions. When some of us were beginning to study visibility on the highway in the early 1930's, the highway and driving conditions were very much different from those of today. Speeds were lower, the requirements for highway and equipment visibility was less and sign visibility and legibility were much poorer. It was common to find a large number of place names, each on a separate wood board mounted one above the other on "totem poles" at road intersections. Figure 1 gives the layout of a typical crossroad installation from an early research report (3). Figure 2 illustrates an early expressway sign, a reduced "totem pole."

As compared to these early highway conditions, present highway signing and traffic conditions are much improved. Speeds are higher on both types of roads, however, and conspicuity and legibility can still be improved. Figure 3 shows an overhead mounted sign on a freeway. This example illustrates not only improved legibility and conspicuity, but also an off-ramp to the left.

As noted in a recent report, conspicuity is more necessary where alignment is contrary to the usual right hand off-ramp which most drivers expect. This expectancy factor is of considerable importance as pointed out by these authors.

FIGURE 1: "Totem pole" sign layout at an intersection studied in early research (3).



Needs for Definitions

Before discussing the various interrelated factors and needs for conspicuity on the highway, definitions of conspicuity and related terms will be considered to avoid possible confusion as to meaning of terms.

Definition of Conspicuity

According to Webster, the term "conspicuity" comes from the Latin meaning "get sight of" and thus means (1) obvious to the eye or mind, and also (2) attracting attention. The latter meaning has also been applied in some uses to auditory and other methods of obtaining attention.

Related Terminology

The following related terms are defined thus--the first three from Webster:

1. Visibility--The distance objects can be identified visually with the naked eye. For certain purposes, this distance is often used as a measure of visibility.

2. Detectability--Characteristics such that the fact of presence or existence can be determined, i.e., this is the minimum even before the object can be identified.

3. Recognizability--Characteristics of the thing such that it will be perceived as something previously known. Thus visibility involves both detectability and recognizability according to these definitions.

4. Attention Value--Having characteristics which attract attention.

5. Target Value--Visual characteristics of signs, usually luminance and contrast, giving visibility and attention value, i.e., conspicuity of one type.

FIGURE 2: Modified "totem pole" sign on expressway in 1941.

FIGURE 3: Modern sign on a freeway.

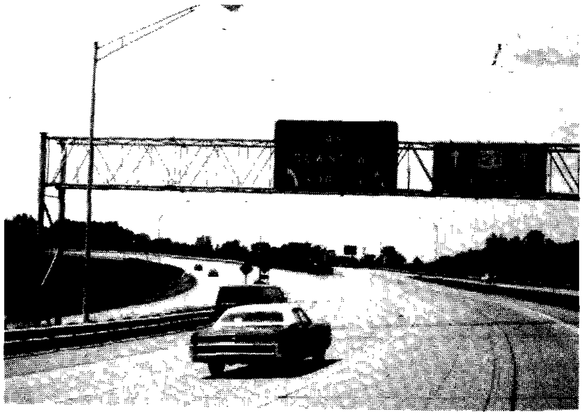


FIGURE 4: View of an intersection illustrating highway elements requiring conspicuity.

This last term was originally used by the late Guy Kelcey referring to attention-getting effects of high luminance of sign legends using retroreflective buttons. It was adopted in connection with some of the earliest studies of highway sign legibility and visibility (3). It, therefore, refers to conspicuity of one type.

Need for Recognizability in Addition to Conspicuity

Conspicuity on the highway may be obtained without recognizability, and recognizability is highly important. For example, a flashing light on the highway ahead will definitely provide conspicuity. But if the driver is to make the required judgments and responses correctly, he must know whether he is seeing a railroad crossing warning, a railroad engine headlight, an emergency vehicle flasher or a police car flasher, or an advertising sign.

Again, a vehicle ahead on a two-lane road may be of sufficient size and color to be conspicuous, but a driver must recognize: 1) whether it is a car, truck, bus (or school bus); 2) whether it is going in the same or opposite direction; 3) and, in overtaking situations, whether it is coming towards him in the wrong lane. He must be able to recognize the proper alternative in order to stop, continue and pass or quickly pull off the road.

What Has to Be Made Conspicuous?

After this preliminary introduction, we will now look at some of the wide range of highway elements, vehicles, people and animals which have to be made conspicuous in the interest of safe and good driving. For completeness, Table 1 lists first highway elements, then vehicles and then animals. It will not be necessary to discuss these in detail since they are rather self-evident, but they will illustrate the range of items to be considered.

Who Needs Conspicuity?

To increase safety and to reduce the probability of accidents, everyone on the highway whether operating a vehicle, motorcycle or bicycle, carrying on various kinds of maintenance tasks, or when crossing or walking along as pedestrians, has a vital need for conspicuity. All of these people can be classified under 1) vehicle operators and regular road users, 2) pedestrians of various types and 3) others on the highway. Table 2 lists these.

Again, it is not necessary to go over these item by item. It is clear that car drivers, motorcycle, moped and bicycle riders all need to be seen by other operators and in turn they need to see vehicles, people, signs, signals and where the road goes. Similarly, maintenance workers, enforcement personnel and others such as railroad crews and drivers at crossings must have conspicuity in order to operate safely. Pedestrians have a vital need for conspicuity in order to be seen and avoided by drivers. Heavy vehicle operators, because of the longer time to stop or avoid hazards, have an especially great need for conspicuity of other vehicles, highway features and other users of the road.

When Is Conspicuity Needed?

All would agree, I think, that conspicuity is needed at all times when driving, walking or just being on the highway or its shoulder. This includes, of course, ordinary daylight but also shadow and partly dark conditions in tunnels. (See Table 3).

Lighting and reflectorization factors are especially important at night, or course. Such factors as even lighting distribution vs. "visual noise" from spotty lighting are highly important as are effects of glare on visibility and conspicuity. Also lighting alone does not necessarily provide conspicuity since sometimes lighting produces shadows which actually hide certain objects.

Practical Methods of Obtaining Conspicuity

Certain basic factors shown in Table 4 are both important and well-known. Many of these factors such as color contrast, brightness contrast, placement and relative size will be discussed in more technical detail later. A few examples follow which illustrate well-known practical applications of such factors.

TABLE 1. WHAT HAS TO BE MADE CONSPICUOUS?

1. HIGHWAY ELEMENTS

   A. Signs
   B. Signals
   C. Pavement markings
   D. Changes in horizontal alignment
   E. Dips or bumps
   F. Pavement vs. shoulder
   G. Obstructions and barricades
   H. Construction areas
   I. Roadside hazards
   J. Bridge approaches

2. VEHICLES

   A. Cars
   B. Trucks and trailers
   C. Busses
   D. Bicycles and mopeds
   E. Motorcycles
   F. Recreational vehicles
   G. House trailers
   H. Other vehicles being towed
   I. Farm vehicles and equipment
   J. Construction vehicles and equipment
   K. Railroad trains and engines

3. ANIMALS

   A. Seeing-eye dog
   B. Pets
   C. Farm animals
   D. Harness animals
   E. Riding animals
   F. Deer and other wild animals

TABLE 2. WHO NEEDS CONSPICUITY?

1. VEHICLE OPERATORS AND REGULAR ROAD USERS

   A. Car and truck drivers, motorcycle, moped, and bicycle riders*
   B. Traffic engineering crews for safety
   C. Maintenance workers and flagmen
   D. Enforcement personnel and vehicles
   E. Emergency personnel and vehicles
   F. Railroad crews and drivers at crossings
   G. Others on special roadways e.g., airport roadway and taxiways
   H. Maritime pilots at highway bridges

2. PEDESTRIANS

   A. General public
      1. Adults
      2. Children
   B. Joggers
   C. Crossing guards
   D. Fire fighters
   E. Police
   F. Construction, maintenance and utility crews
   G. Motorists or repairmen adjacent to vehicles

3. OTHERS ON ROADWAY

   A. Bicyclists
   B. Mopedists
   C. Motorcyclists
   D. Equestrians
   E. People on roller skates or skateboards

*To see: Signs and signals, both urban and rural. Where the road goes, especially rural. Each other; urban, rural, and roadside.

TABLE 3. WHEN IS CONSPICUITY NEEDED?

1. AT ALL TIMES WHEN DRIVING OR WALKING IN:

   A. Ordinary daylight, shadow or tunnel conditions
   B. In dusk, darkness, and dawn
   C. In poor weather conditions - snow, fog, rain and other

2. LIGHTING AND REFLECTORIZATION AS FACTORS AS NIGHT

   A. Even lighting distribution vs. "visual noise"
   B. Lighting alone does not necessarily provide conspicuity
   C. Glare, visibility, and conspicuity

TABLE 4. PRACTICAL METHODS OF OBTAINING CONSPICUITY

1. BASIC FACTORS

   A. Color contrast
   B. Brightness contrast
   C. Intermittent stimulation
   D. Relative size
   E. Placement (re: driver's line of sight and to avoid competing objects

2. EXAMPLES OF PRACTICAL METHODS

   A. Reflectorized signs and high luminance signals
   B. Oversized stop signs and symbol signs
   C. Lane width flashing arrows protecting approach to road work
   D. Fluorescent orange flagman's vest
   E. Flashing lights on police vehicles
   F. Flashing lights on emergency vehicles
   G. Addition of sirens and auditory warnings
   H. Bi-modal stimulation (e.g., rumble strips)

3. INCONSPICUITY - EXAMPLES

   A. Car hits freight train across road
   B. Driver misses one-way arrow, goes wrong way
   C. Road turns, driver continues straight (off road)
   D. Laying recording tapes on highway
   E. Pedestrian on road side
   F. Rear-end stopped vehicle in the rain or without lights

Examples of Practical Methods

Flashing lights as attention getters are well known. Reflectorized and oversized stop signs have been used widely, and there have been studies to determine the best method of using them. Road work approach warnings consisting of flashing arrows and fluorescent orange vests for flagmen are widely used.

Addition of signs and auditory warnings or rumble strips have been found helpful for hazardous locations, toll booths and other special facilities such as bridges.

Examples of Inconspicuity

Of equal importance are examples of lack of conspicuity. Late night accidents where a car hits a freight train across the road happen all too often. A driver who goes the wrong way on a divided highway having missed a one-way sign illustrates a very hazardous effect of lack of conspicuity.

Figure 4 is a daylight scene where a road turns, but the driver at night may easily continue straight ahead. Pedestrian accidents and rear-end collisions with a stopped vehicle are all too common.

Maintenance people, I am sure, will recognize the need for conspicuity to allow road work with reasonable safety. It is very significant that the Institute of Transportation Engineers, in cooperation with various other highway organizations, has developed a special training course on flagging in a training program for construction and maintenance personnel. All of the features in the course are basically concerned with improving conspicuity and safety (1).

Research on Conspicuity Requirements

A great number of researches have been done all over the United States, Europe and Japan, but only a few examples will be mentioned to illustrate research in three areas. These are (1) visibility of pedestrians, (2) visibility of vehicles, and (3) visibility of highway signs. A fourth area is research on visual sensitivity of people which, of course, is basic for visibility of any kind.

Conspicuity of Pedestrians

Visibility of pedestrians depends, of course, on both lighting of the pedestrian and reflectivity of his body and clothing. Many of the same factors apply to visibility of bicyclists and motorcyclists.

Richards (13, p. 8) reviewed his own and other previous studies. In one study, pedestrians dressed in dark brown and a reflective factor of 30 percent. Under headlights on a city street this gave a luminance 50 percent greater than the road at 25 feet but at 100 feet was only half as bright. Therefore, seeing the pedestrian changed from direct to silhouette seeing at about 50 feet. Distances, of course will be different with modern headlights and with different reflectivity of pedestrian clothing and road materials.

Allen (2, pp. 150-153) reports that although 11.8 percent of drivers claim they did not see a pedestrian in daylight, at night 23.4 percent claim they did not see them before the impact. In his studies, pedestrian clothing reflectances ranged from 9 percent for black to 16 percent for gray and 75 percent for white. Dummy pedestrians represented the range of clothing reflectances to be expected on the highway. Critical visibility distances (stopping distances) were checked against visibility distances for the pedestrians. For the darker clothing, safe visibility distance was obtained only to 30 mph, whereas white "pedestrian" clothing increased conspicuity to a 50 mph stopping distance (185 feet). Reflectorized tape increased the visibility distance even farther.

Richards (12) reported an extensive series of tests carried out in Massachusetts by several cooperating organizations to determine the safest color for clothing to be worn by hunters. Attention was given both to normal and to color impaired observers. Lighter colors were the more visible under low lighting conditions such as twilight, but yellow might be confused with white at such times. Fluorescent colors, especially blaze orange, were seen best especially at dusk. Red, on the other hand, tended to disappear at dusk and might be confused with other colors.

Fluorescent orange has been adopted not only for hunters' clothing but also for vests to be worn by flagmen and other personnel who must be on the highway for maintenance or for other purposes at all times of day.

Sleight (15) in his chapter on the pedestrian, summarized research on the pedestrian and quoted the determination of critical visibility distance by Hazlett and Allen (9). He noted the pedestrian accident rate is much higher in darkness than in daylight.

Daytime accidents involving pedestrians also may involve conspicuity. Factors of vehicle design for visibility may affect conspicuity as discussed in detail by several authors (Merrill Allen (2) and Mortimer (1), among others).

Conspicuity of Vehicles

Informal experiments on improving the conspicuity of vehicles have been carried on by bus companies. They have reported that the use of headlights by their busses during daylight as well as at night has reduced accidents. Hard data on this are scarce, but it would be expected that headlights would help with conspicuity by showing which way a bus is going especially on two-lane highways.

Vehicle color and luminance may affect conspicuity of passengers, cars and larger vehicles including recreational vehicles. Allen (2) gives a plot of color against relative visibility through a filter and shows that shades from white to cream have much greater visibility than the darker colors. He claims that 10 times as many accidents happen to black cars as to white ones (2, pp. 138-139).

Contrast with the background against which the vehicle is seen may be as important as the color. Automobiles are often seen against a dark highway or other background which might explain poorer conspicuity and safety for darker colored cars as reported by Allen. However, in northern areas where cars may be seen against a white snow bank, darker colors may have greater conspicuity. Therefore, a combination of dark and light colors may be advantageous for vehicle safety. In daylight and shadow the findings of the Massachusetts hunter study would suggest use of fluorescent colors. At railroad highway crossings, low illumination and shadow conditions are often found. Therefore, markings on the side of railroad cars and on engines might be most conspicuous if light colors and even fluorescent colors are used.

Headlights and Rear Lights

Improving rear signal visibility on automobiles by higher placement of rear signals and use of colors specific to the meaning of the indication are suggested by Allen (2 pp. 130-137). Mortimer (11, pp. 200-212) discusses interference with the view of the driver from the design of the vehicle and methods of avoiding this. He also points out the need for rear visibility requirements and discusses different possible types of vehicle marking and signalling. Problems with certain types of suggested rear light signals are pointed out by Mortimer.

Other studies on improving conspicuity of highway vehicles and railroad cars have been done in past years (e.g., those by A. R. Lauer) but these examples will suffice for the present purpose.

Conspicuity of Highway Signs

A number of investigators have carried on research on visibility as well as legibility of highway signs. As a specific example, as series of 13 studies on visibility and attention value of highway signs was reported by Forbes, Pain, Fry and Joyce (5-7). A very brief review of methods and results follows.

The first part of the study was carried out in the laboratory where simulated highway signs and backgrounds were projected onto a moving picture screen. To make the slides, miniature test signs were made and photographed against pictures of backgrounds obtained at actual highway locations. Groups of about 25 subjects viewed a given set of conditions. Each subject, acting as an observer, indicated which of four signs was "seen first and best."

As an auxiliary "loading task, " the subject was required to relight small red lights in a matrix when certain of the lights were extinguished on a random basis by automatically controlled equipment. At certain times in this sequence, the blank background scene (i.e., without test signs) was suddenly replaced by the same scene with test signs in the picture. By pressing one of four buttons, the subject indicated which of the four test signs he judged to be seen "first and best." The small matrix of red signal lights served as a visual focal point and maintained dark adaptation.

The results were analyzed for each combination of signs. A large number of combinations of different parameters gave results for color, brightness, symbol and sign size, contrast of legend to sign background and contrast of sign background to surround.

The details of the results are given in the three publications listed in the references. Briefly it was found that mounting location over the highway gave better relative visibility than sign mounting beside the highway. Therefore, the remaining presentations and observations were made with mounting over the highway. One of these mountings with test signs as seen by the subject is shown in Figure 5.

Relative size also proved to be a factor, and this was held constant for other analyses. Color and brightness of the sign background and brightness of the white legends or symbols affected visibility.

Contrast with background gave a higher percent seen first. When measured luminance of the colors was plotted against percent seen "first and best" on an average basis for three different luminance backgrounds, the percent increased for the lighter colors (higher luminance). However, contrast proved to be important when percent seen first was plotted separately for each of the three backgrounds (See Figure 6). Here the lighter colors were seen best against the darker background, but against a lighter background, the darker colors gave better visibility.

Figure 7 shows results of actual outdoor observation distances for signs on the highway compared with expected calculated visibility distances. A mathematical model derived from laboratory relationships and based on luminance contrast of legend, sign background and surround background modified by relative size was used for calculated distances.

Applying this result to vehicles would explain why light colored cars would be more visible and may have an advantage for safety when reports from all backgrounds are averaged, but against snow backgrounds a darker car would be expected to have an advantage. Therefore, the combination of a bright and dark color on the same vehicle is suggested.

Another study by Forbes (4) showed that against a relatively even luminous background green and blue were seen better at low levels, while white, yellow and orange required a larger ratio of color luminance for color recognization as the ambient background luminance level increased from .127 to 15.25 cd/m2. In other words, color recognition was affected markedly by the luminance of the surrounding background.

The relationships are complex and will be found in the paper. It is clear from both studies, however, that contrast with surround and background is a very important feature both for conspicuity and for color recognition.

Visual Sensitivity of People

The various characteristics of human visual sensitivity obviously will affect the conspicuity of objects, people, vehicles and other features of a scene. Among the characteristics of most importance are visual acuity, color sensitivity and low contrast sensitivity under night vision conditions.

The first two factors are discussed at length and their optometric characteristics given in detail by Richards (13) and by Allen (2) and cannot be included here. Psychological factors of visual perception are discussed in the next paper.

Low contrast sensitivity under night vision conditions also may be of great importance for conspicuity. A study by Forbes and Vanosdall (8) of 371 subjects of ages 16 to over 60 showed that some individuals have much poorer low contrast sensitivity under night vision conditions than others. Such reduced sensitivity had been thought to be more characteristic of older subjects, but this study indicated that there was also a significant proportion in the younger groups showing this difficulty. It was recommended that all age groups should be educated concerning night vision deficiencies.

It is true, of course, that under night conditions higher luminance usually gives greater contrast of the illuminated object with background. But silhouette seeing of pedestrians with an illuminated roadway behind them may be very important. Thus for conspicuity, luminance contrast is of importance as well as color and luminance alone.

FIGURE 5: Subject observing simulated signs against a bright sky and snow background (5).

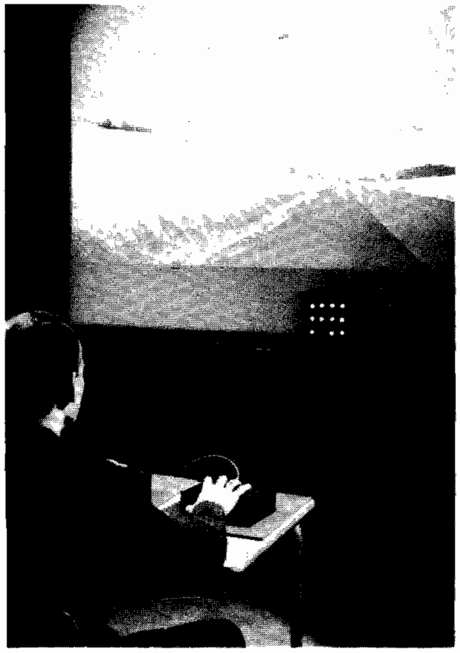


FIGURE 7: Outdoor Observations - Calculated and Observed Distances (7).

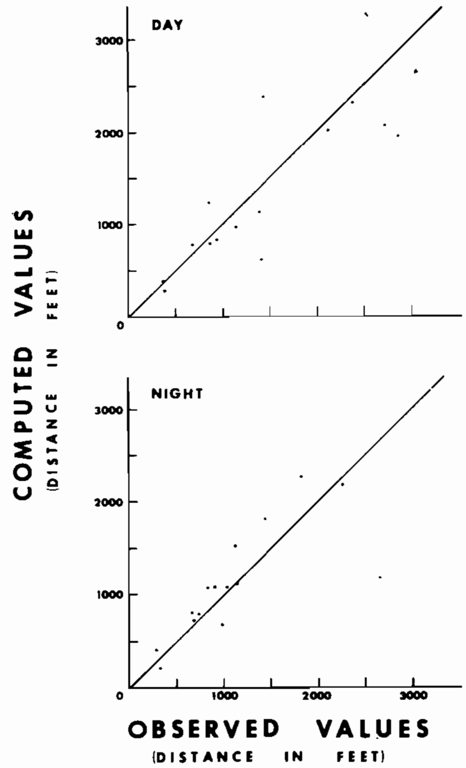
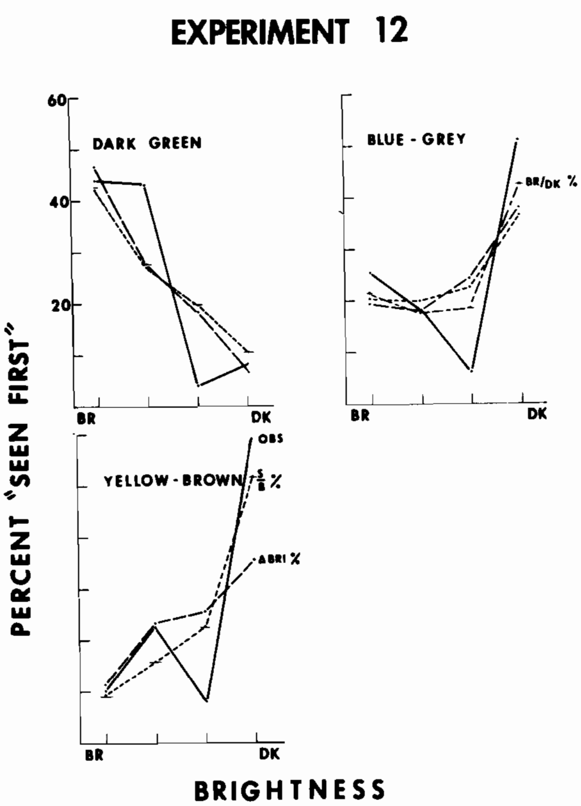


FIGURE 6: Effect of contrast with three backgrounds - green signs of four luminance levels (7).



Summary

1. A brief overview has been presented of the wide variety of highway characteristics, vehicles, people and other objects that must be made conspicuous. It is clear that conspicuity is important for safety and for smooth traffic operation.

2. The complexity of requirements for conspicuity has been indicated. Other speakers deal with certain of these complex factors in more detail.

3. Color and luminance contrast, relative luminance, relative contrast and relative size have been shown to be very important factors for conspicuity and recognition. A few examples have indicated some of the research which has been carried out in related areas. Other examples have been given to show practical application of these factors for safety and smooth operation of traffic.

REFERENCES

1. Alexander, Gerson J. and Lunenfeld, Harold. Positive Guidance in Traffic Control. U.S. Dept. of Transp., Fed. Hway. Admin., Office of Traffic Operations, April 1975, Pp. 57, U.S. Govt. Printing Office.
2. Allen, Merrill J. Vision and Highway Safety, Chilton Book Co., Phila., PA, 1970 Pp. 253.
3. Forbes, T.W. A Method for Analysis of the Effectiveness of Highway Signs. Jour. Appl. Psychol., 1939, VXXIII, No. 6, 669-684.

4. Forbes, T.W. Luminance and Contrast for Sign Legibility and Color Recognition. Transp. Resch. Record, #611, 1976, 17-24.

5. Forbes, T.W., R.F. Pain, J.P. Fry, Jr., and R.P. Joyce. Effect of Sign Position and Brightness on Seeing Simulated Highway Signs. Hway. Resch. Record, 1967, No. 164, 29-37.

6. Forbes, T.W., J.P. Fry, Jr., R.P. Joyce and R.F. Pain. Letter and Sign Contrast, Brightness and Size Effects on Visibility. Hway. Resch. Record, 1968 (a), No. 216, 48-54.

7. Forbes, T.W., R.F. Pain, R.P. Joyce and J.P. Fry, Jr. Color and Brightness Factors in Simulated and Full-Scale Traffic Sign Visibility. Hway. Resch. Record, 1968(b), No. 216, 55-65.

8. Forbes, T.W. and Vanosdall, F.E. Low Contrast Vision Under Mesopic and Photopic Illumination. Hway. Record, # 440, 1973, 29-37.

9. Hazlett, R.D. and Allen, M.J. The Ability to See a Pedestrian at Night: The Effect of Clothing, Reflectorization and Driver Intoxication. Amer. Journ. Optom. and Arch. Amer. Acad. Optom., 1968, 45, #4, 246-258.

10. Institute of Transportation Engineers. Traffic Technician Curriculum, Washington, DC, 1979.

11. Mortimer, Rudolf. Human Factors in Vehicle Design, Chap. IX in Forbes (Ed) Human Factors in Highway Traffic Safety Research. John Wiley and Sons, NY, 1972, Pp. 417.

12. Richards, Oscar W. Massachusetts Hunter - Safety Color Tests. Jour. Amer. Optom. Assn., 1961, Oct., V 33, No. 3, 205-207.

13. Richards, Oscar W. Visual Needs and Possibilities for Night Automobile Driving. Amer. Optical Corp. Resch. Group, Southbridge, MA, 1967, Pp. 194.

14. Richards, Oscar W., Ph.D., Woolner, Ralph W. and Panjian, Lt Jack. What the Well-Dressed Deer Hunter Will Wear. Natl. Safety News, Natl. Safety Council, Chicago, Il, Mar 1966.

15. Sleight, Robert B. The Pedestrian, Chap. X in Forbes, T.W. (Ed) Human Factors in Highway Traffic Safety Research. Wiley - Inter-Science, John Wiley and Sons, NY, 1972, Pp. 417.

PROVIDING FOR VISIBILITY IN NIGHT DRIVING

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Providing adequate visibility on roads of all types is a problem which pushes the state of the art in many aspects of applied science and engineering. While certain "solutions" are in use, the problem has not been fully defined in terms of who the users are, what criteria should be used, how visibility and conspicuity can be quantified, and how these needs can be translated into engineer practice in a practical way.

Visibility of road features is important on all roads, of course, but the economics of providing visibility on low volume roads at night dictate that they act as a worst case for discussion of roadway visibility. Low volume rural roads (i.e., those carrying 400 vehicles per day or fewer) provide indispensable rural accessibility. About 8% of the total U. S. vehicle miles are traveled on these roads, although they constitute two-thirds of the highway mileage (Glennon, 1979). Accident rates are about 70% higher than those for all roads combined. The low probability of two vehicles colliding when volumes are low is partly offset by the tendency of drivers to drive as though they will never meet another vehicle on these roads. Higher standards for low volume roads would quickly increase the cost of maintaining them, and the balance between higher costs and higher safety is difficult to determine. Low cost improvements are especially desirable, though the effectiveness of such improvements is tied to how well the drivers' needs are understood and specified in objective, measurable ways.

Since 60 to 80 percent of all accidents on low volume roads are single vehicle accidents, the limited information provided to drivers--almost all of it visually--is probably partly to blame. While it is recognized that alcohol plays a significant part in single-vehicle accidents, there is no indication that the driving population will ever be totally sober, and even for the somewhat impaired driver, reasonable attempts should be made to describe what is coming next on the highway.

It is well known that as volume increases, accident rates decrease. This is undoubtedly due, in part, to the fact that more money is put into the design, construction, and maintenance of the busier roads. Wider shoulders and lanes, better markings, and more signs all help, but driver behavior is also affected by traffic volume. Drivers expect and plan for other traffic when they meet vehicles every few minutes or more often. Part of this planning includes giving more attention to staying on the proper half of the roadway, especially on curves. The driving is also likely to be at slightly slower speeds, and other traffic may serve as models to some drivers, making them more conservative.

In his summary on the cost-effectiveness of features of low-volume roadways, Glennon (2) suggests speed signs, including warning signs on curves requiring reduced speeds, are the only visible, added roadway element that can be justified in all cases. Centerlines are added at volumes of over 300 vehicles per day, but stop signs, no-passing stripes, clear zones, wide shoulders, and guardrails are generally too expensive. Edge lines, so often mentioned in driver opinions of valuable safety features, are not even discussed because of their high cost.

Sufficiency ratings of some kind are usually developed for assessing the marking of low-volume roads through site visits by individuals or teams, since accident, volume, and hazard data do not exist. The form and thoroughness of such rating visits varies widely, but, in many cases, this "visit" is likely to consist of an occasional drive through the area with the observer looking for specific defects or anything unusual. The lack of general guidelines for such visits, and the fact that they are probably made only in good, daytime weather, means that any reports or recommendations for action depend on the inclination and experience of the individual observer. There are some promising developments which may eventually make the visibility assessment more objective, but the techniques are not yet available for routine use. Since many of the drivers likely to have trouble negotiating a roadway are less familiar with it than the official observer, the observer trying to check a roadway's visibility may not be looking for some of the most critical features in terms of accident likelihood as they affect the average (or below-average) driver.

Lack of light is not the only problem in roadway visibility, of course. Water on the surface changes several aspects of visibility. A recent study by NTSB (4) developed a Wet Fatal Accident Index, based on the finding that fatal accidents are four times more likely on wet-pavement than on dry surfaces. If the percentage of wet road accidents is greater than the percentage of time the roads were wet, the index signals wetness is a substantial safety problem there. The immediate topic of interest in that report is the effect of water on road friction. Especially at night, a wet surface has serious effects on visibility: markings are obscured, reflections are confusing, glare problems are multiplied, splash and spray add to the problem, and even shadows cast by sign posts can look like hazards or pedestrians moving on the roadway. A minor driving error or corrective steering action, brought about by these things, could precipitate a skid and loss of control. Thus, it may be true that visibility was the primary cause of the loss of control, while skidding or reduced braking was the mechanism for the crash. Increased friction may have allowed drivers to maneuver and avoid a collision, but improved visibility may be more basic in preventing the driver error that triggered the need to maneuver.

What are the most critical visible features of a roadway in terms of accident prevention? The driver needs to know what is out there in order to react in the proper way at the proper time. Alexander and Lunenfeld (1) described three levels of driver performance, in their positive guidance approach, as control (of direction and motion of the vehicle), guidance (deciding on the proper path and speed for the vehicle), and navigation (execution of the trip from origin to destination). Each level is contingent on the lower levels, so that navigation, for example, is essentially disregarded by a driver who barely missed a gore sign while confused at a choice point (fails at the guidance level), and both these levels are set aside when a driver gets into a skid (fails at the control level).

The information reaching the driver's eyes depends on what is out there, how much visual energy reaches the driver's eyes from these features, and the context in which the energy is provided. At the simplest level, the driver needs to know only where the lane boundaries are or where the path is in the next few hundred feet, and what obstacles are or may suddenly appear in that path. At night in the rain, most of that information is provided by reflection of the driver's own headlights, though other traffic and the land uses near the roadway may present important cues as well. The patterns of visual energy reaching the driver depend on a multitude of variables, including the vehicle design, dirt on windows, headlight aiming, reflectivity of objects and other surfaces, other lights, the driver's vision, and the heights of the driver's eyes and headlights. The effects of each variable and the interactions among them defy systematic evaluation in any simple way. Physical and geometric descriptions do not necessarily predict the concepts various drivers might form when exposed to a complex visual environment.

Each driver--and almost every passenger--has a concept of the kind of driving situation being encountered. There are several conceptual levels that can be differentiated, and each level has one or more information levels that influence it. For example, the driver has a concept of <u>heading</u>, developed from visual cues, information from the vehicle, and inertial (inner-ear) cues. The driver also has a <u>path</u> concept which involves the curves and hills that are likely to appear, and the width and other characteristics of the highway. The next higher level can be labeled the <u>route</u> concept, where the road becomes part of a network of roadways and has urban-rural and other characteristics of land development. The highest level is the <u>environment</u> concept, which includes cultural or population characteristics that might involve hazards that are regional in character.

Most persons already have these concepts at any moment, but they may be more or less inaccurate, depending on general experience in driving and specific knowledge of a given piece of roadway. For the navigational level of performance, the passenger, in some cases, can contribute to a driver's concepts of the environment and the route, provided they are more complete and accurate than the driver's are. At the guidance and control levels of performance, however, the driver may not have the opportunity to process such additional information, and must act largely on his or her own concepts of heading and path. Since upon entering any roadway a driver's concepts are incomplete or inaccurate to some extent (and somewhat resistant to change even when wrong), the highway agency is responsible for reshaping those concepts to keep the driver out of trouble. Most of this concept reshaping is done by signs and marking, but some of it is carried by the physical structure of the surrounding world. This world does not necessarily reveal itself accurately (or at all) at night without artificial visibility enhancement. This simple fact may not be obvious to those who already have accurate concepts of a roadway. One does not usually add bits and pieces to a concept; rather, it is formed as a whole or "Gestalt" from the entire context in which information is seen. That context starts with the observer's idea or expectancy and is modified --eventually--when the accumulated information contradicting the original concept is great enough. Then, suddenly, a new Gestalt is formulated.

Because of the great lack of predictability among driver reactions, vehicle design and roadway marking are potentially the most controllable aspects of the highway system. In a setting with few visible features, the situation is more predictable than one with a complex visual environment, though it is still far from simple. The narrow, unmarked rural roadway with foliage on all sides, on a wet, overcast or foggy night, becomes a challenge at the most fundamental level: where do I go next? The driver seeing an oncoming or leading vehicle ahead may welcome it for the preview of the road's path that it provides. In this case--which may be unique in that each driver tends to give the other driver credit for some knowledge--each driver assumes that the other knows more about the course of the roadway than he or she does. It can become a case of the blind leading the blind--literally unless conspicuous cues to the roadway course are available.

Besides being conspicuous, the visible cues also must be unambiguous enough to guide even those drivers whose concepts of the roadway are inaccurate. Single bright spots of light from post-mounted reflectors on each post, separated vertically by a standard distance of perhaps 20 cm (8 in.), would give the driver an immediate gauge of the distance to each post, and there would be no uncertainty as to which posts were adjacent. Fewer posts might be sufficient, reducing the total cost. The use of more than one color of reflectors in a row of posts is notorious for complicating the driver's distance judging task, but it is still seen. Reflectors also are suspected of encouraging drivers to drive too fast in fog or rain because their high contrast provides a clear path concept, though other hazards of the route and environment are not made obvious. In this case, a dimmer continuous cue like center lines would probably be safer, though more costly. Unfortunately, the center lines are not continued through the intersections where drivers probably need guidance most when visibility is poor.

While the near-zero visibility case is largely a problem of the economics of providing known visibility aids, the more complex visual environment raises the issues of human information processing and interpretation of visual inputs. In order to react to a stimulus a person must first be aware of it. In a complex scene, the relevant cues for maintaining performance must be "conspicuous." Conspicuity is a concept that is generally understood: A conspicuous object is one that is easily noticed or one that attracts attention by being unusual or remarkable. It is seldom possible to assign a conspicuity rating or value to an object, however, until the setting in which that object is to appear is known.

Drivers are bombarded by thousands of bits of information each second from all their sensory stimulations. Most of that information is ignored because of the brain's limited information processing capability. In order for certain information sources are classified as important or unimportant. In the visual sense, the mechanism which determines the conspicuity of an object is largely (but not entirely) the luminance contrast the object has with its immediate environment. In peripheral vision, motion is likely to make an object conspicuous. The meaning of the object and the driver's readiness to look for and use it also play an important part in the conspicuity rating that observers would give it. The information content of a given object does not directly determine conspicuity, but the information available from a given visual environment is dictated to a considerable extent by the relative conspicuities in that environment. In a given setting, unbiased observers will be relatively consistent in their ratings of conspicuity: item A is the most conspicuous, B is next, and so on for a small number of items. The biases created by a goal-oriented behavior such as driving, however, may change the order of the ratings considerably. Experienced drivers may be quite consistent in their conspicuity ratings, though they might differ from the unbiased observers as a group. The type and amount of experience also affect the observer's perception, but regional, age, and perhaps even sex differences also are important. The range of individual interpretations of a given situation can also be wide. Thus the provision of visual information sources on the roadway must be concerned not only with describing the situation ahead, but also with the drivers' expectation of what will be there, the probability of detection or the relative conspicuity of the visible objects, and the range of the interpretations various road users might make of the information available.

MODELING THE PROBLEM

In order to provide a framework for pulling various facts, concepts, and considerations together, researchers like to build conceptual models of problem areas. A model can be highly complex and mathematical, or it may be merely a means of insuring that all of the most important elements of a situation are kept in mind. The EIDAC ("Eye-dak") driver information processing model to be discussed here is of the simpler variety, though it may also have experimental implications for research in a more sophisticated sense.

The EIDAC model is based on an earlier IDA model discussed by Taylor et al (7). For those who are not familiar with this report, Appendices A and B are highly recommended. They provide 64 pages of detailed discussion of the driver information requirements and delineation needs. For each of 13 "classical" situations presented to drivers, the IDA sequences are described in terms of the information the driver requires, the decisions to be made, and the actions to be taken. The analysis is actually done in reverse order, starting with the actions necessary in a situation. A maneuver requires more than one action, of course. A right turn for example, may involve eight actions: 1) approach vicinity of intersection, 2) change lanes (if necessary), 3) establish position in the lane, 4) approach intersection, 5) enter intersection, 6) begin the turn, 7) complete the turn, 8) establish final lane position. The decisions required for each act can then be stated, and the information required for making the proper decisions, in turn, becomes explicity.

For the situations involving minimal delineation, low-volume, and poor visibility conditions, the actions to be taken may be more elementary in that they are concerned with insuring that the driver can stay on the proper part of the roadway and that the driver can avoid the hazards that are present or may be encountered. The information-decision-action sequence is still valuable, but it is incomplete. To make it complete, two further concepts should be added, one on each end of the sequence. The EIDAC model thus consists of expectancy-information-decision-action-confirmation. With the IDA concept, experienced drivers who are familiar with an area may be guided appropriately. But the drivers unfamiliar with an area and those who are less than average in ability (about half the population) require more preparation, not only on what to expect but also on the fact that something is different ahead. The Europeans have used a simple /!/ sign to denote this. Many drivers need, in addition, assurance that the choice they have made or the course they have taken is correct or is not correct.

Once more, the economic aspects of providing more information are important. Drivers should be prepared for what they will encounter next, and they should be told immediately after (and even during) a maneuver that they are where they want to be or will need to make a corrective action because of a previous error. Where this requires more signing or marking, the cost must be justified, and a persuasive argument may have to be contradicted. That argument is that, if almost everyone understands the signs and markings, the situation is adequately taken care of.

One thing that is beginning to become clear from accident investigations is that the reasons for accidents seem different, not only from place to place, but also from accident to accident at any one place. Unfortunately, there is a tendency to conclude that someone made an error and therefore the driver was at fault so nothing need be done except to increase enforcement or to improve driver education. The frequency of a need cannot be taken as the sole criterion for action. If a specific kind of error is made at some site by only one-half of one percent of the drivers, the result can still be disastrous. Even with light volume, for example 1000 vehicles per day, such an error rate would result in five near-misses or erratic maneuvers each day. Since traffic tends to be distributed unevenly and concentrated at specific times of the day, the erratic maneuvers would also be bunched, so that it is likely that an accident will eventually occur at that point. "High-accident sites" are generally characterized by less than one collision per year on the average.

The traffic engineer is thus charged with providing the information everyone needs for negotiating a road system, but also with providing for the small minority that requires more or different information because their recent experience does not provide the context for fully understanding the situation at hand. The tourist, the teen-ager, the elderly driver, the driver who has a blood alcohol level (BAL) of 0.05 (defined legally as "sober"), and the driver who is not accustomed to night driving, all fit this description.

In order to insure that all that is economically feasible is done to prevent driver problems, the highway engineer must be willing to think in terms of some worst case driver or design driver. Although the middle-aged, male driver with a 0.08 or higher BAL probably has most of the characteristics of the worst case and, in fact, may be almost typical, at times constituting perhaps 20% of the drivers on the road, there is a natural reluctance to "designing the roads for drunks." A more acceptable design driver is probably the 55-year old male who drives less than 100 miles per month at night and a total of about 8000 miles per year. Age usually is correlated with increased reaction times, increased decision times, reduced visual sensitivity and acuity, and a somewhat outmoded understanding of current laws and the newer signs and marking techniques. The advance warning or "expectancy shaping" adequate for younger drivers may not be appropriate for or understandable by this driver. His slower driving speed may help by providing longer times between warnings and the required actions, but his concepts of the road may be more deeply entrenched, so that more information is needed to make him fully aware of unusual or atypical situations. A single curve-warning sign, for example, may not be sufficient if the roadway has been almost straight for some time.

The visual capabilities of older drivers can be simulated to some extent by the use of lenses that are tinted and frosted. The reduction of contrast, the color and brightness changes, and the greater susceptibility to glare that result may help the observer appreciate the limitations of the older or impaired driver. Pastalan (6) has provided some of this information in the form of slides showing scenes with normal and impaired vision.

In spite of advances in instrumentation and improved retroflective materials, the degree to which the nighttime visual environment can be quantified is highly limited. Part of the problem is the lack of a criterion level. For the purpose of sign design, visual acuity is assumed to be 4/6 (20/30), though a large portion of the driving public has no better than 4/8 (20/40) acuity in the daylight and much worse at night. Most other aspects of visual perception are judged subjectively in practice, so that the characteristics of the judges are critical. The visual capabilities provided for cannot be those typical of a young traffic engineer or aide. Perhaps even more important, the information processing and reaction capabilities also must be more representative of the design driver. This includes the expectancies that engineers familiar--too familiar--with the roadway are not likely to appreciate.

Confirmation is probably the aspect of informing drivers that is least appreciated by engineers. Erratic maneuvers after a decision point may be due to the driver's uncertainty regarding the choice just made. If it is clearly correct, the maneuver is likely to be smooth; if it was clearly wrong, the driver will search for possible corrective actions at the next choice points. Where no information is available, the search will continue and may include attempts to read signs intended for the traffic in the opposite direction or to find landmarks or secondary information sources to confirm or disconfirm the previous choice. A driver who knows he has made an error may be more dangerous than usual, but a driver who doesn't know whether he is right or wrong is even more likely to behave in ways that other drivers would label unpredictable or even "stupid".

SOME PROMISING CONCEPTS

Several concepts that may be promising as improvements in the driver's visual environment, both for nighttime and for daytime driving, will be discussed to illustrate driver information needs. The first is the use of symbols for reducing the information processing requirement in complex freeway interchanges. In this approach, a small "trailblazer" sign is added to the usual destination or route signs so that, once a given symbol is understood to be associated with an intermediate destination (a new direction or highway number), the driver need only follow that symbol and can ignore other symbols or written legends temporarily. The symbols also may appear more frequently than regular signs because of their small size, and they can be installed on the pavement to help in lane assignment. The confirmation of route at each choice point is also made practical with these small signs, and the termination of a series can be marked with the new pictorial sign convention, a diagonal line through the symbol, if that is felt to be desirable.

Another common source of erratic behavior on freeways is the missed exit. Drivers are commonly observed backing considerable distances or even driving against traffic on the shoulder in order to use an exit they should have taken originally. While the symbol marking system has been shown to reduce erratic driver behavior, that system is not necessarily appropriate for all exits where backing is common. The reason given for backing is usually that the time and trouble to go to the next exit and double back is excessive, or that the driver feels that it would be difficult to find the same destination from a different approach. For these cases and a few others, drivers would probably make use of U-turn markings if they were provided. Given an authoritative indication of how to get back to a missed exit safely, the risk in backing might become more apparent.

A vehicle design problem that complicates the driver's task unnecessarily is the lack of a concept of the "transparent vehicle." Window, body, and styling designs often prevent a driver from seeing through the vehicle ahead, so that the driver is not aware of other vehicles, brake lights, signals, signs, intersections, and other information sources or hazards ahead of the lead vehicle. While some vehicles, such as most heavy trucks, cannot be transparent, many that now are not, could be. Optional rear window treatments or tints are part of the problem, especially on recreation vehicles and vans, but design of the size, height, and angle of windows and interior features of many vehicles seems to ignore the potential benefits of providing more transparent vehicles in the traffic stream. Drivers would be better informed as to the actions they must take, as well as being more aware of the reasons for the behavior of others. The need for multiple signs and lights as information source would also be reduced if drivers could see ahead of (i.e., through) as well as around other vehicles. Retroflective signing is most effective when it is in the position most often blocked by a lead vehicle, and provided a following driver can see it, the lead vehicle's lights often make a sign visible sooner to the following driver because the angular relationships are adequate and the lead driver may be using high-beam headlights.

As a final example, the visual environment of the low-volume rural road, where the cost of visibility treatments often is hard to justify, can be improved if the concept of delineation is broadened in some ways, and if the analysis is done so as to provide information only where it is needed most. Contrasting shoulder treatments--in color or in texture--are being employed more often since the treatment can usually be done as part of routine shoulder maintenance. Both shoulder maintenance requirements and driver information needs tend to be greater on curves, so that selective installation of contrasting shoulder treatments can be employed to reduce costs further.

Drivers often make use of cues that were not intentionally provided for their use. For example, they can be both led and misled by tree lines and foliage. A change in foliage boundaries alone may bring about a need for added delineation or curve warnings. The signal from the foliage regarding the apparent but wrong path may be so strong that signing or marking must be highly conspicuous in order to overcome that message.

Other, more novel approaches to low-cost visibility augmentation have yet to be exploited. The high likelihood that utility poles will be found adjacent to rural roadways suggests that they might be useful as delineators. While the poles are serious collision hazards themselves, it is seldom practical to place them elsewhere. Many drivers make use of the reflections from the cables or wires strung between the poles as advance warning of oncoming traffic beyond hills or curves. New wire or sheathing is especially effective in this way, but even well-weathered materials can provide several seconds of warning the driver would not otherwise have. The wires could be treated to maximize this effect at little or no cost to the highway agency, and poles could be used to support reflective devices. Even though this geometry is less than ideal, current reflectors mounted on utility poles could be helpful in conditions of marginal visibility or where redundant information sources are needed when rain, snow, or mud obscure road markings. It is also likely that more efficient reflectors could be designed for this purpose, if their use became common practice. It is conceivable that utility companies would accept the argument that collision with a pole would be less likely if they were marked and would mark them at their expense. One caution is worth mentioning; in those cases where the utility poles suddenly start following a line different from the road path, the reflectors must give a danger message (red) or must not be visible to drivers in order to prevent misleading them.

Most of the concepts discussed in this paper and others are expanded in a longer report written for the Federal Highway Administration (Olsen 1980). In that paper there is further discussion of a Visual Quality Assessor (VQA), based on a photoscanner developed by Merritt et al (3). The VQA is suggested as a means of measuring the adequacy of the visual environment, though it has not yet been studied carefully. A photographic technique in which the dark spots on a negative are counted and examined for patterns also is discussed. It too must be developed before it will be practiced.

SUMMARY

Until some of these potential tools are developed we are faced with mostly subjective judgments of the adequacy of visual environments and severely limited budgets with which to attempt to meet all needs. This paper has been a review of the driver's information needs and some of the considerations which may be helpful in meeting them within the confines of practical programs. The EIDAC model was used to remind designers and traffic engineers that users are diverse and most are different in their needs compared to the people who typically attempt to provide for these needs. Observers who are not familiar with an area are better able to judge the users' needs, and if possible, lay volunteers should be included on site visits in which delineation adequacy is under study. The unusual or rare need may still be a highly legitimate one in terms of accident prevention. In most cases, the information system designer must consider all five aspects of the EIDAC model: expectancy shaping, information provision, decision processes, action requirements, and confirmatory information after an action. Some examples of novel and possible visual information sources have also been discussed.

REFERENCES

1. Alexander, G. J., and Lunenfeld, H. Positive Guidance in Traffic Control. Federal Highway Administration, Washington, DC, April 1975
2. Glennon, J. C. Design and Traffic Control Guidelines for Low-Volume Rural Roads. NCHRP Report 214, Washington, DC, 1979.
3. Merritt, J. O., Newton, R.E., Sanderson, G.A., and Seltzer, M. L. Driver Visibility Quality: An Electro-Optical Meter for In-Vehicle Measurement of Modulation Transfer Functions. Final Report, Contract DOT-HS-6-D1426, Human Factors Research, Inc., April 1978.
4. NTSB Special Study - Fatal Highway Accidents on Wet Pavements--The Magnitude Location, and Characteristics. National Transportation Safety Board, Washington, DC, February 1980.
5. Olsen, R. A. Quantifying the Night Driver's Visual Environment. Staff paper, Federal Highway Administration, June 1980 (in press).
6. Pastalan, L. Getting out of the Lab--The Challenge of Application. Presentation to Symposium "Aging and Human Visual Function," NAS Committee on Vision, Washington, DC, 1 April 1980.
7. Taylor, J. I., McGee, H. W., Seguin, E.L., and Hostetter, R.S. Roadway Delineation Systems. NCHRP Report 130, Highway Research Board, Washington, DC, 1972.

DAYLIGHT FLUORESCENT COLOR - THE COLOR THAT SHOUTS

Harry J. Smith, Day-Glo Corporation

Daylight fluorescent colors have a long history of use for virtually dozens of safety related applications. The claim to fame for these uniquely different colors is extremely high brightness in the presence of daylight (up to four times brighter than regular colors).

Most scientists, engineers and consultants who design and/or specify products and materials for safety purposes have a broad awareness of these bright colors and some of their more common uses such as traffic cones, flagmen's vests and warning flags. What is not generally understood is the phenomenon that is responsible for these high intensity color effects. A basic knowledge of this mechanism will also explain why the functionality of daylight fluorescent colors increases several times in dawn, dusk, fog and overcast conditions.

The objective of this presentation is to give a layman's definition for the phenomenon and a brief history of successful uses of daylight fluorescent colors in safety products and applications.

An understanding of the "why and what" of fluorescent color will facilitate judgments on where these extraordinary bright and visible colors can be put to work to reduce, and in some instances eliminate, accidents.

Daylight fluorescent colors are brighter than ordinary colors because they act as converters or transformers of light energy. To prove this we are going to return to the high school physics class for a moment and review a couple of terms.

Let's begin with the question, what is daylight? Daylight can be defined as the energy that is emitted by the sun, travels through space, and strikes the earth's surface. The greatest share of this energy lies within the visible portion of the spectrum--violet, blue, green, yellow, orange and red. On one side of this visible spectrum is invisible ultra-violet and the other side invisible infra-red. But today we are concerned with only the visible portion of the spectrum, which, as you will see, is responsible for color as we know it.

Our next question is, what is color? Color may be defined as the optical effect produced by any portion or portions of the visible spectrum striking the human eye. A series of three filters can demonstrate the effect. For example, a blue-violet filter passes violet and blue light and blocks all the yellow, green, orange and red. A yellow-green filter passes all the yellow-green light in our daylight source and blocks the violet-blue, the orange, and red. An orange-red filter passes orange-red light and blocks all the rest. Thus, a color effect is achieved when portions of our visible spectrum come into contact with the human eye.

What is fluorescence? Fluorescence is defined as the phenomenon in which light energy of a relatively short wavelength is converted into visible light energy of a longer wavelength. In comparing fluorescent and conventional red-orange color examples side by side under simulated daylight, the two surfaces appear quite similar. Both are obviously reflecting red-orange light to our eyes and the primary difference is that the fluorescent example is brighter.

However, when the samples are illuminated with yellow-green light, something very unusual occur. The conventional color appears to darken, while the fluorescent surface continues to emit a distinctive red-orange effect. This is due to its ability to convert yellow-green to red-orange, rather than absorbing the transmitted light as does the regular red-orange.

The effect is even more dramatic with short wavelength blue-violet light. Conventional red-orange goes almost completely black, while the fluorescent again continues to emit bright red-orange color. Thus, fluorescent colors are brighter than ordinary colors because they are capable of converting light energy that is normally absorbed and wasted to visible light, which in turn reinforces the color in intensity. Hence, there is greater visibility in daylight conditions.

In fact, certain fluorescent colors are four times brighter than their conventional color counterparts.

It would be appropriate to mention the exceptional visibility fluorescent color exhibits at dawn and dusk and in conditions of limited visibility such as fog and haze. The reason is that the longer wavelengths of light are unable to penetrate haze, so regular colors undergo a general darkening or graying effect. However, fluorescent surfaces convert the short wavelengths into longer wavelengths, reinforcing the fluorescent color. This not only makes it appear more brilliant but also more visible, especially on hazy days.

There is a common misconception among non-technical people that, because these materials are described as having a fluorescent quality, they glow in the dark. Daylight fluorescent colors do not -- repeat do not -- glow in the dark. Only phosphorescent materials are capable of storing light energy and then re-emitting this energy in darkness.

Today, fluorescent colors are used in substantial quantities by a number of industries outside the field of safety, but it is interesting to note that the first major use for this bright color was for a safety application for the military during the early days of World War II. There were periods during the North Africa campaign when our aircraft were dive bombing and strafing our own ground forces. In fact, mistaken identify was occurring nearly 50 percent of the time. The standard colors on ground to air signal devices were just not visible at high altitudes against a desert background. Fluorescent color corrected this situation. The same message panels, this time in fluorescent colors, were visible at altitudes of up to 20,000 feet. Since World War II all three services, Army, Navy and Air Force, have used fluorescent color for air-ground recognition panels, beach markers and landing panels and on aircraft carriers for signaling systems, rescue clothing and many other uses.

Under the impetus of the military, the extraordinary brilliance of fluorescent color has carried over into a vast number of safety situations. The Air Training Command, and subsequently other branches of the military, used literally thousands of gallons of fluorescent paint for markings on aircraft. In the early 1960's the ATC flight training base at Hondo, Texas experienced 9 mid-air collisions under Visual Flight Rules conditions in one year. After the fluorescent marking program was fully implemented, which involved over 1600, aircraft the number of mid collisions dropped to zero. In fact, there never has been a mid-air collision, during daylight hours, between aircraft with florescent markings.

In other aircraft-related applications, there are scores of factual accounts about disaster having been averted because the pilot was able to see either the fluorescent markings of another aircraft or a ground obstacle under conditions of limited visibility.

During the Navy's "Operation Deep Freeze" in the Arctic, a cargo transport crash-landed on an ice floe and the crew survived. They were observed because they propped a broken wing with a fluorescent painted tip against the side of the downed craft at about a 45 degree angle. It was this small patch of bright orange color that caught the eye of an observer in one of the search and rescue aircraft, and as a result they were sighted and their lives were spared.

A familiar picture these days is the major high speed highway undergoing repair, complete with barricades, flags and traffic cones.

This scene is commonplace, it occurs in almost any major U. S. city on any given day. Fluorescent traffic cones are hard at work alerting motorists and pedestrians of a hazardous contruction site. Fluorescent color has become the standard color for traffic ones and delineators because of its proven capability to visually communicate the presence of dangerous conditions faster and at much greater distances than can regular color.

Another widely used warning device is the triangle used to alert approaching motorists of slow moving vehicles that travel on public roads and streets. This particular device combines the advantages of fluorescence for daytime in the center, and retroflective tape on the outer edge for nighttime visibility which is highly visible to an overtaking vehicle. The red border of reflective sheeting glows brilliantly when illuminated by automobile headlights. Baggage carts at jet age airports also sport this emplem.

The same principle applies to the Department of Transportation safety triangle, which is mandatory equipment on all interstate truck traffic in the U.S.A. and which has just been adopted by the Japanese Diet for <u>all</u> motorized traffic. Placed behind disabled vehicles, over-taking traffic has sufficient notice to move over or slow down.

On water, the use of fluorescent color with water sports has prevented many accidents and saved many lives. According to Mr. Paul Cerosi, Chief, Division of Watercraft for Ohio's Department of Natural Resources and President of the National Association of Boating Law Administrators, "When life-boats and vests are fluorescent colored, skiers and surfers can be spotted immediately, thus showing they would be recognized and picked up faster in the event of a mishap." The State of Ohio has a law requiring pleasure boaters to carry a fluorescent orange colored distress flag.

In the sports world, fluorescent color plays a role in the reduction of mistaken-for-game accidents. In the early 1960's, Jack Woolner, head of Information and Education section of the Massachusetts Division of Fisheries and Game, became highly concerned about the recurrence of mistaken-for-game deaths in his state, especially among deer hunters. As a result, he spearheaded the search for a solution that involved the cooperative effort of the Massachusetts Division of Fisheries and Game, United States Strategic Army Command and the American Optical Company. The conclusion they reached after extensive evaluation was that fluorescent-colored safety garments proved to be the most effective answer to this problem.

Let me quote Mr. Woolner's remarks about the importance of fluorescent color in hunter safety.

> "Research and tests at the Harvard University Center for Cogitative Studies indicate that any man or woman, expert or novice, with a desire to see a deer and aided by sound or color or movement may be able to see a deer when none exist. Given clues in the form of shape, color or movement, the memory bank in the human mind can supply the missing facts and complete the image of a deer that just does not exist. Extensive tests with conventional and daylight fluorescent colors proved that fluorescent orange is the easiest color to see and recognize in the outdoors. Because this color is unlike anything in nature, according to vision and human behavior authorities, the sight of this man-made color would cause immediate mental rejection of any deer association with the object under observation. It follows that a hunter wearing fluorescent Blaze Orange could not be mistaken for a deer. It's a brilliant color to both people with normal vision and almost all of those who have color deficient vision."

In 1962 the Massachusetts legislature passed a law requiring deer hunters to wear two hundred square inches of daylight fluorescent color. Since that date there is no record oa any hunter being shot for game in the state while wearing the correct Blaze Orange garments. The use of Blaze Orange in Massachusetts and Maine has proven that it will reduce deer hunting accidents more than 50%. Since 1962, 39 other states have passed similar legilation. Safety applications of fluorescence abound everywhere. We haven't even touched on existing uses at sea, underwater and even in space. What we have attempted to accomplish today is to first demonstrate why fluorescent color excels over regular colors in brightness and visibility, and secondly, to provide a broad overview of just some of the areas where this unusual brilliance has and is being successfully used. It works so well that some safety experts refer to it as the "Safety Color That Shouts."

I would like to conclude my presentation on this note. The fluorescent color industry is just as eager to find effective solutions to pressing safety needs as you are. One of our primary aims is to identify those areas where the functionality of fluorescent color can be put to work to prevent accidents and save lives.

In this connection, we have had a tremendous amount of experience in working closely with technical people at all levels of government, as well as industrial designers, safety engineers and producers of safety equipment and products. If you have any ideas or projects that you believe fluorescent color should be considered for, and if you have questions about economic or technical feasibility, please feel free to contact us. We will readily put you in direct contact with technical people who are qualified to offer assistance.

DETECTION AND RECOGNITION OF PEDESTRIANS AT NIGHT

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Background

There is, as yet, no definitive study which quantifies the extent of the pedestrian accident problem accounted for by the poor visibility of the pedestrian at night. However, for substantial numbers of nighttime pedestrian accidents, "inconspicuity" is strongly suggested as a major contributing factor. Moreover, it appears that enhancing the conspicuity of the relatively small (with respect to other elements of the traffic environment) pedestrian visual stimulus represents a countermeasure with great potential for accident reduction.

In a study of the causative factors in rural and suburban pedestrian accidents (1) two of the accident types identified might be characterized as nighttime events. The "Walking Along the Roadway" type (11.6% of the study sample) had 55% of its occurrences after dark. This type involves a pedestrian walking in the roadway either with or against traffic. The type called "Hitchhiking," although of lower incidence (1.5% of the study sample), was almost totally an after dark phenomenon (87% after dark). It was also characterized by an absence of roadway lighting in almost half (43.5%) of the studied cases.

Another way to estimate the nighttime pedestrian accident problem is to examine the relative accident risk day and night. This was done by Austin, Klassen and Vanstrum (2) when analyzing pedestrian fatality figures from 1973. When pedestrian exposure and vehicle miles were considered for the nighttime driving situation, the authors calculated the expected number of nighttime fatalities to be 10 percent of the daytime number. In fact, the actual nighttime number was 119 percent of the daytime figure. They concluded that the "night environment is dramatically more dangerous for the pedestrian than the daytime environment is."

The reasons for this apparently large difference in fatality figures are likely to include poor pedestrian visibility as well as the effects of alcohol and fatigue in both drivers and pedestrains. For example, a recent study of the role of alcohol in pedestrian injuries and fatalities (3) found that almost 70 percent of adult (age 14 and older) pedestrian accidents that occurred between 8:00 p.m. and 4:00 a.m. involved a pedestrian whose BAC was .10% or higher. Certainly alcohol involvement cannot be ignored as a casual element in nighttime adult pedestrian crashes.

One approach to correcting a pedestrians's poor visibility at night is to enhance his target value with retroreflective material. This type of material reflects light, such as the illumination from an automobile headlight, directly back to its source. The driver, who is close to the source, sees a much brighter image than could be seen with ordinary diffuse reflecting materials.

Many studies have shown the enhanced visibility that results from the use of retroreflective materials at night.

Hazlett and Allen, in a study of visibility associated with intoxication (4), found a decreasing ability of drivers with increasing blood alcohol concentration (BAC) to detect simulated pedestrians. The study showed that a small amount of reflectorization on a pedestrian increased detectability even by drivers with high BAC's.

Hazlett, Courtney, Stockley and Allen studies various geometric patterns of retroreflectorization on motorcycle helmets (5). In the road test portion of the study, observers riding in an automobile with headlights on low beams detected highly reflectorized shapes mounted on a helmet at an average of 800 feet. This compared with a normal white helmet being detected at only 243 feet and showed the clear superiority of reflectorization.

Based on these and other studies not necessarily associated with pedestrians, there appears to be a potential safety benefit to the addition of retroreflective material to pedestrians at night. Moreover, if there is enhanced conspicuity as a consequence of adding retroreflectorization, it should be measurable in terms of detection and/or recognition of pedestrian targets at night. In this context, detection distance is the range (in feet) at which a subject (driver) determines that a target is in his visual field, and recognition is the range at which the subject unequivocally can identify the target as a pedestrian.

In order to examine the effects of various retroreflective treatments on the detection and recognition of pedestrians at night, two controlled field experiments were conducted by Dunlap and Associates, Inc., with funds provided by the 3M Company.

The first of these studies (6) examined the relative detection and recognition distances for point sources (2" by 2"), stripes (1" by 24") and full figure treatments at varying levels of reflectivity and retroreflectivity (luminance). All trials were run on a totally dark course (Lime Rock Raceway in Lime Rock, Connecticut). Detection and recognition distances were measured directly through on-board instrumentation in the test vehicle activated by the experimental subjects as they drove the course at a constant speed.

The second study (7) employed a similar procedure to examine 16 different garments on a dark course. These garments represented a range of configurations including:

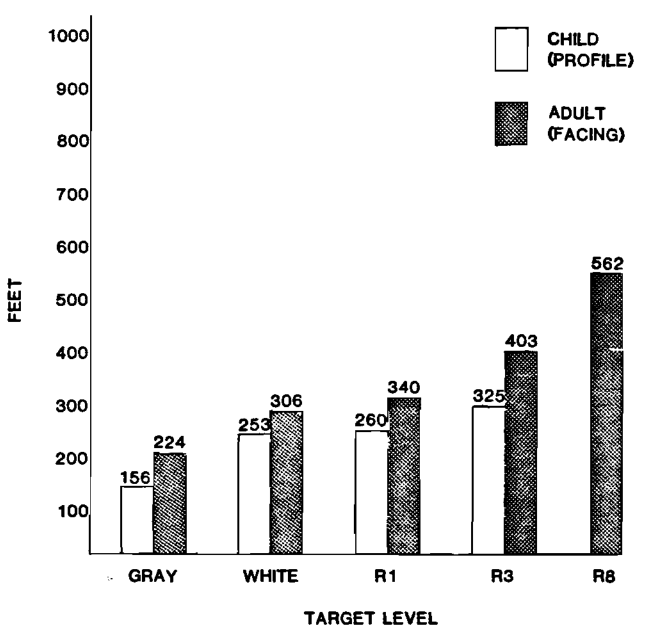
a. child jacket (size 8),
b. medium jacket (size 14),
c. large jacket (size 44),
d. full figure coveralls (large), and
e. trousers (large).

Three levels of retroreflectorization (1, 3 and 8 cpl) as well as white and neutral gray were tested, although not every garment was tested at each target level. (cpl=candles per lumen or candlepower per footcandle per ft.^{2} These levels were designated R1, R3 and R8 in the studies.) In addition, all four of the child jackets (gray, white, R, R3 and R8) were tested in a "typical" suburban environment with ambient lighting from street lamps and potential glare from oncoming vehicles. Only recognition distance was measured for the suburban course while both detection and recognition distances were taken on the dark course (run at an airport after it closed at night).

Some of the data from these two experiments are presented below to aid in the dirivation of some basic principles for maximizing the effectiveness of retroreflective conspicuity enhancement of pedestrians at night. In examining these data, one should keep in mind the following:

1. All data were collected in test cars with new, properly aimed headlamps on low beam;
2. All subjects had normal vision withou correction;
3. Subjects knew their task was one of target detection and identification. Although distractor stimuli were included in every test run and the targets were located irregularly along the course, the measured distances should be considered somewhat long when compared with the detection and identification performance which could be expected from unselected persons driving normally. This aspect of the studies should also add confidence to the comparisions between test stimuli; since subjects were alert and tested under uniform conditions, differences in the data across target configurations should be due only to target differences;
4. Within the first study, six subjects (male) were tested on each target stimulus three times (on three separate nights). In the second, 10 male and 11 female subjects were tested on each target stimulus once. Thus, all the reported data are based on nearly equal numbers of observations. For each stimulus condition, the standard deviations across observations varied from less than 100 feet to about 200 feet. (Smaller values were found in the earlier study and for target stimuli with smaller means across both studies.) As a general yardstick, differences in the means of two target stimuli of 100 feet or more may be considered statistically significant (p. 0.05). All effects described below, however, were tested specifically and found to be statistically significant;
5. Data for the child sized jackets were collected with the target in profile stimulating a child about to dart into the street on a path perpendicular to the vehicle. This is the most typical child accident situation (e.g.,8). All other targets were oriented facing the oncoming vehicle with arms at sides; and
6. All targets were stationary.

FIGURE 1: Suburban course mean recognition distances, jacket targets (7).



Selected Data

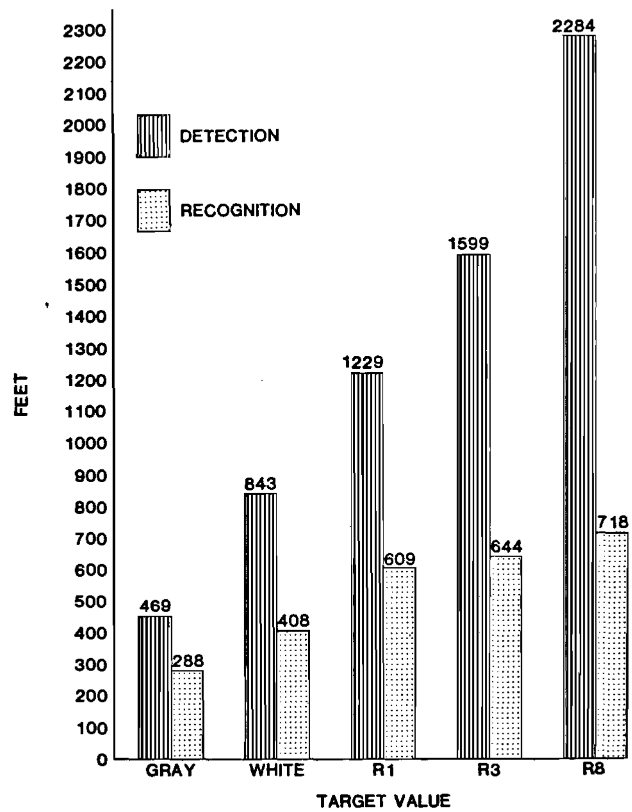
Figure 1 shows the mean recognition distances for the nine targets tested in the suburban setting. Two target shapes--a child figure in profile to the subjects and an adult figure facing toward the subjects--were tested wearing gray pants and jackets of several levels of reflectivity and retroreflectivity. For the same target brightness levels, the larger adult figures were recognized consistently about 70 feet farther away than the smaller child targets. For the same size targets, adjacent luminance levels were also significantly different, with the brighter targets recognized farther away than white ones, but not significantly so.)

The same pattern was found across most other tested conditions. Figure 2 shows the average detection and recognition distances for the five full figure targets tested in the first study on the Lime Rock Raceway. Detection distances increased significantly with each brightness increment, from 469 feet for the all-gray figure to 2,284 feet for the figure with R8 long-sleeve jacket and trousers.

Recognition distances also increased consistently with increasing target brightness. (Only the recognition difference between the R1 and the R3 targets failed to reach significance at the .05 level.) The R8 target was recognized as a pedestrian at two and one-half times the distance for the gray target (718 feet vs. 288 feet) and 75% farther than the white target (408 feet).

While increased detection distances with increased brightness was the rule across all tested conditions, the same was not always true for

FIGURE 2: Dark course mean detection and recognition distances, full figure targets (6).



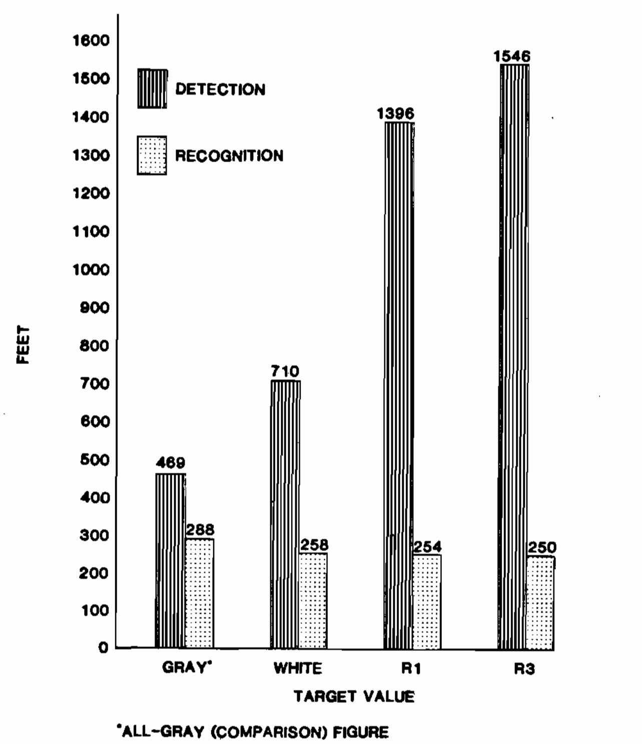
recognition. Figure 3 shows the data for the stripe targets used in the first study--gray figures with a 1" stripe running horizontally across the chest and arms. Data for the all-gray figure are included for comparision. The strip targets were detected farther away than the gray target, and brighter-stripe targets were detected farther away than less bright ones. In fact, the stripe targets were detected about as far away as the full figure targets of the same luminance level. Recognition distances, however, showed no corresponding shift. For the stripe targets as a whole, recognition was slightly (but significantly) worse than for the all-gray target.

Nearly identical findings were seen for the "point source" targets, which had white, R1 or R3 square spots (2" by 2") on the chest of an otherwise gray figure. Again, the data (not shown) suggest that the single bright area may actually interfere with identification of the whole figure (reduced recongition distance).

To further investigate this finding, other less-than-full-figure targets were tested in the dark course segment of teh second study. Figure 4 shows mean detection distances for 13 targets. (Three other targets--of medium size with white, R1 and R3 jackets--were tested as well. Their data were nearly identical to the data for the similar large-jacket targets and have been omitted from the Figure.)

At any target luminance level, the full figure targets showed the longest detection distances, followed by the targets with gray jackets and brighter trousers, then the adult targets with bright jackets and gray trousers, and finally, the child (profile) targets with bright jackets and gray trousers. Targets with higher luminance levels were detected farther away than (similar) targets with lower luminance levels.

FIGURE 3: Dark course mean detection and recognition distances, stripe targets (6).



The corresponding recognition data appear in Figure 5. They show the same basic pattern. Within luminance levels, targets were recognized in the order, from farthest to nearest, or full figure, trousers, jacket and child jacket in profile. For all these target shapes, recognition was better for targets with higher luminance

FIGURE 4: Dark course mean detection distances (7).

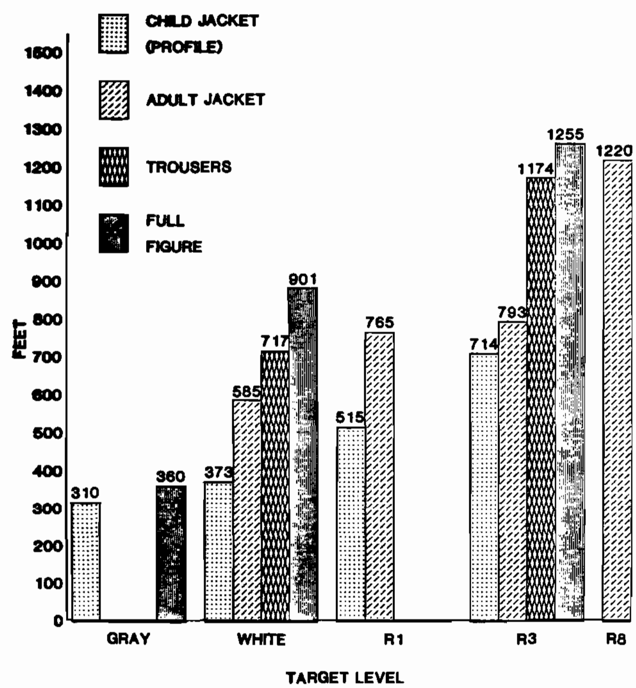
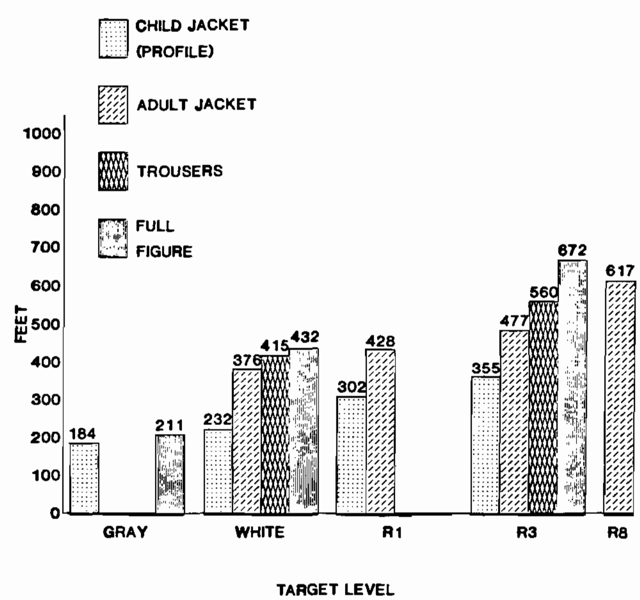


FIGURE 5: Dark course mean recognition distances (7).



levels. The jacket targets, and perhaps even more the trouser targets, had brightness patterns which did not interfere with subjects identifying the target as part of a pedestrian. The target with R3 trousers and a gray jacket, for example, was identified 200 feet farther away than a similar all-gray target was even detected (560 feet vs. 360 feet), a distance at which the gray top of the figure may not have been visible to most of the subjects even though they had already fixated on the lower half of the figure.

The exact detection and recognition distances varied for the same targets between the two studies and between the dark and suburban test courses of the second study. The patterns of results remained consistent, however. Targets detected or recognized farther away when tested under other conditions. This is graphed in Figure 6, for the nine targets tested under both courses of the second study. The values fall very close to a straight line; the correlation between means across test conditions for the nine common targets was .973.

Conclusions

The data presented above clearly indicate that retroreflective treatments on pedestrians can increase the distance at which they are detected and recognized. Thus, it is a reasonable extension of these results to postulate a safety benefit from the widespread use of appropriately designed retroreflective garments at night. However, it must be remembered that all subjects in the reported experiments were alerted, had normal vision and were neither fatigued nor intoxicated when the data were collected. Therefore, care must be exercised in extending these findings, particularly the extent of improvement in detection and recognition, to the entire population of drivers.

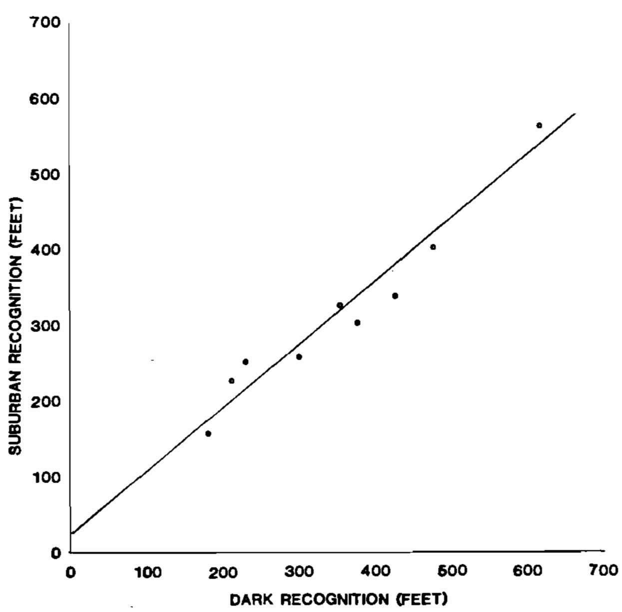
Until additional research can be conducted to refine even further the optimal design for a retroreflective countermeasure for pedestrians, the foregoing findings can be utilized to begin to enumerate several basic principles.

First, to improve detection, one should use bright target materials. Consistently, these studies showed that each increment in target brightness tested produced a corresponding increase in detection distance. In these studies, brightness was a more important influence on detection than was the total target area, even though the targets ranged in size from a minimum of four square inches to a maximum of several square feet.

Second, identification of the targets as pedestrians requres more than mere early detection. Anthropomorphism of the target shape greatly aids recognition. In these studies, shapes which are commonly associated with "people" led to effective identification even though the shapes only partly reproduced the human form. Retroreflective jackets seemed to produce a significant improvement in recognition. Retroreflective trousers were significantly better than jackets, and the combination of the two was better than either alone. Shapes which did not represent human figures, articles of clothing or other visual forms associated with the human figure--spots and stripes--did not enhance and may actually inhibit recognition of the pedestrian figures. Hence, for improved safety, it would appear best to outline the body as completely as possible with the brightest material available.

Finally, the excellent prediction of suburban course results from dark course findings is of interest. It means that the relative effectiveness of new pedestrian conspicuity enhancers can be assessed under totally dark field test conditions, which are easier to establish and control for experimental purposes. Thus, the further refinement of the design of retroreflective treatments for pedestrians should not be significantly hampered by test and evaluation costs.

FIGURE 6: Comparison of dark course and suburban course mean recognition distances (7).



REFERENCES

1. Knoblauch, R.L. Causative factors and countermeasures for rural and suburban pedestrian accidents: Accident data collection and analysis (DOT-HS-355-3-718). Falls Church: Va.: BioTechnology, Inc., 1977. (Available NTIS)
2. Austin, R.L., Klassen, D.J., & Vanstrum, R.C. Driver perception of pedestrian conspicuousness under standard headlight illumination. Urban Accident Patterns, Transporation Research Board Record 540, 1975.
3. Blomberg, R.D., Preusser, D.F., Hale, A., & Ulmer, R.G. A comparison of alcohol involvement in pedestrians and pedestrian calualties (DOT-HS-4-00946). Darien, Conn.:
4. Hazlett, R.D., & Allen, M.J. The ability to see a pedestrian at night: The effects of clothing, reflectorization and driver intoxication. American Journal or Optometry and Archives of American Academy of Optometry. 1968, 45(4), 246-257.
5. Hazlett, R.D., Courtney, G.R., Stockley, L.A.F., & Allen, M.J. Motorcycle helment visibility and retroreflectorization. American Jorrnal of Optometry and Archives of American Optometry, 1969, 46(9), 666-675.
6. Bloom, R.F. Effectiveness of retroreflective treatments for pedestrians. Final Report to the 3M Company, St. Paul, Minnesota, Darien, Conn.: Dunlap and Associates, Inc., April 1976.

7. Jacobs, H.H., Leaf, W.A., & Shaw, C.W. Nighttime visibility of pedestrians wearing conventional and retroreflective clothing. Final Report to the 3M Company, St. Paul, Minnesota. Darien, Conn.: Dunlap and Associates, Inc., January 1980.
8. Snyder, M.B., & Knoblauch, R.L. Pedestrian safety: The identification of precipitating factors and possible countermeasures: Vols. I and II (FH-11-7312). Silver Spring, Md.: Operations Research, Inc., January 1971. (NTIS No. PB 197 749 and PB 197 750)

EFFECTS OF MOTORCYCLE AND MOTORCYCLIST'S CONSPICUITY ON DRIVER BEHAVIOR

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Motorcycles have become a popular form of transportation in the United States. Since 1961, motorcycle registrations have increased at nearly four times the rate of all other vehicles. In 1977, motorcycle registrations in this country passed five million. In the same year about 500,000 motorcycles were involved in accidents, resulting in about 4,000 deaths and 400,000 injuries (1).

Motorcycles offer much less protection to their riders than do automobiles. As a result, when a collision occurs, the motorcyclist is far more likely to suffer injury. Unfortunately, barring major changes to the vehicle itself, this problem cannot be easily solved. Thus, the principal means of improving motorcycle safety seems to be reducing the incidence of crashes.

Motorcycle accident data offer some insights into how motorcycle safety might be improved. In a review of these data (2) the authors point out that motorcycle accidents are characterized by a substantial over-representation of a type of crash in which a straight-traveling motorcycle runs into a car attempting to cross its path. This information, combined with reports from motorcyclists and law enforcement officials, has led to an assumption that motorcycles are not sufficiently conspicuous.

The conspicuity hypothesis has resulted in a number of studies seeking ways to improve motorcycle/motorcyclist conspicuity. A review of this work is provided in (2). Many of the techniques suggested were included in the current investigation.

METHOD

Introduction

The purpose of this study was to determine whether the conspicuity of motorcyles/motorcyclists could be improved to reduce multivehicle motorcycle crashes. Various conspicuity-increasing treatments were fabricated and tested, using a realistic driving situation and measuring the response of naive drivers.

Dependent Variable

A gap acceptance measure was employed in this investigation. A typical situation and the terminology used are shown in Figure 1. The method requires creating a gap in the traffic stream between one or more lead vehicles and a test vehicle. The driver of the subject vehicle may "accept" the gap--that is, merge with or cross the traffic stream--or "reject" the gap (remain stopped). The assumption is that changing the conspicuity of the motorcycle and/or motorcyclist will modify the behavior of other motorists in a way which will reduce the likelihood of short gaps being accepted.

Note that both the lead and subject vehicles in this study were part of the normal traffic at the test site. Their drivers did not know they were participating in a test.

Equipment

The required data were the gap size (in time), whether the subject vehicle accepted or rejected the gap, and the type of maneuver the subject driver executed or planned to execute. A simple instrumentation package was developed which was carried on the back of the motorcycle. It provided a continuous record of time, distance (wheel revolutions), and speed. The motorcyclist coded other required information by pressing buttons which were positioned conveniently on the handlebars.

Test Treatments

The following daytime treatments were evaluated:

1. Car control. A 1969 Maroon Plymouth station wagon was used.

2. Motorcycle control. A normal motorcycle with no lights was used. The driver wore dark clothing and either a white or dark colored helmet.

3. Orange fluorescent fairing. The bike was equipped with a fairing to increase the frontal area. An orange fluorescent fabric was stretched over the entire fairing, including the headlight aperture.

4. Green fluorescent fairing. Same as item 3, except for the color of the fabric.

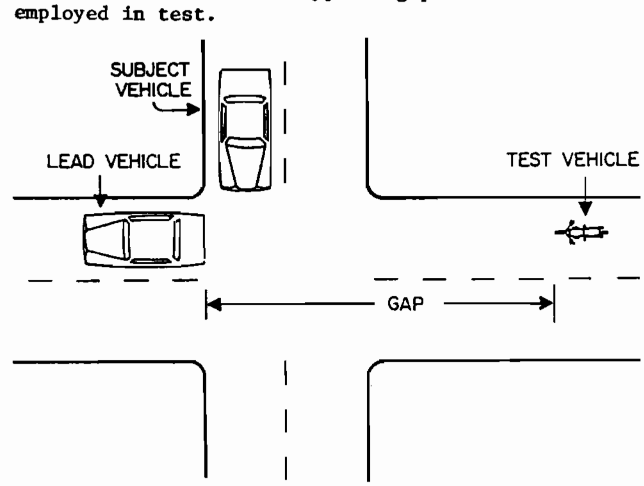
5. Headlamp on. The bike ran with low beam on..

6. Modulating headlamp. The high-beam filament was modulated from low to full intensity at about 3 hz. Low beam filament was off.

7. Reduced brightness headlamp. A neutral density filter reduced the intensity of the low beam to one-tenth normal.

8, Orange fluorescent outfit. The same material as used in treatment 3 was made into a vest and helmet cover to be worn by the rider.

FIGURE 1: Schematic of typical gap situation employed in test.



9. Green fluorescent outfit. Same as treatment 8, using the green material.

10. Orange vest. Just the vest from treatment 8 was used.

11. Orange cap. Just the helmet cover from treatment 8 was used.

The following night treatments were evaluated (note that low-beam headlamps were used in all cases):

1. Car control. The same vehicle was used as in the day condition.

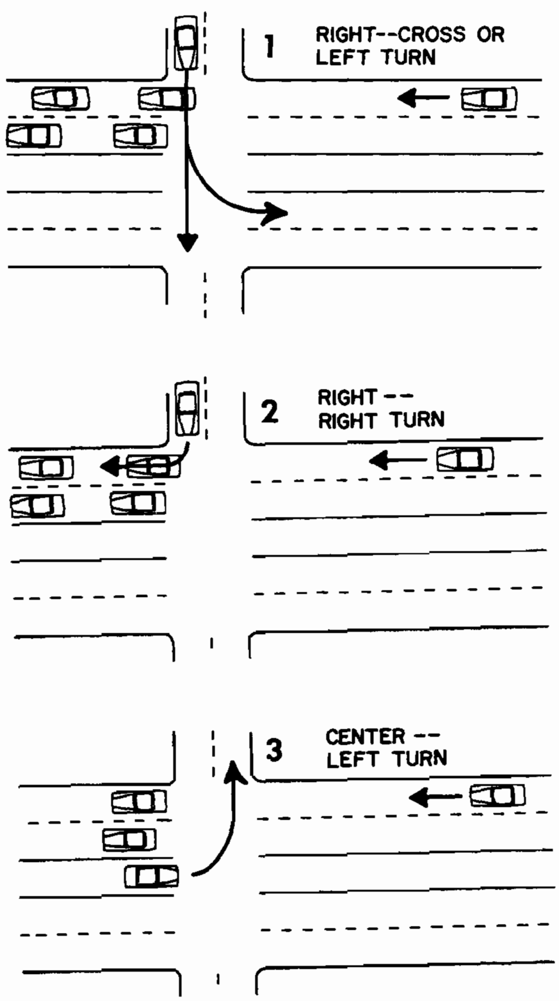
2. Motorcycle control. This was the same bike as was used in the day condition.

3. Retroreflective fairing. The fairing was covered with a retroreflective fabric, leaving the headlamp aperture open.

4. Retroreflective outfit. The same material described in treatment 3 was used to make a vest and helmet cover.

5. Running lights. The turn signal lamps were on full-time (not flashing).

FIGURE 2: Schematics of the three maneuvers investigated.



Maneuvers

Measurements were taken on three maneuvers. These are shown schematically in Figure 2. Note that only maneuvers 1 and 3 show up as particularly troublesome in the accident data literature (2). Data were taken on the "right--right turn" maneuver because it could not be separated before the fact from the "right--cross or left turn" maneuver.

Test Site

A site was sought which had a high volume of vehicles attempting tne maneuvers of interest. A reasonable volume of parallel traffic was required as well to provide lead vehicles for the front end of the gap. The site used for the day data collection was a major thoroughfare near the city of Ann Arbor, Michigan. The street is five lanes wide (center lane for left turns) and lined for most of its length with various small businesses. Speed limits were 70 km/h for most of its length, 55 km/h for the rest. There were three stop lights in the 6.5 km test section.

Most night data were collected during the winter months in the city of Gainesville, Florida. A major thoroughfare having many of the characteristics of the northern site was used. Data taken on the same configurations at both sites did not differ statistically.

RESULTS

Daytime Treatments

"Right--cross or left turn." Figure 3 shows the results of the daytime treatments for this maneuver. The figure shows the percent of gaps of three seconds or less which were rejected for the control motorcycle (dark vertical bar) as compared with all of the various treatments. For example, in this instance for the control motorcyle, 94% of those short gaps were rejected. Anything which appears to the right of the control motorcycle bar constitutes an improvement. In the case of this maneuver, all of the tested treatments and the car control were better than the control motorcycle, many of them significantly better (statistical significance is shown by the small numbers on the right ends of the bars; 01 means 0.01, and 05 means .05).

"Center--left turn." Figure 4 shows the same combination of treatments for this maneuver. In

FIGURE 3: Daytime Treatment: Right--cross or left turn: Percent of gaps of 3 seconds or less rejected.

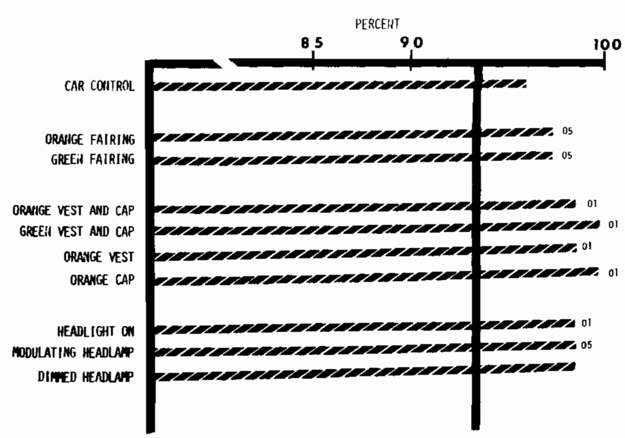


FIGURE 4: Daytime Treatments: Right--right turn: Percent of gaps of 3 seconds or less rejected.

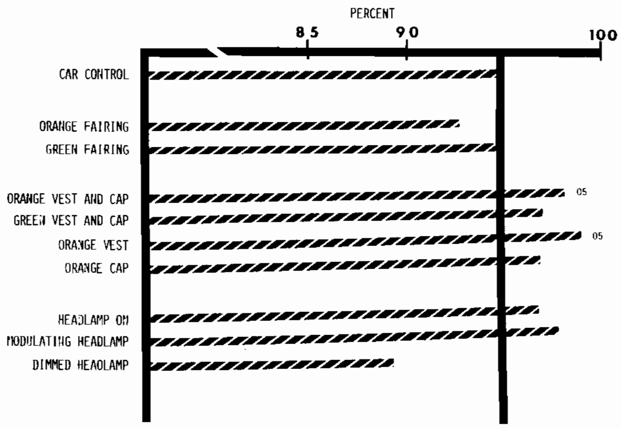
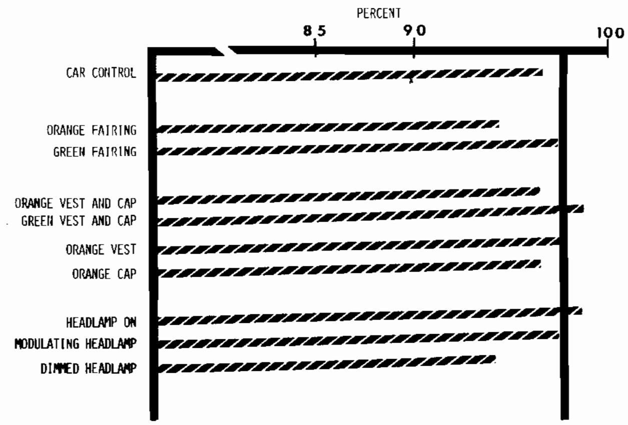


FIGURE 5: Daytime Treatments: Right--right turn: Percent of gaps of 3 seconds or less rejected.



this case, 95% of the short gaps were rejected for the control motorcycle. However, the picture for the various conspicuity treatments is somewhat different for this maneuver than for the "right--cross or left turn." Only the orange fluorescent fabrics worn by the rider appear to be significantly better than the control motorcycle. None of the lighting treatments differ significantly from the control, although the modulating headlamp is just short of significance at the 0.05 level.

"Right--right turn." Figure 5 shows the same treatment combinations for this maneuver. It will be immediately apparent that there is a rather substantial change in the situation confronted by the rider of the control motorcycle, in that 98% of the short gaps were rejected. Because of this, there was little room for improvement, and none of the tested conditions are significantly better than the control motorcycle.

It will note that the right--right turn maneuver does not show up as partiuclarly dangerous in the accident statistics. The explanation may be indicated by the findings of this study, which indicate that potentially encroaching drivers are somewhat more conservative, i.e., more reluctant to accept a short gap, when making a right--right turn maneuver.

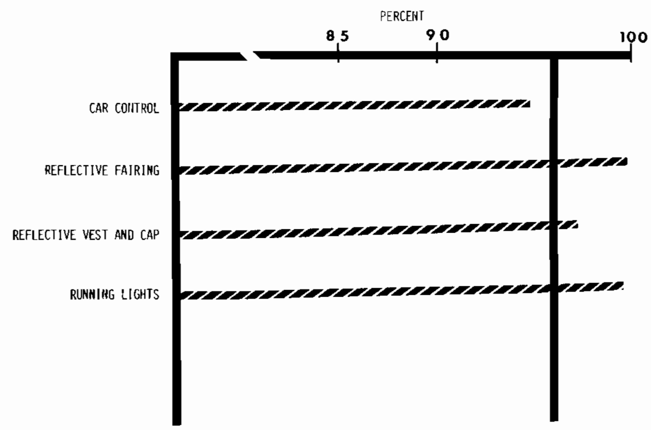
Nighttime Treatment

"Right--cross or left turn." Figure 6 summarizes the results for this maneuver at night. None of the differences are significant, although the running lights condition approaches significance at the 0.05 level. While a reflective fairing seems to be equally effective in terms of percent gaps rejected, this percentage is based on a relatively small number of cases and hence is not significant. It should be noted that, because of the initial right-angle orientation of the test motorcycle and subject vehicle, the use of retroreflective treatments would not be expected to be effective.

"Center--left turn." Figure 7 summarizes the results of this maneuver at night. The probability of short gaps being rejected for the control motorcycle drops to .92 in this instance, and both the car control and the two retroreflective treatments show significant improvements.

Because the two vehicles are initially facing towards one another, this is the only one of the three maneuvers where the retroreflective treat-

FIGURE 6: Nighttime Treatments: Right--right turn: Percent of gaps 3 seconds or less rejected.



ments would be expected to show any measurable effect.

"Right--right turn." Figure 8 summarizes the results for this maneuver at night. The car control is significantly better than the motorcycle at the 0.01 level. The reflective fairing shows a marginally significant difference, but the initial orientation of the vehicle is such that differences would not be expected. Hence, the difference is probably spurious. The running lights and reflective vest and cap do not show significnat differences in comparison to the motorcycle control.

DISCUSSION

Methodology

In general, the gap-acceptance procedure was quite successful in the current application. The data seem meaningful (i.e., intuitively related to the likelihood of accidents) and can be collected quickly, economically, and with relatively simple instrumentation.

This experience suggests that approximately one thousand data points are required per treatment to ensure reliable results. This assumes approximately equal distribution across three maneuvers, or about 300-350 data points per maneuver. It further assumes that the data are

FIGURE 7: Nighttime Treatments: Center--left turn: Percent of gaps of 3 seconds or less rejected.

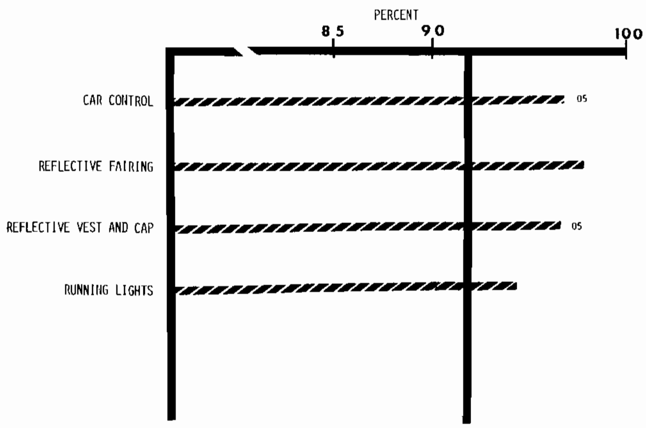
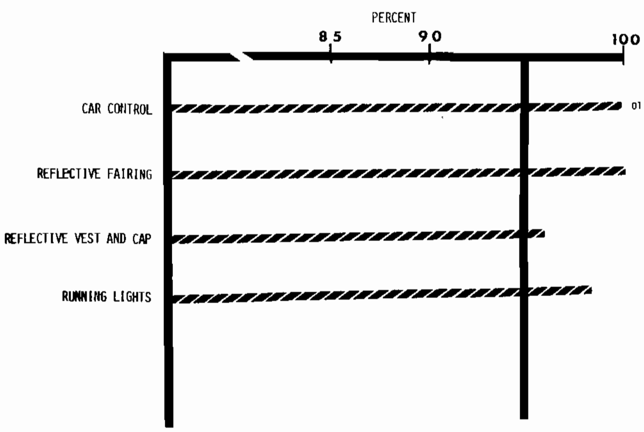


FIGURE 8: Nighttime Treatments: Right--right turn: Percent of gaps of 3 seconds or less rejected.



concentrated in the short gap region, i.e., below a gap-acceptance probability of 0.5.

Two points should be made regarding the validity of the gap-acceptance method in this application. First, the relationship of gap acceptance and accidents is largely unknown at this time. Riding with headlights on seems to be an effective accident countermeasure, as was noted in the literature review section. That the headlamp-on treatment was effective as measured by gap-acceptance in this study is encouraging evidence of validity However, further validation data would be desirable.

The second point concerns a limitation of the method. It can measure only a fairly general response characteristic of automobile drivers. The fact that differences were found in this study does not mean that other, less general, responses cannot account for a significant portion of the problem. If this is the case, different countermeasures may be appropriate.

Finally, a word about safety. The investigators were very concerned about safety since our riders were being asked to deliberately recreate pre-crash configurations known to be overrepresented in the crash statistics. It was hoped that the high level of attention required to be able to take data would reduce the risk. In the more than 20,000 miles accumulated during the tests, the riders experienced one minor crash and a few near misses. Interestingly, none of these occurred while collecting data, but all involved pre-crash configurations of the classic type described earlier in this paper. Based on this experience, the method seems to pose no special dangers to the motorcycle riders.

Means for Improving Conspicuity

It appears that there are a number of ways to improve daytime motorcycle/motorcyclist conspicuity that should have a meaningful effect on the behavior of car drivers. The simplest is to drive with the headlamp on at all times. The modulating headlamp may be somewhat more effective, but does require some investment on the part of the motorcyclist. High-visibility materials seem quite effective as well, but work better when worn by the rider than when fitted to the bike.

The latter finding is somewhat surprising. In the opinion of the investigators, the fluorescent fairing treatment was a more effective attention getter than the fluorescent vest or helmet cover. Yet the field test data indicate the opposite. This suggests that laboratory studies of motorcycle conspicuity can produce misleading results. However, it is not clear why the results came about. One possible explanation is that effectiveness is improved by height. Another is that by emphasizing the rider, speed-spacing judgments are facilitated. This might happen because apparent size is an important distance cue. However, it is based on knowledge of actual size. Most drivers know less about the size of motorcycles, especially motorcycle fairings, than they do about people.

For nighttime riding conditions there may be value in wearing retroreflective garments and using running lights. Retroreflective treatments applied to the bike seem less effective, but may be of help. There are combination fluorescent/retroreflective materials available which can provide day and night conspicuity in one package. It is also possible to treat ordinary fabric with beads and make it retroreflective without changing its appearance under normal viewing conditions. This may have potential for other vehicles with conspicuity problems as well.

ACKNOWLEDGMENTS

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REFERENCES

1. Carraro, B. Update: Motorcycle accidents in 1977, Traffic Safety, Vol. 79, No. 2, February 1979, pp. 8-11 and 29.

2. Olson, P.L., Halstead-Nussloch, R., and Sivak M. Development and testing of techniques for increasing the conspicuity of motorcycles and motorcycle drivers. Highway Safety Research Institute, University of Michigan, Ann Arbor, MI, DOT-HS-805-143, October 1979.

DETECTABILITY OF HIGHWAY SIGNS

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ABSTRACT - *Detectability is one of the primary criteria for an effective traffic sign. Several factors including sign characteristics, condition of the sign, driver information load, sign placement, environment conditions (darkness and poor weather), and individual differences among drivers, influence whether a traffic sign will be detected. Each of these factors is examined in a review of the relevant literature.*

In the driving task, the driver's attention is occupied by many things -- control of the vehicle, guidance information from the roadway, navigational information from signs, elements of the environment, such as scenery, buildings, and billboards, and distraction from passengers and other stimuli inside the vehicle. It is easy to see that driving is a divided attention task in which the driver must attend to a variety of incoming stimuli, some of which are more relevant than others to the driving task. It is therefore essential that traffic signs be highly conspicuous, or have high detectability or attention value for the driver.

Forbes makes the distinction between "target value," the characteristics which determine whether a sign will be seen or not, and "priority value," the order in which signs will be seen, depending on factors such as sign location, relative position, and drivers' reading habits.

Among the factors which can influence conspicuity of signs on the highway are sign brightness, size, and color; contrast between the sign and its background; the placement of the sign relative to the driver's line of sight; importance of the sign to the driver; reduced processing capacity of the driver due to input overload; and individual differences due to motivation, fatigue, intoxication, familiarity with the road, age, sex, and eye movement search patterns. Each of these will be examined in a review of the research relevant to detection of traffic signs.

APPROACHES TO THE PROBLEM

Several approaches have been used to study traffic sign detectability. One roadway technique involves stopping drivers a few hundred meters beyond a sign and asking them whether they detected and could identify the sign just passed on the roadway. Another common roadway technique is to have individuals drive a car or ride as a passenger in a car driven along a specified route, during which time the subject indicates each time he detects a sign. Variations on this procedure involve pressing a button whenever a sign is detected and naming each sign as it is detected. One series of laboratory studies involves a subjective report of which one of a number of signs is seen "first and best", Forbes (1). Both of these methods have their limitations, the laboratory method being somewhat artificial. The roadway experiments also have difficulties; the one in which the driver calls out traffic signs is somewhat unrealistic, since he or she is attending very closely to traffic signs, not the typical situation in driving. Most studies done on the roadway have been carried out in daylight and good weather conditions. Relatively little has been done at night or under adverse weather conditions. In addition, much of the work seems to have been done on freeway guide signs or similar types of guide signs, with little effort to study smaller signs of different shapes and sizes (e.g., warning and regulatory signs).

Numerous laboratory methods used by experimental psychologists provide information about the general issue of stimulus detection, and therefore have implications for learning about traffic sign conspicuity. Some of these will be described later in this paper.

BASIC PERCEPTUAL PROCESSES

Traffic signs are mounted above the roadway, so they often do not appear in the driver's direct line of sight. Therefore their initial detection occurs in peripheral vision. Visual acuity becomes progressively poorer, the farther the image falls away from the fovea of the eye. In order to be easily detected in peripheral vision then, a sign must be relatively large, stand out from its environment, or contain moving or changing components.

In a laboratory investigation of the influence of central search task luminance on peripheral visual detection time Zahn and Haines (2) found that detection time was much slower in peripheral vision under conditions where subjects' attention was directed to a visual central panel of high luminance, as compared with one of low luminance. This has important implications for the distraction likely to arise from brightly lit streets and headlight glare during nighttime driving.

A recent experiment by Nobel and Sanders (3) examined the influence of several variables on the ability to search for and find target traffic signs among several other traffic signs. The variables examined were: number of signs, sign density (whether they were packed closely together or spread out), color — the extent to which color was a major cue in the subject's being able to detect target signs, number of target signs (from one to four), and whether the subject was engaged in a tracking task. The subject's task was to indicate the number of targets (ranging from one to four) present in the array.

The results indicated faster search times to find the targets when color could be used as a cue (the color of the target sign borders in the easiest of the four color conditions was distinctively different from the borders of the non-target stimuli). Search times were faster when the signs were closer together (the dense condition). Search time was essentially a linear increasing function of the total number of stimuli, ranging from ten to nineteen. Performance was somewhat worse (125 msec longer) when subjects were engaged in the tracking task while searching for the targets.

Attention is obviously an important factor in information processing. Lapses of attention, distraction and input overload all reduce the driver's ability to take in information. There is a need for advanced warning in low attention areas, such as rural freeways, so that the driver will be prepared to attend more closely to his driving. For the purposes of preparation and attention, there is an optimal distance between signs. This distance depends upon the various distractions, including competing signs, which use up the driver's information processing capacity. As speed increases, attention to the driving task increases, and the focal point of attention shifts further ahead of the vehicle.

A number of psychological studies have examined the influence of input overload on performance. A distinction is made between input overload (too much total input) and information overload (too much input which is relevant to the driving task). Both situations can impair driving. Various factors influence the point at which performance will deteriorate under conditions of overload. There are various methods of coping with overload. One involves chunking or grouping the information in such a way as to process it more efficiently. In some cases a certain amount of information is missed; that is, only part of the information is detected. Errors also may occur, or it may take a greater length of time to process the same information under high input conditions. A good example of overloading in driving is a very busy intersection with numerous traffic signs, advertising signs, traffic lights, and heavy traffic conditions. Under such circumstances the driver has to take in a great deal, determining which input is relevant, initially, and then processing more thoroughly that which is relevant (or that which he thinks is relevant).

A study by Lee and Triggs (4) required subjects to detect small lights inside their vehicle in their peripheral visual field while driving under various conditions. Detection was much poorer while driving in shopping centers or in suburban locations, as compared with freeway and isolated residential street driving. Surprisingly, there was no difference between performance while subjects were driving and while they were passengers. Under both conditions subjects detected only about half of the lights when driving in suburban areas and in shopping centers.

The importance of distraction by billboard advertising signs has been demonstrated by Johnston and Cole (5) in a study done in Australia. In a laboratory simulation task they found that performance on a tracking task was worse under conditions of distraction from advertising signs than under a control condition. The relevance for this with regard to detection of traffic signs is obvious. Not only are advertising signs likely to serve as visual noise, making it difficult to notice traffic signs in the visual environment, but also they tend to distract the driver from the driving task.

SIGN CHARACTERISTICS

A number of physical characteristics of traffic signs influence their conspicuity. Forbes and his colleagues have done much of the laboratory research on this issue. Forbes (6) describes a procedure developed for measuring the probability that a traffic sign of given brightness, color, and contrast characteristics can be seen against various day and night backgrounds. Requirements for valid measurement of the perception of highway signs and a discussion of the advantages and disadvantages of movies and slides were presented. It was concluded that the discrete presentation method (slides) was to be preferred. Details of the procedure can be found in Forbes' paper in this symposium.

Forbes (1) summarizes a systematic series of studies of sign visibility. A total of 14 laboratory experiments were conducted using more than 500 subjects. For most signs, a green material matching the U.S. interstate green signs was the basic color. Simulated signs of different brightness were made by applying different density neutral overlays. The subject was required to respond by indicating which of the four simulated signs he saw "first and best."

Forbes also had subjects view the signs against a "day-snow" background or against a night background. Four different sign sizes in each of the four brightnesses were varied systematically, as were the four sign positions over the roadway. Results indicated that the signs "seen first and best" were those with greatest brightness contrast against the background, and those which were larger when brightness was held constant. In addition, relative size and contrast might enhance or oppose each other when both were varied. Against a night background, the brightest of four signs was seen best, while against a day background, the darkest sign had the advantage.

Two experiments presented simulated signs against different colored backgrounds. Results indicated that no one color was best against all backgrounds. The brightest green was most visible against dark green trees and the darkest green was most visible against a blue-gray or yellow-brown background. When seven different colors were presented in pairs against dark green trees, yellow-brown hill, gray-blue cliff, and day-snow backgrounds, the light green and yellow were "seen best" most frequently. Mathematical models were developed for relative size and brightness contrast.

In order to check the laboratory simulation studies against actual observations on the highway, subjects rode in the right-hand seat of a station wagon driven by the experimenter, and called out all signs as soon as he saw them, giving the color of the sign and its location, and indicating whether it was an advertising sign or a highway sign. Although there were considerable individual differences, the observed results coincided fairly closely with those predicted from the laboratory studies.

Attention-getting characteristics of highway signs were measured by Pain (7) using Munsell gray chips. The subjective response of "the stimulus which they saw best and quickest", and subjects' eye movements were measured.

The subjective measure was found to be more consistent than the eyemovement measure. Some subjects had no eye-movements to the stimulus which they saw best and quickest, further illustrating the importance of peripheral vision in driving. In general, the stimuli seen best were those with the greatest brightness level and those with the highest brightness ratio.

ROADWAY STUDIES OF TRAFFIC SIGN DETECTABILITY

Laboratory investigations play an important role in evaluating sign detectability and the factors which contribute to it. However, many researchers believe that it is difficult to beat the "real thing" -- measures of detectability on the roadway.

Odescalchi (8) tested white signs of various sizes under open conditions (field and hedge background and shaded trees). Signs were placed at the side of the road according to existing British standards. Subjects were instructed to look down the road, not directly at the sign, and rate the sign as "too large, just too large, adequate, just too small, or too small." It was found that a white sign had to be 1.5 m^2 (16 ft^2) in area to be conspicuous at 225 m (250 yds) and for each additional 90 m (100 yds) the sign should be 1.22 m^2 (13 ft^2) larger, up to the tested maximum of 4.7 m^2 (50 ft^2) at 450 m (500 yds). Larger signs were required in shaded areas.

A second experiment attempted to determine the amount by which signs of various colors would have to be larger (or smaller) than white signs to be equally conspicuous. A paired comparison technique was utilized. The results, in terms of the amount the colored sign area had to exceed the white sign area to be equally conspicuous, were: yellow - 8%; red 7%; blue 24%; green 42%; and black 125%. Conspicuity increased as the luminance factor increased, with the exception of green.

Johansson and Rumar (9) investigated the capacity of car drivers to get information from road signs. Five subjects were driven through the 170 km (105 mile) test area and instructed to press a button each time they detected a road sign. Ninety percent of the total estimated road signs were "registered" by the subject.

In another experiment drivers were stopped and interviewed about 200 m (1/8 mile) beyond the sign. The drivers were asked "What was the last road sign you passed?" All testing was conducted in the daytime and approximately 200 drivers were interviewed for each sign. An attempt was made to explain the data on the basis of the "urgency" of the sign's message. The five signs, arranged in descending order of registration, were: Pre-warning for speed-limit zone (78%); Police control (63%); Road surface damaged by frost (55%); Warning (nonspecific) (18%); and Pedestrian crossing pre-warning (17%). The authors conclude that there "was a signficant difference between the percentage of drivers registering the different signs."

An extension of this work was done by Johansson and Backlund (10). The following objections to the validity of the method were pointed out by the authors. The time and space span between passing the sign and reporting it is fairly large, and there may be a substantial memory decay after 15 to 30 seconds. If so, the percentage of people remembering the signs would be low. The appearance of a police barrier could result in a sudden emotional disturbance, causing the momentary forgetting of the sign. This hypothesis was examined by having half of the police in uniform and half of them in plain clothes when they were stopping motorists. No differences were found.

In the study by Johansson and Backlund (10) signs were tested in different locations. Instead of testing each sign on separate experimental occasions, all five signs were tested on every occasion. When the measurements were repeated with the conditions held as constant as possible, a significant variation in probability of recognition was obtained, casting doubt on the reliability of the results.

A more recent study of traffic sign detection on the highway was carried out by Summala and Naatanen (11). They required subjects to name all the traffic signs they saw as they drive along a 257 km (160 mile) route in Finland. Their subjects were able to report approximately 97% of all signs on the route, a figure much higher than some earlier researchers had found. It was concluded that earlier results suggesting the relative inefficiency of traffic signs were due to deficient motivation of the subjects. The results indicated more unreported signs in urban driving (8.95%) as compared with highway driving (1.06%). This is to be expected, in view of the high visual load and attention demand encountered on urban streets.

SIGN PLACEMENT

Sign placement is very important, since the sign must be properly located to be seen and acted upon in time. Specifications for placement are laid down in sign manuals, however, these regulations are often either violated or turn out to be inappropriate for specific locations and conditions. Buildings, structures such as bridges, and road geometry frequently necessitate modifications in the rules which govern sign placement. Many signs are currently placed so that they cannot be seen by the driver when is using low beam headlights.

A primary concern in sign placement is the angle of view -- how far away from the forward line of vision a driver must look in order to read the sign. The farther off the road a sign is, the larger it must be. Certain messages need to be placed not only on the right side of the road, but also on the left side. In some locations NO PASSING and NO LEFT TURN signs have been placed on both sides of the road. This is desirable, since the driver will be on the left side of a two-lane highway when he is passing, and his view of the sign may be obstructed by the vehicle he is passing.

In a study by Brown (12) a NO PASSING sign, in the form of an isosceles triangle mounted on its side, was placed on the left side of the road. After three months, arrests for illegal passing dropped 63 percent. On three control highways, arrests rose 20, 10 and 7 percent. It has been demonstrated in both field (13) and laboratory (14) studies that overhead signs are easier to detect.

ENVIRONMENTAL FACTORS - DARKNESS, WEATHER, CONSTRUCTION ZONES

Night driving presents a set of visual problems not encountered under daytime conditions. Glare from headlights, reduced visual acuity and color sensitivity, and sudden changes in dark adaptation level can influence perception of traffic signs at night. In addition, the visual properties of the sign may be different at night than in the daytime. Problems can arise from very bright signs which may alter the driver's dark adaptation and impair perception of other signs in the vicinity of the bright sign.

The following factors influence the brightness of a sign: photometric properties of the sign face material, lateral and vertical position of the sign, distance from sign to vehicle, vertical and horizontal alignment of the roadway, driver's eye position, and vehicle headlights (number, type, arrangement, location, and high or low beam). Signs which have adequate conspicuity under daylight conditions may be difficult to detect at night. Therefore, daytime inspection of the adequacy of signs may not be appropriate.

A systematic examination of the surrounds (background) against which signs appear at night was carried out by Woltman and Youngblood (15). Several instruments for measuring luminance of nighttime sign surrounds were evaluated and their accuracy compared with that of a laboratory quality telephotometer. The authors describe a technique for surround evaluation and point out that conventional descriptions are often inappropriate.

The detectability of two types of retroreflective material--engineering grade (EG) and high intensity grade (HIG) were examined at night in a study by Godthelp (16). Subjects drove along an 11 km (7 mile) route on a rural roadway in Holland, and indicated when they could detect each of the 9 signs and when they could recognize the sign shape and read its message. Differences in detectability were negligible when sign detection was at less than 50 m (165 ft) for cars (100 m (330 ft) for trucks). At distances of more than 100 m (330 ft) (200 m for trucks) the luminance of HIG signs was about three times that of the EG signs. Under conditions of dense fog (visibility = 0.2 km or .12 miles) the detection distance for HIG signs was approximately 20% greater than for EG signs.

The NCHRP Report #123 (17) describes a computer program which permits the insertion of the actual highway alignment, taken off construction plans, and the determination of the brightness of any sign at any point along this alignment for any special type of vehicle approaching in a specific lane. This can provide valuable information on sign placement for optimum viewing, whatever the road geometry may be.

Relatively little research has been done examining the conspicuity of signs under adverse weather conditions. One of the most frequently occurring adverse conditions involves rain. A study by Hutchinson and Pullen (18) examined the scattering of light from droplets of dew and crystals of frost on retroreflective sign materials. The relative performances of a number of combinations of signing materials were subjectively evaluated under natural conditions of signing material were subjectively evaluated under natural conditions of dew and frost at night. Various combinations of encapsulated lens enclosed lens and button copy materials were tested. The signs were examined under headlight illumination, using on-site observations and photographs. On the basis of the subjective evaluations, messages mounted on encapsulated lens reflective material performed better than those mounted on enclosed lens material. It was found that all of the combinations of materials were less affected by frost than by dew.

A common cause of poor sign conspicuity, especially at night, is dirt on the sign. A study in Sweden by Rumar and Ost (19) examined the extent to which dirt on traffic signs reduces their effectiveness by reducing reflected light contrast. The signs were measured for dirt accumulation once a week and cleaned each week. Weather conditions were important, with wetness of the road being the most detrimental factor. The reduction in reflected light varied from 0 percent (very rare) to 69 percent.

Another environmental condition which interferes with detection of signs can be found at roadway construction sites. Poor traffic sign conspicuity is a particular problem in construction zones for several reasons: signs are often poorly placed (lower than the recommended height); signs tend to get dirty quickly because of this low placement and because of the increased amount of dust and mud in the vicinity; atmospheric dust reduces visibility; vehicle windshields may also be dirty for these reasons; detours may result in poor roadway alignment, which makes it difficult to place signs in the driver's line of sight; signs may be hidden by machinery, mounds of earth, etc; driver's attention may be distracted due to complex roadway geometry, presence of construction vehicles and personnel, etc. Such problems tend to be magnified at night, especially if good advance warning is not provided.

DRIVER FACTORS

So far a number of factors relating to the sign and the environment have been examined. In all phases of the driving task it is essential to consider the capacity and state of the driver as well.

An important individual difference variable involves cognitive style. As indicated earlier, visual distraction can make it more difficult for drivers to detect signs and other relevant information. A sign embedded in a context of other signs or other distracting visual input is less likely to be detected, as indicated by Loo (20). In a reaction time study (using slides as stimuli) which measured time taken to detect and identify traffic signs he found that it took a good deal longer when the sign was embedded in a natural scene, as compared with when the same sign was presented by itself. Embedding signs in a context led to much poorer performance on this task among subjects who were field-dependent than among field-independent subjects. This difference is to be expected on the basis of the literature on cognitive style. The fact that there was an interaction between field dependence-independence and whether or not the signs were embedded indicates that the impairment was due to increased time required to detect the stimulus, rather than to identify it. Such individual differences are seldom taken into account in studying traffic sign perception or other driving tasks.

Alcohol has been found to narrow the field of view of objects, a phenomenon sometimes referred to as "tunnel vision." This narrowing of the visual field, or inability to detect peripheral targets, seems to occur when attention to the central visual field is required (21). A related phenomenon is the manner in which the driver scans the visual environment when intoxicated. Visual scanning is less active and more limited to the center of the roadway under the influence of alcohol, according to Moskowitz, Zeidman and Sharma (22).

CONCLUSION

Detectability is a primary criterion for any traffic sign, for if it is not detected, obviously its message will never get to the driver. Several factors which influence traffic sign detectability have been examined. A sign may be missed because it is too small, embedded in a complex visual environment, poorly placed, poorly maintained, or because the driver has inadequate visual capabilities, is distracted, or is overloaded by other elements of the driving task.

How can all of these problems be remedied? Greater care must be taken in placing and maintaining signs. Drivers should be made more aware of the problems associated with traffic signs detection. Driver education requires students to learn the meanings of signs and the shape and color codes. They should also be taught efficient means of scanning the environment and processing relevant information such as that on traffic signs. The simple need to detect traffic signs presents many problems to the driver. Those responsible for signs must pay greater attention to the basic information needs of the driver.

REFERENCES

1. Forbes, T.W., "Factors in Highway Sign Visibility", Traffic Engineering, Vol. 40, 1969, pp. 20-27.
2. Zahn, J.R. and Haines, R.F. "The Influence of Central Search Task Luminance upon Peripheral Visual Detection Time", Psychonomic Science, Vol. 24, #6, 1971, pp. 271-273.
3. Nobel, M. and Sanders, A.F. "Searching for Traffic Signals while Engaged in Compensatory Tracking", Human Factors, Vol. 22, #1, 1980, pp. 89-102.
4. Lee, P.N.J. and Triggs, T.J. "The Effects of Driving Demand and Roadway Environment on Peripheral Visual Detections", Australian Road Research Proceedings, Vol. 8, Session 25, 1976, pp. 7-12.
5. Johnston, A.W., and Cole, B.L. "Investigation of Distraction by Irrelevant Information", Australian Road Research, Vol. 6, #3, 1976, pp. 3-23.
6. Forbes, T.W., "Predicting Attention-Gaining Characteristics of Highway Traffic Signs: Measurement Technique", Human Factors, Vol. 6, #4, 1964, pp. 371-374.

7. Pain, R.F. Brightness and brightness ratio as factors in attention value. Ph.D. Dissertation, Michigan State University, Department of Psychology, 1968.
8. Odescalchi, P. Conspicuity of signs in rural surroundings. Traffic Engineering and Control, 1960, Vol. 2, pp. 390-393.
9. Johansson, G., and Rumar, K., "Drivers and Road Signs: A Preliminary Investigation of the Capacity of Car Drivers to Get Information from Road Signs", Ergonomics, Vol. 9, 1966, pp. 57-62.
10. Johansson, G. and Backlund, F. Drivers and Road Signs. Ergonomics, 1970, Vol. 13, pp. 749-759.
11. Summala, H., and Naatanen, R., "Perception of Highway Traffic Signs and Motivation", Journal of Safety Research, Vol. 6, #4, pp. 150-154.
12. Brown, R.I., Iowa tests new idea in signing. Traffic Review and Digest, 1959, Vol. 7, pp. 7-8.
13. Bhise, V.D., and Rockwell, T.H., Strategies in the design and evaluation of road signs through the measurement of driver eye-movements. A paper presented at the Annual Meeting of the Human Factors Society, New York City, October, 1971.
14. Forbes, T.W., Pain, R.F., Fry, J.P. and Joyce, R.P., "Effect of Sign Position and Brightness on Seeing Simulated Highway Signs", Highway Research Record, #164, 1967, pp. 29-37.
15. Woltman, H.L. and Youngblood, W.P., "Evaluating Nighttime Sign Surrounds", A paper presented at the 57th annual meeting of the Transportation Research Board, January, 1977.
16. Godthelp, J., "The Perceptibility of Traffic Control Signs at Night; a Field Study on the Effect of a New Type of Retroreflective Material", Report # 1Zf 1979-CI, Institute for Perception TNO, Soesterberg, Netherlands, 1979,
17. National Cooperative Highway Research Program, Development of information requirements and transmission techniques for highway users. Report #123, Highway Research Board, Washington, D.C., 1971.
18. Hutchinson, J.W., and Pullen, T.A. "Performance of Signs Under Dew and Frost Conditions", A paper presented at the 58th annual meeting of the Transportation Research Board, January, 1978.
19. Rumar, K., and Ost, A., The Night Driving Legibility Effects of Dirt on Road Signs, Report No. 164, Department of Psychology, University of Uppsala, Sweden, 1974.
20. Loo, R., "Individual Differences and the Perception of Traffic Signs", Human Factors, Vol. 20, #1, 1978, pp. 65-74.
21. Moskowitz, H., and Sharma S., "Effects of Alcohol on Peripheral Vision as a Function of Attention", Human Factors, Vol. 16, #2, 1974, pp. 174-180.
22. Moskowitz, H., Zeidman, K. and Sharma, S., "Visual Search Behavior while Viewing Driving Scenes under the influence of Alcohol and Marijuana.", Human Factors, Vol. 18, #5, pp. 417-432.

SIZE VERSUS INTENSITY AS AIDS TO SIGNAL CONSPICUITY

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Providing the motorist with more effective traffic control devices has been the objective of constant efforts by the traffic engineering community, aided by professionals from other disciplines who share their interest in traffic safety. In recent years, an increasing amount of research has been devoted to improving the conspicuity of traffic control devices by manipulating parameters such as size, shape, color, brightness, location, number and so on.

Among the results of this research are the not-so-surprising findings that within limits, the conspicuity of traffic signals can be improved by increasing their intensity, as well as by increasing their size. Of these two improvements, increased intensity would appear to be the simpler alternative, since (in effect) all that is required is a brighter bulb, although there has been increasing use of larger signal heads at "problem" intersections.

In the past few years, however, restrictions in available funds have increased the need to assess the "cost-effectiveness", if possible, of every proposed improvement in the highway system. In addition, growing concern for present and future energy supplies, which may pose an even more pressing constraint than fund restrictions, has injected a new set of values in the cost-effectiveness evaluations, resulting in changes in the "trade-offs" that can be considered "acceptable".

One such trade-off relating to traffic signals has to do with size versus intensity as a means for making the signal more conspicuous and, hence, more effective. This paper describes research that produced findings which may be of value in resolving this issue.

OVERALL METHODOLOGY

The research described below was conducted as part of a larger study directed toward developing more effective warning devices for highway-rail grade crossings. This rather complex project, involving indoor and outdoor laboratory studies as well as the collection of field data, is described in detail in a report by Ruden, et al. (1).

The indoor laboratory study phase of the total project was conducted in the Federal Aviation Administration's Low Visibility Facility at the University of California's Richmond (California) Field Station. This facility consists of a building 1000 feet (305 m) long and 33 feet (10.1 m) wide, with 28 feet (8.5 m) of paved roadway along its length. It is 36 feet (11 m) high at the high end, tapering down to a height of 11 feet (3.4 m) for the last 500 feet (152.5 m). Translucent panels allow natural light to enter the facility, permitting observations to be made under daylight, as well as nighttime conditions. The facility also incorporates equipment for generating artificial fog of controlled density.

The indoor laboratory tests concentrated on determining the conspicuity of pairs of flashing lights, although retroreflectors and stop signs also were studied as add-ons to gate arms. Both incandescent bulbs and xenon flash tubes (strobe lights) were used as light sources, and included among the incandescent light units tested were standard 8-inch (20.3 cm) and 12-inch (30.5 cm) traffic signal heads. The primary variables investigated for the traffic signal heads were

1. COLOR: Red, blue, red and blue, orange, and amber flashing light pairs were tested.
2. FLASHRATE: Tested flashrates ranged from 40 to 120 cycles/minute, with a 50 percent duty cycle, for pairs of lights.
3. BRIGHTNESS: Luminance (brightness) levels used ranged from 275 to 1240 footlamberts (fL). This brightness range, below what one normally sees in steady-burning traffic signal lights, was necessary in order to test blue-filtered incandescent lights at a luminance level equivalent to that of amber-, orange- and red-filtered lights. That is, an incandescent bulb, rich in red wave lengths, is unable to transmit higher energy levels through blue lenses. The luminance values chosen were based on the recommendations of Fisher and Cole (2), as cited in Lunenfeld (3), as to the minimum luminance levels required for daytime viewing.
4. SIZE: Lights with 8-inch (20.3 cm) and 12-inch (30.5 cm) diameter lenses were compared. The lights in a pair were always of the same size.
5. PLACEMENT: Signal conspicuity at three positions was evaluated: "High Center" (17 feet (5.2 m) high, centered over the roadway), "High Right" (equally high, on the "right shoulder") and "Low Right" (9 feet (2.7 m) high, on the "right shoulder"). "Low Left" (on the "left shoulder") and "Low Center" positions also were used, but only as decoys. The various flashing light pairs were presented to the subjects in all positions during the course of the testing.

Some 150 drivers of both sexes and all ages served as subjects in the indoor laboratory tests. Nine subjects were tested per day, from 3PM to 11PM, and each viewed from 100 to 180 "displays". A "display" normally consisted of six "elements" - three pairs of flashing lights with each pair mounted on a separate post (left, center and right), and with a standard reflectorized highway sign mounted on each post below the flashing lights. No signs were used with the flashing lights when they were high mounted, because neither a high-mounted sign nor a large gap between the sign and the flashing light pair would have been appropriate.

In each display, only one pair of flashing lights was considered the primary target and the other two flashing light pairs and any post-mounted signs present served as "decoys". (The subjects were unaware of all this, of course.) Each day, nine subjects (plus two experimenters) were seated in a movable cabin structure, 8 x 16 feet (2.4 x 4.9 m) in size, that approached the display at a speed of approximately 5 mph (8 kph). When the subjects were approximately 450 feet (137 m) from the display, a shutter curtain automatically opened and closed, revealing the display to the subjects for a short time interval, which was varied from 1½ to 4½ seconds during the course of the study. (Short exposure times were used to simulate the time-stressed nature of real-world perception.) For each display presentation, each subject was instructed to record the single element of the display that most attracted or held his attention. This subjective judgement of conspicuity, or target value, then, was the dependent variable. Tests were conducted under daytime, nighttime and 475-foot (145 m) daytime fog conditions. For the nighttime tests, low-beam automobile headlights affixed to the subject cabin were turned on. In all instances, displays were viewed against either a noncompetitive rural or highly competitive urban background, the latter including a variety of lights, signs and/

opposing vehicle headlights (when appropriate). In the daytime fog tests, the flashing light pairs were not accompanied by reflectorized signs on the same posts, since these signs could not be seen at all at the distances at which they were viewed.

OVERALL RESULTS

Before discussing the experimental results specific to the size/intensity issue, it may be of value to understand some of the overall findings of the indoor laboratory tests. In brief, these results may be summarized as follows:

1. COLOR: Excluding white or clear unfiltered light, and with equal luminance for all colored lights, red is the most conspicuous daytime color and blue is the best nighttime color. Amber and orange are slightly better colors in daytime fog. These results are consistent with findings reported by Rumar (4).
2. FLASHRATE: Flashrates of 70 to 90 cycles/minute for alternately-flashing incandescent lights generally lead to greater conspicuity than either higher or lower flashrates.
3. BRIGHTNESS: Brightness increase yielded somewhat greater conspicuity during the daytime and in daytime fog conditions. At night, however, little difference in conspicuity was found, suggesting that even the lowest luminance level tested (275 fL) was more than adequate for detection and recognition.
4. SIZE: Increasing lens size from 8 inches (20.3 cm) to 12 inches (30.5 cm) increased conspicuity dramatically under all conditions, far more, proportionately, than did increasing the brightness (This is discussed in detail below.) When viewed at a distance of 450 feet (137 m), the size difference between the 8-inch (20.3 cm) and 12-inch (30.5 cm) signals was dramatic.
5. PLACEMENT: The "High Center" and "Low Right" positions were more conspicuous than the "High Right" position for all viewing conditions. "Low Right" placement was best for daytime fog conditions. (It should be mentioned that in the real-world situation, the "High Center" - i.e., cantilevered-position sometimes presents a difficult viewing situation to the motorist when the signal aligns with a row of streetlights in the distance.)

SIZE VERSUS LUMINANCE COMPARISONS

The overall indoor laboratory findings described above suggested the influence that size and luminance independently have on the conspicuity of flashing lights. However, they did not reveal the significant interaction that exists between these two critical variables, an interaction that has important implications for signal brightness standards and, ultimately, energy consumption. These implications go far beyond the findings given above, and in order to explore them further, separate indoor laboratory tests were conducted to study the interactive effects of light size and luminance.

Methodology

The conspicuity of pairs of alternatively-flashing red traffic signal lights was tested by comparing them with each other and with decoy targets (described above). Each pair of red lights was either 8 inches (20.3 cm) or 12 inches (30.5 cm) in diameter. Incandescent bulbs were used as light sources, and two luminance levels were used for each size: 620 fL or 1240 fL for the 8-inch (20.3 cm) and 275 fL or 550 fL for the 12-inch (30.5 cm) Each light pair was flashed at a rate of 55 cycles/minute (in keeping with current practice), with a 50 percent duty cycle. Three positions were used for placement of the light pairs: "Low Left", "Low Center" and "Low Right". Observations were made by 81 subjects, all of whom viewed the lights under daytime, nighttime and 475-foot (145 m) daytime fog conditions. Each display was revealed to the subjects for 3½ seconds, utilizing the same test procedure and apparatus as described above.

Results

Based on the frequency with which test subjects selected the target pair of flashing red lights as being the most attention-getting (and attention-holding) element of a display, the following results regarding the relative importance of luminance and size to target value were obtained:

1. Some increase in conspicuity resulted from doubling the luminance of the 12-inch (30.5 cm) heads from 275 fL to 550 fL under all three visibility conditions; however, this increase was not statistically significant (Chi-Square test).
2. A slight increase in conspicuity resulted from doubling the luminance of the 8-inch (20.3 cm) heads from 620 fL to 1240 fL under daytime and nighttime conditions, but once again, this increase was not statistically significant. There was, however, a significant increase in conspicuity ($p=0.001$) (the probability that the obtained difference in conspicuity occurred as a result of chance is less than one in a thousand) resulting from doubling the luminance of these smaller heads under daytime fog conditions.
3. Comparing the two signal sizes under different visibility conditions, as shown in Table 1, the results were quite consistent.
   a. When viewed at night, the larger head had significantly higher target value than the smaller head regardless of their relative luminance levels. This was true even when the larger head, with 2.25 times the area of the smaller head, had only about 22 percent of the brightness (275 fL versus 1240 fL).
   b. In daytime fog, the larger head at 275 fL and the smaller head at 1240 fL had approximately equivalent target value, with both targets being significantly more conspicuous than the smaller head at 620 fL. The larger head at 550 fL was significantly better than the smaller head at 620 fL, and slightly better than the smaller head at 1240 fL, but not significantly so.
   c. Daytime results showed that conspicuity increased in the order: 8-inch (20.3 cm) at 620 fL, 8-inch (20.3 cm) at 1240 fL, 12-inch (30.5 cm) at 275 fL and 12-inch (30.5 cm) at 550 fL, although the differences between the two head sizes were not statistically significant for two of the comparisons.

Discussion of Results

It should be pointed out that in the daytime tests, the primary and decoy targets were viewed against a moderate-contrast background, without backplates, and although the "order of finish" of the four size/luminance combinations was the same as in the nighttime tests, the amplitude of the differences was much less in the daytime results. Although higher luminance levels were not tested, post project analysis of the data suggests that had higher luminance levels for both head sizes been used in the daytime tests, the results might well have been identical in significance to those obtained in the nighttime tests, since target lum-

TABLE 1: Traffic Signal Conspicuity as Related to Size, Intensity and Viewing Environment

SIZE/INTENSITY COMPARISONS	VIEWING ENVIRONMENT		
	NIGHTTIME	DAYTIME FOG	DAYTIME
8-inch (20.3 cm) @ 620 fL v. 12-inch (30.5 cm) @ 275 fL	12" better ($p \leq .02$)	12" better ($p \leq .004$)	12" better ($p \leq .10$)
8-inch @ 1240 fL v. 12-inch @ 275 fL	12" better ($p \leq .05$)	Both about the same	12" slightly better, but not signif.
8-inch @ 620 fL v. 12-inch @ 550 fL	12" better ($p \leq .005$)	12" better ($p \leq .001$)	12" better ($p \leq .05$)
8-inch @ 1240 fL v. 12-inch @ 550 fL	12" better ($p \leq .008$)	12" better, but not significant	12" slightly better, but not signif.

inance would have been further into the supra-threshold range, where the effects of size can more readily be isolated. Outdoor daytime testing with high background luminance levels in all likelihood would require even higher target brightness, plus the use of backplates, to produce results similar to those seen in nighttime viewing. It should be pointed out that the luminance levels used in the study were far below those recommended by the Institute of Traffic Engineers (5), and adopted by reference in the Manual on Uniform Traffic Control Devices (MUTCD) (6). The ITE standards call for 1411 fL for 8-inch (20.3 cm) and 1596 fL for 12-inch (30.5 cm) red signals. (These standards are given by ITE in candelas, but have been converted here to footlamberts, the measure of luminance used by most simple light-measuring devices.)

The results obtained in the study indicate that for daytime and nighttime there exist (different) supra-detection threshold values for the contrast between the light source and the "near" background such that any small increase in the luminance of the light source (such as doubling or tripling) will result in neglible improvement in the target value of the light source. Once the contrast exceeds this supra-detection threshold, increasing signal size is far more effective than increasing signal brightness as a means for improving target value. The nighttime data show that this contrast value was exceeded, while daytime results indicate that, without backplates, it was not. Daytime fog test results suggest that size, while more critical to target value than luminance, is, however, not completely dominant, as evidenced by the significant increase in target value resulting from doubling the luminance of the smaller, 8-inch (20.3 cm) head.

IMPLICATIONS OF THE FINDINGS

In recent years, the concept of dimming traffic signals as a means for conserving energy and reducing unwanted glare during hours of darkness has been given increasing consideration. For example, in 1974 Labrum (7) proposed replacing 8-inch (20.3 cm) signal heads with 12-inch (30.5 cm) heads for increased effectiveness, but suggested reducing bulb size in the 12-inch (30.5 cm) heads from the standard 150 watts to 100 watts, to save energy. (He recommended doing this for the yellow and green indications only, not for the red, because of the differential color sensitivity of the eye.)

Lunenfeld (3) suggested that while there are few instances in which the standard 8-inch (20.3 cm) signals should be dimmed at night, there are many more situations in which the 12-inch (30.5 cm) signal brightness can be reduced to the level of the smaller head without loss of an adequate margin of safety. He states that these decisions must be made on a location by location basis, taking into account such factors as background luminance and competition, geometric design and signal placement relative to the driver's line of sight. King (8) also feels strongly about signal placement, stating that it is the major element in signal effectiveness. This suggests that improved signal placement can be used together with signal dimming to reduce energy consumption without loss of signal effectiveness.

Fausch and Apeldorn (9) addressed the issue of glare, and recommended that all signal systems incorporate equipment that automatically adjusts signal brightness as a function of background luminance. A variety of such devices have been marketed for several years, and have been used by various governmental entitities for dimming signal indications, despite the fact that the MUTCD provides no clear-cut authority for this and that criteria have yet to be developed that establish minimum signal luminance levels based on driver (and pedestrian) needs.

What has resulted is inconsistent, non-uniform application of a principle which appears sound, and in recognition of this, in 1978 the Federal Highway Administration indicated its desire to fund research in this area (RFP 413-8), citing the shortage and cost of energy and the possibility of glare from traffic signals at night, as well as the non-uniform application of signal-dimming techniques throughout the U.S., among the reasons why such research was needed. The FHWA project initially is to deal with driver/pedestrian requirements for the conspicuity, detection and recognition of signals in terms of their color, contrast, size and position in the visual field, and then is to concentrate on signal intensity using both 8-inch (20.3 cm) and 12-inch (30.5 cm) signal heads.

The FHWA research has not yet been accomplished; however, a significant headstart toward answering some of the critical questions addressed by the FHWA has been made by the study described in this paper, as well as by some of the other relevant research efforts completed to date. It would appear reasonable to make the following inferences from the research findings currently available:

1. As presently designed, once a supra-threshold contrast value has been attained, far greater conspicuity can be achieved by using 12-inch (30.5 cm) instead of 8-inch (20.3 cm) signal heads for the same or less expenditure of energy. This does not mean that the larger heads should automatically be used in all situations since, as King (8) suggests, it may be advisable to have a mix of signal head sizes, reserving the larger head sizes for the red indication, where more impact is desired.

2. If we can assume that the results of the present study, which used flashing lights, can be extended to steady-burning traffic signals, then there is no question but that the standard 150-watt bulb used in 12-inch (30.5 cm) signal heads is consuming excessive electrical energy during hours of darkness, with miniscule target value advantage over the same head in a dimmed operation. There is some question as to the value to conspicuity of powering 12-inch (30.5 cm) signal heads with 150-watt bulbs at any time; that is, if they are needed for driver detection in bright daylight, then clearly the standard 8-inch (20.3 cm), 60-watt head has to be seriously deficient in the same application.

3. Signal dimming is feasible; signals at night are often too bright, but additional research is needed to establish the exact values for required luminance in daytime in relation to size, and the degree of dimming permissible at night.

4. It is likely that energy savings can be accomplished along with both an increase in conspicuity and a decrease in glare, by manipulating size, intensity and placement of signal heads. However, it will be necessary to study each case individually, and take into account background, highway geometry and other factors.

5. It is likely that the costs associated with conversion to the larger head sizes will, in the long run, be more than offset by energy cost savings (let alone the absolute reduction in energy consumption as a social goal). This cannot be confirmed, of course, without a cost-benefit evaluation; however, if energy costs continue to rise and energy supplies become more critical, whether or not the conversion to larger head sizes will "pay for itself" may become immaterial.

REFERENCES

1. Ruden, R.J., Wasser, C.F., Hulbert, S., and Burg, A. Motorists' Requirements for Active Grade Crossing Warning Devices, San Ramon, CA: MB Associates, Report No. FHWA-RD-77-167, October 1977.
2. Fisher, A.J., and Cole, B.L., The Photometric Requirement of Vehicular Traffic Signal Lanterns, Proceedings, 7th Australian Road Research Board Conference, 1974.
3. Lunenfeld, H., A Human Factors Assessment of Decreased Traffic Signal Brightness, Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration, December 1976.
4. Rumar, K., Conspicuity of Beacons for Emergency Vehicles, Sweden: University of Uppsala, Department of Psychology, Report 152, 1974.
5. A Standard for Adjustable Face Vehicular Traffic Control Signal Heads, Washington, D.C.: Institute of Traffic Engineers, Technical Report No. 1, 1970.
6. Manual on Uniform Traffic Control Devices, Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration, 1971.
7. Labrum, W.D., Reduction of Energy Requirements for Traffic Signals, Western ITE, V. 28, No. 6, May 1974.
8. King, G.F., Guidelines for Uniformity in Traffic Control Signal Design Configurations, Final Report on NCHRP Project 3-23, Huntington, N.Y.: KLD Associates, 1977.
9. Fausch, P.A., and Appeldorn, R.H., Controlling Signal Intensity and Uniformity to Improve Signal Visibility, Traffic Engineering, January 1973, pp. 12-15, 63.

DETECTION OF WORK ZONE TRAFFIC CONTROL DEVICES

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Before discussing any data, there had best be some definition of the topic at hand. The work zones studied and the data reported herein are of the long-term (over 24 hours), high-speed (45+ mph) variety usually found in freeway or four-lane highway settings.

Detection has several definitions, but for this presentation will have two meanings: (1) when do drivers see that a device is present, and (2) when and how do drivers react to devices?

Particular emphasis will be placed on channelizing devices, with less consideration of advance signing and delineation.

BACKGROUND CONCEPTS

Traffic control devices (TCDs) are part of an information system that is supposed to meet those driver information needs required to traverse a work zone (1). Therefore, major concerns about TCDs are what behavior is elicited from drivers at what point in the work zone.

While behavior can be observed and measured, current information needs statements leave several unanswered questions (2). Does optimal (in terms of safety and throughput) work zone operation require speed reduction; should merging at lane closures be spread out as much as possible; and should channelizing devices provide advance hazard warning and lane closure information, in addition to delineating a clear path through the work zone? For purposes of this paper, the assumption was made that channelizing devices serve both roles. The rationale behind this is that people seem reluctant to change lanes until they see the need. In other words, past experience has led many drivers to disbelieve advance warning signs; they are not always correct.

Given the assumption, at what distance should channelizing devices provide warning and lane closure guidance information? The decision sight distance concept (3, 4, 5) encompasses the time, expressed in distance at different speeds, taken by drivers to detect, recognize, select speed and path, perform a maneuver safely. The times given in Table 1 were derived from experiments with subjects driving an instrumented car through a variety of city, arterial, and freeway situations. These distances provide one performance standard to use in assessing detection distance results.

ADVANCE SIGNING

Relatively little research has been conducted on advance signing. The major research effort has been on color coding, with the result that orange is the standard construction zone sign color (e.g., 6). Like other types of signs, work zone signing is equally in need of nighttime illumination or reflectivity. Advance signing legibility has not been overly studied, and there is little evidence that legibility of black on orange is sufficient on current signs. The greatest problem with advance signing has little to do with detection. Drivers often read the advance signing message and act accordingly, only to find the work zone situation is different. Signing quickly loses credibility and, subsequently, effectiveness in eliciting the desired driver behavior.

ARROW BOARDS

Extensive study of arrow boards (7) indicates they can be initially detected anywhere from 2500 to 5000 feet away. Identification of the arrow and direction occurs between 1500 and 2500 feet. These values are well in excess of the recommended recognition distance of 725-1175 feet, depending on speed. Field evaluations indicate arrow boards are most useful for lane closures, where they promote earlier merging. Only in specific situations were they helpful in lane diversion (crossover) operations. Placing the board on the shoulder at the start of the taper was more effective than placing it in the closed lane farther back in the taper. A second arrow board in advance of the taper was also effective. Human factors studies (8) indicates that the flashing arrow, then chevron, configurations are more effective than the sequential arrow. Hooded lights and automatic dimmers are necessary design features.

CHANNELIZING DEVICES

Concrete Barriers

A study of concrete barrier visibility (9) focused heavily on the durability, over a two-year period, of six reflective products. Both photometric readings and observer ratings of visibility were

TABLE 1: Decision Sight Distances (Adapted from McGee and Knapp (5))

Speed	Detection Through Maneuver Time (sec)	Distance (ft)
30	10.2 - 11.7	450 - 525
40	10.2 - 11.7	600 - 675
50	10.2 - 11.7	750 - 850
60	10.2 - 11.7	900 - 1025

used to assess performance in a median setting. Recommendations for mounting materials, installation cost, etc., are given in the report. From a visibility perspective, reflectors were superior to reflectorized tape. The specific reflectors recommended in the report represent something of a compromise in that no one product was rated high at the beginning and end of the two-year time; there was switching of visibility rankings over time. Other findings include: spacing - 80 feet on tangent, 40 feet on curves; position - mounted on top, horizontal surface, reflectors weathered best; glare is a problem at night; and reflector visibility enhanced under wet night conditions, when barriers are usually least visible.

Other Channelizing Devices

A study of cones, tubes, barricades, panels, drums, and steady burn lights was recently reported and is summarized here in (2). (Research reported was supported through NCHRP Project 17-4.)

A comprehensive literature review was conducted to identify: (1) the safety problem at highway work zones as it relates to channelization devices; (2) the use and effectiveness of traffic control devices in work zones; and (3) measures which can be used to evaluate the performance of channelization devices. The findings of the literature review supported the original contentions that there are many types and designs of channelization devices being used. Furthermore, the data are lacking that would support current design of these devices or their arrangement on the job. The products of the literature review include an extensive bibliography, a literature synthesis, and a chart highlighting current standards and usage guidelines for the various devices.

The next task prior to actual experimentation was to develop performance measures that would reflect drivers' response and the relative effectiveness of particular devices. Using the inputs of the literature review, an Information-Decision-Action (IDA) task analysis procedure was utilized to derive candidate performance measures. By analyzing the driving task, it was possible to identify the desired driver and vehicle responses and, in turn, translate these into performance measures for evaluation. Most of these measures were incorporated into the design of the various experiments which followed.

The experimental program consisted of three types of studies. The first of these was a laboratory study which was aimed at optimizing the design characteristics of barricades and panels. The design features studied were: stripe configuration (horizontal, vertical, diagonal, and chevron), width, and meaning; white-to-orange color ratio; and height-to-width ratio. Subjects saw small bar or panel-shaped stimuli with different design features against a visually noisy background. The background was divided into quadrants, and subjects had to search to find and then detect the stimulus. After seeing the stimulus for 0.4 second, subjects indicated where the target was located, the target shape, and its configuration.

Using the results of the laboratory experiments to define additional problems, another series of experiments were conducted on a closed highway using an instrumented vehicle (the DPMAs on loan from NHTSA) driven by test subjects. The various devices, with varying sizes, spacings, reflectivity, auxiliary lighting (steady burn lights), and configurations were compared to determine their relative effectiveness in eliciting desired driver responses. This study provided additional findings related to the effectiveness of alternate devices and device designs when placed in a channelizing array.

A factorial design was used in which 10 subjects, stratified by age and sex, were exposed to each treatment. Separate groups saw devices day and night. A total of 300 subjects participated.

The dependent measures were speed, speed variance, laterial position, displacement from the centerline (weaving), array detection distance, point of lane change, steering wheel movement, and accelerator and brake pedal movement. The only measures which differentiated between devices were detection distance, point of lane change, and speed.

Only the detection distance results for single devices and device arrays, day and night, are summarized below:

Day: Seven of the devices have mean detection distances of 2000 feet or better. The remaining devices vary from 550- to 1750-foot mean distances.

Night: There was no significant difference between day and night mean detection distances for single devices in general, i.e., all devices pooled together. However, there are changes for specific devices between day and night.

Cones and the 42" post, while detected from 2400-2500 feet in the day and equivalent in detection performance to drums and Type I barricades, became statistically significantly less detectable at night. However, only one amount and type of reflective collar (6") was studied and there is no evidence to suggest this represents an optimum nighttime configuration for cones or tubes. Note that another NCHRP-sponsored project is currently conducting a more thorough test of cone and tube performance.

Arrays: Array detection distance was significantly longer in the daytime than single device detection.

Array detection distance at night was significantly higher than single device detection only for certain devices (3' x 12" barricades, 12" x 24" panel, 28" post and cone, steady burn light, 2' x 8" Type I barricade with chevron stripe).

Array detection in the day was at significantly greater distance than at night.

Single device detection scores were not necessarily predictive of array detection distances.

Variability in Detection: Considerable variability around the mean detection scores was evident.

Using a 1000-foot decision sight distance as a minimum, the 12" x 36" panel, drum, steady burn light, and 8" x 24" panel with chevron could meet the criterion of 97% (2 SDs) of drivers at night. In the day, only the 42" post, 36" cone, and 28" cone met the criterion for 97% of drivers.

The final experiments were conducted in real world situation wherein three types of devices (cones, barricades, and vertical panels) with design and layout variations were tested at three work zone types—a traffic diversion site, a left-lane closure site, and a right-lane closure. Measures of mean speed, speed variance, lane changing, and traffic conflicts were compared to determine relative effectiveness.

Collectively, these experiments provided sufficient data to support several recommendations concerning the use of the alternative devices and their design and layout parameters. In general, it was found that most of the channelization devices studied were equally effective in providing a path for the motorist. However, not all devices were equally effective in their alerting function, as it was shown that several types had longer detection distances associated with them.

In conclusion, the findings indicate relatively successful detection and path guidance performance by most devices. One of the major deterrents to effectiveness is not the device, but the position, dirty, or overturned devices destroy the visual line or path created by channelizing devices. Therefore, use of appropriate devices is important but diligent set-up and care of the work zone is equally important.

References

1. Pain, R.F. and Knapp, B.G. Motorist information needs in work zones. ITE Journal, 49:4, April 1979.
2. McGee, H.W., Pain, R.F., and Knapp, B.G. Evaluation of traffic controls for highway work zones: Final report, Volume I, Technical Report, and Volume II, Appendices. Prepared for NCHRP, Project 17-4, by BioTechnology, Inc., February 1979.
3. Alexander, G.J. and Lunenfeld, H. Positive guidance in traffic control. U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., April 1975.
4. Post, T.E., Robertson, H.D., Price, H.E., Alexander, C.J., and Lunenfeld, H. A user's guide to positive guidance. Federal Highway Administration, January 1977.
5. McGee, H.W. and Knapp, B.G. Visibility requirements of work zone traffic control devices. Prepared for FHWA by BioTechnology, Inc., July 1978.
6. Shah, S.C. and Ray, G.L. Advance traffic control warning systems for maintenance operations. Research Report 105, Louisiana Department of Highways, July 1976.
7. Graham, J.L., Migletz, D.J. and Glennon, J.C. Guidelines for the application of arrow boards in work zones. FHWA-RD-79-58. Federal Highway Administration, Washington, D.C., December 1978.
8. Knapp, B.G. and Pain, R.F. Human factors considerations in arrow board design and operation. Transportation Research Record, No. 703, 1979.
9. Mullowney, W.L. Center barrier visibility study. FHWA/NJ-80/002, New Jersey Department of Transportation, Trenton, New Jersey, January 1978.

NIGHTTIME DETECTION OF BICYCLES

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BACKGROUND

The purpose of this paper is to summarize what research has been done, what we have learned so far and what suggestions can be made with regard to the nighttime detection problem of bicycles.

Most of the suggestions are based upon research studies carried out at Ohio University (O.U.). Details about these research studies are given in a six-volume O.U. human factors engineering and design laboratory report (1). Volume I describes a computer model developed to simulate the performance of a reflectorized object, such as a corner cube reflector, located ahead of a vehicle with a selected headlamp system at night.

Tables and graphs illustrate the performance of selected corner cube reflectors at night for various geometric, vehicle and headlamp configurations, as well as for various environmental conditions. Reflector performance is expressed in terms of how many times the illumination at the eyes of an observer is above the 98% detection threshold level for a selected representative background luminance (for detection threshold levels as a function of the background luminance see Fig. 3-49, p.3-35, IES Lighting Handbook, 1972) (2).

Volume II contains a computer analysis dealing with the visual detection of point light source signals such as a tail lamp at night or during daytime. Volume II also contains an extensive review of the visual threshold data and background luminance data published in the literature.

Volumes III, IV, V and VI describe field experiments dealing with the foveal and peripheral detection of bicycle and shoe reflectors at night. Volume III provides field research results for detecting, ahead of a stationary car at night, a bicycle equipped with pedal reflectors and a rear wide angle reflector moving parallel to the car's axis. Volume IV provides field research results with regard to the detection of static vs. dynamic pedal reflectors at night. Volume V provides field research results with regard to massed vs. distributed reflectors at night, and Volume IV provides field research results with regard to detection of shoe reflectors at night. Volumes III through VI report not only the distânces at which the various reflectors or reflector arrangments were detected, but also information as to how many times the illumination level at the eyes of the observers was above the 98% detection threshold level for a representative background luminance of the experimental environment.

REVIEW OF RESEARCH LITERATURE

Only a few studies can be found that deal with the nighttime detection of reflectorized objects in the field. There exist many studies in the literature, however, which deal with the visual detection of targets against various backgrounds, the detection of point sources, or the detection of chromatic light sources in the laboratory. For examples or references, see pp. 3-33 to 3-39, IES Lighting Handbook, 1972 or W.E.K. Middleton's book "Vision through the Atmosphere," 1952 (3), or the Visibility Issue of Applied Optics, May 1964, Vol. 3, No. 5 (4). Four studies will be discussed here only briefly. They are reviewed in detail in the Ohio University volumes described above.

The report by K.G. Cook entitled: "Reflector Analysis," 1969 (5), provides useful information about reflectors, reflector usage, reflector standards and tests, the computational aspects and methods to analytically assess reflector performance, results of an analytic assessment of reflector performance and results of controlled field observations of reflective materials.

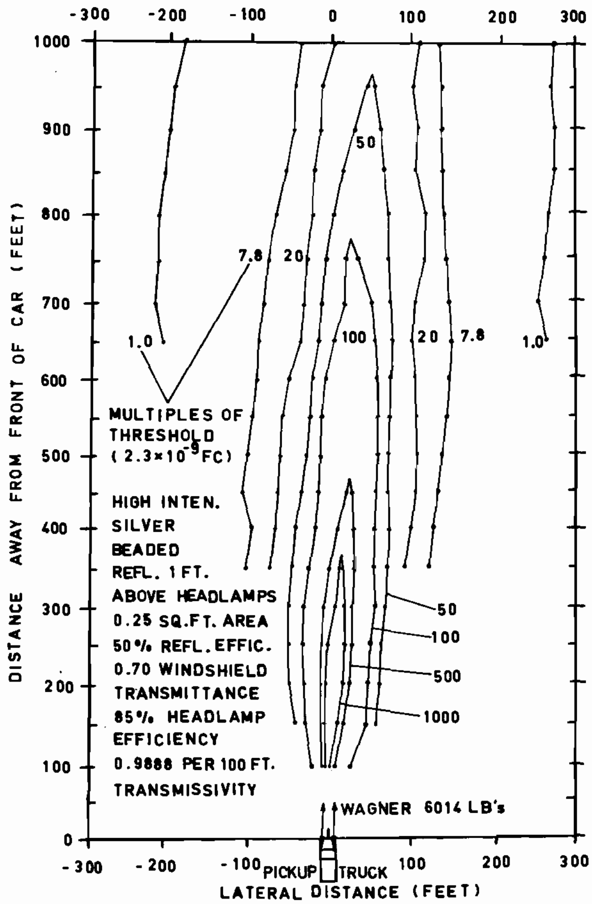
Burg and Beers report in the Journal of Safety Research, on two studies that were conducted to test the relative effectiveness of prismatic retroreflectors and retroreflective sidewall tires (6). Primary emphasis was on increasing the conspicuity of bicycles and motorcycles viewed from the side. The main findings were: 1) from a pure threshold detection standpoint, brighter stimuli are better, regardless of color, and point light sources such as prismatic reflectors are better than extended reflectors such as reflectorized sidewalls of equal brightness; and 2) in the night environment with moderately high visual clutter a relatively high luminance contrast as provided by prismatic reflectors does not result in easy recognition of a stationary or slowly moving stimulus object, however, the unique closed circular shape of reflectorized sidewall tires is very distinotive and thus far more effective as a recognition clue than the higher point brightness of prismatic reflectors. McGinnis reports on an analytic computer study dealing with the reflectorization of railroad rolling stock (7). Although this study does not directly deal with the bicycle detection problem, the approach, many of the calculations and the results have relevance to the bicycle detection problem. This author has used his own computer model and recomputed the visibility regions given by McGinnis. Figure 1 illustrates a number of selected threshold multiple curves (1.0, 7.8, 20, 50, 100, 500, 1000) for a pickup truck (driver eye height of 5 feet, horizontal distance from eyes to headlamps 6 feet, headlamps 2.125 feet above ground and 5 feet apart, and driver at 1.25 feet to the left of the car axis). Because of the larger observation angles for the pickup truck, visibility regions for the truck are smaller than for a typical car.

Another source of information is the Stoovelaar and Groot report on a study conducted under the auspices of the Royal Dutch Touring Club ("A Visible Bicycle," 1976) (8). This study emphasizes pattern-recognition rather than the factors used in classical visibility studies such as luminance and contrast.

Discussion of SAE and CPSC Reflex Reflector Standards

To this author, the SAE J594f (9) and the Consumer Product Safety Commission (10) reflex reflector standards have a number of shortcomings. First, both standards, are strictly stated in photometric terms and make no reference or justifications with regard to human capabilities and limitations. Second, both standards do not prescribe a minimum reflector area. Third, both standards specify the minimum photometric requirements for only two observation angles (0.2° and 1.5°, exception CPSC standard for pedal reflectors, additional observation angle 0.3°). And fourth, the specified photometric values are highly inadequate from a safety point of view and far below the state of the art capability of the reflex reflector manufacturing technology. It is also this author's opinion that the increases in the photometric values (50%) for the 0.2° obser-

FIGURE 1: Computed Threshold Multiple Curves for a Reflector as a Function of the Lateral and the Longitudinal Distance Ahead of a Pickup Truck



vation angle in the CPSC standard when compared to the SAE J594f standard are far too small to effect a significant positive change from a safety point of view. It should be noted that all the photometric values for the 1.5° observation angle in the CPSC standard remained unchanged when compared with the SAE J594f standard. One might argue that the CPSC standard includes photometric reflector values for additional larger entrance angles (for front, rear, and side reflectors only, 30°, 40° and 50°), however, the specified magnitudes for the 0.2° and 1.5° observation angles, especially for the 1.5° observation angle, are so small and inadequate that even extremely modest positive safety benefits in the real world would appear highly questionable.

In terms of creating more effective reflex reflector standards for bicycles, four major changes are needed. First, the minimum photometric values must be stated and justified in terms of human capabilities and limitations for a representative night environment. Second, the minimum photometric values must all be raised subject to constraints such as the state of the art of the reflector manufacturing technology, the minimum and maximum feasible or desirable reflector area, etc. Third, the practice of specifying the photometric performance of a reflex reflector for only two observation angles (0.2° and 1.5°) must be discontinued. It should be replaced by a new practice where, for each specified entrance angle, a continuous photometric reflector performance curve is specified over the observation angle range from 0.1° to 2.0° (measurement equipment to record continuously the photometric values as a function of the observation angle is available and in use for some time). Fourth, for each reflector type (front, rear, side, pedal) the minimum and possibly also the maximum area of each single reflector must be specified, along with the corresponding photometric curves. Further, for each of the reflector types, the standard must include specifications about the spatial reflector arrangements, the reflector shapes and color composition (individual rear reflectors could have two colors, red and amber, in order to reflect more light and still meet legal requirements). For example, two horizontally extended rear reflectors might improve factors such as position determination and the estimation of closure rate.

Another comment is in order with regard to the CPSC standard for the retroreflective tire test. The measurement procedure, the criteria and the minimum acceptable values for the quantity A defined in the retroreflective tire test procedure should be modified and simplified so that one can make quick approximate comparisons between different reflective material configurations on a cp/fc or luminance basis. An approximate cp/fc-value or milli-candelas/lux-value per unit length or unit area instead of A would be far more helpful for design and comparison purposes. Additionally, all of the suggestions made previously with regard to prismatic reflectors should be incorporated in the CPSC retroreflective tire test standard, if applicable.

The "Multiples of Threshold" Concept and the 1000 Criterion

The primary purpose of the "multiples of threshold" concept is to provide a system of measurement that allows a one to one comparison of visual detection results for light sources against backgrounds with different luminance levels. Figure 3-49 of the IES Lighting Handbook, (see Reference 2), depicting threshold illumination at the eye from a white point source for about 98% probability of detection as a function of the background luminance, represents the basis for the "multiples of threshold" concept. After extensive review and calculations, this author has concluded that the curve shown in Figure 3-49 represents a reasonably good compromise of the visual detection results reported in the literature. It is improtant to note that most published threshold values were obtained in the laboratory, against uniform backgrounds, with highly alerted and motivated subjects. Looking at the curve in Figure 3-49, one can observe that the threshold illumination levels increase rapidly with increasing background luminance (for example, at 0.01fL the 98% threshold illumination level is 0.28493×10^{-8}fc, at 0.1fL the 98% threshold illumination level is 0.80303×10^{-8}fc or 2.82 times higher).

Based upon field experiments which investigated both foveal and peripheral detection at night, this author feels that the illumination level at the eyes of a driver due to a point light source must be at least 1000 times above the 98% laboratory detection threshold level (for a representative night background luminance level) in order to assure the timely detection of a bicycle ahead of the car. A list of reasons why a threshold multiple of at least 1000 is required is given in the Ohio University laboratory report Volume II. They include: unalerted vs. alerted driver, peripheral vs. foveal detection, non-uniform background, low information processing workload vs. high information processing work load, timely detection or earliest possible detection in order to provide a maximum amount of time to the driver for the subsequent recognition, decision and control action phases, environmental factors such as fog or rain, other traffic, age effects, CO, drugs including alcohol effects, dirt on headlamps and/or inside-outside windshield, etc. The 1000 times above laboratory threshold illumination level criterion requires (for a representative night driving background luminance level of 0.01fL) 2.85×10^{-6}fc, or 3.07×10^{-5}lux, or 79.4 miles candles, or 30.7km candles. Using a representative background luminance of 0.01fL, a transmissivity value of 0.99 per 100 feet (clear to light haze), the 1000 times above laboratory threshold would be obtained by a light source of 2cp intensity located 805 feet away. In light fog (transmissivity 0.88), the corresponding distance would be 579 feet. Considering the present state of the art about decision sight distance requirements (for 50mph design speed 750-1025 feet, for 60mph design speed 1000-1275 feet, "Decision Sight Distance for Highway Design and Traffic Control Requirements," (11), the 1000 times threshold multiple is certainly not excessive or unrealistic and actually a rather modest proposal. Further, looking at Figure 21, p. 816, of Breckenridge's and Douglas' publication dealing with the "Development of Approach-and Contact-Light Systems" (Illumination Engineering, November, 1945) the 1000 times above threshold value for 0.01fL background luminance lies between the human brilliancy ratings of "satisfactory" and "bright". Here, illumination levels corresponding to the brilliancy ratings form a geometric series, the brilliancy scale goes from visible, faint, weak, satisfactory, bright, glaring, to blinding and the increase of one step in the rating required about a fourfold increase in the illumination level at the eyes of the observers.

Foveal vs. Peripheral Detection

Figure 2 illustrates typical eye fixation locations for a driver when driving on a straight level two-lane rural road at night with low beams, from data recently recorded and analyzed at Ohio University. Looking at Figure 2, one can observe that in spite of the severly limited richness of the visual scene at night there exists quite a dispersion among the eye fixations both in the horizontal and vertical directions (the spatial dispersions of the eye fixations are somewhat larger when driving through curves). Therefore, the initial detection of a bicycle with a bicyclist on the road ahead will most likely occur peripherally, rather than foveally. The results from a number of field detection experiments conducted at Ohio University indicate that the illumination detection thresholds are lowest for foveal detection and increase (U-shape) with increasing distance away from the fovea (both nasal and temporal). For example, at -10 degrees (left) in the periphery the illumination detection thresholds are on the average about 2 to 40 times higher than at the fovea. It should be noted that all field experiments employed highly alerted drivers who had no other task than to detect an approaching bicycle with a specific reflector arrangement.

It is common knowledge that a high visual workload and a high information processing level, as exist when a driver negotiates a curve, have detrimental effects upon the peripheral detection of visual stimuli. For these reasons, any field studies dealing with the nighttime detection of bicycles must include the measurement of a driver's peripheral detection capabilities along with the foveal detection capabilities. Further, when investigating a driver's recognition capabilities, peripheral recognition capability must be investigated along with foveal recognition capability. A peripheral angle of 10 or 15 degrees might be the most representative angle at which a driver's peripheral performance (detection and/or recognition) ought to be investigated for night driving conditions.

The Need for an Adequate Bicycle Taillight in Addition to Adequate Reflectors

A bicyclist with a bicycle outfitted with the best state of the art reflectors and reflector arrangement is still at the mercy of the motorist. Reflectors are a passive system of illumination and if the headlights of a car are misaimed, covered with dirt, or even worse, if the left headlight is burned out, the reflectors may not return enough light to assure timely detection, timely recognition, etc. An energized lighting system (taillight) also has an advantage in sharp vertical or horizontal curves, where the reflector performance at higher entrance angles is considerably lower. Again, any standard for an energized vehicle or bicycle rear lighting system must be expressed or justified in terms of human visual detection capabilities and a threshold has been proposed.

In the context of the earlier discussed decision sight distance requirements, a distance of 800 feet (approximately 10 seconds driving time at 55 mph) has been selected as a representative detection distance value. Figure 3 indicates that to meet the 800 feet detection distance and the threshold multiple of 1000 criteria in relatively clear weather (transmissivity 0.99 per 100 feet), with a representative background with a luminance level of 0.01fL, a 2cp light source is needed. Since the taillight would be red, the actual candlepower of the bulb behind the red lens would have to be 8cp. The SAE J585e standard for taillamps (rear position lamps) specifies a minimum candlepower requirement of 2.0cp for H-V and a maximum of 18cp at H or above. Actually most automobile taillamps "run" at around 8cp. Table 1 proposes minimum cp-values specified in the SAE J585e standard.

There is no reason why a bicyclist should not enjoy "equality" on the road in terms of the minimum cp-values for a taillight. While these values appear rather high, especially considering what has been available in the past, a specifically designed highly efficient sealed beam taillamp using about 1 watt of power (about one third of generator output) could probably meet the proposed minimum requirements. This author feels that in the past, too large a fraction of the power output by the generator has been used for the bicycle headlamp and too small a fraction has been used for the taillamp. It is hoped that future energized bicycle lighting systems will be so designed that both forward and rearward visibility needs are considered. Using up to 40% of a generator's output for the taillight would not be excessive and not too detrimental to the front visibility needs.

Some Computer Model Results of Evaluating Nighttime Detection of Reflectorized Objects

Input for this FORTRAN computer model consists of: 1) geometric input related to the road geometry (straight or curved), 2) car dimensions including headlamp aim and driver eye position, 3) background luminance and corresponding minimum 98% detection threshold, 4) transmissivity value of the atmosphere, 5) reflector area, position and orientation, 6) cp-matrix (horizontal and vertical) for beam pattern, and 7) cp/fc/area-matrix for reflector (as a function of observation and entrance angles.

The output consists of a number of selected distance values ahead of the car for which the following variable values are printed out: 1) observation

FIGURE 2: Driver Eye Fixation Plot for Night Driving

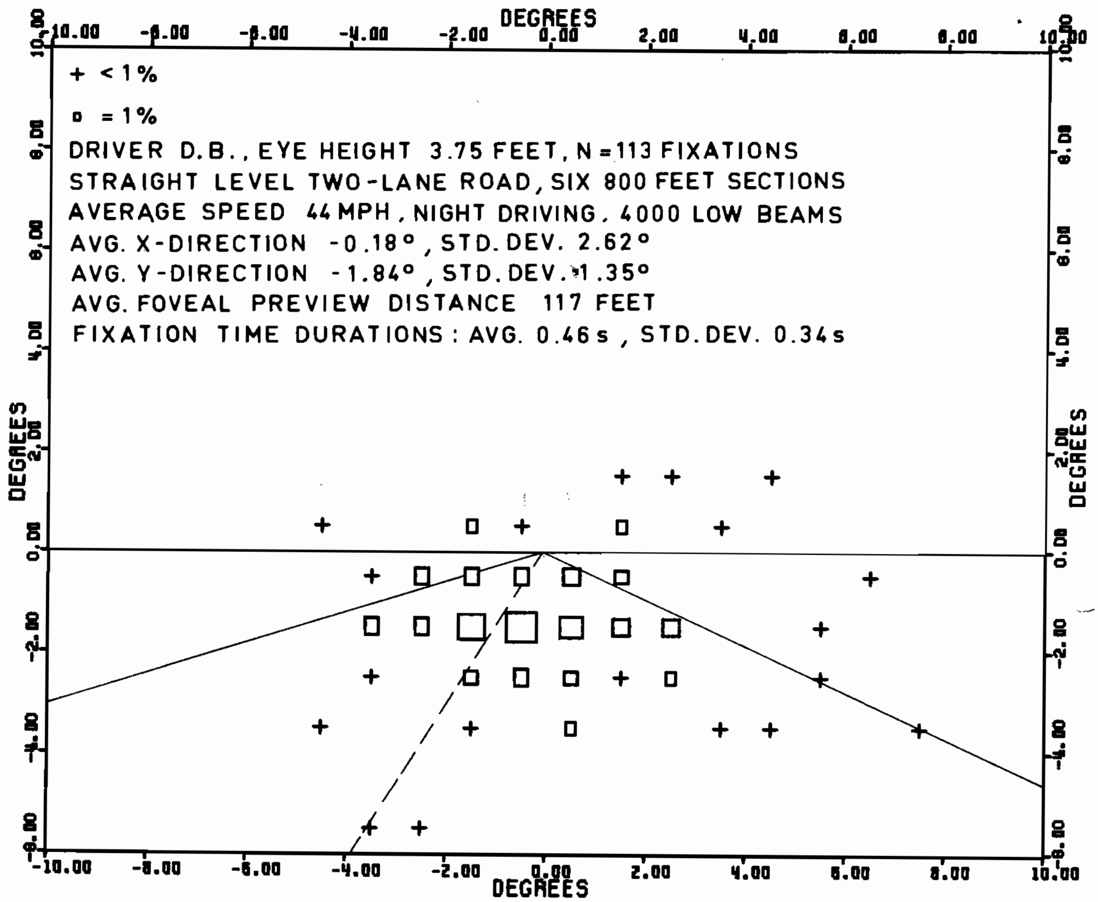


FIGURE 3: Detection Distances for Point Light Sources for Selected Threshold Multiples as a Function of Source Intensity

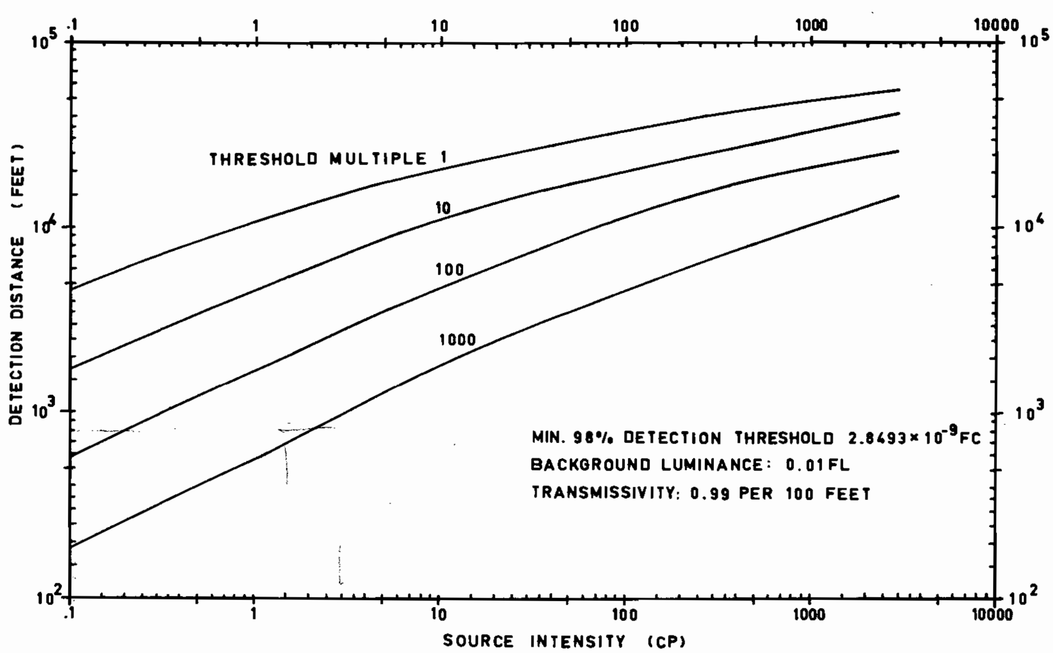


TABLE 1: Proposed Minimum Design Candlepower Requirements for Bicycle Taillamps (Improved SAE J585e Standard)

Test Points, degrees: Vertical	Test Points, degrees: Horizontal	Candlepower (for One Section Taillamp)
10U	10L	1.2
and	V	1.6
10D	10R	1.2
	20L	1.2
	10L	1.6
5U	5L	2.0
and	V	2.0
5D	5R	2.0
	10R	1.6
	20R	1.2
	20L	1.6
	10L	2.0
	5L	2.0
H	V	2.0
	5R	2.0
	10R	2.0
	20R	1.6

Note: The SAE J585e standard does also specify that the signal from lamps on both sides of the vehicle shall be visible through a horizontal angle from 45 degrees to the right. To be considered visible, the lamp must provide an unobstructed projected illuminated area of the outer lens surface, excluding reflex, at least 2 square inches 912.5cm^2) in extent, measured at 45 degrees to the longitutinal axis of the vehicle.

With regard to the proposed bicycle taillamp standard the above specification of the SAE J585e standard ought to be stated in a different way and as follows: 1) the maximum horizontal angle of 45° ought to be at least doubled, 2) at additional selected test points such as ± 45° and ± 90° horizontal and -10°, 0° and 10° vertical candlepower values ought to be specified (in the range from 0.1 to 0.3cp), and 3) as recommended in a previous section for the reflectors, all candlepower values could be specified as continuous curves (rather than for single points) for selected horizontal and/or vertical angles.

angle for left headlamp and for right headlamp, 2) entrance angle for headlamp and for right headlamp, 3) candlepower value for left headlamp and for right headlamp, 4) illumination at reflector due to left headlamp and due to right headlamp, 5) cp-value at reflector due to left headlamp and due to right headlamp, 6) total illumination at the eyes of the driver, and 7) number of times illumination at the driver's eyes is above the minimum 98% threshold value.

The model does not use any geometric simplifications or approximations and can handle one or more headlamps. Any headlamp type and reflector material (prismatic or beaded reflectors) can be investigated, provided that adequate information about the beam pattern (isocandela distribution and/or cp-matrix) and the reflector material (cp/fc/area or cp/fc curve as a function of observation angle for selected entrance angles and/or cp/fc/area or cp/fc matrix) is available. Additional information about the model, beam patterns, reflector matrices and selected analyzed nighttime detection situations can be found in Volume I of the O.U. report.

Table 2 illustrates one type of program output. Reflector performance is given as a function of the distance ahead of the vehicle, in this case a pickup truck with two type 6014 low beam headlamps. The reflector ahead of the vehicle is positioned along a curve section with a radius of 1438.15 feet with the reflector optical axis tangential to the arc. The distance ahead of the vehicle is defined as the shortest distance between the front of the vehicle (center of car between the two headlamps) and the position of the reflector. The selected measure of reflector performance is the number expressing how many times the illumination due to the reflector at the eyes of a driver is above the minimum 98% laboratory detection threshold level, for a representative background luminance of 0.001fL. The last column in Table 2 shows that the threshold multiples decrease in an exponential fashion as the distance ahead of the vehicle increases. Table 2 also illustrates that an observation angle of 0.2° or smaller is reached only at distances above 800 feet (LHL 820 feet).

Table 2 illustrates clearly that reflectors must perform well not only at an observation angle of 0.2° but also at somewhat larger observation angles, for instance, up to 0.8°. It is hoped that future prismatic reflectors will be designed so that some of the present high optical performance within the observation angle range from 0° to 0.2 is "shifted" into the observation angle range from 0.2° to 0.8°. While this would improve performance in that range, increased reflector area and improved reflector quality will probably produce the major performance improvements.

It should be noted that the observation angles used in Table 2 are relatively large, because the vehicle assumed is a pickup truck rather than a car. For a car, using a 3.75 feet eye height, an observation angle for the left headlamp (LHL) of 0.2° or less is obtained for distances above 460 feet. The larger observation angles obtained for a pickup truck are due to the longer vertical distance between the eyes and the headlamp (34.5" for pickup vs. 19.5" for car). It should also be noted that the reflector performance in left curves is worse than in right curves and on straight roads when driving with low beams, since the low beams are slightly aimed down and to the right (to reduce glare to the oncoming motorist). For example the 6014 low beam pattern used to compute the results has its "hottest point" (26015cp) 2.0° down and 2.5° to the right.

The table also shows that the cp-values for the left and right low beam headlamps for any distance ahead in the left curve are rather modest, between one and two orders of magnitude smaller when compared with the "hottest point" (26015cp). One can observe too that the entrance angles for the left and right headlamps, after an initial dip between 70 to 100 feet, increase in a linear fashion with increasing distance (these entrance angles would get smaller and smaller exponentially with increasing distance for a straight road). While the entrance angles are sensitive to horizontal curvature, the observation angles show only relative small changes and are not that sensitive to horizontal curvature. For example, for a straight road at 70 feet, the entrance angles for LHL and RHL are both 2.06° (3.45° and 0.69° for 1438') and the observation angles for LHL and RHL are 2.45°

TABLE 2: Reflector Performance as a Function of Distance Ahead of the Vehicle

CURVATURE OF ROAD TO LEFT: 1438.15 FT. BACKGROUND LUMINANCE: 0.001 FL. TRANSMISSIVITY: 0.99 PER 100 FT.
REFLECTOR TYPE & COLOR : WIDE ANGLE RED RE-280 REFLECTOR, 6.16 SQUARE INCHES AREA, MIN. THRESHOLD 2.3XE-09 FC.
BEAM PATTERN : TWO 6014 LOW BEAMS REFLECTOR HEIGHT FROM GROUND LEVEL : 29 IN. EPSILON :0.
HEIGHT OF HEADLAMPS FROM GROUND LEVEL :2.125 FT. DISTANCE BETWEEN HEADLAMPS :5.0 FT. EYE HEIGHT :5.0 FT.
DISTANCE BETWEEN EYE & CAR AXIS :1.25 FT. DISTANCE BETWEEN EYE AND FRONT OF CAR :6.0 FT., PICKUP TRUCK.
AIM ANGLE OF IN-CURVE HEADLAMP IN HORIZONTAL PLANE :0. AIM ANGLE OF OUT-CURVE HEADLAMP IN HORIZONTAL PLANE :0.
AIM ANGLE OF IN-CURVE HEADLAMP IN VERTICAL PLANE :0. AIM ANGLE OF OUT-CURVE HEADLAMP IN VERTICAL PLANE : 0.

DIST ANCE FEET	OBS.ANGLE LHL	OBS.ANGLE RHL	ENTR.ANGLE LHL	ENTR.ANGLE RHL	CANDLE POWER LHL	CANDLE POWER RHL	ILLUM. AT REFL LHL FC	ILLUM. AT REFL RHL FC	REFL. CP LHL	REFL. CP RHL	ILLUM. AT EYE FC	NO: OF TIMES THRESHOLD
40	4.10	6.36	4.40	2.81	2819.64	539.64	1.751305	0.334017	0.258869	0.041688	0.1409E-03	61274.41
70	2.40	3.79	3.45	0.69	2499.02	642.97	0.506656	0.129903	0.083186	0.016001	0.1703E-04	7404.62
100	1.69	2.71	3.43	0.59	1249.26	662.72	0.123814	0.065453	0.023574	0.008914	0.2861E-05	1243.96
130	1.30	2.12	3.69	1.50	991.63	650.39	0.057994	0.037904	0.014119	0.005939	0.1070E-05	465.30
160	1.06	1.75	4.08	2.30	798.40	627.04	0.030736	0.024055	0.010921	0.004297	0.5435E-06	236.30
190	0.89	1.49	4.54	3.04	715.44	609.80	0.019474	0.016541	0.010785	0.003333	0.3606E-06	156.78
220	0.76	1.31	5.04	3.74	660.02	589.23	0.013360	0.011885	0.010736	0.002889	0.2610E-06	113.47
250	0.67	1.16	5.56	4.42	620.54	570.26	0.009698	0.008881	0.010886	0.002649	0.2015E-06	87.59
280	0.59	1.05	6.10	5.08	590.84	549.92	0.007339	0.006807	0.010658	0.002533	0.1568E-06	68.19
310	0.54	0.96	6.65	5.73	566.16	526.84	0.005720	0.005304	0.010967	0.002533	0.1311E-06	57.00
340	0.49	0.88	7.21	6.37	539.97	522.34	0.004522	0.004359	0.010769	0.002576	0.1078E-06	46.86
370	0.45	0.82	7.77	7.01	513.06	551.65	0.003617	0.003875	0.010614	0.002716	0.9089E-07	39.52
400	0.41	0.76	8.35	7.64	545.61	512.17	0.003281	0.003069	0.011196	0.002603	0.8045E-07	34.98
430	0.38	0.72	8.93	8.27	524.70	426.61	0.002722	0.002206	0.011097	0.002207	0.6706E-07	29.16
460	0.36	0.68	9.51	8.90	431.74	433.64	0.001952	0.001953	0.009363	0.002274	0.5120E-07	22.26
490	0.33	0.64	10.10	9.52	434.36	440.36	0.001725	0.001743	0.008811	0.002319	0.4309E-07	18.74
520	0.31	0.61	10.69	10.14	435.43	375.78	0.001531	0.001317	0.008727	0.001585	0.3539E-07	15.39
550	0.30	0.58	11.28	10.77	367.00	349.31	0.001150	0.001091	0.007279	0.001457	0.2676E-07	11.63
580	0.28	0.56	11.88	11.39	352.66	366.37	0.000991	0.001026	0.007228	0.001500	0.2399E-07	10.43
610	0.27	0.53	12.47	12.01	369.07	335.87	0.000935	0.000847	0.007647	0.001337	0.2228E-07	9.69
640	0.26	0.51	13.07	12.64	324.11	299.34	0.000743	0.000684	0.006692	0.001150	0.1763E-07	7.67
670	0.24	0.49	13.68	13.26	303.08	311.14	0.000632	0.000647	0.006174	0.001195	0.1509E-07	6.56
700	0.23	0.48	14.28	13.89	315.33	302.03	0.000601	0.000573	0.006293	0.001226	0.1407E-07	6.12
730	0.23	0.46	14.89	14.51	289.59	268.17	0.000506	0.000467	0.005634	0.001125	0.1161E-07	5.05
760	0.22	0.45	15.50	15.14	OUT OF RANGE OF THE CP TABLE							
790	0.21	0.43	16.12	15.77	OUT OF RANGE OF THE CP TABLE							
820	0.20	0.42	16.73	16.40	OUT OF RANGE OF THE CP TABLE							
850	0.20	0.41	17.35	17.03	OUT OF RANGE OF THE CP TABLE							
880	0.19	0.40	17.97	17.66	OUT OF RANGE OF THE CP TABLE							
910	0.19	0.39	18.59	18.29	OUT OF RANGE OF THE CP TABLE							
940	0.18	0.38	19.22	18.93	OUT OF RANGE OF THE CP TABLE							

and 3.70°, (2.40° and 3.79° for 1438'), 340 feet, the entrance angles for LHL and RHL are both 0.42° (7.21° and 6.37° for 1438') and the observation angles for LHL and RHL are 0.52° and 0.79° (0.49° and 0.88° for 1438').

The 6014 low beam pattern used to obtain the results in Tables 2 and 3 is based upon actual laboratory measurements of 20 GE 6014 low beam headlamps (each cp-matrix value represents the average of 20 measurements). A comparison between the isocandela distribution for the averaged actual data and the isocandela distribution given in GE drawing 381.B.1478 indicates that the averaged actual pattern is shifted 0.5° further down than GE pattern (i.e. "hottest point" in averaged actual data is 2° down while "hottest point" for GE data is only 1.5° down). With the exception of the 0.5° vertical shift of the whole beam pattern, the isocandela curves for the averaged actual data and the GE data compare reasonably well with each other.

The reflector values used to represent the optical performance of the red "cat eye" RR-280 wide angle reflector will be briefly described below. For an entrance angle of 0° and observation angles of 0.1°, 0.2°, 0.3°, 0.5°, 0.8° and 1.5° the cp/fc values (actually measured) are: 19.0, 9.3, 5.4, 1.9, 0.61 and 0.18. For an entrance angle of 20° and observation angles of 0.1°, 0.2°, 0.3°, 0.5°, 0.8° and 1.5° the cp/fc values (actually measured) are: 10.4, 6.15, 3.70, 1.35, 0.43 and 0.08. The reflector values used to represent the optical performance of the amber RR-0218 pedal reflectors (see Table 3) will be briefly described below. For an entrance angle of 0° and observation angles of 0.1°, 0.2°, 0.3°, 0.5°, 0.8° and 1.5°, the cp/fc values (actually measured) are: 8.3, 7.6, 6.4, 4.0, 2.4 and 1.07.

For an entrance angle of 20° and observation angles of 0.1°, 0.2°, 0.3°, 0.5°, 0.8° and 1.5°, the measured cp/fc values are: 3.9, 3.4, 2.8, 1.5, 0.57 and 0.185. These values are based on the 1.2 square inch reflector area of one pedal. The computer model assumes two static pedal reflectors of about 2 square inch area.

Table 3 presents summary results for selected nighttime detection situations. Four distances ahead of the vehicle (70, 160, 340, 700 feet) were chosen to provide insight into the nature of the nighttime detection problem. In all instances, the points are taken from smooth monotonically decreasing curves, thus making interpolation within the given range from 70 to 700 feet feasible. All results given in Tables 2 and 3 are based upon headlamps operating at 100% efficiency and vehicle windshields transmitting 100% of the light. The minimum 98% laboratory detection threshold level is assumed to be 2.3×10^{-9} fc (for a background luminance level of approximately 0.001fL). If one is interested in obtaining multiples of threshold for a 0.01fL background luminance level (2.8493×10^{-9}fc) one might simply multiply the multiples of threshold given in Table 2 and 3 by 0.8072. Table 3 also contains information about the performance of a red taillamp operating at the SAE minimum specified cp-values (see SAE J585e using a special model.)

Table 3 shows clearly the increased nighttime danger of driving a pickup truck, of driving through sharp left-curved roads and the extreme danger of driving with only the right low beam headlamp working. The table further indicates the relative superiority of amber pedal reflectors and the superiority of a red taillamp operating at the SAE J585e minimum specified cp-values. The superiority of the

TABLE 3: Summary Results From Computer Model for Selected Analyzed Nighttime Detection Situations-Multiples of Threshold[1]

Situation Analyzed	Selected Distance Ahead of Car in Feet			
	70	160	340	700
Straight Road, Wide Angle Red RR-280 Refl., 29" Above Ground, 6014 LB's	[2] 11256.17 [3] 13259.70	741.96 1879.92	162.24 375.30	36.76 60.10
L'Curved Road, 1438' Radius, W.A. Red RR-280 Refl., 29", 6014 LB's	[2] 7404.62 [3] 8749.91	236.30 601.43	46.86 117.02	6.12 13.22
L'Curved Road, 700' Radius, W.A. Red RR-280 Refl., 29", Pickup, 6014 LB's	3941.50	203.06	21.08	-
L'Curved Road, 350' Radius, W.A. Red RR-280 Refl., 29", Pickup, 6014 LB's	2976.62	63.12	-	-
R'Curved Road, 1438' Radius, W.A. Red RR-280 Refl., 29", Pickup, 6014 LB's	10495.20	1255.54	199.86	11.56
L'Curved Road, 1438, Radius, W.A. Red RR-280 Refl., 29", Pickup, 6014 HB's	81068.88	4728.77	368.26	-
Straight Road, W.A. Red RR-280 Refl., 29", Pickup, 6014 HB's	87587.75	6921.25	1803.31	426.75
L'Curved Road, 1438' Radius, W.A. Red RR-280 Refl., 29", Pickup, Only Right 6014 LB Working	1194.51	66.72	9.04	1.00
Straight Road, W.A. Red RR-280 Refl., 29", Pickup, Only Right 6014 LB Working	1573.48	123.02	28.31	9.88
Straight Road, W.A. Red RR-280 Refl., 29", GE 4000 LB's according to GE 381.B.1479	[2] 9550.49 [3] 11236.04	516.83 1292.54	122.80 283.49	25.24 41.27
L'Curved Road, 1438' Radius, W.A. Red RR-280 Refl., 29", GE 4000 LB's	[2] 5419.07 [3] 6359.03	239.99 601.78	58.23 145.01	5.12 11.05
Straight Road, RR-0218 Amber Pedal Refl., 17.5", Pickup, 6014 LB's	129141.44	7112.90	533.93	46.28
L'Curved Road, 1438' Radius, RR-0218 Amber Pedal Refl., 17.5", Pickup, 6014 LB's	87217.50	2040.72	144.81	9.87
Straight Road, RR-0218 Amber Pedal Refl., 4.5", 6014 LB's	[2] 271630.44 [3] 458347.88	11398.05 18299.14	717.64 1017.87	53.19 60.13
L'Curved Road, 1438' Radius, RR-0218 Amber Pedal Refl., 4.5", 6014 LB's	[2] 198041.56 [3] 343332.88	3014.49 4673.47	177.80 245.38	10.57 11.75
Straight Road, Red Taillamp, SAE min. Specs., 29", Pickup	142935.56	30844.91	7061.32	1644.14
L'Curved Road, 1438' Radius, Red Taillamp, SAE Min. Specs., 29", Pickup	138607.69	29945.15	5207.47	517.92
L'Curved Road, Red Taillamp, SAE Min. Specs., 29", Pickup	[4] 134036.56 [5] 101421.50	22067.48 8042.45	2203.59 1133.06	260.45 -

[1] 0.001fL Background Luminance, 2.3×10^{-9} fc Minimum Threshold, Transmissivity .99per 100 Feet

[2] Pickup, Eye Height 5', Headlamps 2.125' above Ground and 5' apart

[3] Car, Eye Height 3.75', Headlamps 2.125' above Ground and 5' apart

[4] Radius 700'

[5] Radius 350'

red taillamp over the reflectors would be even more pronounced if the cp-values proposed in Table 3 were used in the calculations, especially for left and right curve situations.

Summary Results of Nighttime Detection Field Studies

The objective of this section is to present briefly a typical field study and a few selected results from the O.U. detection studies. The field study selected deals with the question of "massed" vs. "distributed" reflectorization. The objective was to test, for both foveal and peripheral detection, whether Cook's statement (p. 69, Reference 5) that massed reflectors were better than separate small patches was true.

A. Reflectors and Arrangement

Two pairs of photometrically matched amber bicycle pedal reflectors (#1750, Signal Products Division) were used. For an entrance angle of 0^o and observation angles of 0.1^o, 0.2^o, 0.3^o, 0.5^o, 0.8^o and 1.5^o the typical cp/fc values (actually measured) of one #1750 pedal reflector are: 10.35, 9.75, 6.40, 3.20, 1.99 and 0.41. For an entrance angle of 20^o and observation angles of 0.1^o, 0.2^o, 0.3^o, 0.5^o, 0.8^o and 1.5^o the typical cp/fc values (actually measured) of one #1750 pedal reflector are: 4.40, 4.40, 3.80, 1.75, 0.55 and 0.285. For the "massed" experimental condition, the two pedal reflectors were fastened close together (longer side parallel to ground, one above the other) on a special bicycle fixture (flat black) extending beyond the front wheel of the test bicycle. The center of the two pedal reflectors coincided with the vertical axis of the bicycle and was 11 inches above the ground. For the "distributed" experimental condition two other pedal reflectors were fastened (longer side parallel to ground) at the ends of a horizontal bar of the special bicycle fixture, each reflector being 20 inches away from the vertical bicycle axis (total horizontal distance between the two pedal reflectors 40", height above ground 11"). No other reflectors were visible on the test bicycle when viewed from the front.

B. Test Car

The test car was a 1976 Ford LTD with type 4000 low beams. Photometric measurements of the beam patterns and the background were taken with a Pritchard photometer. The dry concrete surface straight ahead of the car at 165 feet had luminance values from 0.015 to 0.029fL, at 435 feet from 0.012 to 0.015fL, at 585 feet from 0.011 to 0.016fL, and the sky close to the horizon from 0.005 to 0.018fL depending upon car heading angle, moon size and position and extent of cloud cover.

C. Test Site

The test site was unused 75 feet wide concrete airport runway located at the edge of a small city and a small shopping mall. A two-lane state highway with moderate traffic is located parallel (about 250 feet away) to the runway. A number of luminaires and a few lighted advertising signs were in the field of view of the subjects (mainly left periphery along highway).

D. Subjects

Two groups of five subjects each were used. The five subjects in the first group were tested only with the "massed" reflectors, while the five subjects in the second group were tested only with "distributed" reflectors. All subjects appeared to be well motivated, adequately dark adapted and highly alerted. They had nothing to do but detect the approaching bicycle with the reflectors (i.e., low visual workload and low information processing load). All subjects had valid driver licences and many were students.

E. Procedure

The bicycle approached the stationary test car (with about 10mph) from the dark along one of three paths parallel to the runway axis. The front center of the test car was placed above the center line of the runway. Looking forward from the car, path 1 was 12.5 feet to the left of center. Path 2 was 6.25 feet to the right of center (fairly representative lateral position for a bicycle ahead of a car on a straight road) and path 3 was 25 feet to the right of center. Paths 2 and 3 were included to create some uncertainty with regard to detection location and to simulate curve situations.

The car heading angles were -10^o (car axis aimed 10^o to the left of the runway center line), 0^o (car axis above runway axis), 10^o, 20^o and 40^o to the right of the runway axis. The different car heading angles were necessary to investigate the peripheral detection capabilities (subjects were instructed to look in the direction of the car axis). The order of presentation for car heading angles was random. All observations for a given car heading angle were made consecutively since it took some time and effort to correctly place the test car. Thus, for each car heading angle, subjects made 9 consecutive observations since there were 3 paths and the bicycle approached the test car 3 times on each path. The order of presentation for the three paths was random, subject to the requirement that each path had to have 3 approaches. Each subject had a total of 45 presentations (5 car heading angles, 3 paths, 3 replications). The subjects, who sat comfortably in the stationary test car with low beams on and the engine in idle, were instructed to switch on the high beams for a moment as soon as they detect the reflectors and/or the approaching bicycle (the bicycle rider wore dark clothing and dark shoes).

A simple manual method was used to mark and record the detection distances. Four experimenters were used to conduct the detection experiments (one at test car, one on test bicycle, two to measure and record detection distances).

F. Results

Table 4 provides the analyzed detection distance statistics for the "massed" and the "distributed" reflector conditions. In general, the detection distance statistics for the "massed" condition are considerably shorter than the corresponding values for the "distributed" condition, especially for the peripheral angles.

These detection distance statistics have been further used as input into a FORTRAN program containing the appropriate beam pattern, reflector matrix, test car and driver dimensions, path geometry, representative background luminance and representative transmissivity value. This program calculates the visual detection angle and the threshold multiples, and produces the output for Figures 4 through 8. These figures illustrate the typical relationships between the threshold multiples (plotted logarithmically) and peripheral visual detection angles for the "massed" and the "distributed" conditions.

The threshold multiples for the "massed" and for the "distributed" condition based upon the minimum, $\bar{x}$-s, $\bar{x}$, $\bar{x}$+s and the maximum detection distance statistics, are shown in Figures 4 and 5. The large range in threshold multiples between the minimum (most relevant from a safety point of view) red taillamp over the reflectors would be even more pronounced if the cp-values proposed in Table 3 were used in the calculations, especially for left and right curve situations.

Summary Results of Nighttime Detection Field Studies

The objective of this section is to present briefly a typical field study and a few selected results from the O.U. detection studies. The field study selected deals with the question of "massed" vs. "distributed" reflectorization. The objective was to test, for both foveal and peripheral detection, whether Cook's statement (p. 69, Reference 5) that massed reflectors were better than separate small patches was true.

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The threshold multiples for the "massed" and for the "distributed" condition based upon the minimum, $\bar{x}$-s, $\bar{x}$, $\bar{x}$+s and the maximum detection distance statistics, are shown in Figures 4 and 5. The large range in threshold multiples between the minimum (most relevant from a safety point of view)

TABLE 4: Detection Distances for Two "Massed" vs. Two "Distributed" Bicycle Pedal Reflectors[1]

All Distances in Feet

Car[2] Heading Angle	Minimum	$\bar{x}$-s	Average $\bar{x}$	$\bar{x}$+s	Maximum	Standard Deviation s	No. of Observ.
Path 1 "Massed"							
-10°	330.0	407.47	466.73	525.99	565.5	59.26	15
0°	352.0	560.89	708.40	855.91	871.0	147.51	15
10°	111.0	123.77	161.06	198.35	234.0	37.29	15
20°	0	(-18.99)	17.33	53.65	137.0	36.32	15
40°	0	0	0	0	0	0	15
Path 2 "Massed"							
-10°	165.0	251.83	357.66	463.49	599.0	105.83	15
0°	297.0	560.57	731.40	902.23	976.0	170.83	15
10°	232.0	245.60	264.33	283.06	290.0	18.73	15
20°	38.0	57.60	104.00	150.40	229.0	46.40	15
40°	20.0	22.21	36.00	49.79	70.0	13.79	15
Path 3 "Massed"							
-10°	154.0	176.65	266.46	356.27	437.0	89.81	15
0°	470.0	617.26	763.60	909.94	920.0	146.34	15
10°	238.0	291.68	326.73	361.78	379.0	35.05	15
20°	119.0	144.36	176.46	208.56	229.0	32.10	15
40°	34.0	47.72	60.73	73.74	81.0	13.01	15
Path 1 "Distributed"[3]							
-10°	480.0	542.24	703.47	864.70	1010.0	161.23	15
0°	320.1	422.01	655.98	889.95	1076.3	233.97	15
10°	0	184.03	332.50	480.97	505.1	148.47	15
20°	0	(-0.19)	167.82	335.83	489.8	168.01	15
40°	0	(-8.30)	15.25	38.80	61.9	23.55	15
Path 2 "Distributed"							
-10°	364.67	413.71	609.99	806.27	1006.3	196.28	15
0°	491.50	553.94	801.91	1049.88	1145.2	247.97	15
10°	180.00	289.83	426.33	562.83	637.3	136.50	15
20°	105.00	132.67	262.33	391.99	547.4	129.66	15
40°	25.00	52.87	105.67	158.47	198.6	52.80	15
Path 3 "Distributed"							
-10°	234.58	279.43	463.15	646.87	787.1	183.72	15
0°	525.00	589.71	818.93	1048.15	1241.3	229.22	15
10°	264.33	367.54	513.54	659.54	694.4	146.00	15
20°	138.42	220.39	337.51	454.63	512.5	117.12	15
40°	55.92	49.43	115.65	181.87	262.8	66.22	15

[1]Reflectors 11 inches Above Ground

[2]1976 Ford LTD With Type 4000 Low Beams

[3]Reflectors 40 inches Horizontally Apart

FIGURE 4: Multiples of Thresholds for Two "Massed" Bicycle Pedal Reflectors Based Upon Selected Detection Distance Statistics for Path 2 as a Function of the Peripheral Visual Detection Angle

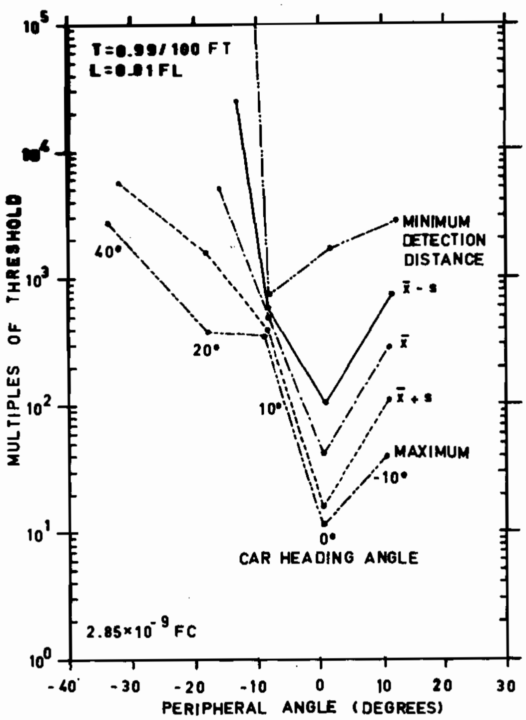
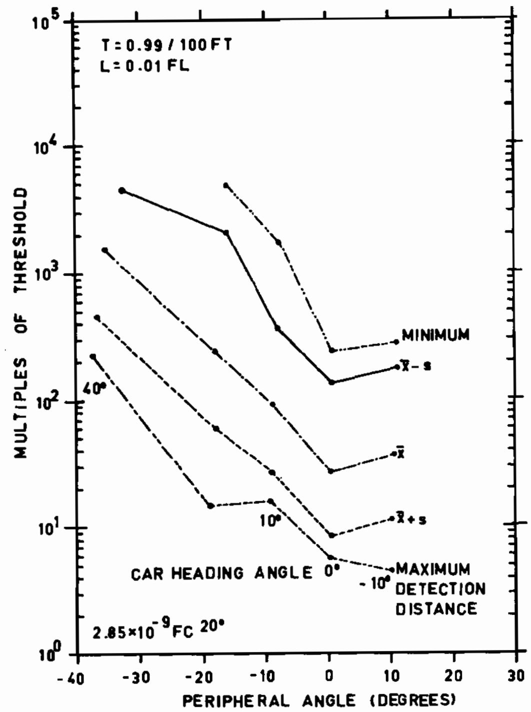


FIGURE 5: Multiples of Thresholds for Two "Distributed" Bicycle Pedal Reflectors Based Upon Selected Detection Distance Statistics for Path 2 as a Function of the Peripheral Visual Detection Angle



and the maximum detection distance statistics is clear. The U-shape of the threshold multiples as a function of the peripheral visual angle is clearly visible. Figures 4 and 5 also show that the range of the threshold multiples extends from less than 10 to more than 10^5.

The curves in Figure 4 ("massed") are somewhat steeper than in Figure 5 ("distributed") indicating that, especially in the periphery, two "distributed" reflectors of equal total area are more easily detected than two similar "massed" reflectors. Figure 6, which shows the threshold multiple curves for the average detection distance statistics for "massed" vs. "distributed" reflector pairs, illustrates this phenomenon even more distinctively.

Figures 7 and 8 illustrate the threshold multiples for the average detection distance statistics for paths 1, 2 and 3 for "massed" vs. "distributed" reflectors. The threshold multiples differ little between paths 1, 2 and 3. Again, the threshold multiples curves for paths 1, 2, 3 are steeper for the "massed" reflectors than for the "distributed" reflectors. At the -10^{o} peripheral angle (representative of driving into a left curve), the threshold multiples for the "massed" reflectors (based upon $\bar{x}$, average for paths 1, 2 and 3) are about 700 and the corresponding threshold multiples for the "distributed" reflectors are about 100 or seven times smaller.

G. Discussion of Results

The "massed" vs. "distributed" reflector results demonstrate that in the periphery two distributed visual stimuli are detected earlier than a single visual stimulus of equal total strength. In fact, the "distributed" reflectors are even slightly better for the case of foveal or near foveal detection when compared with the "massed" reflectors. The advantage of the "distributed" reflectors over

FIGURE 6: Multiples of Threshold Based Upon the Average Detection Distances for Path 2 for Two "Massed" and Two "Distributed" Bicycle Pedal Reflectors as a Function of the Peripheral Visual Detection Angle

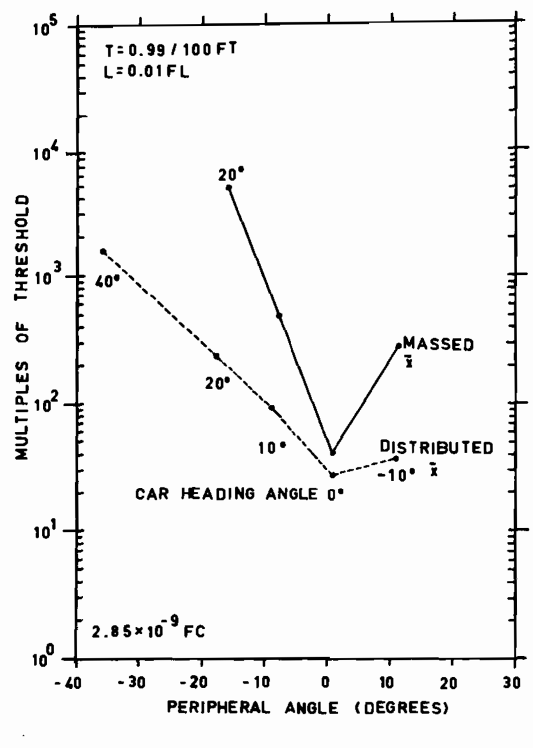


FIGURE 7: Multiples of Threshold Based Upon the Average Detection Distances for Two "Massed" Bicycle Pedal Reflectors for Paths 1, 2 and 3 as a Function of the Peripheral Visual Detection Angle

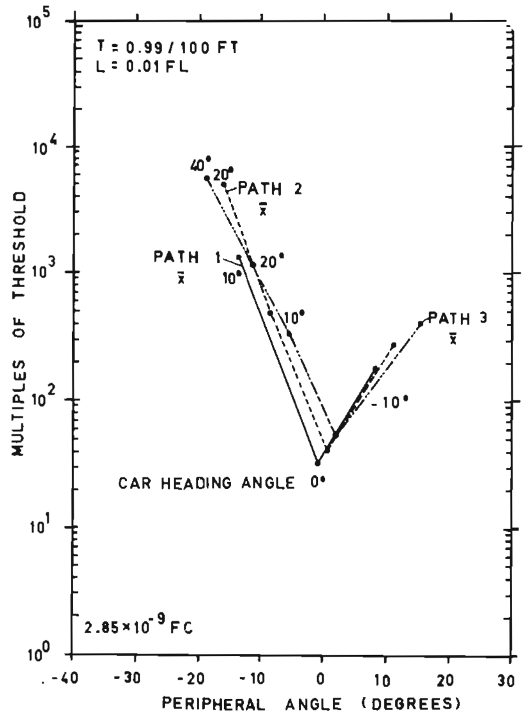
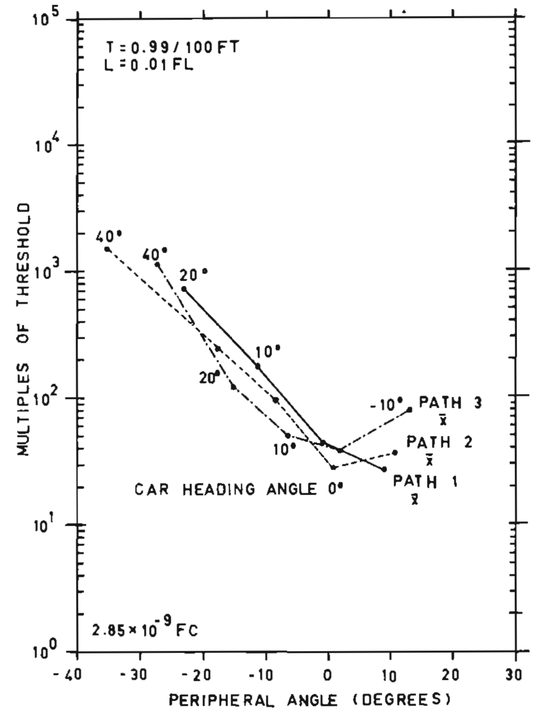


FIGURE 8: Multiples of Threshold Based Upon the Average Detection Distances for Two "Distributed" Bicycle Pedal Reflectors for Paths 1, 2 and 3 as a Function of the Peripheral Visual Detection Angle



the "massed" reflectors gets larger with increasing peripheral angle. This study might serve as a good example to demonstrate that foveal visual performance should not be "extrapolated" to include peripheral visual performance without having appropriate research results to justify such an extrapolation.

A case has been made in this paper for the importance of peripheral visual detection in the nighttime bicycle detection problem. Based upon the findings of this field study, a reflector arrangement consisting of two horizontally separated high performance rear reflectors in combination with an improved taillight and improved pedal reflectors would seem highly promising and beneficial with regard to the rear conspicuity (detection) problem of bicycles at night.

More research is needed to get a better understanding of the human visual detection mechanisms involved in foveal vs. peripheral detection at night. Also more research is needed to examine the detection distance statistics and threshold multiples for more than two reflectors, for various reflector arrangements and separation distances, for various reflector or visual stimulus intensity levels and to determine appropriate correction factors to be used when performing engineering illumination or visibility calculations involving peripheral visual detection.

CONCLUSIONS

The information presented here suggests that there exists an adequate level of knowledge, adequate analytical and engineering design methods and an adequate state of the art manufacturing technology to effect immediate major improvements with regard to the bicycle conspicuity problem. While a number of suggestions to improve the night conspicuity of bicycles have been made here, there is still no doubt that the bicycle conspicuity problem is far from being solved.

Future conspicuity research must not be limited to the detection phase, but must include the recognition phase, the decision phase and the driver control action phase. The use of a driver eye movement and recording system in an instrumented car would appear to aid any future conspicuity field experiments. The effectiveness of reflective clothing or reflective stripes, bands or patches (contour or silhouette striping) for bicyclists must be determined in the real world.

All new reflector and lighting designs must be examined in terms of a cost-benefit framework. While this author believes that every traffic participant (including the bicyclist) is entitled to some minimum level of safety benefits regardless of the magnitude of cost-benefit ratios, the cost-benefit ratios could be helpful when comparing various design alternatives on a relative basis.

The day conspicuity problem must also be further researched and any solutions must be integrated into the design approach to solve the night conspicuity problem. It is hoped that bicycle designers will use an appropriate systems design methodology that considers from the start the conspicuity and visual safety requirements on an equal basis with the aesthetic, structural and dynamic force requirements. With such a systems design methodology, bicycles may recieve frame changes and additional brackets for more protective and reliable reflector, generator and lamp placements.

Last but not least, inexpensive micro-electronic devices could contribute to solving the nighttime and/or daytime bicycle conspicuity problem. Small scale scanning laser systems located close to the drivers eyes, ultrasonic or infrared object detector tors (now used in cameras and which could be used both for cars and/or bicycles), new high efficiency sealed beam lamps with micro electronic power regulation equipment (generator and/or battery) for bicycle lighting, new high efficiency bicycle generators built with new improved magnetic materials and combined with micro-electronic controls, could be used. Inexpensive, more efficient, more compact and more reliable solar cells and sturdy light weight solar panels combined with micro electronic controls to collect energy from light could also be used to power bicycle lamps.

REFERENCES

1. Zwahlen, H.T. Ohio University Human Factors Engineering and Design Laboratory Report 80-1, Detection of Reflectorized Objects and Point Light Source Signals, Volumes I through VI, July 1980.
2. IES Lighting Handbook, Fifth Edition, 1972, Illumination Engineering Society, 345 East 47th Street, New York, N.Y. 10017.
3. Middleton, W.E.K. Vision Through the Atmosphere, University of Toronto Press, 1952.
4. Visibility Issue of the Applied Optics Journal, May 1964, Vol. 3, No. 5, pp. 549-598.
5. Cook, K.G. Reflector Analysis, Final Report, Contract No. FH-11-6950, NTIS DOT/HS-800302, PB195176, August 1969.
6. Burg, A. and Beers, J. Reflectorization for Nighttime Conspicuity of Bicycles and Motorcycles, Journal of Safety Research, Summer 1978, Vol. 10, No. 2, pp. 69-77.
7. McGinnis, R.G. Reflectorization of Railroad Rolling Stock, Transportation Research Board, Transportation Research Record 737, 1979, pp. 31-43.
8. Stoovelaar, F. and Groôt, R.E. A Visible Bicycle, Report of a study conducted under the auspices of the Royal Dutch Touring Club ANWB, January 1976.
9. SAE Handbook Supplement HS 34, 1979 Edition, Lighting Equipment and Photometric Tests. Published by Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA 15096.
10. Consumer Products Safety Commission, Bicycles, Republication of Safety Standard, Federal Register, Part IV, Vol. 41, No. 19, Wednesday, January 28, 1976, pp. 4144-4154.
11. McGee, H.W. et.al. Decision Sight Distance for Highway Design and Traffic Control Requirements, Final Report No. FHWA-RD-78-78, February 1979. Available through NTIS.

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