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REVIEW OF THE LITERATURE AND PROGRAMS FOR PEDESTRIAN AND BICYCLIST CONSPICUITY

Allen Hale
Peter Zeidler

Dunlap and Associates East, Inc.
17 Washington Street
Norwalk, Connecticut 06854

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16. Abstract

This report reviews literature bearing upon the problem of pedestrian and bicylist conspicuity, discusses the activities and accomplishments of various programs conducted to enhance the conspicuity of pedestrians and bicyclists.

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FOREWORD

This technical report is a companion product to the final report for Contract No. DTNH22-80-C-07052 between the National Highway Traffic Safety Administration and Dunlap and Associates East, Inc. The final report, entitled "Conspicuity for Pedestrians and Bicyclists: Definition of the Problem, Development and Test of Countermeasures," culminated an effort begun in September 1980 and ended in November 1983. The overall contract objectives were to analyze existing pedestrian and bicyclist accident data bases to estimate the extent and nature of the problem attributable to a lack of conspicuity. Incorporating a review of conspicuity-based literature and safety programs, this information was to be utilized to identify conspicuity treatments for pedestrians and bicyclists which could be rigorously tested in the culminating field experiment. The final report concentrates on the field test portion of this study, although the entire study chronology and intermediate results relevant to the design or conduct of the field test are presented.

In this volume the results of the world-wide search for conspicuity-relevant literature are reported along with descriptions of national and foreign programs to enhance pedestrian, bicyclist and motorcyclist conspicuity.

In reviewing this document, the reader should bear in mind that the original date of preparation for this report was August 1981. Also, the level of discussion of this document is addressed to a reader with background in the technical aspects of human vision in the highway setting.

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I. INTRODUCTION

This report undertakes a review of world-wide scientific and technical literature bearing on the subjects of pedestrian, bicyclist and motorcyclist conspicuity. Moreover, an attempt has been made to identify and describe domestic and foreign programs to enhance pedestrian and bicyclist safety.

The principal objectives of this report were to identify and/or organize valid principles which support or detract from conspicuity enhancement and present the results of specific attempts to enhance the daytime and nighttime conspicuity of pedestrians, bicyclists and motorcyclists. The derived benefits of meeting these objectives were seen as providing a behaviorally sound basis for the selection of candidate conspicuity-enhancing treatments for testing in the field experiment, and the development of a suitable and valid experimental design for the field test.

The report is organized into three major sections as follows:

I. Introduction
II. Literature Review
III. Conspicuity-Enhancing Programs

II. LITERATURE REVIEW

A. Introduction

For a research area such as pedestrian and bicyclist conspicuity, the potential sources of relevant literature and research are legion. It is a multi-disciplinary area involving highway safety as well as the general psychological literature. Consequently, the highway safety literature data bases, namely National Technical Information Service (NTIS) and Transportation Research Information Service (TRIS) have been accessed for any studies dealing with conspicuity or visibility of people and vehicles. Within the general psychological literature embraced by the Psychological Abstracts, studies dealing with visual perception, signal detection, information processing and related subjects were also sought. Beyond this, an ongoing collection of literature in these areas has been conducted by Dunlap and Associates East, Inc., over the recent years, and that file of amassed literature has been incorporated into this review.

While it is not really possible for any search and review of literature in any area so massive as this to be absolutely definitive, the attempt has nevertheless been made to be as representative and comprehensive as possible.

The literature to be reviewed was searched as of June 1981. The scope of search was international, involving direct contact with numerous foreign national safety organizations and safety experts in addition to the computer based searches.

The literature reviewed is organized into basic functional groupings as follows:

- Concepts of Conspicuity
- Basic Driver Visual Capabilities
- Factors Affecting Driver Vision
- Conspicuity-Enhancing Approaches
- Literature Review Summary

B. Concepts of Conspicuity

Attempts to operationally define the concept of conspicuity in the traffic setting have been conducted by several investigators in recent times. From an overall review of this issue it is fair to say that there does not presently exist a generally accepted operational definition of conspicuity in the highway setting. This lack of definition and any coordinated efforts within the highway safety community to develop such a definition have inhibited the development and use of effective materials to enhance the conspicuity of pedestrians and bicyclists.

In an article that assesses the nature and measurement problems surrounding the term "conspicuity," Cole and Jenkins (1980) propose an operational definition of conspicuity: "A conspicuous object is defined as one that will be seen with certainty within a short observation time (i.e., without search) regardless of the location of the object in relation to the line of sight." The definition relies on the probability of seeing the object when observation time is short (approximately 250 ms) and the angle between the direction of the object and the direction of fixation is specified, i.e., the angle of eccentricity. Reaction time and search time are equivalent measures at least for conspicuous targets. However, their use implies the additional criterion of minimum response time, while the end points of reaction/search time scales are uncertain. An alternative measure is conspicuity area: this uses the angle of eccentricity as the scale, such that conspicuity is specified as the eccentricity beyond which the probability of seeing is less than some specified value. The authors recommend this measure for all conspicuity investigations.

In a broad overview of the conspicuity issue, Forbes (1981) first examines a definition of conspicuity and concludes that besides having attention-getting value a conspicuous object on the highway must be readily recognizable so that a driver may make timely and appropriate responses. The author asserts that "...everyone on the highway..." to include vehicle operators, pedestrians and bicyclists have "...a vital need for conspicuity. Conspicuity is needed when driving, walking or just being on the highway or its shoulder" and must be available at all times, i.e., day, twilight and nighttime. Proper lighting and retroreflectorization aid conspicuity at night, while fluorescence enhances conspicuity during daylight/twilight. The basic visual conditions or factors which promote conspicuity, Forbes (1981) contends, are: brightness contrast, color contrast, intermittent stimulation, target area/size and target placement regarding line of sight.

Holmes (1974) has suggested that conspicuity be defined as that stimulus property which has attention-getting value. Forbes (1964) uses the term <u>attention value</u> in his study of the visibility of road traffic signs and distinguishes two components, target value (the extent to which a sign stands out from its background) and priority value (the attributes which determine the order of noticing signs of equal target value). Cole and Brown (1966) offered the term "optimum signal intensity" and defined this as being the intensity that afforded both a high probability that the signal would be seen <u>and</u> quickly responded to by alerted observers.

Engel (1977) views conspicuity as that combination of properties of a visible object in its background by which it attracts attention. His concept is based on the presumption that an inconspicuous object has to be fixated very closely to be noticed and he, therefore, measured conspicuity by determining the angular area surrounding the point of fixation within which an object is noticed (the conspicuity area). Engel (1971) defines conspicuity operationally as "...that combination of properties of a visible object in its background by which it attracts attention via the visual system and is seen as a consequence."

Cole and Jenkins (1978) believe that various approaches to an operational definition of conspicuity can be united by regarding a conspicuous target object as one that will attract attention and will be seen with certainty, within a short observation time (t—minimum) regardless of the location of the object in the visual field (angle of eccentricity from line of fixation). "A conspicuous object then is one that commands attention and requires no search for it to be noticed."

Klassen (1974) addressed the concept of conspicuity in his study of the day and night visibility of public employees on highways. The investigation involved subjects making subjective responses to various retroreflective garment configurations. More specifically, the intent of the study was to determine:

> "...the supra-threshold aspect of conspicuity which is needed to alert a complacent, distracted or inattentive driver to the presence of a person or object in the roadway. Mere detection is not sufficient visibility protection, because the pedestrian is so vulnerable. The level of conspicuity for a roadway target to be easily seen or command attention has been hypothesized to be considerably greater than the minimum or threshold detection values. The present study was concerned only with the variables of brightness and area of retroreflective material in regard to the aforementioned aspects of pedestrian conspicuity."

After detection thresholds were established, subjects were asked to put themselves into a driving situation and to rate each supra threshold target presented in terms of one of three categories:

> "Visible—Can see the target but could miss it in a driving situation. The target is not easily visible and requires at least a slight amount of effort to see it. The existing visual distractions, pavement surface, lane lines, etc., might cause a driver to miss seeing the target at 550 feet in a driving situation.
>
> Easily Visible—Can see the target easily despite existing visual distractions if looking right at it but might miss it if looking elsewhere on the roadway. It does not require concentrated effort to see it. It is comfortably visible and not glaring.
>
> Attention Getting—Not only easily visible but bright enough to attract your attention even if you were not looking directly at the target."

Interpolated test results indicated that to raise pedestrian visibility to the "attention getting" range from all orientations, a pedestrian would have to wear a fully reflectorized suit. The Klassen (1974) study stated that the results of this study were not influenced by such possible enhancing factors as target motion, recognizable shape and color. Klassen (1974) concluded by saying that "...beyond just visibility, recognition of an object is important so driver decisions are correct and the proper avoidance maneuver is made."

Miller (1975) asserts that the efficacy of an emergency signal "...depends chiefly upon two phenomena: 1) the ability of the signal to be sighted and to attract attention, and 2) the meaning of the signal after it has been sighted and attended to." He goes on to say that:

> "...for a given stimulus to be detected the stimulus must contrast signficantly against its surroundings. The parameters of contrast include size, luminance, chromaticity, movement and position in space. It is important to note that most information about our world which we obtain through the sense of vision, depends upon

our ability to contrast these parameters for all tangibles. Objects are recognized only because they have a different size, luminance, color and/or position from their surroundings."

The relative conspicuity of various colored and patterned reflectorized-fluorescent flagman vests was examined by Smith and Janson (1976). Observers were asked to rate pairs of candidate vest configurations in operational deployments of flagmen in urban and rural work settings according to which vest was better, based on "...the subjective criteria of attention getting, conspicuity, recognizability, meaning and connotations of danger or hazard." The authors defined "attention getting" as "...being not only bright enough to be easily visible but bright enough to attract one's attention even if not looking at the target."

Finally, Burg and Beers (1978) investigated the relative effectiveness of bicycle/motorcycle spoke prismatic retroreflectors versus tire sidewall spherical retroreflectors as aids to nighttime conspicuity. The authors concluded that:

> "For a motorist to successfully avoid conflict with a hazard, he must not only detect its presence, he must also recognize what it is in order to better predict its behavior and modify his own behavior accordingly. In addition, if the hazard is moving, some indication of direction of movement or relative closure rate is desirable if the motorist is to make an accurate appraisal of the situation."

C. Basic Driver Visual Capabilities

In this section, an overview of the literature dealing with basic driver visual functions and capabilities is presented. Generalizations which may be drawn in such topical areas as visual/psychomotor behavior, foveal vs. peripheral vision scanning behavior, flashing and intermittent signals, colored lights, object size, luminance, shape and contrast, object motion, and information processing in signal detection are presented. This material is seen as forming an essential foundation of conspicuity principles upon which to base the design and/or selection of conspicuity-enhancing materials for pedestrians and bicyclists.

1. General Visual/Psychomotor Behavior

Fosberry (1958) states that even in daylight in clear conditions the driver's visibility, both forward and rearward, is restricted by the structure of the vehicle. Important sections of the view can be obscured; thus a windscreen pillar/post can obscure a pedestrian or bicyclist until it is too late to avoid an accident. A given vehicle has certain visibility characteristics.

A wide range of cars and commercial vehicles was examined to better appraise design based visibility characteristics. The main points of comparisons between vehicles are the extent of the forward obscuration by the windscreen pillars and hood and the vertical and horizontal angles of rearward vision. In cars these factors are affected by styling. In particular, with low rooflines, the eye level tends to be high in the car, where the pillar thickens to meet the roof, resulting in large obscurations. The high eye level also restricts the positioning of internal mirrors in that it is difficult to obtain good rearward visibility without causing undue forward obscuration.

In a related investigation on safe nighttime visible distances, Johansson and Rumar (1968) demonstrated the visible distances that can be considered realistic during night driving on non-illuminated roads. From the experimental data the approach speeds were calculated that can be considered as safe for various conditions and states of the driver, the car and the road. Four hundred and thirteen drivers volunteered to participate in their own cars in 14 different places in Sweden. Each driver's task was to drive his car towards a stationary car, both cars with dipped headlights, and to brake as soon as he was aware of a dark-clothed dummy that was placed in the middle of the lane beside the stationary car. A special experiment compared the results of this semi-dynamic test with those of a fully dynamic test.

The median visible distance was 23 m and the 10th percentile 15 m. The calculated safe approach speeds for the tested drivers varied between 25 km/h and 50 km/h depending on the conditions chosen. The authors concluded by saying that:

> "A driver can never know the exact position and the reflectance of any obstacle on the road. This means that he has to allow for the worst conditions—the conditions that have the shortest visible distance—when he has to determine his speed in various situations. The test-situation was very unfavorable from the visibility point of view and, thus, the safe speeds (25-50 km/h) calculated from the visible distances obtained experimentally can be considered valid.
>
> The light conditions during night driving are obviously too bad to permit normal highway speeds if safety is required. Yet there would be strong public opposition against driving at the above-mentioned approach speeds. The human visual system cannot be changed and thus we have to improve the lighting system (e.g., by introducing polarized headlights). A less effective but more immediate measure would be to mark obstacles, pedestrians, etc., with reflective material."

An article by Allen (1969) on "Vision and Driving" cites a number of factors which increase the visual handicap of a driver, causing him to fatigue sooner and resulting in his failure to see a hazard in time. Among these are alcohol, excessive speed, windshield dirt, darkness, glare, obstructions from the rearview mirror or vehicle structure, and refractive error in the eyes of the driver. Good central visual acuity and its associated clear retinal image are necessary for the early recognition and reading of road signs and early detection of small but hazardous objects. For example, a man with 20/40 vision by day will have less than 20/100 at night on the highway, and will need much more light to drive safely at night than is currently available. Peripheral vision is extremely important, and may be blocked by bulky spectacle frames with wide ear pieces. Allen recommends non-licensing of those drivers whose visual field limits drop below 70 degrees to the right and 70 to the left. Stereopsis, or binocular parallax, is also a necessary visual factor at night, when the majority of monocular cues are missing (e.g., relative size, position with respect to the horizon, overlay, brightness, contrast and movement). People with color vision defects should not use colored sunglasses or drive with a tinted windshield, even in daytime. Alcohol—and drugs which synergize with alcohol, tobacco or other drugs—reduce the ability to see at night and slow response time. Tobacco smoke residue will contribute to windshield glare.

Bewley (n.d.) argues that many modern, stylish spectacles create visual obstructions for the wearer. One of the most ignored ocular failings in driving, notes the author, is tunnel vision, responsible for many thousands of accidents. Tunnel vision may be caused by ocular or neurological pathology, as well as by automobile design. Finally, tunnel vision may result from the frame used to hold prescription or sunglass lenses needed for good foveal vision. The Bewley study concludes that style and size of spectacle frames do affect the field of vision and may reduce it below the minimum safety requirement of 140 degrees.

Brown and Huffman (1972) investigated drivers' psychophysiological and vehicle control responses under actual driving conditions. They were tested during day and night driving sessions in four traffic conditions: a) residential driving; b) rural, two-lane highway driving; c) four-lane expressway driving; and d) four-lane business district driving. The good record drivers had significantly lower mean rates of galvanic skin responses, accelerator reversals, and brake responses than the poor record drivers. Mean accelerator reversal and steering wheel reversal rates were higher during night than during daylight driving sessions; lateral eye movement and galvanic skin response rates were lower at night. Among the four traffic conditions, significant differences occurred for all measures except heart rate. Lateral eye movement and brake response rates were highest for residential driving and significantly different among all four conditions; galvanic skin response rate was significantly lower for rural driving than for the other three traffic conditions; accelerator reversal rates were significantly higher for residential driving; steering wheel reversals were significantly higher for rural and expressway driving than for the other two conditions.

Rumar (1979) points out that drivers can steer vehicles with peripheral vision without the need to fixate on the road or road edges. In estimating the speed and predicting the direction of other vehicles in the visual field, the driver appears to analyze and interpret motion vectors. In night vision as opposed to day vision contrast sensitivity is of vital importance. Yet reduced contrast sensitivity and increased glare sensitivity are two common visual deficiencies in night traffic. Another problem is night myopia due to the lack of adequate fixation points in the nighttime visual field. Rumar indicates that in most developed countries about one-third of the highway traffic occurs at night. This proportion is seen to be on the increase. However, the risk of a nighttime traffic accident is about twice that of a daytime accident. The author suggests that since our night vision is so degraded, drivers should be screened for serious deficiencies in night vision and be trained to use it better.

Triggs (1980), investigating the influence of on-coming vehicles on automobile lateral position, recorded the performance of automobiles along two sections of a four-lane suburban road. Cameras mounted unobstrusively on the experimental vehicle enabled video records to be made of the vehicle being followed. Analysis of these records showed that, as vehicles approached from opposite directions while in adjacent lanes, there was a systematic linear movement away from the road centerline. This lateral displacement commenced approximately 3.6 secs. before the vehicles met in one of the road sections and 2.4 secs. in the other section. The displacement increased steadily up to the point of the two vehicles passing in both sections. The data appear to refute the claim that drivers show a general tendency to steer toward objects of perceptual significance.

Henderson and Burg (1975) assert that a great deal more research is required before we can adequately answer the question of the importance of night vision screening of driver license applicants. Presently we know that visual performance is seriously degraded under conditions typically encountered in night driving, i.e., low levels of illumination, glare and low-contrast targets. It may well be that target contrast is the key parameter, since both low levels of illumination and glare tend to reduce target contrast. Further, some individuals are much more severely affected by these factors than others, and as a result the total variability in visual performance of the driving population increases significantly as level of illumination decreases, glare increases, or contrast decreases. What is lacking is clear evidence of a relationship between poor night vision performance and high accident probability.

2.. Foveal vs. Peripheral Vision

Research conducted by Wolf (1962) indicates reduced critical flicker frequencies in the extreme periphery of subjects of 60 years or greater. These people thus perceive flicker/fusion where younger subjects would perceive flicker indicating a lower degree of stimulus efficiency/perception in the periphery.

A laboratory study was conducted by Vallerie (1966) to determine the effectiveness of peripheral vision displays for presenting dynamic tracking information during difficult control tasks such as landing high speed aircraft or rendezvousing spacecraft. It was hypothesized that peripheral displays could be successfully used to improve performance provided visual switching between information sources is normally an essential part of such tasks. The study clearly demonstrated that tracking performance deteriorates as visual switching increases and that peripheral displays can be used to overcome its adverse effects by allowing attention shifts for peripheral information without requiring a change in foveal fixation. The peripheral display clearly demonstrated the capability for a vehicle controller to perceive information in the visual periphery without looking at it.

In a related experiment, Grindley and Townsend (1970) studied the problem of visual search using six patterns which were geometrically simple and familiar to the subject. In each case the subject's task was to say where, among the complex patterns, a particular pattern (the "test object") appeared when the exposure of the whole display was so brief as to prevent scanning by the eyes. The subject could be informed visually (in Experiment I) or verbally (in Experiment II) which pattern was to be regarded as the "test object." In both experiments it was found that foreknowledge of what was to be the test object gave a significantly higher standard of accuracy than knowledge given later. The authors hypothesized that something analogous to visual search can occur without eye movements.

Relating lateral visual field to age and sex, Burg (1968) obtained visual field measurements by means of a screening perimeter for nearly 17,300 subjects, ages 16-92. The major findings were: a) temporal and total fields are maximum to about age 35, after which field constricts progressively with advancing age, b) nasal fields increase to a maximum occurring about age 35 or 40, after which a progressive decline takes place, and c) females consistently demonstrate slightly larger visual field than men.

In a laboratory study relating luminance thresholds for peripherally presented stimuli, Leibowitz and Appelle (1968) found that when attention is focused on stimuli which are presented to the fovea, peripheral stimuli presented simultaneously will be difficult to detect. This study differs from others like it in that the authors are able to quantify the increased difficulty of detection of the peripheral stimuli in luminance units, rather than in terms of visual accuracy or difficulty in detection. This study in mirror image terms supports the conclusions previously discussed of Vallerie (1966).

Zahn and Haines (1971) investigating the effects of luminance upon peripheral vision detection time, exposed twenty subjects to a wide range of luminances (8.5, 55, 792, 400 fL) of a centrally located diffuse white search panel. The findings suggest that the visual field constricts with increased central panel luminance. This is shown by an increased peripheral detection time (DT) and by more undetected peripheral test lights, even though difficulty of the central search task was held constant.

3. Scanning Behavior

Mourant and Rockwell (1970) filmed eye movements of eight drivers as the drivers traveled on a local expressway at 50 miles per hour. Search and scan patterns of the drivers became more compact and the center of location shifted down and to the left as the drivers became more familiar with the route. The center of the final pattern was located above the right road edge marker and slightly higher than the horizon. The task of car following appeared to induce greater visual workload as indicated by increased sampling rates of lane markers and greater visual travel distances to examine road signs and other traffic. The search and scan patterns verified that the peripheral area of the eye is used for monitoring lane position, other vehicles, and road signs so that the fovea may be directed for a closer examination when the situation demands it.

Mourant and Rockwell (1972) monitored the eye movement (including blinks and glances to the vehicle's mirrors and speedometer) for six novice drivers who drove a 2.1 mile neighborhood route and a 4.3 mile freeway route. The visual behavior of a control group, consisting of four experienced drivers, was also videotaped on the same routes. The results showed that the novice drivers: 1) concentrated their eye fixations in a smaller area as they gained driving experience; 2) looked closer in front of the vehicle and more to the right of the vehicle's direction of travel than the experienced drivers; 3) sampled their mirrors less frequently than the experienced drivers; and 4) made pursuit eye movements on the freeway route while the experienced drivers made only eye fixations. These results suggest that the visual acquisition process of the novice drivers was unskilled and overloaded. Thus, the search and scan patterns of the novice drivers may be considered unsafe in terms of impairing the drivers' ability to detect circumstances that have high accident potential.

A study by Louie (1978) investigated the effect of mixed contrast schedules on target detection times in both unstructured (free search) and structured (systematic search) field situations, where the subject had no prior knowledge of target contrast. The structured situation and its associated search pattern were identical to those of a previous study. The overall results suggest that detection times are largely the product of two factors: the contrast schedule and the condition of the visual field. The structured field produced higher detection times for high contrast targets, whatever the level of contrast uncertainty (i.e., whatever the schedule). It may be concluded from this, therefore, that the mere presence of contrast uncertainty was sufficient to make subjects generally slower, and perhaps more cautious in the detection of high contrast targets in the structured situation.

Apparently, systematic search reduces detection time only for low contrast targets and even then only where contrast uncertainty is low. Higher contrast uncertainty may in fact produce higher mean detection times for low contrast targets in the structured situation. Also, systematic search under these circumstances tends to increase detection time for high contrast targets, whatever the level of contrast uncertainty. Finally, in high contrast uncertainty conditions, some combination of free and systematic search is recommended.

Data are presented by Robinson (1972) on the visual search of automobile drivers during two maneuvers: 1) entering a highway after a stop; and 2) changing lanes on a multi-lane highway. Head movement measurements were used to infer patterns and timing of search. Both the above maneuvers place severe demands on the driver's visual input system, primarily because of the large visual angles between the necessary information sources.

Findings of importance to the interpretation of the highway data were that the head initially lags the eye by about 50 msec for all target angles, the eye movement stops at about 40 degrees for all target angles (greater than this value) and the maximum velocities for the eye are on the order of 1,000 degrees/sec., and for the head about 450 degrees/sec. It appears that increased complexity of the visual input task (e.g., more traffic) leads to more visual searches, and to a lesser extent, to longer individual searches.

Rackoff and Rockwell (1975) found that measures of driver visual search patterns are sensitive to day and night differences, to sites with different accident rates, and to illumination. The results from the measurements taken on highway intersections with illumination lend encouragement to using eye movement data to evaluate methods of improving nighttime driving. Results obtained in one study reveal that:

- On the unlighted freeway, eye movement pattern shifted down and to the left from day to night by about one visual degree. This shift seems due to glances at headlights of oncoming cars which were made about 20 percent of the time. Drivers did not fixate on oncoming traffic in the daytime.
- Eye movements were more disperse at night than during the day on the unlighted freeway.
- On the unlighted freeway, glances to road edge lines increased from one percent in day to nearly 45 percent at night, and glances straight ahead decreased at night.
- On the illuminated route few differences were observed between day and night conditions.
- On the rural unlighted highway, drivers viewed straight ahead more at night than during the day. They appeared to be searching for targets beyond the headlights to increase preview time.

In a second study it was found that the degree of highway illumination can affect visual search. At illuminated sites, drivers apparently decrease the mean look time per fixation, and increase the mean time viewing the scene ahead.

4. Flashing and Intermittent Signals

In early studies by Gerathewohl (1951) the superiority of flashing over steady lights of equal brightness was established in terms of detectability. Latour (1962) obtained wide variations in thresholds for subjects perceiving flashes of lights from eye movements. It was found that vertical stripes must be brighter to be seen by the laterally moving eye. Horizontal stripes are seen better under these circumstances than vertical stripes.

An experiment by Crawford (n.d.) was carried out to find the effect of the number of irrelevant lights on the human response time to light signals appearing among them. Both the signal lights and the irrelevant lights could be made steady or flashing. This produced four conditions of coding of the signal lights from the background, i.e., flashing signal with steady background and so on. It was found that the geometric mean response time increased to an unusually large extent, from 0.8 seconds with no background lights up to nearly 2 seconds with 21. A background of flashing lights was found to increase the response time more than a background of steady lights, whether the signal was flashing or not. The shortest response times were obtained when flashing signals were seen against a steady background and the longest with flashing signals against a flashing background. Crawford concluded that flashing signals should not be used in conditions where a number of them may appear together within the field of view.

In another study by Crawford (1963) he has shown the danger of increasing the number of irrelevant lights in a driver's field of view and that the signal most easily seen is one which flashes while the irrelevant lights are steady. However, a flashing light which may be an important signal to one driver may be irrelevant to other drivers in the vicinity. In this second experiment with the same general conditions as before, Crawford (1963) examined the effect of mixing flashing and steady irrelevant lights as a background to an essential signal. It was found that the advantage gained by the use of a flashing light as a signal was lost if even one other light in the background was flashing. It was a definite disadvantage to have the signal flashing if three of ten irrelevant lights flashed, and when the number flashing was more than four, the ability to perceive flashing signals was seriously impaired.

In a study of how the human eye manages visual problems, Thomas (n.d.) argues a number of different theories as well as empirical facts. The most common major eye movement, the saccade, is discussed, as well as camera observations of the eye movements of drivers in actual traffic. A driver's eye constantly samples the road ahead in a moving vehicle. At intervals he flicks quickly to the near curb, as if to monitor his position. However, this monitoring relies chiefly on the streaming effect—the flow of blurred images past the edges of the visual field. Strong attractions for visual attention are the edges of other vehicles and sudden gaps between them. The faster the vehicle is moving or the greater the traffic density, the more frequent are the saccades. Flashing lights are one of the strongest visual attractions, and act effectively through the periphery of the retina. Although this area of the eye is poorly equipped for resolving detail, it is very sensitive to object movement and signal periodicity (blinking). The retina functions as an effective wide-angle warning system, and a strong peripheral signal will pull the eye for a foveal fixation. Eyes move more often when the viewer is interested in the visual scene. There are also more corrective jumps serving to bring the image of the object of interest toward the center of the fovea. There are also fewer eye blinks, the eyes are opened wider and the pupils are dilated.

Connors (1975) asserts that for most pilots, collision avoidance continues to depend on visual sightings. The purpose of her study was to examine the stimulus characteristics of lights that might aid a pilot to "see and avoid" by alerting him to a potential threat. This study examined the relative conspicuity of foveally equated, point-source, steady and flashing lights of several brightnesses, seen against a star background. From the subject's viewpoint, these target lights could appear anywhere within a large (40 degree horizontal by 35 degree vertical) field of view. The lights appeared at random time intervals while the subject was periodically distracted by a simulated cockpit task. The results indicated that correct target detection increased and reaction time decreased with increased target intensity. Steady lights were missed more frequently and acquired more slowly than flashing lights, but no significant differences were found among the wide range of flash rates employed. The intensity of the light had a greater effect on both detection and reaction time to steady lights than to flashing lights. The longest reaction times were recorded to lights which appeared either at the extremes or at the very center of the visual field.

5. Colored Lights

The conspicuity of foveally-equated colored lights was investigated by Connors (1975). Subjects who were periodically engaged in a distracting aircraft cockpit task were required to search a large visual field and report the appearance of a target light as quickly as possible. Targets were red, yellow, white, green and blue and appeared either as steady or as flashing lights. Results indicated that red targets were missed more frequently and responded to more slowly than lights of other hues. Yellow targets were acquired more slowly than white, green or blue targets; responses to white targets were significantly slower than responses to green or blue targets. In general, flashing lights were superior to steady lights, but this was not found for all hues. For red, the 2 Hz flash was superior to all other flash rates and to the steady light, none of which differed significantly from each other. Over all hues, conspicuity was found to peak at 2-3 Hz. Response time was found to be fastest, generally, for targets appearing at between 3 degrees and 8 degrees from the center of the visual field. However, this pattern was not repeated for every hue. Conspicuity response times suggest a complex relationship between hue and position in the visual field that is explained only partially by retinal sensitivity.

Experiments on the visual threshold in the periphery, including the extreme periphery, were conducted by Middleton and Wyszecki (1961). The psychophysical method of adjustment was used to obtain the threshold for steady white, red and green signals subtending an angle of 2.6 minutes at the dark adapted observer's eye. It was found that the threshold for red is more than an order of magnitude greater than that for white or green, the difference increasing with angle. The relatively small difference between white and green is not much dependent on horizontal angle, but appears to be greater in the upper and lower parts of the retina.

Allen (1964) contends that the use of red lights on automobiles neglects the laws of physiological optics. He asserts that red, long a symbol of danger and an internationally used stop signal, is used illogically as a running light (taillight) on the rear of automobiles—it goes against the laws of physiological optics. The red taillight on cars currently can mean go, stop or turn, depending upon intensity and whether or not some are flashing. The ambiguity of this signal system is, therefore, dangerous. Chrome stereopsis in the human eye, or lateral chromatic aberration, is the cause of one's perception of red as farther away than any other color including white in about 2/3 of the population. Green taillights, Allen asserts, would have none of the disadvantages of the red lights. Certain physiological requirements would thus be met: a) the retina generally is most sensitive to green, and thus green would be the color most likely to be in focus on the retina; b) in any defect of color vision, green is not subject to serious brightness loss; and c) hypermetropic or myopic individuals would still be able to see green. Allen recommends red stop lights and flashing turn signals coupled with green taillights. Green could indicate "go" in the sense of "it is safe to follow" while red would mean stop.

Connors (1968) investigated the luminances necessary to perceive red (642 nm), green (521 nm) and blue (468 nm) at nine visual angles ranging from over one degree to 21 second of arc diameter. Monocular, foveal measurements were made by the method of constant stimuli at exposures of 44 and 700 msec duration. Three dark adapted color-normals served as observers. The results show that, with sufficient luminance, these hues can be seen even for stimuli as small as 0.35 min of arc diameter. Red is generally perceived at lower luminances than blue or green.

The Institute of Transportation and Traffic Engineering (1969) conducted a series of subjective tests under various visibility conditions to determine the visual detection contrasts for red, green and amber luminous area targets against correspondingly colored backgrounds. The results show that under clear weather conditions, daytime or nighttime, there was no significant difference in target to background detection contrast for the three colors. In fog of 100 - 150 feet visual range, the detection contrast was generally lower for red targets than for green, with amber being intermediate between the other two colors. These differences were more pronounced in daytime fog than in nighttime fog of the same concentration.

Reynolds (1972) conducted two experiments designed to determine effective colors for stimulus lights as measured by speed of detection and accuracy of identification. The nature of the interactions between stimulus color, background color and amount of ambient illumination were also assessed. Responses to four stimulus lights, i.e., red, green, yellow and white were evaluated against four colored backgrounds, viz., copper, tan, blue and green, under two levels of ambient illumination. It was found that to choose the most effective signal color in a specific situation, stimulus color, background and amount of ambient illumination must all be considered. The overall ordering of stimulus colors as measured by speed of response was, from fastest to slowest, red, green, yellow and white. For errors in color naming, the order from least to most, was green, red, white and yellow.

Muhler and Berkhout (1976) determined the distance threshold for visibility in daylight for four flashing incandescent signal systems and for two types of gas discharge tube arrays. The distance threshold was found to be a function of the physical construction of lamp housings and the flash patterns as well as of effective intensity. Major studies in this area have been conducted by the California Highway Patrol (CHP). They reported that the behavioral impact of various lights depended on color and flash pattern, as well as intensity. The CHP studies resulted in adoption of a roof-mounted light combining red, blue and amber incandescent lights with auxiliary mirrors. This system had the maximum slowing and diverting effect on the stream of traffic in the multi-lane highway field test. The performance measure in the Muhler and Berkhout study consisted of the distance from the subjects, in miles, at which the light first disappeared on ascending trials and first became visible on descending trials. Results indicated that the gas discharge tube systems had relatively poor performance as a result of the less effective light output per flash compared to the incandescents. The authors found that red filters on gas discharge tube lights were preferable to blue for daytime use although any filtering of a gas tube light greatly reduces its intensity. The authors conclude by saying:

> "Conspicuity against a variety of backgrounds, freedom from obstruction, and the transmission of information concerning vehicle direction and rate of travel must also be considered. The lights identified as having the longest distance threshold in the study would not necessarily excel in these other dimensions as well."

In a study by Ruden and Burg (1981) to examine the conspicuity of traffic signals with respect to varying signal intensity versus lens size, variables such as color, flash rate, brightness, size and placement were accounted for in the experimental design. Results of the study indicated that, excluding white or clear unfiltered light and with equal luminance for all color lights, red is the most conspicuous daytime color and blue is the most conspicuous nighttime color. Amber and orange are slightly better colors in daytime fog. A flash rate of 70 to 90 cycles per minute has greater conspicuity than either higher or lower flash rates. Brightness increases led to somewhat greater conspicuity during the day and daytime fog conditions, but little effect was found at night. Increasing stimulus lens size (from 8 to 12 inches) increased conspicuity dramatically under all conditions, far more proportionately than did raising brightness. The authors concluded that once signal contrast exceeds supra-detection threshold, increasing signal size is far more effective than increasing signal brightness as a means for improving signal conspicuity.

6. Object Size, Luminance, Shape and Contrast

Eriksen (1953) investigated the speed in locating objects on a visual display under the following conditions: a) when the various classes of objects on the display differed from one another on only one of the four visual dimensions of form, hue, size and brightness; and b) when the classes differed from one another on two or on three of these dimensions.

For the single dimensions, location time for hue differences was significantly faster than for form differences, and hue and form were both significantly faster than either brightness or size. The location times for the compounds of two and three dimensions were found to correspond to a weighted geometric mean of the single dimensions of which they were composed. Compounds involving both the form and size dimensions were an exception due to an interaction between these two dimensions.

A study examining target luminance detectability by Teichner (1972) reviewed the literature on the absolute threshold for seeing. A method for estimating the probability of detection of a light given only the luminance threshold value as information, and for predicting the luminance threshold as a function of target size and duration was developed. The analysis supported the general conclusion that, for small visual areas and up to a critical duration, there is a reciprocity between duration and luminance and that the critical duration decreases with increasing area. It did not support the conclusion of a similar reciprocity or trade-off between luminance and area.

Cole and Jenkins (1979) asked 22 subjects to identify the location of white discs superimposed on projected colored photographs of ten scenes representative of urban and semi-rural road traffic scenes. A subject's fixation was maintained on a point at the geometric center of the projected scenes and the time of presentation was limited to 250 ms. The proportion of correct responses was taken as an index of the conspicuity of the white discs. In the first experiment, the discs varied in size and, in the second experiment two sizes of disc varied in luminance. The results suggest that a white diffusely reflective object needs to have an angular diameter of at least 50 min of arc (1455 mm at 100 m) if it is to be conspicuous when offset 6 degrees from the line of sight. If the object is offset 12 degrees, a diameter of 118 min of arc (3434 mm at 100 m) is necessary for it to be conspicuous. Objects smaller than these dimensions would need to be self-luminous if they are to be conspicuous since a brightness greater than that possible for white naturally lit objects is necessary to compensate for the low conspicuity of small size. It was also noted that a conspicuous object offset 6 degrees from the line of sight would seem to remain equally conspicuous as it was approached, the gains in conspicuity due to increasing size being almost exactly offset by the loss of conspicuity due to increasing eccentricity. With regard to basic visual mechanisms, the authors inferred that sensitivity to luminance differences decreases with increasing eccentricity but, at any one eccentricity, there are several luminance detecting mechanisms in the visual system and the one that is brought into operation depends on the size of object.

Jenkins and Cole (1979b) conducted an experiment where the conspicuity of two discs was measured as a function of the angle of eccentricity between the fixation point and the stimulus; the objective of this study was to provide data necessary for the interpretation of later experiments involving the detection of discs embedded in a complex background which in turn will attempt to elucidate the determinants of conspicuousness.

Major conclusions of this study were that: a) discs are discriminated in size by virtue of their difference in diameter rather than differences in area; b) the P50 percent (detection probability) and P90 percent levels of size and luminance contrast between two discs are linear functions of eccentricity at least to 14 degrees eccentricity; c) the visual system is better at discriminating size contrast at all eccentricities tested than it is at discriminating luminance; and d) a fundamental difference exists between mechanisms which mediate size and luminance discrimination.

7. Object Motion

McClogin (1960), investigating movement thresholds in peripheral vision, examined absolute velocity thresholds at 48 positions in peripheral vision. An aircraft-type instrument, with a standard altimeter hand, was located at random positions on the concave, black surface of an 80 inch fiberglas hemisphere. Four types of movement were investigated (clockwise and counter-clockwise rotation, vertical and horizontal motion) under conditions of constant photopic lighting. While the subject fixated on the center point of the hemisphere, the absolute velocity threshold of each type of movement was determined for each position using the method of limits. Ten airline pilots served as subjects. There is no apparent difference between a subject's ability to see clockwise or counter-clockwise rotation. An individual's ability to perceive vertical motion is slightly better than his ability to perceive horizontal motion in the area adjacent to the horizontal axis. Velocity and area swept by the instrument hand are significant factors in the perception of movement, but they are not similarly correlated for all types of movement.

The relative roles of contrast and motion in the detection of targets were investigated by Petersen and Dugas (1972) using a television display of an artificial target inserted in several different backgrounds of varying complexity. Independent effects of both contrast and motion on the detectability of targets were found. The magnitude of these effects can be accounted for in the detection probability function by modifying the exponent with a linear contrast term and a second-power velocity term. At target speeds greater than about 5 deg/sec, the detection probability began to level off, probably due to interference of the boundaries of the display. Single-fixation experiments confirmed a larger detection field for moving targets than for static, but also demonstrated a gradual increase in the fixation time required to detect a target as a function of its distance from the fixation point.

A model was constructed consisting of four basic factors, which give the overall probability (P) of target acquisition: $P = P_1 P_2 P_3 n$, where P_1 = the probability that an observer who is searching a scene will look in the direction of the target with his foveal vision; P_2 = probability that a target will be detected if viewed foveally for one "glimpse period"; P_3 = probability that a target, if detected, will be <u>recognized</u>; n = an overall degradation factor due to noise in the image that is viewed by the observer.

8. Information Processing and Signal Detection

A paper by Shinar (1978) reports on two studies that examined the relationship between field dependence and on-the-road visual search behavior. In the first study, concerned with eye movements in curve negotiation, it was found that field-dependent subjects (individuals who consistently have difficulty overcoming an embedding context in order to perceive relevant targets) have a less effective visual search pattern. In the second study, young and aged drivers were compared on several information processing tasks and on their ability to maintain their eyes closed part of the time while driving. Of the various information processing tasks, only field dependence and visual search time correlated significantly with the mean time the drivers needed to maintain their eyes open while driving. Together the two studies indicate that field dependent subjects require more time to process the available visual information and are less effective in their visual search pattern.

In a study involving signal detection and attention, Posner (1980) concluded that detection latencies are reduced when subjects receive a cue that indicates where in the visual field the signal will occur. This shift in efficiency appears to be due to an alignment (orienting) of the central attentional system with the pathways to be activated by the visual output.

Posner also found that, when subjects are cued on each trial, they show stronger expectancy effects than when a probable position is held constant for a block, indicating the active nature of the expectancy. While information on spatial position improves performance, information on the form of the stimulus does not. Expectancy may lead to improvements in latency without a reduction in accuracy. Finally, there appears to be little ability to lower the criterion at two positions that are not spatially contiguous.

Using this framework, it appears that attention shifts are not always closely related to the saccadic eye movement system. For luminance detection the retina appears to be equipotential with respect to attention shifts, since shifts to unexpected stimuli are similar whether foveal or peripheral. These results appear to provide an important model system for the study of the relationship between attention and the structure of the visual system.

D. Factors Affecting Driver Vision

In this section a wide array of factors which affect the effectiveness of driver vision are examined. In general, these factors may be thought of as limitations which, to a greater or lesser degree, impair the visual function. Literature is reviewed related to the following areas of contribution, i.e., the driver, the vehicle and the traffic environment.

1. Driver Origin

a. General

Forbes (1960), in combining the results of certain published research yielding background information on human reactions, brings out certain relationships of importance in the design, operation and safety of the traffic environment. Some of these affect night driving efficiency. Increased task difficulty leads to longer perception-decision-response times. At night, driver response time may be slowed an additional amount by reduced visibility. Data on time for dilation and constriction of the pupil of the eye in adapting to light and to dark indicates that the "dark hole" effect in entering a tunnel can be eliminated by design taking account of the human reaction. Fatigue results in reduced human efficiency and, for most drivers probably will be greater at night. Studies in industry indicate that moving bright sources in the periphery of vision tend to induce fatigue. They may be also a factor in inducing sleep. An experimental study of drowsiness in driving showed an increasing frequency of eye closure leading up to actual drowsing behind the wheel. Turnpike and other studies of one car accidents seem to indicate a high proportion of sleep accidents between midnight and 6:00 a.m. It is suggested that discomfort glare may be of great importance as a fatigue and drowsiness inducing factor and that the threshold for discomfort glare may be lower under sleep deprived and fatigued conditions of the driver.

In a review of literature by Wolf (1962), the principal effects of age on the visual function are reviewed to include:

- Increasing inability to focus at near range.

- Declining ability to dark adapt—scotopic sensitivity in the aged may be only 1/100 of that found in young individuals.

- Above the age of forty, sensitivity to glare increases and recovery from glare becomes progressively less efficient.

Kaluger and Smith (1970) investigated the changes in eye-movement patterns of three drivers after prolonged driving and sleep deprivation. In the first experimental condition, subjects drove for approximately nine hours with only minor stops for equipment setup and calibration on refueling. Prior to the second nine-hour driving task, the same subjects were deprived of sleep for 24 hours. Eye movements were filmed under open-road, daytime conditions at three speeds: 40-50, 60-70 and 85 mph. The eye movements were examined both spatially and temporally. Among the major findings was the sleep-deprived drivers has more foveal viewing time as opposed to areas normally monitored peripherally.

Thus, there existed a decrement in "peripheral sensitivity," i.e., a perceptual narrowing. Additionally, there was a tendency to make more and longer pursuit eye movements as a result of sleep deprivation. Fatigued drivers exhibit a less responsive eye movement pattern. Instead of looking ahead down the road and monitoring other vehicles and signs, the fatigued drivers tended to fix their gaze on the right road edge as if totally preoccupied with the task of steering the vehicle within the lane.

b. Alcohol and Drugs

In the laboratory phase of a study by Hazlett and Allen (1968), it was found that at low levels of illumination an individual's sensitivity to contrast decreases as his blood alcohol level increases. All subjects exhibited a significant ($p < .01$) decrease in contrast sensitivity at blood alcohol levels greater than 0.04%. In the road test phase of the study, visibility distances were found to be unacceptably short for "dummy" pedestrians covered with black or gray fabric. Dummies covered with white fabric were safely visible for a driver traveling up to a speed of 50 mph. However, only reflectorized dummies were safely visible above that speed. At blood alcohol levels greater than 0.04%, all of the observers exhibited a significant ($p < .01$) decrease in the mean visibility distance for each of the simulated pedestrian conditions.

Hamilton and Copeman (1970) examined the effects of alcohol and noise on a complex tracking and signal-detection task with particular reference to changes in selective attention. Operators were instructed to give the tracking task priority. In noise, tracking performance improved, but detection of lights placed on the periphery of vision was degraded. Alcohol had the same effect on peripheral detection, but tracking performance fell. The authors concluded that the effect of alcohol on such simulated driving skills embodied two factors: the first an increase in attentional bias toward the high priority regions of the visual field, and the second a decrease in the information transmission rate. The loss of peripheral awareness found even at the low alcohol levels used was of apparently serious proportions.

Perrine (1973) examined the effects of alcohol on vision and reports several findings. The more simple visual functions are relatively insensitive to the influence of alcohol; retinal functions are either not impaired by alcohol or not substantially impaired. This is true especially for visual acuity, color vision, visual field, dark adaptation, etc. In sum, adults do not suffer impairment of static visual acuity until blood alcohol concentrations in excess of .08% have been reached. Regarding dynamic visual acuity, motoric coordination of binocular motility or visual tracking accuracy was significantly impaired in all subjects at BAC's up to 0.10% and in some subjects as low as .03%. Regarding visual field, even relatively high doses of alcohol do not cause any noticeable reduction in the sensitivity of the lateral visual field. Regarding dark adaptation, recent studies have shown significant detrimental effects of medium doses of alcohol (.08%). There is no compelling evidence that glare resistance is appreciably decreased by blood alcohol concentrations up to .08%. In fact, even at higher doses, subjects do not show a major decrease in glare resistance.

In a divided attention visual task analogous to driving, Moskowitz and Sharma (1974) tested 12 males under a control and two alcohol treatments in a perimeter apparatus used for testing peripheral vision. They were required to fixate either on a steady-state central fixation light and detect peripheral lights, or to count blinks produced by the cessations of the fixation light and to detect peripheral lights. Alcohol produced an impairment of peripheral vision only under conditions where the central fixation light blinked and thus required information processing. No performance decrement occurred when the central light did not blink and the subjects could concentrate on peripheral stimuli. The results suggest that alcohol interferes with central information processing rather than peripheral sensory mechanisms. In addition, reaction time to peripheral lights was not significantly impaired by alcohol. Thus, the authors conclude the behavioral mechanism supporting the perceptual ability to divide attention seems to be sensitive to alcohol impairment, rather than the sensory or motor components. Alcohol, therefore, seems to affect our ability to allocate attention.

Sekuler and MacArthur (1977) conducted several experiments which confirmed that alcohol ingestion causes a loss of visual sensitivity following glare. They found, however, that non-retinal processes are primarily responsible for the effect of alcohol on glare recovery. The non-retinal origin of this alcohol-induced visual disability does not lessen its potential for adversely affecting driving and related visual tasks. On the contrary, uncertainty about the location of possible targets imposes a reduction of visual sensitivity of any driver. If alcohol either retards a driver's target acquisition or causes him to mislocate the target, visibility necessarily will be reduced and his ability to respond to a target impaired. The possibility that in driving, the visual effects of alcohol studied can sum with other, previously identified perceptual consequences of alcohol ingestion cannot be overlooked.

Shinar (1978) has indicated that the visual scanning of the alcohol intoxicated is less active and more concentrated on the center of the road and less affected by the presence of other objects or vehicles on the road. Sharma (1976) has shown that barbiturate intoxication disrupts the ability to visually track moving objects, degrades reaction time, division of attention and vehicle handling skills.

A study by Moskowitz, Sharma and McGlothlin (1972) examined the effect of marijuana upon peripheral vision in the context of the driving task. Peripheral vision effects were examined under three conditions of central vision attention demands. The visual demands of this task were viewed as perceptual analogs to driving under different tracking requirements while surveying the environment for possible danger signals. Results indicated that peripheral vision is impaired progressively by increasing doses of marijuana as shown by increased failure of light detections. In addition there is a concomitant failure to handle information presented to central vision as shown by increased error in counting the central light blinks.

In regard to the effects of marijuana, Klohoff (1974) observed that after smoking marijuana drivers were slower to respond to green lights at intersections, missed more traffic lights and stop signs, and were less aware of pedestrians and stationary vehicles.

c. Glare

Burg (1967), examining normative data on light sensitivity as a function of age and sex, tested some 17,500 subjects, ages 16 to 92, for both form recognition ability and glare recovery time under scotopic levels of illumination. The results showed: a) a progressive deterioration of performance on both tests with increasing age; b) a very low correlation between form recognition ability and glare recovery time; and c) no consistent difference in performance between males and females.

In an investigation of glare produced by a waxed windshield, Allen (1975) made photographic determinations of seven automobiles that were washed and waxed at four car washes. When wet, the waxed windshields scattered three times more light than in the normal human eye. The wet wax scattering was 24.8 times higher than when dry. The author concluded that no wax residues should be permitted on windshields and the NHTSA should issue a mandatory windshield cleaning requirement after waxing.

A study of glare sensitivity and peripheral vision by Wolbarsht (1977) was conducted with approximately 1500 driver applicants examined in 30 stations throughout a state. The distribution of elevated glare sensitivity and defects in peripheral vision in the driving population were determined and correlated with individual accident records. There were clear indications that a large percentage of older drivers had elevated glare sensitivity. Those drivers limited their driving to nonglare conditions in many cases. A future line of investigation indicated by the present study is the correlation between this test and the present standard used by the Medical Evaluation Board for restriction to daytime driving. Wolbarsht concluded that more data are needed on driver applicants over the age of 50 about possible elevations in glare sensitivity and accident records.

2. Vehicle Origin

a. Headlamps

A study examining the relationship between daytime headlight use, position on the highway, and driver reaction was conducted by Allen, et al. (1960). Photographic recordings of the position of oncoming automobiles on the open highway in the daytime were made both with and without low beam headlights displayed on the camera car. A speed of 55 mph was maintained on the two-lane U.S. Highway 37 north of Bloomington, Indiana. The positions of 1,127 vehicles were recorded. The oncoming cars occupied a narrower zone in their lane with fewer cars near the edge of the concrete as well as fewer near the center line when the camera car had its headlights on. It appeared that the oncoming drivers were more alert when they faced approaching headlights in the daytime.

Mortimer (n.d.) examined differences in characteristics between automobiles and trucks, such as driver eye height and headlamp mounting height, as well as roadway vertical and horizontal curvature and meeting beam patterns and lamp aim. Effects of these variables were evaluated by a computer simulation of nighttime meetings on a two-lane road. The visibility distance and direct and indirect (mirror) glare discomfort effects were measured.

Results suggested that low beam headlamps on trucks should not be mounted at more than about 36 inches (0.91 m) from ground level, the increase in visibility provided by the mid beam is less for truck drivers than for automobile drivers, the mid beam is less affected by vertical aim variations than the low beam, the mid beam should be extinguished by the vehicle in the inside lane on curbs when meeting other vehicles and when following another vehicle at less than about 200 feet (61 m).

Rumar (1974) in an investigation of the problem of dirty headlamps, conducted three experiments. In the first, dirt layers were systematically collected under various road conditions. The wetness of the road was found markedly to influence the amount of dirt deposited. In the second, light reduction caused by dirt on cars in traffic was measured. It was found that even in dry weather on seemingly clean roads light reduction due to headlamp dirt is normally 10 to 20 percent. In bad (slushy) road conditions few cars have light reduction below 50 percent. Drivers normally do not react to light reduction below 60 percent. In the third experiment, reduction in visibility during night driving was measured as a function of light reduction. Light reduction of 60 percent causes a 20 percent reduction of high beam visibility and a 15 percent reduction of low beam visibility.

The research documented in a report by Schwab and Hemion (1971) confirms that at night on rural highways most motorists overdrive their headlights. Studies conducted to determine visibility of various highway vision targets and the effect of various lighting configurations on driver performance are summarized. Means by which night visibility may be improved are discussed. It is concluded that: a) a polarized headlighting system is the most promising system likely to solve the night visibility problem; b) the system is technically and economically feasible in regard to today's vehicle population; c) the system would be advantageous in terms of improved visibility with less glare for motorists; and d) the results of the use of such a system would be increased vehicular control, safety and comfort and probably improved traffic flow and utilization of highways at night. A public test and evaluation of polarization in an isolated location is recommended prior to nationwide implementation to determine more precisely the benefits, side effects and operational problems.

In an experiment carried out to obtain visibility distances that can be considered representative for those common on the roads, Rumar (1971) tested lighting conditions with full and dipped headlights (conventional and halogen) under various combinations and in some special situations. The results indicated that in open road driving both types of full headlights give acceptable visibility distances. The more intensive halogen bulb results in a 25 percent increase of visibility. The first part of a vehicle meeting is made on full headlights. A difference in intensity is followed by an increase of visibility for the driver with the more intensive light and a corresponding decrease for the other one—who then of course wants to dip his light earlier. The clear difference obtained with full headlights contrasts sharply with the hardly noticeable difference in visibility for dipped headlights.

Causes and prevention of night driving accidents have also been investigated by Rumar (1975). The main ways to improve night driving are in increasing the use of road lighting and improved vehicle headlighting. Many present night driving accidents, e g., hitting a pedestrian, are not accidents by the normal definition. They are bound to happen when two on-coming vehicles and a pedestrian appear in a special position relative to each other. Rumar contends that polarized headlighting seems to be the most effective solution, while retroreflective material should be more widely used. However, since one cannot be sure that everything important on the highway is marked by retroreflective material, it is important that better headlighting be developed.

Another study relating visibility and headlighting by Helmers and Rumar (1975) makes a number of significant points regarding visibility distance to human size obstacles on the right-hand side of a relatively straight road. In high beam without opposing traffic there is very little gain in visibility distance with increases of intensity above 50,000 cd. The visibility distance in normal high beam intensities (87,000 to 150,000 cd) and speeds (90 to 110 km/h) is more than twice the normal necessary stopping distance (about 100 m). The normal visibility distance in high beam does not, therefore, constitute a traffic safety problem.

The optimum distance from a visibility point of view for switching from high to low beam is very dependent on low beam aiming. In the experiments this distance was shown to vary between 250 m and 400 m when the two vehicles had about the same high beam intensity.

Rumar (1976) reviewed the components of night traffic based on experimental evidence and contends that the possibilities to improve vision are very limited. There is some hope to test night traffic vision and thereby eliminate those drivers with deficient vision. The effect on safety seems marginal. Street lighting has proved very effective and only some optimization such as design of pedestrian crossings remains to be carried out. Headlighting and especially the low beam is the weakest link in night traffic. There is little hope to find a solution with the present dipping system. The most promising solution is the polarized headlights. Immediately, the most effective action would be to substantially increase the use of good retroreflective materials—on pedestrians, other obstacles, the road, etc. This is the most promising way to counter-balance the visual deficiency in night traffic.

Bhise, Farber and McMahon (1976) have presented the results of field research conducted to study the applicability of laboratory threshold visibility data in predicting seeing distance to stand-up and road-surface targets by use of different headlight beam patterns. A vehicle equipped with a precision odometer system was used to measure detection distance of 12 subjects under different target-background-glare conditions. The subject testing was followed by extensive photometry to measure the target, background, and veiling brightness of each target condition. The reflectance properties of the pavement and road shoulder were also documented. Detection distances were predicted from directly measured brightness and brightnesses computed from target and background reflectance data, ambient brightness, and assumed headlamp beam patterns. A comparison of field-observed and predicted seeing distances showed good to excellent agreement. The necessary contrast multipliers needed to account for factors such as complexity of road surface delineation and transient adaptation are also discussed.

Olsen, Sivak and Henson (1981) argue that "low beams" which are used by most drivers at night, do not provide adequate visibility under many driving conditions. Yet headlight beam patterns and aiming are not likely to improve in the future. The major constraints for headlamp design are seen to be the human visual system and limitations for headlamp mounting and conditions of use. In reviewing the human visual functions, the authors contend that we see objects primarily because they contrast (typically by brightness, color, shape, contour, texture, etc.) with their background. In night driving object detection is based almost entirely on brightness contrast (i.e., lighter or darker than background). Opposing headlight glare initially because of excessive scatter causes everything ahead to be illuminated and, therefore, brightness contrast is reduced along with detection distances. Glare also compromises the mesopically or scotopically adapted eye for some period of time after exposure. Object detection distances at night are thereby reduced. The author emphasizes that many factors affect aiming of headlights (e.g., fuel level, passenger loading, road alignment). With standard low beams, on average, a pedestrian standing at the edge of a dark rural road will be detected at about 180 feet and with high beams at about 300 feet. As these numbers were averages generated from data acquired from alerted subjects, it would be appropriate to reduce these detection distances by 50 percent for unalerted drivers. The authors conclude by recommending that pedestrians walk facing traffic and wear light colored or reflectorized clothing. It should be worn below the waist since low beam headlights illuminate the legs first.

b. Windshields

The importance of liquid glass tints on driver visibility has been examined by Allen and Crosley in a 1965 article. Two automobile glass tints were tested for light and heat transmission. An evaluation was made of the visual limitations imposed by various tint concentrations and the glass area to which this tint should be applied. Recommendations regarding tinted windshields are that no windshield should be tinted in any area which might interfere with the driver's vision of the roadway; also, the tinting of side windows should allow at least 50 percent visible light transmission. Rear windows should not be tinted, and the above recommendations should be legally enforced.

Haber (1955) studied the effects of tinted automobile windshields upon visibility distances on the highway at night. The loss percentages in visibility distances caused by replacing clear windshields with tinted were calculated as functions of the variables involved, viz., transmittance of the tinted optical medium, isocandle profile of the headlamp, angular size and reflectance of the target. The loss percentages in visibility distances were dependent upon the distance of the target itself, with the losses increasing with decreasing distances. Losses in visibility distances caused by commercial brands of tinted windshields amount to between 9 and 15 percent at visibility distances ranging between 1000 and 200 feet. The analysis shows further that the losses in visibility distances are greatest for targets so nearly matched to the background that they may be seen even with clear windshields only at short distances. Under these conditions the losses may be as high as 30 to 45 percent.

The effect of surface deterioration on automobile windshields was also examined by Allen (1969). Thirteen used windshields from General Motors automobiles were randomly selected for test. Code monograms on each indicated they probably were the original equipment windshields. Photographs were made through each of the scattered light surrounding automobile headlights. Damage from windshield wiper action seemed to be related to miles of travel. Damage from hand cleaning and ice scraping operations was unrelated to age in this small sample. Pitting from small high velocity particles also showed up. On a subjective rating scale, 8 of the 13 windshields were judged to be damaged enough to cause a noticeable increase in glare, especially at night, and to warrant consideration of replacement with a new windshield. Four were judged to be unsafe for night driving.

3. Traffic Environmental Origin

The factors influencing wet weather accidents are complex, a fact sometimes ignored during the current popularity of blaming low tire pavement friction for most wet weather accident problems. A factor of significance is visibility, as influenced not only by rainfall intensity but to a great extent by traffic speed. A report by Ivey et al. (1975) presents a number of direct visibility observations and develops a framework useful in interpreting these data to determine the influence of reduced visibility on the operation of motor vehicles. Information from the literature shows the low probability of high intensity rainfalls. Conclusions concerning the hazard of passing maneuvers during rainfall of one inch per hour or more, and the need to reduce speed under wet weather conditions, are also presented. Specifically, visibility of an on-coming vehicle is greatly extended for an opposing driver if the headlamps of the on-coming vehicle are on low beam. At present, there is no consistency between different states with respect to headlight display during wet weather.

E. Conspicuity-Enhancing Approaches

Considerable research data have been generated in the last fifteen years regarding methods and materials for enhancing the conspicuity of pedestrians, bicycles and bicyclists, motorcycles and motorcyclists and traffic control devices. Research offerings in these areas dealing with both daytime (principally fluorescent materials) and nighttime (principally retroreflective and active light sources) conspicuity enhancement are discussed below.

1. Pedestrians

Richards (1961) in a comprehensive field experiment to determine which daytime color is least confused with a "white tailed" deer used subjects from Fort Devens, Massachusetts. Silhouettes were used as visual targets placed in several different locations in the woods and field environment. Several thousand soldier subjects made 22,346 observations of targets during early fall with colored leaves, late fall with bare ground and during the winter with snow cover. Standard red, standard yellow, fluorescent yellow, fluorescent orange, fluorescent red and conventional white hunter's vests were used. Subject recognition was tested along a 2.5 mile trail in typical deer hunting territory. Error scores were recorded in daylight ranging from good afternoon lighting to too dim for hunting. The results showed that the fluorescent orange was easiest seen and recognized as a bright "unnatural" color. Standard reds were seen to almost disappear under poor light. Yellow was observed to appear white early and late in the day. Blue became confused with shadows. Greens and reds were often not seen or confused by people with partial color blindness.

Six colors (white, yellow, fluorescent yellow, fluorescent orange, fluorescent red-orange and fluorescent red) were compared by Michon, Eernst and Koystaal (1969) to determine which was to be recommended for safety clothing for people who work on or near the road. It was found in a variety of circumstances that fluorescent orange is advisable. Non-fluorescent yellow was found to be better than fluorescent yellow. Fluorescent red is at least as good as fluorescent orange for people with normal color vision but may be compromised when viewed by people with defective color vision. White is significantly worse as a safety color than any of the other alternatives, and should not be used without an additional colored surface. Little effect was found from some simple designs (e.g., a chevron) nor does it seem necessary to dress a man fully in fluorescent clothing. A 30-cm wide band around the body was recommended as sufficient.

Allen's (1970) study of pedestrian self-perceived visibility involved analysis of over 1,700 observations made on the road at night involving actual pedestrians and cars with low beams to test three aspects of pedestrian visibility. Of 26 pedestrian observers, ages 18 to 35, the one pedestrian most pessimistic about his visibility closely estimated his true visibility of 175 feet. Each of the remaining 25 pedestrians estimated his visibility to be up to three times farther than it actually was. The average pedestrian thought he was visible at 343 feet. Actual pedestrian visibility was enhanced from about 175 feet for normal dark clothing to about 790 feet by using reflectorized clothing. In the presence of headlight glare, black clothing was seen at about 167 feet while the reflectorized clothing was seen at 680 feet. The clothing was reflectorized with a one-inch fabric tape outlining the collar and wrapped around the sleeves. The reflectance of the tape was 50 candles/ft^2/ft candle of incident light.

Richards (1970) presents a consolidated review of research relating to vision at levels of night road illumination published over the three-year period from 1967 to 1969. Among the more interesting findings was a study on pedestrian visibility given varying contrast and headlight beam misalignment which showed that silhouette is no help within about three feet from the edge of the road. He recommends requiring self-protection for the pedestrian. Retroreflectorization of helmets for motorcyclists is recommended. Regarding color protection, daylight fluorescent orange is recommended for the protection of pedestrians.

Silhouette effects in night driving were investigated in a series of experiments by Gunnar and Rumar (1971). Two stationary opposing cars standing at given distances from each other were used, these distances (100 to 400 m) being determined by previous experiments. On the area between the cars "iso-silhouette" curves were measured using a special method for a number of silhouette relevant conditions. Factors favorable to pedestrian silhouette effects were found to be: narrow road, short distance between the cars, high road surface reflectance, inner bend, the driver's eyes being high above the road, particles in the atmosphere, and a large spread of the meeting headlight beams.

In a simulated roadway (large building interior) in dark static conditions, the problems of driver "detection," "recognition" and "attention" were examined by Austin, Klassen and Vanstrum (1972) using pedestrian targets with various retroreflective treatments, black, gray and white targets. Static area targets were displayed at 550 feet in dark conditions with low beam headlights. The authors concluded that the approximate area available for reflectorizing a pedestrian was about 981 square inches head-on and about 675 square inches from the side for an adult. Objects of much larger area such as road signs achieved attention getting subject ratings with a given reflective sheeting because of the area advantage over the same material used on a pedestrian. The authors contend that area reflectorization of pedestrian figures provides shape information which contributes to appropriate judgments of pedestrian speed and distance by drivers. Also, it was clear that a pedestrian dressed in "normal" clothing on the roadway cannot be seen adequately on the roadway by a driver with normal vision.

Lewis (1973) examined children's use of aids for conspicuity in the context of the introduction of British Standard Time in 1968, which was the occasion for extra effort to encourage children to wear conspicuous clothing. The opportunity was taken to study factors such as attitude, social class, age of child, etc., which were thought to influence the wearing of aids to conspicuity. In some schools specific items of clothing were made available to 5 to 11 year old children including reflective/fluorescent armbands, dangle tags, bibs, jackets, badges and patches. In other schools children were advised to carry flashlights or wear light colored clothing. From questioning children, parents and teachers, the following results were obtained:

- Children not accompanied to school by an adult tended to wear protective items more often than those who were accompanied, with unaccompanied girls surpassing the boys.

- Children who had to cross "dangerous" roads wore conspicuous materials more often than those who did not have to do so.

- Children travelling to school by car were less likely to wear protective items than those who walked.

- Few children below the age of six objected to wearing any of the materials; children in the higher elementary school grades were less ready to wear the materials.

- More girls than boys wore protective items with the proportion of boys wearing the materials decreasing with increasing age.

- The percentage of children wearing protective items was slightly greater for children who had to make longer journeys to school.

- The type of items used rank ordered from most frequent to least frequent were: armbands, jackets, hats, bag/satchel, belt, scarf, hankerchief (pinned to clothing), dangle tags, gloves, flashlight.

Lewis concluded that more promotional efforts needed to be directed at parents, rather than school officials, to encourage children to use the materials.

A study by Utech, Fourt and Hollies (1974) discussed conspicuity aspects of the firefighter's turnout coat. The performance requirements for a firefighter's turnout coat are broken down into five major categories: hazard protection, comfort, durability and wear, appearance and visibility, and other requirements. Appropriate test methods for measuring each performance requirement are identified and discussed. The design and performance of present turnout coats are evaluated in terms of the performance requirements. Included in this category are color, visibility, ease of cleaning and colorfastness. Black remains the most common outer shell color for turnout coats in use today. Recently, there has been a trend toward other colors, particularly yellow. Arguments in favor of yellow are superior infra-red reflectance and greater visibility. There is no generally accepted test method for evaluating the visibility of three-dimensional objects under defined lighting conditions. There have been reports of tests in which turnout coats of various colors were illuminated by automobile headlights and their relative visibility judged by observers positioned behind the lights. These tests produced the expected conclusion that yellow and white coats are more visible than black or red coats. An alternative solution to the problem of visibility is the strategic placement of reflectorized tape. Most departments already specify the sewing of such tape around the bottom of cuffs down the front opening and across the back of coats.

Rumar (mimeo) studied requirements for a freely hanging, string-suspended retroreflecting device worn by a pedestrian (dangle tag). He states that a functionally efficient retroreflector must satisfy the requirement that, worn by a pedestrian in real nighttime traffic, it can be seen by a car driver at a distance of at least 125 m in a passing situation when both cars have dipped headlights. The retroreflective material itself must show a coefficient of retroreflection of at least 5 cd/lx/m^2.

Solomon (1974) in an article on fire fighter visibility, offers the following conclusions drawn from previous research:

> Greenish (lime) yellow is the best color to use in daytime.
>
> White or silver is the best color to use in the dark.
>
> Fluorescent colors are the brightest colors under daylight conditions. Greenish yellow is the best fluorescent color (considering the basically dark background in which fire fighters work).
>
> Fluorescent material is totally ineffective at night.
>
> Retro (reflex) reflectors are the best nighttime materials.
>
> The best material of all is one which is fluorescent greenish yellow by day and a white reflex reflector at night; such a material is commercially available.
>
> Retroreflectors can be seen only when viewed along the light beam. They do not glow and are not visible when off the light beam axis. They will not act as an attention getter for snipers.
>
> A minimum of 232 sq. in. of fluorescent/retroreflective material must be used on the front and on the back of the fire fighter.

The general pattern should be marking on the hands or wrists and feet combined with vertical and horizontal stripes on the coat and including a job identification symbol. Additionally, any combination of department name, number, etc., can be used. The pattern should be standardized throughout the fire service."

Hills (1975) examined the visibilities of a pedestrian dummy and disc objects of varying size and contrast under dynamic night driving conditions on an unlit open road and in a road lighting situation for which the average pavement luminance was 0.8 cd/m^2. The visibilities of the objects could largely be described by a standard luminous increment-visual area characteristic. Under road lighting conditions, negative contrasts (silhouette vision) were found to give slightly greater visibilities than positive contrasts. It was found that a contrast multiplier of four was required in applying laboratory 50 percent probability of detection thresholds to a "just visible" criterion level of visibility in the field experiments, though in practical conditions contrast multipliers as large as 30 may be required.

The relative conspicuity of various colored and patterned reflectorized-fluorescent flagman vests was examined in an experiment by Smith and Janson (1976). Observers were asked to rate pairs of candidate vest configurations in operational deployments of flagmen in urban and rural work settings according to which vest was better, based on "... the subjective criteria of attention getting, conspicuity, recognizability, meaning and connotations of danger or hazard." In the daytime and twilight conditions, the fluorescent yellow-green patterned vest was preferred over the following other colors in descending order: yellow, fluorescent red and orange. The non-fluorescent yellow ranked almost as high as the fluorescent yellow-green. In the nighttime urban condition, the reflective yellow pattern was again preferred for its "attention getting" value. The most effective pattern for viewing turned out to be a "Y" pattern rather than an "X" pattern. The authors define "attention getting" as "...being not only bright enough to be easily visible but bright enough to attract one's attention even if not looking at the target." The yellow and red reflective colors were preferred by observers to silver because "...they felt that the silver could be mistaken for on-coming headlights or for fixed lighting in the area." In the rural area, relatively devoid of competing background light sources, the reflective red materials ranked highest. Although silver patterns were most visible, observers commended they could have easily interpreted the silver patterns as on-coming headlights but the red had more "warning" value albeit less brightness.

In tests conducted by Janson (1980), he used fluorescent and reflectorized vests of a yellow-orange color, and showed that brighter vests with distinctive patterns were preferred over others. Daylight tests revealed that a vest pattern which consisted of a double chevron was preferred most while second and third place preferences were given to the "stick man" vest and the fully reflectorized vest. Finally, even though a fully reflectorized vest was the observer choice in twilight, a double chevron pattern is recommended since this pattern is fluorescent as well as retroreflective.

Williams (1980) describes the circumstances under which 60 jogger-motor vehicle collisions occurred. Most of these incidents occurred after dark. Nearly 53% of the 55 collisions studied found the struck joggers to be traveling on or alongside roadways "with traffic." In 24% of the collisions, joggers were proceeding on or beside roadways "against traffic," or facing oncoming vehicles. Risk factors include jogging after dark, jogging with other people, and jogging on roadways in the same direction as vehicles. The study recommends that joggers not run on roads when dark; if they do so, light-colored clothing and reflective materials should be worn. Williams emphasizes that joggers should run against traffic, and should run on the shoulder or close enough to the edge of the road that vehicles in the nearest lane do not have to alter their paths.

In a report of research conducted for the 3M Company on a reflective treatment of entire garments such as jackets, full figure overalls and trousers, Blomberg, Leaf and Jacobs (1981) reported that the reflective treatments increased the distance at which pedestrians are detected and recognized as pedestrians at night. The studies showed that each increment in target brightness produced a corresponding increase in detection distance. Brightness was a more important influence on detection than was total target area. Moreover, anthropomorphism of target shape was shown to greatly aid target recognition. Retroreflective trousers were better than jackets alone and the combination of both was superior to either one. The authors conclude by saying that an outlining of the body shape with the brightest retroreflective material available is the best protective course of action.

Shinar (1981) studied the effects of headlight beams (high and low), glare, and the use of a retroreflective dangle tag by a pedestrian upon the actual pedestrian nighttime visibility distance and the pedestrian's estimate of the visibility distance. It was found that with a dark-clothed pedestrian for each of the visibility conditions studied (high beams, low beams, and low beams + glare), the use of a retroreflective tag approximately doubled the pedestrian visibility distance. Furthermore, the reflective tag invariably made the pedestrian visible at a distance greater than the stopping distance for a car traveling at 90 km/h (about 56 mph). The pedestrian's estimate of his or her visibility distance also varied as a function of the same variables but in the case of high beam it was twice as far as the actual visibility, and when the approaching car had the low beams on it was 1.4 times as far. Only in the presence of glare, the pedestrian's estimate of the visibility distance was on the average less than the actual visibility distance.

2. Bicycles and Bicyclists

The Standards Association of Australia (1978), in examining bicycle conspicuity, states that bicycles shall be fitted with rear, side, and pedal reflectors where at least one red rear reflector is included. Each wheel shall be fitted with yellow side reflectors visible from both sides of the bicycle; yellow pedal reflectors shall be mounted on both sides of all pedals. Also recommended is an efficient bell or some other suitable warning audible device. Reflectors are seen to effectively increase the visibility and safety of bicyclists during the period dusk to dawn. Traffic accident statistics show clearly that the majority of accidents involving bicyclists during this period resulted from the bicycle being struck from the side or rear. For this reason, "AS 1927 Bicycles," which is largely based on regulations prepared by the Consumer Product Safety Commission of the United States of America, includes mounting specifications for reflectors. This standard specifies the colorimetric and photometric performance of such reflectors. These requirements are similar to those specified in the U.S. regulations and the committee considered that these should be the minimum requirements for bicycle reflectors in Australia. In particular all reflectors, except pedal reflectors; must meet photometric requirements for entrance angles up to and including 50 degrees left and right. Many reflectors in use at present in Australia reflect less light than is specified in this standard; this light being reflected within the smaller range of entrance angles of up to 30 degrees left and right.

Stoovelaar et al. (1976) discuss the factors determining the visual impact of a bicycle, and emphasize the relative importance of recognizability as opposed to mere visibility or conspicuousness. A lack of attention to pattern recognition is noted in conventional visual research as applied to traffic problems. The authors contend that the overemphasis on quantitative luminance may lead increasingly to visual noise.

Several light/reflector configurations were investigated under night and dusk/dawn conditions regarding bicycle safety. For the rear view, one effective approach resulted in a configuration to be fastened as a unit to the rear fender which was from top to bottom: taillight (red, with small collector lens in red prismatic reflector); prismatic reflector (red); vertical strip with retroreflective sheeting (yellow). A vertical shape in general was considered more conspicuous than a horizontal shape. Pedal reflectors (yellow) further enhance recognizability ob bicycles in front and rear view. Side-view perceptibility was greatly enhanced by retroreflective sidewall tires.

A summary of the research comparing rigid spoke reflectors to 360° tire reflectors by Kratz (1977) indicates:

- Although brightness per cm^2 of the rigid reflectors is greater than that of reflectorized tires, both materials are recognizable with low beam at a distance of about 200m.
- Reflectorized tires are recognized earlier when entering or leaving a crossing zone than rigid reflectors and provide better range estimates.
- The reflectorized tires of the two-wheeled vehicle turning to the left are superior to the rigid reflectors because of the better wide-angularity of the beaded reflector on the tires.

Watts (1979) conducted a study of the effects of bicycle safety devices on vehicle passing distances. Among relevant findings of his investigation were the following:

- Small but statistically significant increases in average vehicle distances while passing bicycles were produced by all the devices tested. The Swedish flag and Finnish disc devices (a horizontally extended flag/paddle) on average produced the largest effect and did not differ significantly. The fluorescent waistcoat/vest had on average less effect on passing distances and was found to be significantly different from the other two devices.

- Risks in rural areas may be greater than in urban areas.

- The conspicuity of the bicycle and bicyclist when viewed from the rear is increased by these aids and in particular by the fluorescent waistcoat/vest.

Watts (1980) reviews a survey in the UK which has shown that the brightest materials that are available for daytime use are "saturn-yellow" (lime-yellow) in color. For nighttime, good battery-powered or dynamo lights are essential, and are detected at much greater ranges than are retroreflective devices. If a dynamo is used, a standby light should automatically cut in when the bicycle is moving slowly or is stationary. Pedal reflectors or reflectorized ankle bands will help in recognition and provide side visibility for the bicyclist. Spoke reflectors also improve side visibility.

In an article on conspicuity-enhancing devices for bicycles and their proper use, DeLong and Schubert (1980) note than a difference exists in the amount of protection necessary to signal one's presence to a properly attentive motorist, and the amount of protection necessary to be seen by an inattentive, negligent or intoxicated motorist. Particularly useful for early-morning cycling is a flashing light; not particularly useful is the reflector as recommended by SAE. Pedal reflectors are a slight improvement because of their movement and yellow color. However, flashing lights are by far the most effective (or a moving light, e.g., a leg light). A flash rate of at least 50 per minute is recommended. Also of interest is the finding that reflectors mounted at lower levels, including pedal reflectors, perform much better than reflectors located at levels above the rear tire. This is because automobile low beam headlights, used 90% of the time, are distributed lower and to the right than high beams so as not to blind oncoming drivers. The authors contend that, in general, larger, less-bright objects attract attention more readily than a smaller, brighter object. Other factors which detract from reflector performance are: background brightness; the glare of opposing headlamps; the lag in return to full-dark adaptation after headlamps have passed; age; visual acuity and less than 20/20 vision of the driver; raindrops; backscatter of light from headlamps by raindrops or fog; bad wipers; competing lighting from billboards and street lights; distraction from passengers; and drugs and alcohol.

In an attempt to study ways to improve bicycle conspicuity at night, Zwahlen (1981) tested a new approach to the employment of rigid reflex reflectors and the concept of a rear taillight. The author reviewed some important background concepts as well, namely:

- The assertion that a field point source illumination level at a driver's eyes must be at best 1000 times above the 98% laboratory detection threshold level to assure the timely detection of a bicycle ahead of the car. This level is seen as necessary to account for such variables as an unalerted versus an alerted driver, peripheral versus foveal detection, non-uniform background, low information processing workload versus high information processing workload, visibility degradation (fog, rain, dirty headlamps, dirty windshield), driver impairment (fatigue, alcohol, drugs). This level would roughly correspond to a light source of 2 candlepower, 805 ft. away from the viewer.

- The initial detection of a bicyclist ahead on the road will occur more likely in the retinal periphery.

- Numerous field detection experiments conducted at Ohio University show that the lowest detection thresholds were obtained in the fovea and increased in a U-shaped curve into the periphery. All field experiments employed alerted drivers with no competing tasks. Since high visual workload and information processing inhibit the peripheral detection of visual stimuli, field studies dealing with nighttime detection of bicycles must measure both the foveal <u>and</u> peripheral detection capabilities.

- In further elaboration of the 800 ft. detection distance criterion (approximately 10 seconds driving time at 55 mph), the author suggests that an effective 2 cp taillight source on the rear of a bicycle would be required to compensate for some of the inevitably encountered inadequacies of retroreflectors alone.

The results of the empirical phase of this study showed that the detection distances for the "massed" reflectors (two rectangular rigid prismatic reflectors fastened close together 11 inches above the ground, one above the other) were considerably shorter than for the "distributed" reflectors (two rigid rectangular reflectors 20 inches either side of the bicycle's vertical axis and 11 inches above the road), especially when the targets were viewed in the visual periphery. All reflectors used had equal photometric properties. The advantage for the distributed reflectors increased with increasing peripheral angle.

Zwahlen (1981) concludes by saying that the case has been made for the importance of peripheral detection of bicyclists at night. Moreover, he asserts that the study findings indicate that "...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 problem of bicycles at night." Moreover, Zwahlen concludes by saying that:

> "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."

3. Motorcycles

An experiment designed to assess conspicuity vis-a-vis motorcycle helmet visibility was conducted by Hazlett (1969). Twenty subjects made 1,100 judgments in the laboratory on the identifiability of a circle, triangle, square and rectangle of solid and open configurations at low luminance levels. The rectangle was the most identifiable with the triangle, square and circle following in order. The open configuration was almost as visibile as the solid which had twice as much reflective sheeting in it. Six subjects made over 360 dynamic observations from an automobile. The various reflectorized shapes were detected at an average of 801 ± 21.4 ft. while the normal white helmet was detected at 243 ± 143 ft. Recognition distance of the open triangle was the greatest, with the open circle, open square, open rectangle, total reflectorized helmet and no reflectorization following in that order.

Olson (1974), in a study of 10,000 motorcycle crashes in Texas in 1975, found certain types of pre-crash orientations much more relevant in motorcycle than in car crashes. The most common configuration involves a straight traveling motorcycle and a left-turning car. Other findings from this analysis were: a) far fewer crashes occur where drivers are wearing bright colored clothing; b) conspicuity problems may not be as serious at night. Daytime conspicuity could be significantly improved by: a) causing the headlamp to modulate at about 3 hz; b) having the headlight on when riding; c) wearing high visibility (fluorescent) garments. The same high-visibility materials, however, do not seem as effective when attached to the motorcycle. Nighttime conspicuity was enhanced by the use of running lights and retroreflective garments. However, these same retroreflective materials on the bike did not seem as beneficial as when used on the motorcyclist.

A study by Woltman and Austin (1975) compares the daylight visibility of two fluorescent and four conventional pigments against representative backgrounds for clear and overcast sky conditions, representative solar altitudes, and cardinal directions. In detection and identification, fluorescents are comparable to conventional high-visibility pigments under optimum viewing conditions; however, fluorescents show a substantial improvement when illumination levels decrease toward dusk or when conditions for visibility are least advantageous. As a result, fluorescent colors are now used for certain safety appliances and devices where particularly hazardous conditions are common. Aspects of night visibility suffer from extremes of contrast, low levels of available light, and ineffectiveness of any conventional color to render objects visible at night. Visual clues are dependent on learned patterns of light sources rather than on natural information acquired from daytime driving. Transferral of visual skills from day to night is substantially inhibited by the widely differing aspects unless some "natural" visual information is preserved. The night factors and materials that tend to visually preserve natural information have long been employed for traffic signs and safety appliances. Their extension to cyclist and vehicular use is a promising means of enhancing rapid night visual comprehension.

The visual area of the motorcycle and rider is approximately a third that of a conventional automobile. The conventional automobile is the size of vehicular hazard to which the motorist most frequently and successfully adapts.

The more frequent failure to correctly cope with the smaller motorcycle hazard might be improved by perceptual aids employing highly visible and contrasting colors such as fluorescent orange in sufficient size to be readily seen. At night, if both motorcycle and operator were reflectorized, depth perception would be enhanced. This increased bright area would communicate relative distance and speed better than traditional motorcycle lighting.

Halstead-Nussloch (1976) discusses the detection failures in terms of three stages of the motorist's sensory/cognitive processing, i.e., detecting the motorcycle, identifying it, and deciding how to react to it. About 30% of all U.S. motorcycle accidents involve the motorcycle conspicuity problem. Motorcycles are more conspicuous at night than during the day. Lighter motorcyclist garment colors tend to be associated with daytime motorcycle accidents, darker colors tend to be associated with nighttime crashes. Among countermeasures which are discussed are five classes: 1) increased luminance or luminance contrast; 2) creation of a color contrast; 3) increase of both 1) and 2); 4) use of a temporal sequence of luminance or color contrasts to encode a special message, e.g., a flashing light; and 5) special measures to deal with night visibility. Conspicuity treatments recommended for daytime evaluation are: headlight on, running lights on, flashing lights, fluorescent orange garments, fluorescent green garments, denim garments, perhaps with fluorescent striping. Recommended for the nighttime are: retroreflective tires, running lights, flashing lights or spoke reflectors, retroreflective orange garments, green garments, denim garments with embedded retroreflective material and striping.

Ramsey and Brinkley (1977) conducted several studies to evaluate commercially available visual signal warning devices as a means of improving the noticeability of motorcycles and riders during daylight conditions. Active lighting systems including revolving lights, prisms, reflectors, and strobes were analyzed. Field data were obtained by mounting a test device on the motorcycle's front fender and then interviewing motorists who passed the motorcycle as it attempted to enter traffic from a side street intersection. Results indicated only 15 to 25% of motorists noticed the motorcycle without a device and that a small, low intensity device on the fender was of no value in improving conspicuity. Two larger, higher intensity devices were selected for subsequent field study, and noticeability was improved over 300% when using either device.

Williams and Hoffman (1979) investigated the detectability of four devices (high-beam headlight, low-beam headlight, a white triangular wind fairing (fitted to the front of the motorcyle to increase its frontal area), and a bright red fluorescent jacket) relative to a standard motorcycle, in both "cluttered" and "clean" visual environments in daylight. A clean environment involved no other vehicles on the roadway near the motorcycle, although there were parked vehicles, trees, shrubs, etc., in the vicinity. A cluttered environment contained other motor vehicles of various sizes and shapes on the roadway, either behind or beside the motorcycle. While combinations of these devices were not tested, it was found that the high-beam headlight was superior to other devices in both environments. Specifically, in order of effectiveness, the devices were ranked high-beam headlamp, low-beam headlamp, wind fairing, and fluorescent jacket. This order was maintained irrespective of background conditions. The experiment itself was conducted in a laboratory where conditions were projected onto a screen to which subjects responded.

Thomson (1980) notes the over-involvement of motorcycles in accidents, and examines the effects of headlights during daytime in reducing accidents. While some U.S. States have laws in this regard, and other places including Australia have recommendations that such a policy become law, a study was made to help a decision as to whether or not the policy should be introduced into New Zealand. Studies reviewed included those of accident characteristics, those concerning daylight, running-light use on automobiles, and those involving daytime light use on motorcycles. It was concluded that compulsory usage of motorcycle headlights should be favored and that New Zealand is very likely to have a benefit-cost ratio exceeding 1 if such a policy is adopted.

A study was conducted by Olson, Halstead-Nussloch and Sivak (1981) to develop and evaluate various means of making motorcycles more conspicuous. More than 30 conspicuity treatments were developed, and the most promising ones were evaluated in day and night tests involving ordinary car drivers on public roads. The tests established which conspicuity treatments effectively deterred motorists from accepting short time gaps. Findings showed that daytime conspicuity of a motorcycle is significantly improved if: 1) its normal low-beam headlamp is turned on or 2) its high-beam headlamp is turned on and is modulating in intensity three times per second or 3) the motorcyclist is wearing a high-visibility (fluorescent) vest and helmet cover. Nighttime conspicuity is significantly improved when the motorcycle uses additional running lights or the cyclist is wearing a retroreflective vest and helmet cover. Given that about three out of four motorcycle accidents occur in daytime, one major conclusion drawn from the study is that the most effective means of improving daytime conspicuity (considering performance, cost and cyclist convenience) is to require motorcyclists to drive during the day with their low-beam headlamp turned on. Additionally, high visibility materials when worn by the motorcyclist were more effective than when fitted to the motorcycle. The authors surmised that treating the motorcyclist is superior because a motorcyclist's size is readily understood by drivers when making distance judgments and that the size of a motorcycle or fairing is not as well understood.

4. Bicycles and Motorcycles

Two studies by Burg and Beers (1978) were conducted to test the relative effectiveness of prismatic retroreflectors and retroreflective sidewall tires in increasing the nighttime conspicuity of bicycles and motorcycles. Pure detection distances were primarily dependent upon the absolute luminance values of the stimulus objects (reflectors or tires) with prismatic reflectors being superior from a pure detection standpoint. Reflective sidewall tires, however, were found to be superior to prismatic reflectors in aiding recognition of a bicycle or motorcycle in a simulated rural intersection with common nighttime visual clutter and also were of greater value in identifying the direction of movement of these vehicles. The findings suggest that standard amber and red reflectors in bicycles and motorcycles are inadequate to provide an oncoming motorist with a safe stopping distance and that shape cues can greatly enhance luminance in providing adequate advance detection and recognition.

A study by Watts (1980) used a peripheral detection technique to evaluate bicyclist clothing and attachments. In daylight conditions, the aids evaluated were a fluorescent orange cycle spacer pennent (area $.01m^2$) mounted horizontally on the rear off-side, a diagonally black striped fluorescent yellow panel (area $.06m^2$) mounted vertically below the handlebars, a fluorescent orange cycle helmet, a fluorescent orange vest, a fluorescent yellow vest, a fluorescent orange jacket, a non-fluorescent yellow jacket and dark blue jacket. In daylight and under overcast sky conditions, the shoulder and sleeves of the jacket were five times brighter than the front of the jacket. The top of the hat was about seven times brighter than the jacket. Thus, for maximum conspicuity, high visibility materials should be placed in these highly illuminated regions. Jacket styles are therefore preferable to vest styles. The yellow jacket was more visible against the dark background than the dark blue and fluorescent orange jackets because of greater luminance contrast (not color contrast). Watts concludes that visibility is not always improved by wearing bright clothing per se. The actual advantages to be gained over darker clothing are critically dependent on the contrast of the background. Regarding color, the most readily detectable one against a dark background using peripheral vision was found to be a fluorescent yellow jacket, following by a non-fluorescent yellow jacket.

Nordisk Trafiksikkerheds Rad (1980), a multi-national working committee (Denmark, Iceland, Finland, Norway and Sweden), makes several observations regarding the visibility of bicycles and other two-wheeled vehicles. It is stressed that bicyclists are a very accident involved group and that the most common collisions are struck from the rear end, struck while going straight through an intersection and struck while turning at an intersection. Therefore, bicycles should be equipped with both lights to the front (which illuminate the road ahead) and rear of the bicycle and reflex reflectors to the front, rear and both sides, as well. Regarding lighting systems in use, the committee felt that front and rear lamps should be designed to provide better dispersion of light sideways.

In addition to the front, rear and lateral (tire or spoke) reflectors recommended in addition to a lighting system, a so-called "visibility stick" is also recommended (no further explanation). To achieve 360^{o} visibility, the various reflex reflectors must be effective in wide sections (i.e., wide entrance angle characteristics). "Nordic" standards for rigid and flexible pedestrian reflectors have been established with which manufacturers are voluntarily complying. A "Finnish" standard for bicycle reflectors has achieved good voluntary compliance with manufacturers.

The committee believes that all helmets for the moped and motorcycle drivers should be treated with retroreflective material.. The group also stresses using retroreflective materials in the protective clothes often used by moped and motorcycle drivers. Location of retroreflective materials on the wrists and/or hands is particularly recommended for the drivers who have to show turn signals with their hands.

The committee concludes by indicating that adequate levels of visibility enhancement can be achieved via the development of proper standards and subsequent cooperation with trade associations and manufacturers to assure compliance.

5. Motor Vehicles

Allen (1965) conducted a study on daytime running lights for automobiles. Based on questionnaire results sent to 181 companies that were known to be using running lights in 1964, Allen concludes that use of a single 21 cp light in city driving in Indiana is associated with a real reduction in accidents per mile of travel.

Evidence does not precisely indicate, however, whether the improvement is due to increased vehicle visibility or due to non-visual factors such as increased safety consciousness of the drivers.

In his discussion of "vehicle visibility problems," Allen (1966) notes that peripheral vision detection sensitivity is most acute for moving objects. Running lights both front and rear have been shown to reduce accidents. Allen also notes that, with buses, the use of a reflectorized strip five or ten inches wide outlining the rear, front and sides of the bus would serve the same purpose almost as well as total surface reflectorization. Daytime use of fluorescent yellow or orange yellow (not red) is recommended. On school buses, the signal arm should be lowered to driver eye level or below; it should be reflectorized, painted with fluorescent paint and include the word "stop" as well as carry a bright red light of 1200 to 1500 candle power shining both to the front and to the rear. For emergency vehicles, fluorescent yellow or orange paint should be used for daytime protection and extensive use of reflectorized tape in yellow, orange, or white should be applied for nighttime visibility. Lights mounted to light the sides of the vehicle and the roadway around the vehicle will increase its conspicuity and reveal its nature quite effectively. Again, red lights should not be used for various reasons. As many people are red deficient in their vision and the distance perception of red is not accurate, all vehicles should have forward-facing lights which should be white, and rear-facing lights which should be a blue-green. Orange-red brakelights should be above the green running lights and separated from them between three and six inches. The flash rate of turn signals should increase from the one to two per second currently in vogue to five to nine flashes per second.

Crosley and Allen (1967) criticize the rear signals of autos, trucks, and buses as being obsolete and deficient in lamp placement, light distribution, light output, reliability, freedom from damage and dirt, and lack of standardization. It is recommended that taillights and reflectors allow following drivers to detect the presence, speed and location of a moving or stationary vehicle at night at distances comparable with those possible during the day. Rear lighting should also convey to the following driver what the preceding vehicle is doing. In a study of the influence of changes in apparent brightness of taillights, changes in their apparent area (size), and changes in the apparent distance between the two lights, the separation (visual angle) and brightness cues were found superior to the area cue. The authors recommend floodlighting to augment the present truck and bus rear lighting. Also suggested is a system (such as directed air) to reduce the normal accumulation of dirt, mud, snow, etc. on the rear lights. The entire rear of trucks and buses, in fact, should be lighted, thus improving the distance and differential speed judgments by a following driver.

Allen (1968) has criticized the poor visibility of the rear of commercial vehicles on our highways, and recommends white or retroreflectorized panes be placed low on the rear of the vehicle in order to accurately localize a truck or tractor-trailer. Another option is to use black tread rubber that is retroreflectorized either by putting glass beads in the main tread substance or within the grooves in the tread pattern.

A study of the effectiveness of reflectorized license plates by Stoke (1975), involved distribution in Virginia, of 100,000 sets of experimental reflectorized and 100,000 sets of control nonreflective 1971 license plates at random. The results indicated that there was no statistically significant difference between the number of night rear-end collisions of vehicles equipped with reflectorized license plates and those with control non-reflective license plates. No difference was found in day crashes as well.

The effect of automobile daytime running lights on conspicuity and a brief research history of same is described in a report by Rumar (1979). The utility of daytime running lights for motor vehicles came under consideration in the United States during the 1960's. In the 1970's the idea was again taken up, this time in the Nordic countries. At the present time, Finland and Sweden have compulsory daytime running lights (normally low beam) for cars and motorcycles. Norway is expected to follow suit and Denmark, as well as many other countries, has a similar requirement for motorcycles. A regression analysis of running light effect on accidents in Sweden showed:

- multiple accidents in daylight decreased by 32 percent
- multiple accidents in darkness decreased by four percent
- single accidents in daylight decreased by four percent
- single accidents in darkness increased by six percent
- overall accident reduction was approximately ten percent

In a study by Horberg and Rumar (1979), peripheral detection distance was investigated using varying levels of running light intensity to increase vehicle conspicuity in daylight and twilight. The results indicated that fainter running light intensities tested of 50 and 150 cd did not reliably enhance peripheral conspicuity in daylight. However, in central vision these intensities increased the subjectively estimated conspicuity. No statistically significant effect on detection distances was obtained by the use of different running light surface areas; nor was there a difference between white and yellow running lights. It was concluded that light intensity is the main factor determining the effect of a running light on vehicle conspicuity.

A study by Reilly, et al. (1980) was a field validation of the effectiveness of an auxiliary high-mounted stoplamp in reducing rear-end collisions. A previous study (DOT-HS-803-467), using taxicabs, found a 54 percent reduction in rear-end impacts to vehicles equipped with the auxiliary stoplamp. The present study used 5,400 telephone company passenger vehicles, half test, half control, which accumulated 55 million miles during a 12-month continuous data collection period. The results showed a statistically significant 53 percent reduction in rear-end impact rate in the test group as compared to the control group. The findings were thus consistent with the previous study on taxicabs.

6. Miscellaneous Vehicles

Federman and Siegel (1973) reviewed several approaches for maximizing aircraft conspicuity. Optimum visibility is dependent on several factors: brightness, contrast, atmospheric attenuation, size and shape of the viewed object, color contrast, and distance between the object and the observer. Colored markings aid inflight detection of aircraft under daylight viewing conditions. High visibility fluorescent hues contribute more to attention focusing and to increasing detection distance than their ordinary paint counterparts. Fluorescent pigments may be found in a variety of materials, but only two are useful for marking the exterior of aircraft--paint and thin film tape (with pressure-sensitive adhesive backing). This study surveyed manufacturers and users of the pressure-sensitive tapes. The thin film fluorescent materials were compared with polyurethane paint and fluorescent paint for marking seven different aircraft types for each of the three different marking schemes, from the points of view of added drag, added weight, and cost/utility. The analysis suggests support for the use of the thin film fluorescent materials on the basis of possible conspicuity enhancement, minimum added weight, no differential drag effects, and favorable cost/utility ratio.

Research conducted by Hopkins (1974) (Federal Railroad Administration) to enhance the visual conspicuity of the trailing end of trains has included guidelines to the optimal form such warning systems should take. Three primary criteria have been identified: high conspicuity, uniqueness and provision of range information. The study recommends the use of clear xenon flash tube beacons, mounted on opposite sides of the car roofline, flashing at a simultaneous rate of between 45 and 75 flashes per minute. The effective intensity is to be greater than 400 candles (not more than 800) at night, and 4000 in the daytime.

7. Traffic Control Devices

Forbes (1964) describes an experimental procedure for measuring the probability that a highway traffic sign of given brightness, color and contrast characteristics can be seen against various day and night background conditions. From the laboratory measurements with this technique, probabilities that a sign will be seen can be determined.

Ohmart and Blackwell (1965) have investigated the influence of location upon the "signal-value" of traffic signals. Data taken in a simulator attest to its general feasibility for the present study, and suggest that the simulator may prove useful in additional studies of the parameters available in the design and proper location of traffic signals and warning devices to be used in urban intersections. In each intersection, one location may be considered "centered" since it corresponds to the center down which the vehicle moved. The other two locations may be considered "off-axis," since they are clearly off the axis of the line-of-sight adopted by the test subject while steering. Each index for each test subject showed superior performance for the signal lights placed in the centered location, when superior performance was indicated by fewer misses and shorter response time.

The effect on traffic flow of distress signals placed near a "disabled" vehicle was studied by Allen, Miller and Short (1973). Both strontium nitrate flares (fusees), and reflectorized triangles were used. Daytime traffic flow was not affected in the presence of signals, while at night the flares were more effective in slowing traffic, in addition to providing light for emergency repairs. Subjectively, the cube corner Tri-Lite triangle was rated as inferior to the 3M Company reflectorized sheeting triangle because the latter was larger (50 cm on the side) and significantly brighter. Allen, et al. warn against the false sense of security that any distress signal may impart to a motorist; the motorist must be trained to the presence of danger in such a situation. Flares gave the greatest protection as judged by speed reduction past and movement away from the disabled vehicle. With flares it was common to have traffic slow below 30 mph and to have an occasional motorist stop to help.

A study of emergency use of highway warning signals by Miller (1975) determined that, during the day, traffic speed passing a non-signalled emergency is not significantly different from that which is normal for the area in the absence of an emergency. However, nighttime shows that the emergency itself, without signal devices, will be responded to with lower than normal driving speeds. The effect of the disabled vehicle itself showed that 32 percent of traffic during the daytime and 27 percent at night veered away from the shoulder.

Differential analysis of signal efficacy showed that pyrotechnic fusees, either singly or in multiples, had a constant and significant effect as a daytime safeguard and a dramatic effect at night. The standard hazard flasher system had a constant and favorable effect, but only at night was it highly significant. Daytime use of fluorescent triangles had a less consistent and less favorable effect. No difference was observed between larger units vis-a-vis smaller units. Driver reaction to nighttime use of reflectorized triangles was characterized by a reduction in speed and higher proportion veering away from the disabled vehicle.

A laboratory study by Olson and Bernstein (1979) was performed to define the effects of luminance, contrast, color and driver visual characteristics on sign legibility distance. At the same time a computer model was developed which could predict the legibility distance of a sign, based on the laboratory data as well as geometric and photometric variables. A field study was then conducted in which legibility distance predicted by the model was compared with legibility distance measured on a number of real and simulated signs using a sample of normal drivers. In general, the predictions were within ten percent of the measured legibility distances. The results indicate that more highly reflective backgrounds permit somewhat greater legibility distances. Reflectorized backgrounds reduce the effect of changes in viewing conditions, which can be quite substantial in the case of nonreflective backgrounds. The contrast provided by the legend is very important. Luminance contrast requirements are lowest for highly reflective backgrounds and increase as background reflectivity decreases.

Godthelp (1979) carried out a field experiment to study the effect of a new type of retroreflective material on the perceptibility of traffic control signs at night. Detection and recognition distance of signs of different materials, with or without illumination, were measured under clear weather as well as fog conditions. Conventional beaded retroreflective material (engineering grade) was compared with the new type (high intensity grade) and with externally illuminated signs. It appears that the magnitude of the positive effect due to the use of high intensity grade as predicted in the theoretical study should be considered as a maximum. Godthelp (1979) concludes that the new material should primarily be applied in areas where signs are to be detected and recognized under disturbed conditions, i.e., against a background with public lighting, under conditions with glare from opposing lights, etc.

An experiment was conducted by Lanman, Lum and Lyles (1979) at the Federal Highway Administration's Maine Facility to examine the relative effectiveness of roadside signs and vehicle signals for warning motorists of the presence of a slow-moving vehicle on the road ahead in a rural two-lane situation. The principal finding was that the use of standard four-way flashers by a slowly moving vehicle is an effective device for reducing the hazardousness of the overtaking situation relative to reaction distance, speed reduction, and vehicle following characteristics. The effects of the roadside signs were positive in the vicinity of the sign placement (out of sight of the slow-moving vehicle), but there were no lasting effects relative to the actual overtaking maneuver.

A field investigation was performed by Sivak and Olson (1981) on the effect of driver's age on nighttime legibility of highway signs. Subjects of two age groups (under 25 and over 61 years of age) participated. The results indicate that legibility distances for the older subjects were 65 to 77 percent of those for the younger subjects with equal high-luminance visual acuity. This finding implies that older drivers are likely to have less distance (and thus less time) in which to act on the information transmitted by highway signs. Consequently, it is argued that: 1) legibility standards for highway signs should not be based exclusively on data obtained from young observers and 2) standard (high-luminance) acuity tests have questionable relevance to nighttime visual performance.

F. Literature Review Summary

A summary of the salient findings of the literature reviewed are summarized in this section.

1. Concepts of Conspicuity

There seems to be a growing consensus among investigators that mere attention-getting properties of an object are not sufficient for a meaningful operational concept of conspicuity in the highway safety environment. An early recognition factor in the "signature" of a pedestrian or bicyclist should be provided that indicates this object is alive, human and capable of locomotion. In addition, any attributes of conspicuity enhancement which can provide the approaching motorist with the location, distance and direction of movement of the pedestrian or bicyclist should be considered within an idealized operational definition of conspicuity.

2. Basic Driver Visual Capabilities

a. General visual/psychomotor behavior

The act of becoming an automobile driver limits, to some extent, the otherwise available visual capabilities an individual has. Door posts and mirrors can obstruct the views of traffic objects. Parts of a motor vehicle may reflect sunglare. Individuals who must use heavy-framed spectacles to drive may also have their peripheral vision limited to some extent. Windshield hazing, abrasion and tint may combine in various ways to reduce the contrast of objects in the traffic environment, as well.

b. Foveal versus peripheral vision

The ability to perceive signal periodicity (flashing, blinking) in the retinal periphery decreases with advancing age (60 years or older). Several studies show a clear capability to alternatively shift attention between stimuli fixated in the fovea and stimuli perceived in the periphery. As attention is drawn to fixated central stimuli, it appears that sensitivity to peripheral stimulus detections decreases.

c. Scanning

In the driving task it appears that the periphery is used to monitor lane position, other vehicles and road signs and the fovea is directed to those situations warranting closer examination.

Less experienced drivers seem to employ more restricted scanning patterns than more experienced drivers suggesting that their visual behavior is necessarily more concerned with vehicle control. The more complex or difficult a visual tracking task is the more frequent and longer will be the related fixations.

Distinctly different patterns of driver eye fixations seem to be associated with the type of road driven at night (rural, limited access, etc.) and whether it is illuminated or not.

d. Flashing and intermittent signals

Flashing light sources are superior in detectability to steady light sources of the same hue and intensity, but should not be overused as they can be confusing and distracting to the viewer. Horizontally flashing light displays seem to be more detectable than vertical displays for the horizontally scanning eye.

Flashing light signals and moving visual objects have low thresholds of detection in the visual periphery.

e. Colored Lights

Some evidence points to a red vehicular marker light in the traffic environment as subject to being misjudged as farther away than it really is. In general, it seems as if red lights can be seen at lower luminous intensities than blue or green. A red light appears to be more readily detected in fog conditions than amber or green. In terms of foveal reaction times, red lights provide the shortest reaction time followed by green and white. Research results tend to indicate that red lights are most conspicuous in daytime (photopic) conditions and blue lights most conspicuous in nighttime/twilight (scotopic, mesopic) conditions.

f. Object size, luminance, shape and contrast

Research evidence suggests that objects are more readily located which differ in color (hue) rather than form. Additionally, objects which differ in color and form are more quickly located than objects which differ in brightness or size. Smaller sized objects should be self-luminous in the traffic environment to be readily seen.

The greater detectability of an object which is being approached in the traffic environment and increasing in size (and brightness very likely as well) is often offset by the loss of "conspicuity" due to increasing angle of eccentricity (offset from the line of sight). At varying angles of eccentricity the human visual system seems better able to discriminate size contrast rather than luminance contrast.

g. Object motion

Some evidence has accumulated that vertical motion is more readily perceived than horizontal motion. Luminance contrast and object motion may operate independently on the detectability of targets. A larger sensitivity "field" exists for the detection of moving objects than for static ones. However, the time to detect a target gradually increases as a function of the target distance from the fixation point under photopic conditions.

h. Information processing and signal detection

Field dependent subjects require more time to process available visual information and are less effective in their visual search patterns. Attention shifts usually, but not always, track eye fixations.

3. Factors Affecting Driver Vision

a. Driver origin

1) General

Reduced visibility at night slows driver response time. Fatigue, which frequently occurs at night, diminishes human visual efficiency. Bright, moving light sources occurring in the periphery tend to induce fatigue and may precipitate sleep. The threshold for discomfort glare may be lowered under a fatigued condition. Fatigued drivers tend to lose peripheral visual sensitivity, and exhibit less efficient scanning patterns with more frequent fixations on the right-hand road edge—seemingly preoccupied with vehicular control.

Increasing age (45 to 50+ years) leads to a progressive inability to focus at a near range while driving, a declining ability to dark adapt and an increased sensitivity to and poorer recovery from headlight glare.

2) Alcohol and drugs

A driver's sensitivity to contrast at low light reveals decreases as blood alcohol concentration increases. Alcohol impairs the detection of peripherally presented stimulus lights coincident with a primary tracking task whose performance is also degraded. Increasing levels of blood alcohol seem to cause attention to be directed toward the central region of the visual field, reducing sensitivity to peripheral stimuli. This impairment may be central or attention-related rather than peripheral or retinal in nature.

Alcohol may also cause an increased loss of visual sensitivity following glare exposure. Visual scanning behavior becomes less active and more fixated near the center of the road in the presence of alcohol.

The ability to detect light signals in the retinal periphery is impaired progressively by increasing doses of marijuana. Marijuana also slows reactions to traffic control devices, pedestrians and stationary vehicles.

3) Glare

The detection and localization of objects in the presence of headlight glare and readaptation following a glare encounter, progressively deteriorates with increasing age (50+ years). Wax residues on windshields can exacerbate the effects of headlight glare.

b. Vehicle origin

1) Headlamps

Daytime use of headlamps seems to encourage better vehicle separation on the highway and more alert drivers. Road film and dirt accumulation on headlamps may reduce the otherwise available light output 20 to 60 percent. Drivers typically do not react to headlight reduction below 60 percent.

Polarized headlighting systems may ultimately provide brighter headlamps with less glare for motorists. Quartz halogen high beam headlights offer a 25 percent increase in visibility over conventional headlamps. However the use of low beams predominates (as much as 90 percent according to some estimates) at night and drivers typically overdrive their low beam headlights in terms of brake stopping distance. Conspicuity enhancement of vulnerable objects on the highway at night, such as pedestrians and bicyclists, therefore, seems essential.

2) Windshields

Over time the surface of windshields deteriorates due to the abrasive action of windshield wipers and road particles so as to increase glare effects for drivers and degrade the optical performance of the windshield.

c. Environmental origin

Clearly smog, fog, haze, precipitation and sun glare are all conditions of the natural traffic environment which can degrade driver vision through obscuration and light-scattering effects.

4. Conspicuity-Enhancing Approaches

a. Pedestrians

There is evidence that for daytime use, a fluorescent "blaze"-orange color is a highly effective conspicuity enhancement, not vulnerable to any problems associated with a common problem in males of red color weakness or blindness. Other researchers have found that a fluorescent greenish or "lime"-yellow is the superior conspicuity-enhancer in daytime (considering 90 percent or more traffic backgrounds are basically dark) from the standpoints of color contrast and apparent light energy in twilight conditions.

Reflectorized treatments of pedestrians at night can raise pedestrian visibility to approximately four times what it would be in dark clothing. This can compensate for the fact that pedestrians overestimate their visibility up to three times what it is in normal dark clothing. Some researchers conclude that area reflectorization of pedestrians aids recognition, speed and distance judgments by drivers.

In regard to retroreflective trim, while white or silver materials are photometrically brighter than colored materials some studies show a viewer preference for retroreflective yellow or red-orange as attention-getting and less likely to be confused with on-coming headlights in a quiet rural environment. As far as retroreflective trim patterns on a safety vest, a double chevron (two V's touching at the points) has been shown to be particularly attention-getting.

In considering area reflectorization of pedestrian garments, it appears that overall target brightness is a more important influence on detection than total target area. Anthropomorphic target shapes greatly aid target recognition.

b. Bicycles and Bicyclists

Research has shown that, in addition to the standard complement of acrylic reflectors presented found on bicycles (front, rear, sidewalls or spoke, pedal), that a taillight (red) plus a yellow vertical strip reflector would also be efficacious. For a strip reflector, a vertical shape is considered more conspicuous than a horizontal shape on a bicycle in open flat country. In the city, vertical shapes lose their effectiveness.

Recognizability is considered extremely important aspect of bicycle/bicyclist conspicuity. Overemphasis on pure quantitative luminance may lead to a highly cluttered visual environment.

Several studies show a greater recognizability for reflective bicycle (and motorcycle) tire sidewalls over the prevalent spoke reflectors. The retroreflective/fluorescent pennants or paddles which extend horizontally from bicycles have been shown to substantially increase the lateral distances at which motor vehicles pass bicycles.

Lower mounted reflectors (below the tire top) perform best to pick up low beam headlight patterns. Pedal reflectors and reflectorized ankle bands and leg lights seem particularly effective in improving bicyclist detectability and recognizability. Reflectorized wrists and hands would accentuate hand turning signals at night.

Several authorities consider a bicycle lighting system employing a forward oriented headlight and a taillight essential for safe bicycling at night and twilight--particularly twilight where the effectiveness of retroreflectors is noticeably compromised by the available background lighting and the inefficient adaptation level of the retina.

Recent research has shown that two horizontally spaced retroreflectors (some 20 inches either side of the bicycle's vertical axis) are more detectable, particularly in the periphery, than two identical reflectors spaced closely above one another.

c. Motorcycles and Motorcyclists

Significantly enhanced frontal conspicuity for motorcycles has resulted from the daytime use of headlights. It also appears that this level of daytime conspicuity enhancement can be further increased by causing the headlamp to modulate at about 3 hz.

Reflectorized open geometric figures, particularly a triangle, on a motorcyclist's helmet were found to be most recognizable at night. Fluorescent orange and green garments, in addition to motorcycle lighting systems, are recommended for daytime use to enhance the visibility of motorcyclists. Retroreflective treatment on the motorcyclists (upper body, helmet) at night is also recommended as the upper body of the motorcyclist is in a relatively vertical position providing a good entrance angle for retroreflection. High visibility treatments to motorcyclists rather than motorcycles seem to have a greater useful effect on conspicuity, particularly target distance estimates. Drivers are likely to be more familiar with the size and shape of a motorcyclist than with various motorcycles.

Though lighting systems on motorcycles and mopeds are highly effective conspicuity enhancers, especially in the daytime where approximately three out of four motorcycle accidents occur, authorities contend that existing systems should have better dispersement of light to the side to provide better lateral protection.

d. Motor Vehicles

Evidence suggests that modest powered running light(s) used on vehicles during the daytime and twilight have reduced city traffic collisions. The nighttime rear-end collision reduction potential of reflectorized license plates, while suggested, has yet to be statistically substantiated. High mounted auxiliary stop lamps have been shown to reduce rear-end collision with so-equipped taxicabs vehicles by 54 percent and 53 percent for equipped telephone company passenger vehicles.

e. Traffic Control Devices

Traffic signals located near the pathway a vehicle will travel ("centered") are more quickly and reliably "processed" than offset traffic signals.

Pyrotechnic fusees appear more effective than retroreflective/ fluorescent warning triangles or four-way flashers during the day or night in slowing or displacing passing traffic.

Factors which appear to positively affect the conspicuity of traffic control devices are:

- larger size
- edge sharpness and contrast
- color/shade contrast
- luminance contrast

In consideration of these factors some investigators conclude that many presently situated traffic control devices are not sufficiently "conspicuous," especially for certain target groups such as older drivers.

III. CONSPICUITY-ENHANCING PROGRAMS

A. Introduction

An overview of conspicuity-enhancing programs for pedestrians and bicyclists is presented in this section. The programs identified were known by the authors to be in effect on or before June 1981. By the term "program" is meant any mass distribution of conspicuity-enhancing materials to the public by any agency in the public or private sector accompanied by a supporting public education program. A conspicuity-enhancing program would, thus, transcend the "normal marketing" of conspicuous materials by manufacturers and distributors.

The programs reviewed fall into two basic categories: domestic and foreign. Some of the programs discussed are currently running or about to recycle. Most have been discontinued or have elapsed. While every reasonable attempt has been made to identify and describe all conspicuity-enhancing programs conducted as of June 1981, it must be recognized that some programs may have escaped detection.

Following the description of domestic and foreign programs, a summary of the program experiences is presented with an eye towards identifying any promising approaches to educating the public on the safety problem involved as well as to means for encouraging use of conspicuity-enhancing materials by the public.

B. Domestic Programs

1. Federal Programs

Since the early seventies, the U.S. Department of Transportation has provided "402" funds to interested and qualifying states in support of conspicuity-enhancing programs—notably the "hot dot" programs for school-age pedestrians described in subsequent sections for several states.

As for direct support of a program, in the late sixties, the U.S. Public Health Service sponsored a promotional campaign entitled "Be Safe, Be Seen" as a means to encourage the use of conspicuous materials by pedestrians at night. In support of this campaign, kits of materials which included "Be Safe, Be Seen" dangle tags (2-3/4" x 1-1/2" reflective tags which were to hang by a string from a wrist or article of clothing), sew-on, stick-on and iron-on reflective trim material for garments and bicycle frames were marketed nationally by the 3M Company. No substantial information has been found regarding the scope of distribution or impact of this program upon public awareness or conspicuity-related pedestrian or bicyclist accidents.

2. State Programs

a. Virginia

In materials received from the State of Viriginia Department of Public Affairs (1974), it was learned that in 1972, accidents involving pedestrians in Virginia were perceived as being on the rise. While public information campaigns had been conducted to reduce automobile crashes, little had been done specifically about autos striking pedestrians in Virginia. Yet, of 1259 persons killed on Virginia's highways in 1972, 248 were pedestrians. And nearly 40 percent of those were killed after dark.

The Highway Safety Division of Virginia and the U.S. Department of Transportation commissioned a study in Virginia to find a new kind of public information program to increase public awareness of the serious nighttime problems of the pedestrian. The principal objectives seen for this public information program were:

- Alert the motorist to be more careful in looking for pedestrians along roadways
- Educate the pedestrian to the dangers of walking at night
- Create greater total public awareness of the pedestrian safety problem
- Reduce nighttime accidents involving cars and pedestrians

Words were not seen to be enough. An "action-education" program was created to make it easier to see pedestrians at night. This was achieved through mass distribution of small (3/4") reflectorized stick-on disks which were developed specifically for the Highway Safety Division of Virginia. These hot dots, with the help of gas station operators, Boy Scouts, 4-H Club members and scores of civic organizations, were distributed during the next 24 months in Virginia, in numbers reaching 8-1/2 million. Hot dots and their pedestrian safety theme were promoted through statewide television spots and interviews, thousands of radio spots, newspaper stories, editorials, speeches and posters.

According to the Virginia Highway Safety Division, Public Information Officer (1974), the following results were achieved:

"• 110,000 Virginia volunteers were actively involved in distributing hot dots. As a result these volunteers became personally concerned with the drive for pedestrian safety.

- Thousands of school children received hot dots for use on books, clothing and shoes. They learned why it is vitally important for pedestrians to be seen at night.
- Nearly every Virginian (motorists and pedestrians) heard or saw the hot dot story through hundreds of newspaper articles and editorials, statewide radio and television spots, posters, and word of mouth.

- Nighttime pedestrian accidents dropped by 50 percent during the hot dot campaign in a four-city test area.

- Throughout Virginia during 1973 pedestrian fatalities were reduced by 20.9 percent."

Moreover, the Virginia Public Information Office (1974) went on to say that:

> "During the winter of 1973-1974, more than 100 million hot dots will have been distributed by states, municipalities, volunteer groups, national guards, schools and private firms. By May 1974, hot dots will be worn by children and adults in the following states:
>
> | | | |
> |---|---|---|
> | Alabama | Michigan | Oregon |
> | Arkansas | Montana | Pennsylvania |
> | Delaware | Nebraska | Tennessee |
> | Connecticut | New Hampshire | Texas |
> | Florida | New Jersey | Utah |
> | Idaho | North Carolina | Virginia |
> | Louisiana | North Dakota | Washington |
> | Massachusetts | South Dakota | Wyoming |
>
> By next winter, it is estimated that the total number of hot dots in use will exceed 300 million. Furthermore, they will be in use in all 50 states."

It is believed that "402" funded hot dot programs never reached the level of all state participation anticipated above and that all but a few ever continued or remain in effect today. In information supplied by the Reflexite Corporation (1980), apparently additional hot dot campaigns were conducted in the states of Alabama and Delaware.

b. New Hampshire

In 1974 a program was initiated to distribute fluorescent red/orange reflective hot dots (3/4" diameter disks with adhesive backing) to kindergarten through sixth grade children in New Hampshire's public and parochial schools. This long-standing program has been active on an annual basis through the 1980-81 school year. The estimated annual costs for the program are about $20,000 according to the New Hampshire Highway Safety Agency. This covered the costs for the distribution of about 1,000,000 hot dots to about 100,000 students and safety literature to their parents in the 1979-80 school year. The literature encouraged parents to encourage children to put the hot dots on their jackets and coats worn during the winter months with shorter daylight hours when the children are frequently on the roads during twilight or semi-darkness.

A 1979 brochure for the New Hampshire Highway Safety Agency states:

> Since the inception of this child safety 'hot dot' program in New Hampshire's public and parochial elementary grade schools beginning in 1974, the annual average death rate amont youngsters has declined from a yearly average of 8.7 fatalities for the four years prior to the program, to an annual rate of 4.0 fatalities during the last six years.

Mr. William Ware, Agency Field Representative of the New Hampshire Highway Safety Agency, in a letter to Dunlap and Associates East, Inc. (1980), makes the following comments about the New Hampshire "hot dot" program:

> Attached is a previous study done on our "hot dot" program covering youngsters from K through 6. Although our statistics include age levels up to 15 years of age.
>
> From 1970 to 1973 were the non-"hot dot" years. We had 35 child pedestrian deaths during these four years.
>
> Enclosure 2 are figures covering the "hot dot" years 1974 to 1977. We had 21 child pedestrian deaths for these 4 years or a reduction of 40%.
>
> To make our figures more current I added the child fatalities for 1968 and 1969 to the 1970 and 1973 figures which were still non "hot dot" years. We had a total of 54 deaths for this 6 year period vs. deaths during the two additional "hot dot" years added to 1977 or adding 1978 and 1979 giving us an extended 6 year time period from 1974 to 1979. We had 35 youngster's pedestrian deaths during this 6 year time period for a reduction of 35.2%.
>
> However, we make no elaborate claims for the "hot dot" as a saver of lives. Too many other variables are involved. If you notice not many young children were killed by cars during the nighttime hours between 1968 and 1973.
>
> Some children who were struck before and after the "hot dot" time period were too young to have received "hot dots" since they were not of school age. Others were beyond the 6th grade level.

> We use the "hot dot" program as a means to acquaint very young children with pedestrian safety and to promote safety around the classroom and in the home.

The interesting safety concept inherent in this hot dot program is that the hot dots have not only "concrete" life and injury-saving potential as conspicuity-enhancers but also are intended to serve as "symbolic" mechanisms to foster and reinforce an overall attitude of pedestrian safety.

c. <u>Connecticut</u>

In communications received from the Reflexite Corporation (1980), in January 1974, the Connecticut General Life Insurance Company distributed 7,500,000 reflective hot dots to Connecticut school children. On or about this time, several hundred thousand reflective sash bands were also distributed to Connecticut school children by the Connecticut Safety Commission. In information received from the Connecticut Department of Public Safety (1981) and the National Highway Traffic Safety Administration (NHTSA) Project Reporting System (1981), it was learned that during the period of October 1979 to September 1980, the Connecticut Department of Public Safety distributed about 1.5 million hot dot reflective stick-on disks and 200,000 brochures to town school systems throughout the state. Letters were sent to the superintendents of school systems asking for their cooperation and participation in the program. For those participating school systems, the descriptive pamphlets and hot dots were picked up at their nearest state police barracks (a cost-saving distribution system). The pamphlet and hot dots were then distributed to principally the kindergarten through fourth grade children who were instructed to take the materials home to their parents who would suggest and supervise the use of the hot dots. The pamphlet also contained a mail-back three item questionnaire on the reflectorization program. Approximately 129 out of 164 Connecticut communities participated in the program. Responses received from parents filling out the questionnaire were overwhelmingly favorable regarding the perceived worth of the program.

No accident data were tabulated or analyzed and no information was available on the estimated degree of use of the hot dots distributed. The Connecticut Department of Public Safety planned to repeat the program during the 1981-82 school year.

d. <u>Pennsylvania</u>

In information provided by the Reflexite Corporation (1980), in September and October 1974, approximately 250,000 reflective sash bands were distributed in the schools by the Pennsylvania Department of Education. This was probably supported by 402 funds awarded the state. No information is available on impact or effectiveness.

3. Commercial Programs

A diverse manufacturing and marketing concern, the Dimension Weld Organization in Stamford, Connecticut, is aggressively sponsoring a national program of reflectorization for school children. In March 1981, a mailing to 16,000 elementary schools was made. It is called a "Street Safety" program featuring a "See-Me Kit" which is in two parts. The first part is an educational approach spelling out safety guidelines for pedestrians and bicyclists—emphasizing the importance of being seen in the dark hours. The instructional package for the "instructor" provides step-by-step lesson plans for teaching street safety. Included also are several practical exercises specially designed for various age groups which reinforce what the children have learned in the classroom. Certificate award cards feature the "Lightning Bug," the program mascot. Posters are also included as visual aids to the lesson plans.

The second part of the street safety program consists of packaged reflective consumer products intended to "...reflectorize your school or group, even the whole community." Each see me kit which is offered at "discount" to program participants contains the following retroreflective items fabricated from vinyl, prismatic Reflexite:

- one "dingle" tag (a pendant reflector)
- one "stic-n-sew" reflective emblem
- six "reflect-o-stics" adhesive figures
- sixteen hot dots adhesive reflective disks

No information on program effectiveness was available as of June 1981.

C. Foreign Programs

1. Norway

Information obtained from the London Sunday Mirror (1980-81) and the Scanflex Corporation, Inc. (1981) has indicated that in Norway, with an estimated population of 4-1/2 million citizens, large banks give away reflective disks (2-1/4") as a public service. Principal among the donors are the large banks such as the Bergeri Bank which distributed 70,000 disks in 1979. Only about one in ten disks distributed are sold over the counter, principally by food stores. Also ten to 15 percent are distributed as premiums. These rigid, prismatic reflectors are intended to be used by pedestrians and bicyclists at night. The pendant reflectors or "dangle tags" are designed to be attached by a pin and some string to an article of clothing and to dangle freely. At least two are recommended for use, one on each side of the body. Thus, they show an attention-getting twinkling or blinking reflection when headlights strike them. It is estimated that under ideal viewing conditions, the disks may be seen up to a half mile away at night. It is estimated that about 1.5 million of these disks are distributed annually in Norway and over 11 million have been distributed to date. According to communications from the Scanflex Corporation, the principal distributor of the disks in Norway, Norwegian hospitals "...report that nine out of ten persons struck down at night were not using the disks."

There is no Norwegian law presently requiring that the disks be worn. However, numerous governmental agencies, including Parliament, strongly recommend usage. There is a performance standard that specifies the minimum amount of reflectivity for the disks. The Norwegian government requires reflectivity testing of all disks to verify that they meet the minimum requirements of the standard. This standard consists of photometric specifications for rigid disk reflectors and for retroreflective trim material which would be affixed to the body or clothing. Collectively these two specifications are commonly referred to as the "Nordic Standard." As such the Nordic standard is a guiding principle in the Scandinavian countries.

2. Sweden

Information from the Reflexite Corporation (1980) reveals that a government sponsored program conducted in Sweden during 1964 and 1965, to encourage pedestrians to wear reflective dangle tags, purportedly (according to U.S. Public Health Service) resulted in a 26.2% reduction of nighttime pedestrian fatalities and a 21% reduction in injuries. According to reports, none of the pedestrians killed at night while the campaign was active were wearing dangle tags.

3. Finland

In several reports reviewed from the Central Organization for Traffic Safety in Finland (Oranen,1976, 1980) the recent national experience of Finland with pedestrian and bicyclist reflectorization has been documented. In Finland use of reflectors by pedestrians is voluntary.

In a study conducted on pedestrian reflector use and opinions during 1979 (Oranen, 1980) involving observations, interviews, and accident surveys with approximately 25,000 pedestrians, the general findings of this inquiry regarding the use of reflectors on roads were:

- More pedestrian reflectors are worn in rural/country (60 percent) locations than in towns (50 percent).
- More children use reflectors than adults.
- The most common type of reflector used was the pendant reflector or dangle tags. Moreover, the pendant reflector was more common among adults than children, while children used more ribbon-type or pattern-type reflectors applied to garments.
- About 15 percent of the population studied placed the reflectors inappropriately (either too high on the body where the visibility is not optimum for drivers using low beam headlights, or worn on the side of the body away from traffic).

- In 1978 12 percent of all pedestrian accidents involved a pedestrian being struck while walking parallel to the roadway. Of these approximately two-thirds (67 percent) occurred during dusk or dark while only less than half (47 percent) of all pedestrian accidents took place in dusk or at dark. Sixty percent of the accidents studied involved pedestrians walking on the right side of the road with traffic and 40 percent when pedestrians were walking on the left side of the road, against traffic. During daylight the accident percentages were nearly the same for each direction of walking. Sixty-five percent of the accident involved pedestrians had walked on the right side of the road in the direction of traffic at dark. For the accident involved pedestrians in dusk and dark, no more than 2.6 percent wore reflectors. On dark unilluminated roads no more than seven percent of the pedestrians wore reflectors. From these data it was determined that a pedestrian walking without a reflector on a dark, unilluminated road faces a risk of a traffic accident 8.5 times that of walking with a reflector.

An opinion survey carried out regarding the use of reflectors revealed the following:

- Sixty-six percent of the interviewees owned one or more reflectors. Slightly over half of the interviewees owned pendant reflectors, about 24 percent owned trim materials attached to garments and footwear and 11 percent used flashlights.

- Women used reflectors more often than men; 72 percent to 57 percent respectively. Women used more of the pendant type reflectors while men used more of the ribbon or pattern type reflective trim materials.

- Thirty-one percent of the interviewees indicated they always use reflectors when traveling at night. The remaining 69 percent indicated that they didn't always use reflectors for assorted reasons, including: 1) forgetting the reflector (34 percent); 2) rarely traveling outdoors at night (25 percent); 3) never acquired a reflector (21 percent).

- Seventy-three percent of the persons interviewed knew the correct way to locate the reflector.

- Seventy-three percent of the individuals interviewed thought that reflector use should be compulsory.

In an earlier study (Oranen, 1976) concerning the use and marketing of pedestrian reflectors, several points of interest are brought forward. The notable sources for obtaining reflectors in Finland are:

- Department stores
- Self-service shops
- Grocery stores
- Drug stores
- Sportswear shops
- Service stations

About 56 percent of these sources had reflectors for sale. In the towns and cities, pedestrian reflectors were best available at department stores and service stations and least available at self-service shops. In rural areas the supply was more uniformly available over the various sources.

The most commonly available reflector was the pendant-type or dangle tag which was not prominently displayed at service stations.

Of the over 2,000 consumers interviewed, nearly 70 percent indicated that they owned a reflector with the pendant-type being most popular. Less than half of these individuals said they always used a reflector at night, one-quarter said sometimes and one-quarter indicated they never used a reflector. Women generally had a more favorable attitude toward reflector use than men and persons under 20 years of age were more positively disposed towards reflector use than individuals over 50 years of age.

Nearly everyone contacted (97 percent) thought pedestrian reflectors were necessary and 80 percent believed use of pedestrian reflectors should be made mandatory.

Tape or emblem treatments affixed to garments were felt to be best suited to children, whereas the pendant reflector was considered best for adults. The pendant reflector was thought to be more vulnerable to damage with children and more likely to tear clothing.

Reflectors, in general, were thought to be unsightly in the case of adults. Every second person interviewed thought that tape and figure reflectors affixed to clothing were "unaesthetic."

Regarding the generally positive views towards pedestrian reflectorization in Finland, the reader should be advised that there are considerably more hours of twilight and darkness in Scandinavian countries, as opposed to the United States because of their northern latitude locations.

4. Switzerland

Information received from the 3M Company (1980) indicated that, as of the fall of 1980, Switzerland was initiating a major pedestrian reflectorization program employing 3M shoe sole reflectors (i.e., adhesive rectangular patches of retroreflective sheeting to be affixed to the sole of a dress shoe just forward of the heel). While more visible to a vehicle overtaking a pedestrian moving in the same direction, these reflectors do present a noticeable retroreflection when a vehicle and a pedestrian are on opposing courses. The Road Safety Institute and the Red Cross are selling and promoting the use of shoe-sole reflectors, supported by public service announcements on television. Over two million of the reflectors have been sold in 1980. In a public survey 80 - 85 percent of the children polled were aware of the shoe-sole reflectors.

5. England

Apparently the intense interest in pedestrian reflectorization, as documented in the London Sunday Mirror (1980, 1981), was sparked by a tragic incident occurring on a dark November afternoon in 1979. A 15-year-old girl was struck on the highway near her home in Fetcheam, Surrey. Her mother, a medical doctor, was on afternoon rounds when she came across the accident and discovered the struck pedestrian was her daughter. She did all she could to save her daughter, but her daughter died two days later. A Norwegian living in London read this story in the Sunday Mirror and was reminded of the well received program of pedestrian reflectorization in Norway. This prompted this individual to contact the Sunday Mirror with the request that this well distributed newspaper support a campaign to encourage pedestrians to use disk reflectors like the ones in Norway. Such a campaign was started in January 1980. The reflectors are injection molded polystyrene, prismatic, two-faced disks approximately 2-1/4 inches in diameter. They are designed to be pinned to an article of clothing on the end of a length of string and to dangle freely—thus creating a "twinkling" reflective return as the reflector rotates.

The thought was that the reflectors would have both intrinsic and symbolic safety value. The intrinsic value would be the heightened visibility afforded the user by the retroreflector. The symbolic value supplied would take the form of an overall increased awareness of pedestrian safety from using, thinking about and seeing the reflectors during both daytime and nighttime conditions. As of May 1981, over 3,000,000 disks have been sold in England.

The principal mechanism for promoting sales and distribution of the disk reflectors has been an intensive and aggressive publicity campaign conducted by the Sunday Mirror to encourage purchase and use of the disks by the public. To coincide with the fall time change when the clocks were turned back on 26 October 1980, the Sunday Mirror declared 27 October 1980 "Glow Worm Day" when the children should wear the disks to and from school during the hours of diminished lighting. In particular, the most successful approach has been to encourage large corporations or organizations to order several thousand disks, with their imprinted logo, and for the corporation to donate/distribute the disks to the public or their employees.

The orders for disks (1,000 minimum) are placed through the Sunday Mirror or the Royal Society for Prevention of Accidents. The orders are filled and supplied via the manufacturers of the disks in Norway. The disks were scheduled for manufacturing in England.

Public support for the so-called glow worm campaign has come from several quarters. From the official/government sector, the major national safety organization, RoSPA has publically supported the campaign. In a letter to the editor of the Sunday Mirror, the President of RoSPA, Lord Kearton wrote:

> "RoSPA has over the years tried several measures to reduce pedestrian accidents and was particularly pleased that the Sunday Mirror has focused attention on the reflective discs, so widely used in Scandinavia.
>
> I am sure that this initiative will assist greatly in gaining the support of British Industry and Commerce. The wide use of the discs can only help to make pedestrians, particularly children, more easily seen by drivers.
>
> Once again congratulations and thank you on behalf of RoSPA and pedestrians of Britain."
>
> (February 17, 1980)

In addition, RoSPA approved the display of the RoSPA seal of approval on each disk.

Prince Charles, in a statement issued specially for the Sunday Mirror stated:

> "At a time when the number of road accidents involving children has reached such horrifying proportions, measures designed to reduce the toll deserve our special support.
>
> I am sure that wearing reflector discs will help achieve this aim, both by illuminating children on the road and by making them more aware of road safety.
>
> I commend the Glow-worm Disc Campaign and the National Glow-worm Day for Schools and hope that they gain the wholehearted support of commerce and industry."
>
> (October 19, 1980)

Finally, Prime Minister Margaret Thatcher issued the following statement:

> "I congratulate the Sunday Mirror on its Glow-Worm Campaign. I hope the children will find the reflector disks attractive so that they will wear them. Many lives may be saved which might otherwise be lost on our roads."
>
> (November 2, 1980)

The public support for the program extended to the world of entertainment, involving numerous supportive public statements and appearances being made by such personalities as the following:

- Lynda Carter, Wonderwoman
- Kevin Keegan, European soccer star
- Peter Adamson, star of Coronation Street
- Roy of the Rovers, star of a weekly soccer comic strip
- Bob Monkhouse, t.v. quiz personality
- Captain Beaky, children's t.v. personality
- The Wurtzels, recording stars
- Larry Hagman, star of "Dallas" t.v. series
- Green Cross Man

The responses from commercial enterprises and governmental agencies regarding the purchase and distribution of the disks have been substantial and diverse to this point. Some of the representative participants and the quantities of disks ordered are listed below:

Organization	Quantity of Disks Ordered
• IBM (United Kingdom)	15,000
• Honeywell Control System	14,000
• Piccadilly Rodeo	20,000
• S&R Driving Service	10,000
• Jersey Post Office	50,000
• Skypak International	10,000
• Cycleguard (Association of British cyclists)	10,000
• Adscene (newspaper publishers)	10,000
• Chequers Chippy (fish and chips shop)	1,000
• Dobcroft First School Parents Association	1,000
• National Westminster Bank	100,000
• Burntwood Town Council from Walsall, Staffordshire	10,000
• Royal Military Police	2,000
• Maclean's Toothpaste	100,000

- RAF Wives Club 1,000
- Oakdale Primary School PTA 1,000
- Ocher Hill Junior School Parents Association 1,000
- Grampion Police Accident Prevention Dept. 1,000
- Mayor of Southwich, London 10,000
- Boston Limited Football Club, Lincolnshire 10,000
- Reed Corrugated Cases 10,000
- Cadbury Chocolate 10,000
- Esso Petroleum, Fawley, Hampshire 10,000
- Co-operate Wholesale Society 50,000

Some of the ways in which the disks have been distributed include being given away to school children, company employees and customers, used as a premium (involving Maclean's toothpaste boxtops), and given away to paper boys and girls and to the National Deaf Children's Society and the Royal National Institute for the Blind. Apparently, over-the-counter, direct commercial sales have not been productive or attempted on any large scale.

Claims thus far made for the safety benefit of these disks are apparently only qualitative. Statements such as a "...dramatic reduction of child pedestrian accidents..." have appeared in print frequently without benefit of substantiating accident statistics.

Moreover, of all the millions of reflective disks purchased, there has been no official estimate of how many disks are being used regularly. The most salient feature of this program of pedestrian reflectorization in England is the apparent high public interest created in the reflective disks in addition to the sale of over three million of the disks. The unrelenting campaign of the Sunday Mirror to encourage the purchase and use of the reflective disks has undoubtedly been instrumental in the apparent success of the program thus far. Moreover, one cannot dismiss the potential persuasive impact of numerous public figures and personalities endorsing the program. It also seems that a large, if not the largest, part of the appeal of the disks is as a "fun"—"everybody is doing it"—kind of thing. The question arises as to whether this kind of motivation is conducive to sustained and appropriate use of the disks.

6. Germany

A controlled study of pedestrian reflectorization was to be sponsored by a section of the German Schutzpolizei. The Scanflex Corporation of Norway has supplied 100,000 two-inch, prismatic, pendant reflectors (dangle tags) to the Schutzpolizei which have in turn been distributed to 100,000 children (ages unknown) in the fall of 1980 with instructions for proper use. The names of the reflector recipients supposedly have been entered into a computer along with a matching population of children's names. For a period of approximately one year the "disk" and "non-disk" populations were to be tracked for traffic accident experience. Sometime during the fall of 1981, the comparative traffic experience of the two populations were to be analyzed and the results made public.

In recent communications received from Werner Kampen (1983), Director of the Schutzpolizei in Detmold, Germany, the following comments were made relative to the distribution and use of the prismatic, pendant reflectors in Germany:

- Pedestrians using the prismatic reflectors can be seen for more than 150 meters on low beam automobile headlights and with opposing headlight glare, whereas a pedestrian in dark clothes may only be seen at 20-30 meters and one with light clothes only slightly better.

- Older people and children were perceived to be the most vulnerable groups of pedestrians needing reflectorization.

- In actuality, about 97,500 prismatic reflectors were distributed to kindergartens, elementary schools and old-age homes in November of 1980. Police representatives distributed the reflectors and at the same time made a presentation of the safety benefits of using the reflectors.

- Dangling prismatic reflectors should be placed between 50 and 60 cm off the ground and allowed to rotate freely to have maximum conspicuity. Fixed attachment of reflectors should be avoided.

- Of the shapes of reflectors distributed, those resembling animals were most popular with children. Heart-shaped or cloverleaf forms were particularly liked by senior citizens. Use of reflectors was perceived to be greater among children than senior citizens.

- In the winter of 1982/83 approximately 40,000 reflectors were distributed. The accident results were reported as favorable—the number of injured children was reduced.

- In closing, the following programmatical summary statements were made:

  - To achieve a noticeable reduction of accidents requires that about 1/3 of the citizens be fitted with reflectors.

- Each recipient must be motivated to carry and use the reflector at all times by personal contact of officials (police, etc.) with the pedestrian.

- Only an oral explanation of the safety benefit of reflectors is not always sufficient; written instructions as a supplement are important for people to take with them.

- Circular, prismatic reflectors have the greatest reflective intensity. Animal and geometric shapes are carried more often, however.

- Media coverage of the pedestrian reflectorization program is important to maximize the safety impact.

7. Japan

While no information has been obtained of any organized, sponsored programs to promote the use of conspicuous materials, pedestrian or bicyclist, it is known that retroreflective accessories for pedestrians and bicyclists are being marketed in Japan. Specifically, distributors of 3M and Reflexite retroreflective accessories and products are known to be operating in Japan.

D. Conclusions

Any conclusions which may be drawn from this overview of conspicuity-enhancing programs are few at this point. Looking at the U.S. experience, it appears that the absence of any conspicuous accomplishments could be attributed to public apathy and lack of awareness of the conspicuity problem as well as a lack of consistent sponsorship and commitment to conspicuity-enhancing programs by all levels of government. With the apparent exception of Connecticut and New Hampshire, the 402 funded hot dot programs of the early seventies appear to have ceased. Why? It is not clear whether it has been public or governmental apathy or uncertainty as to the results (if any) being achieved by the programs. One apparent reason for the continuing activity of such programs as in Connecticut and New Hampshire is that the state governments and the people "like them." Beyond that, it is difficult to say what propels the programs as no scientifically conclusive evaluations of these programs, to the best of our knowledge, have been carried out.

In Norway, Finland and Sweden there seems to be sustained public interest in pedestrian reflectorization with modest public education and no regulatory coercion. The fact that twilight and darkness prevail to a greater extent in these geographical locations (as opposed to the United States) may, in fact, be a self-evident point of public education and interest in pedestrian reflectorization. The apparent success and appeal of the disk reflectors in Scandinavia are noteworthy. The expressed attitudes of the young adult and older Fins favoring disk reflectors over reflective garment trim are also of importance. Three interpretations come to mind. One is the expressed opinion that trimmed garments (sewn-on, stuck-on) are more appropriate for children. Another notion is that attached tapes and patches are often perceived as unaesthetic and do not appear attractive to many people except on uniforms and sportswear. And, finally, from an economic standpoint, trimmed garments are relatively expensive items and several complete changes of clothing would be needed for a reasonable level of protection from day to day, without undue wear to the garment or retroreflective trim.

The program of pedestrian reflectorization in England is interesting from several standpoints. First, the degree to which an apparently high level of public interest in pedestrian reflectorization has been achieved is remarkable. Yes, a strong print media campaign has been waged by the London Sunday Mirror which is acting as the reflective disk ordering agent on behalf of the Scanflex Corporation. Moreover, numerous governmental officials and celebrities have publicly backed the glow-worm program, not the least of which were ROSPA, Prince Charles, and Margaret Thatcher. This kind of high-powered public appeal must have a demonstrated impact on public opinion and perceived importance of the program. The appeal to the public, it must be noted, has not been one of a scientific quantification of the hazards associated with walking at night on the roads, the types of pedestrians involved in nighttime accidents or the magnitude of nighttime pedestrian accidents. Quite to the contrary, the descriptions of the hazards involved have only been very general. Basically, the appeal has been that the reflective disks being distributed are the very ones specified in Norway and doing an apparently good job in Norway. Also, a number of important people think it would be a good thing if everybody used these disks in England, and just as important, for the children especially, is that the disks are seen as entertaining items.

Another important feature of the English pendant reflector program is that over-the-counter commercial sales of the disks are virtually non-existent. The marketing/distribution thrust has been to sell large companies or agencies on the idea of buying the disks and distributing them free with an imprinted logo—thus a form of "public-spirited" advertising. The appeal of this type of motivation seems substantial and to date numerous subscribers have participated to the extent that over three million disks have been sold and distributed to date.

The actual implementation and use of the disks by the English population remain to be measured. A potential shortcoming of the English program, when one considers the conditions under which the disks have been promoted, is that once the novelty wears off, many people will simply forget or not bother to use the disks.

Quantitative accident data, as a measure of effectiveness for the German Schutzpolizei pedestrian reflectorization program, are apparently not presently available. Moreover, any pure, conspicuity-based effect of the reflectors themselves could be difficult to separate from any behavioral impact of the "hands-on," safety education method of distributing the reflectors. Notwithstanding the foregoing comments, the Schutzpolezei reflectorization program appears to be well received by safety officials and the public. That pedestrian reflectors have become part of the traffic picture in Germany, as Kampen (1983) has indicated, more than suggests that the opportunity for, if not the realization of, improved nighttime pedestrian safety now exists.

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