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QUANTIFYING THE NIGHT DRIVER'S VISUAL ENVIRONMENT

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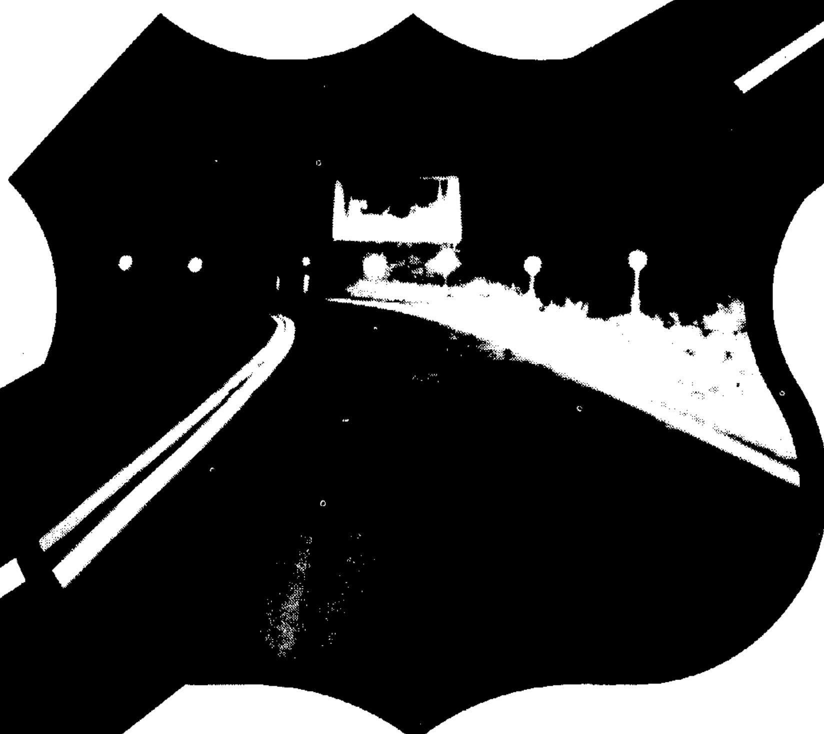

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FEDERAL HIGHWAY ADMINISTRATION
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Foreword

The work reported herein was written as an FHWA staff study by Dr. Richard A. Olsen during a temporary appointment with the Environmental Division, Office of Research. The study was developed to explore new areas for research relating to the visual guidance of drivers at night on the highway system. This review of selected literature was conducted during the period of June through August, 1979.

for D. Solom
Charles F. Scheffey
Director, Office of Research

NOTICE

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16. Abstract

The complexity of a driver's tasks in safely and efficiently utilizing the highway system is largely dependent upon the inputs presented to the visual senses. Visual complexity is determined by road geometry; maneuvering of other traffic; adjacent land uses; pedestrian activity; weather; traffic control devices, lighting, and maintenance of the road features; and many other factors. Darkness changes the visual environment by reducing many cues and by adding a few others. Some of these are added for the driver's benefit, some for other purposes, and some are uncontrolled or uncontrollable at least by highway agencies.

In this review of selected literature and research approaches, the objective is to suggest promising next steps toward making decisions on design, selection, and provision of aids to drivers for night driving.

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Quantifying the Night Driver's Visual Environment

Richard A. Olsen, PhD.*

A. THE PROBLEM

The complexity of a driver's tasks in safely and efficiently utilizing the highway system is largely dependent upon the inputs presented to the visual senses. Visual complexity is determined by road geometry; maneuvering of other traffic; adjacent land uses; pedestrian activity; weather; traffic control devices, lighting, and maintenance of the road features; and many other factors. Darkness changes the visual environment by reducing many cues and by adding a few others. Some of these are added for the driver's benefit, some for other purposes, and some are uncontrolled or uncontrollable at least by traffic operation agencies. It would be useful to have a means of quantifying the visual complexity and the adequacy of visual cues in various driving situations. If a means for specifying the driver's visual needs were available, warrants for the installation of various aids to enhance the flow of traffic could be developed on a more rational basis. Ultimately, a procedure is desired which can determine the cost effectiveness of combinations of marking and lighting techniques for providing and maintaining adequate night guidance information for any specific driving environment.

In discussing warrants for fixed lighting, Walton and Rowan (1974) used the following definition of a suitable night driving environment: "An environment in which there is readily available the visual information necessary for a given driving population to safely and efficiently perform the driving tasks under the prevailing night driving conditions." The definitions of at least five concepts contained in that statement are left to personal interpretations.

Traffic engineers in the various districts or municipalities are faced with professional, legal, and ethical responsibilities for providing a suitable environment. In doing this they are constrained by limited funds and time, and must use readily available data and personnel resources. Complex decisionmaking schemes can only hinder them.

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*This report was written while the author was on a temporary appointment to the Staff of the Federal Highway Administration. The opinions and conclusions are those of the author and do not necessarily represent those of the Administration.

Often they are forced to defend the logic of their decisions to less technically oriented citizens, political representatives, and governmental managers. Anyone who has had experience in the courts with concepts such as the conservation of momentum can testify that incontrovertible scientific facts are apparently incomprehensible to many quite intelligent people, and decisions thus are made which are clearly wrong from the technical standpoint. The technical specialist is often in the difficult position of trying to get non-technical users to follow or accept "unnatural" or "illogical" procedures because the facts are too obscure or complex to be made obvious.

We are faced with a need to grossly simplify one very complex area of human-machine-environment interaction. However, only through simplification will our findings have hope of being implemented to any significant degree. Successful simplification implies the reduction of a complex set of interrelationships to a concise set of fundamental, easily measured variables which continues to reflect the actual situation. The expression must, in addition to being reasonably easy to calculate, provide a reliable tool for making decisions on installation or maintenance of devices, or on major investments for facility redesign and reconstruction.

In this review of selected literature and research approaches, the objective is to suggest promising next steps toward making decisions on design, selection, and provision of aids to drivers for night driving. Many specialized areas are touched upon, and many generalities are made. Some of these generalities presumably are unwarranted and can be corrected or modified by those more expert in that topic or more familiar with the complete literature in that specialty. This is assumed to be part of the process: a good hypothesis (assumption) is one that can be disproved quickly and decisively, making way for a more accurate one.

B. BOUNDARIES ON THE PROBLEM AND THE GENERAL APPROACH

1. Analytical Approaches and Gestalt Perception

Most past attempts at modeling of and providing for the visual needs of drivers have been attempts at engineering solutions to problems which are deeply rooted in the science of psychology. With tongue in cheek, science can be described as piecemeal attempts to make sense out of isolated facts, while engineering is the attempt to make something work based on assumptions and approximations. In spite of this they both contribute to each other and to public benefit generally. But good engineering is limited by lack of specific scientific understanding and prediction.

Visual perception is the result of a number of non-additive factors. The simplest demonstration can provide highly polarized arguments on how and why: observe one light flashing on and off in the dark at a distance. Add a second flashing light next to it and there are two lights flashing. But alternate the on and off phases of the two lights and people generally "see" one lamp swinging back and forth, even though they "know better." Add a third flashing light and a variety of things can happen but the "swinging" probably stops.

Models of visual perception attempt to combine a few visual variables and predict the perceptual outcome. Limited success has been achieved in specilized cases, but as attempts are made to include more variables or wider ranges of variables, the successes become fewer. Perception is the outcome of complex, non-rational, nonlinear sensory systems and biased information processing systems with a quantity of unknown inputs and transfer functions. The fact that some things can be explained is remarkable; that most cannot is inevitable.

Perception is a Gestalt--a whole or construction or form--and the analytical approximation will remain gross as long as any small number of variables are examined. The variability across individuals defeats attempts to reduce a complex visual input to exact values. For this reason the diagnostic teams and professional judgments will remain as useful decision tools for some years to come. The question at hand is to what extent these decisionmaking processes can be aided or supplemented by new tools (e.g., measurements or checklists) or useful approximations (e.g., models or formulas).

2. The Number and Ranges of Variables and Their Interactions

In the search for a technique for determining when and to what extent a given environment or situation is adequate for nighttime driving, it immediately becomes apparent that there are many variables within several topic areas that must be specified before any metric can be applied. Some of these topics are:

a. In what weather--dry, wet, fog, ice, rain, etc.

b. On what roadway--geometric design elements, design speed, access, condition, etc.

c. Under what operational conditions--following, crossing, or meeting vehicles, heavy or light traffic, the presence of trucks, etc.

d. In what visual environment--urban, busy, rural, quiet, commercial, built-up, mountainous, wooded, etc.

e. For which drivers--"average," all, worst, best, typical, "design driver I," etc.

Eventually it might be possible to handle all combinations in a well-developed method, but for now, limits or boundaries must be set. Not only does each topic have a series of variables which can cover broad ranges, but any variable may interact with one or many of the other variables.

Weather has a strong impact on driving visibility and on the skill needed for safe driving. Wet roads are overrepresented in accidents (Smith, 1976) and the differences in visibility supply and visibility demand (Walton and Messer, 1974) between wet and dry roadways are complicated in large part because of the decreased atmospheric transmissivity (Middleton, 1952) caused by rain. Even fog, snow, ice, and other common and potentially devastating conditions are beyond the scope of this search. Since some roadways are "wet" about half the time they are in use in many areas (P. Gordon, 1977), this complicating factor must be retained in any practical technique. Few if any methods used for assessment of dry roads can be extended to the wet condition (P. Gordon, 1977). Even the definition of wet is elusive in a practical sense (but see CIE, 1978).

Roadway type or section is another variable which has a broad range of specific demands and visual characteristics. The easiest to describe (because they were designed to control the information flow) is the rural freeway. The harder types are the commercial arterial and the two-lane rural roadways where interest is greater because the accident and severity rates are much higher. The types of roadways most likely to be given low priority in this kind of study are the central business district, urban and suburban residential, and perhaps the rural controlled-access roadways. The remaining types present enough of a challenge.

The operational conditions of roadways vary on several dimensions. Some of these are discrete, like one-way versus two-way or number of lanes, but many are continuous, like traffic volumes, vehicle mix, or speed distribution. Any metric must have a reasonable number (preferably 10 or less) of variables which are easily measured (counts) or easily classified (up to about 5 categories). Attempts have been and are being made to use such variables in models for various purposes; none has approached the visual environment very successfully so far, but several (e.g., Bhise, Faber, Saunby, Troel, Walunas, and Bernstein, 1977; Allen and McRuer, 1977; Olson and Bernstein, 1977 and 1979) have made some progress. This progress has been concerned primarily with describing in each particular model one very limited aspect of the overall visual problem. These models utilize many simplifying assumptions which reduce their complexity but also limit their usefulness. Typically, such investigations use alert drivers who know where and what to look for: uniform background, dry, clear weather, etc.

The physical environment near the roadway largely determines the visual characteristics of each road section. The visual characteristics of a given location usually are more variable than design or geometric features of that type of road, but less variable than the operational factors. The wide variety of backgrounds or visual contexts (e.g., Woltman and Youngblood, 1977) used in previous studies precludes comparison in any but the most general sense (Brown, 1976). Depending on the general quality of the road, any lights and objects adjacent to the road have more or less potential to influence the driver. Higher design standards tend to push such influences away from the driver's line of sight, but commercial pressures to attract the higher volume of drivers to some extent compensate for this distance by increases in conspicuity of the signs and objects. (The colloquial meaning of "conspicuity" will be used until a later discussion elaborates on the concept and its implications.)

The remaining topic from the list of variables given at the beginning of this section is the driver. It is not possible to design all roads (or any road) to meet the needs or capabilities of all drivers (e.g., Alexander and Lunenfield, 1975; Walton and Rowan, 1974). Several groups, notably several committees of the Transportation Research Board, have discussed (and postponed) the formulation of a set of specific characteristics which might constitute the "design driver." Of course there may be many design drivers, one for each type of facility or function (and implicitly there is one in every design, though the characteristics are seldom spelled out explicitly, and, even less often, justified empirically). Brown (1976) has made a good first step toward defining a design driver by summarizing several major characteristics which have already been adequately measured. When a design is tailored to a specific set of human capabilities and limitations, persons whose characteristics deviate from that set are likely to be poorly accommodated. When this set is not made explicit, an inconsistent or compromise result may follow because certain assumption are met while others are not; there is no explicit examination for incompatible or antagonistic conditions. Thus, at least one set of design driver specifications is desirable for visual task studies. Ultimately at least four design drivers may be necessary for the different types of roadways and driving conditions.

Roadways are not usually designed for a narrow range of uses, nor are they designed for all potential users. Some cutoff values and some acceptable ranges of other values are assumed, consciously or implicitly, by the designers or builders.

Highway lighting has been the subject of a long series of studies which have attempted to make use of estimates of operator and task needs. The Roadway Lighting Handbook (FHWA, 1978) is a recent effort intended to provide practical procedures for selecting and furnishing night driving aids. While lighting is only one alternative, and a costly one in most cases, the handbook concludes that there are no research results currently available which make the decision regarding lighting versus delineation treatments straightforward and objective.

3. Research Measures and Practical Measures

While there are a few States and municipalities that have extensive computer facilities and routinely use them in operational decision-making, the great bulk of our roadways, especially the lower design roadways on which accident and severity rates are high, are under the jurisdiction of engineers and maintenance groups which have little or no such capability. Measures which are useful in major design projects, research projects, or laboratory studies frequently require evaluation of complex relationships; field measures for decisions on maintenance or improvements in traffic operations cannot.

Much of the work on standardization and measurement of lighting has come from a few laboratories. Among the most influential has been the work of Blackwell and his associates at Ohio State University, but it is clearly recognized (e.g., Blackwell and Blackwell, 1974) that the application of the findings is not always straightforward and is seldom simple.

Progress in instrumentation and small computer technology is being made, however, and new techniques are becoming available for field use. For example, a Visibility Quality Meter (VQM) has been demonstrated (Merritt, Newton, Sanderson, and Seltzer, 1978) which shows the contrast transmittance (modulation transfer) in 256 samples of a visual aperture. This device is simple to use and accurately predicts when an object will or will not be visible to the average observer. While this "average" is not fully specified, the device is similar to a scanning spot photometer and may prove to be a practical tool with some further development.

As indicated previously, decisions in the field must be relatively straightforward, not dependent on numerous measurements and complex formulas. Engineering judgment, the assessment that the majority of experienced, qualified practicing engineers would agree upon, is accepted as a routine evaluation process. This is often supplemented by diagnostic teams or "Delphi" methods* for greater confidence where the number and range of uncontrolled variables is unmanageable by other practical means. A few representative examples of the use of teams in highway safety efforts are Walton and Rowan (1974), David and Norman (1975), Taylor and Thompson (1973), Woods (1972), Segal (1969), and Ogren (1978). While all the observers may agree and be essentially correct, there is no assurance that the optimal solution or the least costly of the alternatives is chosen. Consensus by the using populations is the ultimate criterion, of course, implying some public survey methods may be needed during development of operational criteria.

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* An iterative opinion-assessing process in which opinions are gathered and anonymously fed back to all participants where the range is wide, until a final consensus is achieved.

Intermediate between formulas and the judgment of a single engineer is the checklist or rating sheet from which some form of index can be obtained. An index form of output is especially desirable because it allows the local decisionmaker to set priorities, no matter what the current extent of the problem might be. For example, if an index of 80 is considered minimally acceptable as a target, an engineer with a reasonably good budget and roads which are in good general condition might treat those road sections that fall below, or even somewhat above, a value of 80. At the same time, an engineer faced with a low budget and with roads in poorer condition will treat only those on the bottom of the list--perhaps those with index values of 40 or 50. At the very least, the index values should be measureable by or available to the one responsible for road maintenance, even where financial pressures are extreme.

Without a great deal of evaluation, certain requirements or principles seem to be apparent:

a. The night driving visual environment must be described by some convenient technique to quantify the visual inputs in a small number of reliably distinguishable categories.

b. The quantification technique should not require extensive training, elaborate equipment, or excessive time.

c. The quantification should be possible on spot locations (intersections, shopping centers, etc.) as well as on more homogeneous, extended sections of roadway.

C. VISUAL CAPABILITIES AND LIMITATIONS

1. Specification and Testing of Driver Vision

Drivers set the requirements for visual environments. It is logical, therefore, to stress what is or is not known about visual perception. A clear statement of needs will set a sound foundation for the development and maintenance of cost-effective visual environments.

Traditionally drivers have been tested for central visual acuity and few attempts have been made on a mass basis to assess any of the many other visual skills. The latest guidelines (Milkie, 1974) widely used by driver license examiners suggest 20/40 (4/8 in metric) acuity as a minimum (20/30 or 4/6 for persons with one functioning eye) and a minimum of 140 degrees (115 degrees for one eye) of peripheral field. It is still common for States to require only one vision examination, most often at age 16, though major aspects of vision are known to vary sharply with age (e.g., McFarland, 1960; Davson 1962; Allen, 1970; Brown 1968; Burg 1967a, 1968b; and Henderson and Burg, 1975, Hills and Burg, 1978). This one examinaion often includes only central visual acuity as a criterion for passing, and even that is weakened by questionable procedures and opportunities for cheating by memorization or by substituting another person for the applicant. While the degree of outright cheating and the number of unlicensed and unlicensable operators of vehicles is not known, their presence on the road and the fact that drivers for whom corrective lenses are required officially commonly drive without their glasses, implies that conventional wisdom holds that sharp acuity is not required for driving. Burg (1967b; 1968a) and Hills and Burg (1978) showed that acuity has little relationship to accidents though Hofstetter (1976) has shown that drivers with poor (lower quartile) binocular acuity were highly overrepresented among drivers (over age 19) who reported two or more accidents in 12 months. Dynamic visual acuity (ability to perceive detail on a moving object) was more strongly related to accidents than static acuity or any other test in Burg's data, but even these correlations are low.

More comprehensive tests of vision must remain practical, especially if drivers are going to be reexamined routinely every few years. An automated Mark II Vision Tester has been under development by the National Highway Traffc Safety Administration and is currently undergoing field testing using a short (15-minute) test cycle (Henderson, 1980), although even this is long compared to those now in use.

An independent screening study for visual field was conducted recently by Keltner and Johnson (1978). In a sample of 1,027 California driver license applicants, 5 percent had significant defects in field extent or continuity and even among the 2 percent who had marked losses (were unable to see one-fourth or more of all targets), most people were unaware of having any defect. This screening required only about 2.5 minutes per eye and found defects that probably are related to the risk of accidents involving crossing traffic or pedestrians. This defect rate is no doubt a low estimate since those with known problems would be less likely to volunteer for the test.

Even more pertinent to night driving is the problem of night myopia. An estimated 10 to 20 percent of the driving population (Richards, 1966, 1967) has trouble seeing in the low levels of illumination typical of night driving (Spivak and Olson, 1978). Some of this is due to poorer sensitivity and reduced contrast perception which correlates with age, but much is directly attributable to errors in accommodation which are predictable from a test of resting accommodation distance (Owens and Leibowitz, 1976; Leibowitz and Owens, 1975, 1977, 1978). This distance, at which the eyes focus in complete darkness, varies widely from person to person, appears to be distributed normally, and is independent of other refractive errors. Persons for whom this distance is short (about 50 to 60 cm) will have poor acuity at night; if it is long (over about 150 cm), any correction for day vision will be equally as good at night. The presence of serious night myopia can be detected in routine eye examinations if the clinician is aware of the concept (few are now). The solution is special (more negative) lenses for night driving, tailored to the driver's own dark focus distance. Vehicle design can also be improved to reduce the need for far, intermediate, and rear acuity which is difficult, especially for older drivers, to maintain (Welsh, Rasmussen, and Vaugn, 1977), but this is beyond the immediate scope of this paper.

While it is not universally agreed that normal acuity is essential in itself for most driving tasks (Leibowitz, Post, and Ginsburg, 1979), reduced acuity also reduces the observer's sensitivity to low contrast targets and increases the time it takes for changing accommodation (focus) for different distances. It is likely that some drivers who restrict their night driving voluntarily because of "night blindness" would be given added mobility as well as added safety margins in all conditions of reduced visibility if night myopia wre routinely corrected for. An even more promising approach might be to remove the requirements for sharp acuity from the roadway as much as possible.

Since an object that is out of focus must have greater contrast to be detected, and since "for a simple target, pure contrast ratio predicts driver visibility with considerable accuracy (Gallagher and Meguire, 1974), measures of contrast sensitivity of some kind may be more fundamental to driving. As a parallel, performance on machine tests of stereopsis (improperly called "depth perception") probably cannot be related to driving ability, although the ability to perceive stereoptic fusion is a good indication that the entire visual system is functioning well. In the same way, some general measure of contrast sensitivity may be sufficient as a screening technique.

One approach to measuring contrast sensitivity which incorporates acuity is the modulation transfer function. Snyder (1973) says "The modulation transfer function (MTF) simply defines the percent original contrast that is transmitted by a system as a function of the spatial 'closeness' of two elements in the original object plane." (p. 95) "The eye's contrast threshold varies not only with spatial frequency (resolution or acuity) but also with image signal to noise level and with such variables as glare, vibration, and adaptation level." (p.103) In one study of photo interpretation, Snyder (1973) found a correlation between the modulation transfer function area (MTFA) and performance in terms of errors of detection of -0.93. It intuitively seems promising to pursue this line of investigation as a means for the comprehensive assessment of the state of the driver's visual system. Because MTF values are multiplicative, the effects of observer, windshield, atmosphere, precipitation, and target characteristics can be predicted from individual measures and combined in a variety of ways.

2. Two Visual Systems

It has been recognized that peripheral vision is important in certain kinds of visual search. Objects detected in the periphery are then examined, via eye and head movements, with central vision. Acuity and color perception (Graham, 1965) fall off rapidly in the retina as the angle from central (foveal) vision increases. Sensitivity to dim sources, however, peaks at about 3 to 8 degrees off center where rods are most numerous and dense. The fovea, made up of color-sensitive cones, operates best at moderate or high intensity levels. Because of the poorer acuity and color sensitivity of peripheral vision it is commonly thought of as a very limited detector and signaling system similar to but grossly inferior to central vision. Sensor densities do decrease in the periphery but neural connections within the eye also change in character Moreover, the pathways to the brain and the destinations also change. Accordingly, the functions of central and peripheral vision are different, although it is not yet clear how or to what extent they overlap. However, rather than one, there seem to be two visual systems (Ophthalmic Reports, 1977), , roughly corresponding to peripheral (motion, location, or orientation) and central (identification) perception. The two systems, formally known as "ambient" vision and "focal" vision, seem to derive information from partially overlapping areas of the eyes' receptors, but to be processed by different parts of the brain and through different neural pathways, resulting in different functional properties.

Recent work (Leibowitz and Owens, 1977; Johansson, 1977 a,b) has begun to produce implications for practical problems such as driving. For example, the perception of locomotion (movement of self) can be induced in the ambient system by simple stimulation in peripheral vision. For example, a person sitting in a stationary vehicle may perceive a backward translation when in fact only the adjacent vehicles are moving forward. Johansson (1977b) induced a false sensation of up and down motion with a single dot oscillating in the periphery. The sensation (vection) is reliable and reliable despite intellectual knowledge of the true situation, but when the spot is observed with central (focal) vision the up and down sensation cannot be induced.

Peripheral vision does not require good acuity for its functions, (Leibowitz, Post, and Ginsburg, 1979), though experimental correction of refractive error (which is largely independent of refractive error in central vision) does reduce the threshold for perception of motion (Johnson, 1972). According to Leibowitz, Rodemar, Shupert, and Dichgans, (1979):

> "A convenient technique for producing vection in the laboratory is to rotate a striped cylinder around a stationary subject. This produces a compelling feeling of self motion within 5 to 10 seconds such that the actually moving stripes appear to stand still. This phenomenon, known as circular vection, is strikingly independent of both refractive error and luminance. If only the vaguest pattern is perceptible the latency and completeness of circular vection are not different from the values obtained with clear vision at high luminance levels. Specifically, an induced refractive error of up to 20 diopters has no influence whatsoever on circular vection. In contrast, a refractive error of only .25 to .50 diopter will interfere significantly with reading behavior and an uncorrectable refractive error of 2.5 to 3.0 diopters results in legal blindness as defined by the U.S. Internal Revenue Service."

There is at least indirect evidence that the inputs from peripheral vision are useful but not consciously appreciated by the individual driver. Salvatore (1969) reported greater accuracy among driver estimates of speed when central vision was blocked than when peripheral vision was blocked, although the subjects had little confidence in the better estimates when they could not "see where they were going."

Leibowitz and Dichgans (Ophthalmic Reports, 1977) also feel that data from subjects, who are blind by the usual definitions but can successfully "guess" where a spot of light is placed or are affected by moving patterns they cannot "see," suggest that the ambient function need not become conscious in the usual sense to be useful. This is a case of unconscious perception--a contradiction in terms as they usually are used. It would explain why little evidence is found for utility of peripheral visual inputs: no one can verbalize the stimulation therefore it does not "exist." Posture and orienting behavior is influenced without conscious knowledge of the inputs, just as the subliminal perception of very short exposures to a photograph of a parched desert reportedly can make one thirsty even though the glimpse of the scene was so short it cannot be recalled.

Certainly our perception of space, posture, movement, and relative motion have been so basic to our survival as a species that it is understandable that much of this process has become automatized and no longer requires conscious awareness.

Evidence of discrimination in speech perception without the subject's awareness has also been reported by Forster and Govier (1978), strengthening this idea of unconscious perception. In order to discover what is relevant, an observer or listener must somehow discover that most of the potential inputs are not relevant. Several abstracts indicate similar work at the Applied Psychology Unit in Cambridge, England (see Marcel's abstracts 1204-1207, APU, 1978), in which behavior is changed by inputs the subject claims no conscious awareness of. The impact of this for applied problems, especially those using interview data, is obvious.

The point in the previous discussion is twofold: much has yet to be discovered with regard to the various aspects of visual perception, but also, inputs to peripheral vision may provide cues to tracking and guidance behavior and to driver confidence that have not been suspected and therefore not capitalized upon. If cues for use by the ambient system can be (or are already being) provided by occasional, low contrast, low resolution objects, it might be possible to develop reliable predictions of road character which depends on these effects, and to produce low cost aids for situations in which the cues are deficient by considering the addition of targets for peripheral vision. These targets might take the form of simple posts or patterns along the roadside. The low luminance and resolution requirements of such targets suggest inexpensive techniques might suffice to make widespread installation practical.

3. Visual Search and Perception of the Environment

The pioneering work of D. A. Gordon (1966a) and of Mourant, Rockwell, and Rackoff (1963, 1969) on visual search in automobile driving certainly has contributed greatly to our understanding of the driver's visual requirements. Much work has been done on specific types of visual search (e.g., Williams, 1966; Mourant and Rockwell, 1970; NAS, 1973; Gould and Carn, 1973; Lawson, Cassidy, and Ratches, 1978; Snyder, 1979; Akerman and Kinzly, 1979) but even in the military setting where applied needs are foremost and tasks are specific, the predictability of search patterns and visual search efficiency is not very good. Many studies are confined to artificial arrays of simulated objects, dots, or discs and randomly placed targets. Brown (1976) says that: "There is an obvious need for methods of quantitatively specifying search backgrounds; most backgrounds in real-world search tasks are not 'randomly' determined but have some constraints or order imposed on them." (p. 441) The data from eye movement studies give some insight as to where the eye is pointed, but the limited accuracy of the measures, the fact that "looking is not seeing," and the (partially) parallel information processing and attention switching or time sharing decision-response systems, which integrate all types of past and present information into a single concept, make scan patterns and fixation times less than complete for predicting behavior.

The driver's visual inputs, especially at night, are restricted to a relatively small variety and location. For tracking and guidance purposes, the most basic concept is probably the vanishing point (VP) in the perspective view of the road ahead. Although search is largely restricted to edge lines, centerlines, and possible hazards within about 200 ft, (Mourant et al., 1969; Shinar, McDowell, and Rockwell, 1977), the VP is the conceptual target or goal. It is frustrating to move from concrete data such as percent time spent on various target types and the fixation durations to nebulous concepts such as immediate destination or perceptual goals, but it appears that this level of abstraction is necessary.

Related to the VP is the focus of expansion--the point from which all streaming patterns of relative motion appear to issue. The focus is the only point which appears motionless in the environment of the moving observer, and it shifts with curvature of the path (Gordon, 1966; Allen, O'Hanlon, McRuer, and others, 1977). The concept of immediate destination or "path" is modified by cues from the streaming patterns and the visible preview of the road ahead, but the concept of path is not entirely determined by information being received in real time. Stephens (1970) discusses specific responses and mediation of responses in the driver as being controlling or regulating processes, primarily for comparison of stored information and sensory and motor reafference at cortical levels. This implies that information obtained at one moment is updated by new information (partially corrective, mostly confirmatory) and any necessary responses are thus determined. To this should be added the path or road concept that existed previous to the current trip. Where the concept is incomplete, more data may be processed (slower driving speed or slower subjective passage of time); where the pre-existing concept is faulty, even more new information is needed to break down the erroneous expectations and to determine a reinterpretation which requires response patterns different from those initially expected.

The exact sources of the information used to build these concepts is not always known or recognized officially. For example, the route or path delineation provided by overhead utility wires and poles is considerable in many rural roads. These inputs could be enhanced considerably by techniques that are cheap compared to the maintenance-hungry edgelines now widely used.

This information processing approach, of course, is not separate from visual search patterns. Senders et al. (1967) assumed the driver "drives to a limit" in setting the information acquisition and processing rate to that which is comfortable in the situation. A given sampling rate or situation determines the speed the driver selects. Their uncertainty growth model is related to a path concept in that the driver will continue without additional visual sampling until the memory has decayed to some level and must be renewed. The difference in the case of the path concept is the addition of a stable concept of the roadway being traversed.

While the differences between memory of the road and a road concept are not great, there is no doubt that something is different about drivers who are familiar with a roadway or road type from those who are not. Some inputs to the driver's decision processes are beyond the visual scan pattern and the sampling rates. In fact, road concepts, at least in part, determine the drivers' scan and sampling strategies, while the real-time information shapes their tactics.

D. MEASURING AND RECORDING THE VISUAL ENVIRONMENT

1. Luminance and Contrast in Night Driving

The distinction between light levels for day and night driving must not be equated with that of photopic (cone) and scotopic (rod) vision (e.g., see Ruedy, 1942). While a representative value for daylight illumination of the earth's surface is about 10,000 ftL, the range for visual sensation is wide--about 10^{15} (Graham, 1965), from 10^{-6} ftL at the absolute detection threshold to the damaging 10^{9} ftL for the sun's surface. Night driving is generally considered to cover the mesopic, mixed receptor range of about .01 to 10 ftL. Both rods and cones contribute to perception at these levels, though there is some controversy over the exact functions of each at these intermediate light levels.

The average luminance of driving scenes varies over a wide range, both among locations and with time. Urban commercial areas and oncoming headlights provide the most common example of these two sources of variation. The luminances range over several log units. Individual measures of luminance levels have some utility in assessing adequacy of visibility, but the context in which these levels are encountered, both in space and in time, are at least as important. One practical error related to this was pointed out by Pinkney, Ayad, and Walker (1976). It is commonly reported that pavement reflectance increases with distance from headlights, though visibility of a given object obviously should not. This effect is due to backscattering from the atmosphere which increases with distance and can reach 50 percent, even on a clear night, at about 500 ft. Telephotometer readings must be corrected by substituting known targets at the same distance and comparing the known and unknown in order to get readings that are independent of atmospheric effects.

More important for most practical questions than luminance is contrast. Target size, location on the retina, and adaptation level all determine the contrast threshold (for 50 percent success, or the limen) and the many variables and their interactions make modeling difficult. Akerman and Kinzly (1979) illustrated the application of a model to detection of aircraft against an unstructured surround. In this kind of application, detection in the visual periphery is an important practical issue. Five models compared by Akerman and Kinzly (1979) vary widely in their predictions of the threshold contrast value for small targets beyond about 25 degrees off the visual axis.

More relevant for our concern is that visual search for aircraft is not similar to visual search in seeking night driving guidance cues. Allen et al. (1977) conclude that, for a clear night, a contrast of 2 between the painted delineation and the road surface is adequate; higher values are required for adverse conditions, though a contrast of 10 is probably the greatest obtainable in practice.

Visual search may not even be a relevant issue for the driver's tracking task in night driving. The cues are patterns, all of which point to a steering input or control state. For detection of hazards or informative signs, there is a very limited search; pattern detection is more at issue for the tracking part of vehicle guidance. Unfortunately, pattern perception is very loosely definable; it ultimately is measured by driver opinion of a roadway's visual adequacy and only secondarily by driver behavior.

Tracking (guidance) and hazard detection (of objects and intersections where other traffic might enter) converge to a single narrow range of visual concern if speed is controlled. Ideally, the speed is such that the decision stopping distance (DSD) is no greater than that illuminated by the headlights or fixed illumination (see McGee, Moore, Knapp, and Sanders, 1978). A simplistic guideline might be to provide guidance preview only to the DSD, but drivers continue to behave as though that approach were completely unrealistic in its conservatism. In other words, drivers drive too fast for the visibility researchers claim they now have. While the evidence is mixed on the safety values of edge lines, it is clear that drivers travel faster in poor visibility (e.g., fog) when good edge lines are present than when they are not (Bali, Potts, Fee, Taylor, and Glennon, 1978). The addition of raised pavement markers (RPM) or post-mounted delineators (PMD) seems to help reduce accidents in some cases and usually is hailed as an improvement by drivers (see also Walton and Rowan, 1974). The problem is one of providing sufficient tracking cues for poor visibility (for which RPM and PMD are good) without encouraging excessive speed or reduced vigilance when conditions are marginal.

In the Ford visibility model (Bhise et al., 1977) is was assumed that about 2 seconds of visual input was needed, based on the findings of Rockwell, Ernst, and Rulon (1970), McLean and Hoffman (1973), Kondo and Ajimine (1968), and Allen et al. (1977) which generally agree that driver performance does not change appreciably when preview of more than about 2 seconds (perhaps 4 seconds in curves and at high speeds) is provided. From this, an "ideal" delineation system might be that which provides 2 second preview for just that speed which represents the hazard detection distance. This implies that edge and lane lines of high contrast are preferable over PMD or RPM because the lines retain high visibility at short ranges in poor visibility, but the visible distance tends to decrease with visibility in the desired way. PMD and RPM, on the other hand, remain visible at greater distances in poor visibility as desired by motorist opinion but contrary to safety considerations. Visibility distance could, in theory at least, be limited by manipulating entrance angles to the PMD at specified distances. Whether the public would tolerate such short preview with lines only on this kind of argument is not known. The data in terms of absolute numbers of accidents do not show reduced visibility to be a major problem, though it is commonly felt to be "dangerous" (Schwab, 1972).

One factor limiting the utility of PMD for guidance is the point-in-space perception which, in winding roads with isolated PMD's, can give no cue as to distance or location in space. Where a pattern of delineators is installed (and maintained), the individual points form a discernible path. Where the points are isolated, the driver perceives each point as having some relationship--more or less accurate--to the road's course, and the relationship depends on distance. The addition of a second bright spot at the same location (for corner-cube discs) or a longer dimension (for reflective sheeting) allows, with standardized dimensions and driver familiarity, the assessment of distance through the well developed principle of size constancy. When the delineators are not standardized (as STOP sign sizes are not) one can predict (Leibowitz, Wilcox and Post, 1978) that errors in distance judgment will occur for the less frequent sizes. (Oversize STOP signs, unless they are made easily distinguishable from more usual sizes by design, will be perceived as closer than they are.) This misleads drivers and requires more information processing time for sorting out the various consistent and inconsistent cues. While drivers tend to stop too soon when first encountering an oversize STOP sign, even this conservative behavior requires more processing time and may cause undesirable reactions in traffic.

Contrast, rather than brightness (intensity) is directly related to visibility. But the threshold contrast ratio which is sufficient for reliable use in signaling depends upon which part of the luminance range of the eye is being employed. The relative contrast sensitivity (RCS) was related to background luminance by Blackwell (1946) and was found to be a necessary term in the visiblity index (VI) developed by Gallagher and Meguire (1974). These investigators started with 10 original visibility indices and reduced them to three which were to be evaluated further. "For a simple target, pure contrast ratio predicts driver visibility with considerable accuracy." The VI is basically contrast (C_1) corrected for an "average" value of RCS for the range of luminances the driver is exposed to and for glare in terms of a disability glare factor (DGF). In equation form:

$$VI_1 = C_1(DGF)\frac{RCS}{5.74}$$

The factor providing the greatest amount of information about the visibility was constant (Gallagher and Meguire, 1974). Even so, caution was urged in the application of this index in complex visual environments, especially when high glare sources and nonuniform luminance conditions are present. The factors they used to correct for glare and luminance changes were weak, but such conditions are known to exist in many facilities and better handling of them in future metrics will be required. The urban backgrounds they dealt with had a range of luminances of only 0.1 to 0.4 ftL. In this study, DGF varied only from 0.873 to 0.918, and RCS/5.74 reduced to a range of only about 1.0 to 3.0 for a few common urban settings with an 18-inch (46-cm) truncated traffic cone (6 percent reflective grey) as the target for detection by unsuspecting drivers in actual traffic.

Contrast sensitivity depends on the brightness levels to which the observer's eyes have become accustomed or "adapted." This adaptation level is determined by search patterns; sign, surround, and background luminances; headlights and other glare sources; and the time history of the observer's recent visual experiences in addition to wide individual differences (which Johnston, Cole, Jacobs, and Gibson, 1976, have begun to attack). Exposure to bright snow, summer beach, or desert sun, for example, can reduce sensitivity for many hours or even days. In addition, there are simultaneous contrast effects and afterimages, local effects (only that part of the retina that images headlights, for instance, is light adapted to that level) and many others. Most of these pale in comparison to individual differences which are heavily biased by age effects. It may be necessary, for a practical metric, to lump most influences into a field factor and to base the contrast requirements on the capabilities of a "design driver," specified for a type or range of operational conditions. The danger in this approach is that of setting too conservative (and thus too costly) an approach. Fortunately for the driver, pattern recognition and visual or perceptual integration often allow humans to form useful visual concepts from tiny pieces of information that cannot easily be put into a formula. Developing some such formula which predicts, without undue conservatism, when drivers can see well enough to perform is the ultimate objective of this report.

2. Photometric and Photographic Approaches to Description

In an analytic approach to describing a visual setting, the luminance of each visible object can be measured and a contrast can be calculated for each significant object and its surroundings. While this provides complete, accurate, and exhaustive data in a physical sense, the behavior of an observer controlling a vehicle in this setting is, at most, only grossly predictable from these measurements, even if they were practical to obtain for a large number of road environments.

On the other extreme is the photographic technique using movie film or video tape to capture each view as the observer passes through a section of the roadway. Once again the practicality of obtaining measures from these many records is questionable. Moreover, film does not see the scene exactly the way a driver does, either in terms of visual search patterns, the breadth of field or relative sensitivity. Search presumably could be approximated from a wide-angle scene with an appropriate model. If it were wide enough, peripheral visual inputs might be (but generally have not been) provided. Contrary to prevalent concepts (e.g., Taylor, McGee, Seguin, and Hostetter, 1972, and Allen et al., 1977) lowered acuity or contrast sensitivity in peripheral vision is not a reason to discount its use as a driving information input. This was discussed in section C2.

Filters are available to bring the sensitivity of the iconoscope or film down to the same relative spectrum of light that the (normal) eye can receive. However, even with these corrections, film has a much narrower range of representation. The density of the negative is proportional to some function of intensity of luminance, but it is more steeply condensed than the intensity-brightness function of the human eye. The human interprets intensity on approximately a log-log linear scale (Graham, 1965), so that an increase of one million fold (10^6) in luminance above threshold (L) is perceived as an increase in "quantity" of brightness (B) of 10 times. (This is a power function of the basic form $B=L^b$, with b=1/6 in this case.) With film, the density of the negative has a range of only about 10^3 in the best conditions. This can only approximate the wide range of luminances perceptible--at least 10^5 in night driving, and 10^{15} overall. A logarithmic intensity-grey scale function for video tape may be a more feasible technique for this translation, but this possibility will not be discussed further in this paper.

One of the most serious deficiencies of film or video is its representation of glare sources. Glare is the eye's reaction to light intensities much greater than the eye's adaptation level. It is also largely a function of the optical condition of the individual eye, so that a film representation cannot be expected to be realistic if the intensities and contrasts are reduced. It may be possible to reproduce an approximation of real-world contrast from a recorded scene by some non-linear reconstruction technique using high intensity projectors, but a model with field verification of results seems more promising, if it can be evaluated successfully.

A manual technique for on-site measurements might also be feasible. A hand-held solid state survey instrument (photoscanner) has been suggested by Allen et al. (1977), and the Visibility Quality Meter (VQM) discussed earlier has been developed by Merritt et al. (1978) which might be adaptable to this need. The VQM was intended for assessment of the contrast transmittance of an optical system in order to set limits on degradation of target images. By comparing the received contrasts with those known to make up a target, the modulation transfer function (MTF) can be calculated. This concept and its possible adaptation for assessing visual quality will be discussed in section F2.

Even with their limitations, the film or video techniques seem to provide more of the attributes required in a field quantification procedure than the analytic techniques do. Analysis of entire movies and video tapes probably must give way to analysis of representative sample frames. A scanning technique using a nighttime photolog series, for example, could be automated, assuming standardization of conditions and filming were assured. (No night photologs are known to exist at this time.)

In one study employing a photographic technique, Pinkney et al. (1976) used the "light amplification effect" of time exposures to provide good contrast sensitivity for filming small variations in luminance. Because of considerable variation in film density resulting from differences in sensitivity among film rolls and in developing processes, a self-calibrating feature was found to be necessary. This was done using targets with known reflectances which were shot at least once on each roll used. The spectral effects, due to film's high sensitivity to ultraviolet light compared to the eye's, can result in photos that appear quite different from what an observer sees. They conclude that "photographs cannot be used to infer visual performance characteristics without careful analysis of the luminance conditions." Researchers and engineers continue to use photographs, however, and this warning is heeded only to the extent that they recognize it is hard to get a "good" picture (i.e., one that looks like the site does) in many cases. A jury technique for matching photos to actual perceptions may be necessary for photos which are to be used as standards of comparison or for selling a concept or design. This is not always a simple procedure--it is easy to demonstrate that photos do lie.

The long exposure (10s to 270s) used by Pinkney et al. (1976) were necessary to obtain film densities that were on the linear portion of the film's characteristic curve (density versus luminance X time). This allows automated densitometer readings of the film for translation into contrast values. Such precision and the use of long exposures are impractical in the kinds of field measures of interest here. A few preliminary thoughts on more practical photographics methods are given in section F2.

3. Types of Visual Inputs

At the most basic level, detectable light patterns form visual cues for the night driver in three categories: (1) "cues"--relevant visual inputs necessary or useful for successful driving, (2) "noise"--irrelevant inputs that have no direct positive or negative effect on the driver's perception of the driving task, or (3) "miscues"--misleading or harmful visual inputs which imply conditions or situations that are not consistent with the actual driving task or which prevent the driver from making use of relevant visual inputs. (Glare is included here under miscues. While glare may be thought of as an extreme case of noise, visual noise is not necessarily a problem if the driver is not overloaded or confused by miscues. Misleading visual inputs or disabling ones like glare are considered a third category.)

Insuring enough relevant inputs or cues is the primary concern of highway and traffic engineers in designing a roadway. Further light sources or patterns, added for a variety of other reasons, remain visible to the driver. Irrelevant visual inputs or noise inputs are relative in nature: a light source which is irrelevant in a setting can become relevant if others are added to form a pattern which aids the driver in seeing hazards or in getting advance knowledge of the road's path. The same light source can be misleading or a miscue if it becomes a distraction or if other lights are added nearby which form a pattern that seems to be related to the roadway but is not. The importance of patterns and the human propensity to perceive patterns complicates the descriptive process and may largely prevent a purely analytical process from being very useful.

For the sparsest visual environments an analytical procedure may be of some use. In the absence of any other visible patterns, even minimally effective delineation and hazard warning signs become easily identified and located. However, where there is little or no redundancy, the loss of a single cue or the appearance of a miscue or glare source (oncoming vehicle headlights, for example) can leave the driver with only a stored road concept to drive on. If this lack of information is brief enough (e.g., see Senders et al. 1967) or the miscue not too believable, the driver may be able to maintain control. But, for example, the removal of a curve warning sign on a road that has been straight for some time can be dangerous. As another example, where cues are sparse, the reflection from a beer can on the road surface could be interpreted as one coming from a post-mounted delineator which is supposed to be beyond the right shoulder; this may modify the driver's road concept sufficiently to result in a sharp veering to the left.

In richer visual environments, the presence or absence of a single visual event is not so likely to cause problems, unless that event is the introduction of a source of glare which is painful or which obscures other important cues. Richness implies redundancy in cues, and the daytime view (in clear weather) provides a richness that few nightime scenes can match.

The engineer's responsibility is to ensure that adequate cues and reasonable redundancy are maintained for the sparse visual environments, and to ensure that cues in richer visual environments are not swamped by visual noise or miscues including glare. This may require cue augmentation or noise and miscue suppression in rich visual environments. Sources of direct glare are fairly well controlled with regard to fixed lights. While new glare sources from adjacent land use must be detected and reported, most jurisdictions have formal or informal power to control this potential hazard if it is acted upon. Glare from headlights is not usually controllable except on major highways where median barriers are feasible.

Visual noise and potential miscues make up the bulk of the engineer's difficulty in terms of interpreting how to detect and treat problem environments. In the sparse visual environment the problem is largely one of economics: whether the investment in adding or maintaining delineators be justified. To some extent, weather and seasonal changes make paint markings difficult to maintain year around, but this is also related to costs. The difficulty in complex visual environments is more fundamental: when is there a problem?

The noisy or rich visual environment brings up a host of fuzzy concepts, some of which are listed below. Some of these will be discussed in greater detail elsewhere; the others will be covered briefly in this section.

a. What patterns do drivers use for guidance control?

b. How important is conspicuity of various cues, noise, and miscues?

c. What is the role of expectancy in a noisy visual situation?

d. What is the driver's capacity to detect hazards in a noisy visual environment?

e. How does the problem change when the road surface is wet or other glare sources are encountered?

f. How does visual complexity affect driver fatigue or sustained performance?

The problems of quantifying or defining pattern recognition were touched on in an earlier section. There appears to be no alternative to subjective assessments in this realm. Pattern recognition is extremely important in certain driving settings, it is an active specialty area for research, and some general guidelines can be stated, but is is not yet quantifiable in a general way. There is some indication, from studies of evoked cortical potentials, that the brain may be used as a preprocessor. In other words, the pattern recognition itself is beyond our current analytical state of the art, but there may be signals within the EEG that denote "a pattern has been perceived." Conceivably, this EEG signal could be part of the process of determining an adequate visual setting. For the immediate future its equivalent is likely to be called "engineering judgment."

In a more common framework, the roles of conspicuity and detection must be examined. They might be said to serve as anchor points on a continuum of consciousness of a visual input. Conspicuity is critical where competition for attention from non-relevant inputs is high (e.g., a bright, dynamic, "busy," urban section), while the emphasis must be on detection and visual thresholds where the setting is visually impoverished (e.g., a dark, static, undeveloped rural section) or where visibility is limited by atmospheric transmissivity (e.g., in fog). Conspicuity is discussed further in the next section.

The role of expectancy also is related to the degree of richness of the visual input. In a complex visual environment there is usually a wealth of visual inputs, but guidance information must be sought out from the irrelevant clutter and potentially misleading inputs. Expectancy determines when and how this information is sought and how the information is used. It also determines whether a visible pattern is a miscue or just noise. In the impoverished visual environment the driver is actively seeking scarce cues for guidance and hazards. Conspicuity is less of an issue, provided the situation does not violate current expectancies by presenting unannounced surprizes, such as sudden sharp curves or stop signs. Expectancy is obviously a function of the driver's concept of the roadway.

Conspicuity for a sign may be high (it is easily detected) in this setting, while the same sign in an urban setting would be completely inadequate. If the driver's concept of the road section includes sudden curves, "inconspicuous" signs will be adequate; if it does not, special efforts must be made to insure that drivers see the warnings of various types and that they have confidence in them.

The driver's ability to detect, recognize, and evade the various hazards which might be met on a roadway logically should be affected by the information processing demands or other stresses present or experienced recently. Probability of various types of hazard also form part of the driver's road concept. Many studies of hazard detection have been done, and this topic will also be discussed along with conspicuity.

The topics of vision with wet surface reflections (see CIE,1978) and driver fatigue can only be touched upon in other sections. Each lacks firm guidelines for practice, but each is the subject of current research. Glare has also received attention in past research programs. It will be discussed further after the section on conspicuity.

4. Conspicuity of Guidance Cues and Hazards

The dictionary (Morris, 1976) definitions of "conspicuous" are:

1. Easy to notice; obvious.
2. Attracting attention by being unusual or remarkable.

According to definition 2 then, no sign or object can be used routinely and repeatedly and remain "conspicuous." By definition 1, a sign or object can be conspicuous or not depending on the environment in which it is located. Conspicuity thus becomes not a matter of characteristics alone, but a matter of context and the observer's priorities: the most noticable or most obvious object present is conspicuous compared to other objects which, for practical purposes, might be said to be either inconspicuous or "absent" in the sense of being unperceived by a time-limited sensory scanning device--the driver.

Drivers are not necessarily aware of everything that influences their behavior (e.g., see the discussion on peripheral vision, section C2), but where conspicuity is of concern, the implication is that some important conscious behaviors or decisions may be called for by a sign or signal.

It is not clear whether conspicuity is a continuous quality or a binary one. An object could probably be rated as high (large, bright, colored, moving, flashing, central) or low (small, camouflaged, dark, low contrast, static, poorly located) in conspicuity, but in any setting, only one or a few items are "conspicuous." These items can be ranked as one (most conspicuous) etc. down to perhaps three or four, but the other items that are visible no longer seem to fit the connotations of "conspicuous."

Conspicuity must retain this environmentally relative definition but also be definable in an operational context for the needs of the traffic engineer. Objects can be ranked on their conspicuity in a given visual assimilation, but they cannot reliably be rated on conspicuity independent of the environment.

A "visual assimilation" is more than a glance, a fixation, or an exposure. It is the total visual experience of the observer in some finite period of time, probably on the order of a fixation duration (0.25s to 0.40s) in length. It is influenced by the individual's history, recent experience, motivation, physical and mental condition, and time stress. Many flashing lights can be perceived even with the eyelids closed; colors have intrinsic (or overlearned) meanings that belie relative luminances; priorities set by expectancies predetermine visual search; peripheral vision is strongly compelling where intense or moving stimuli are involved, regardless of lowered acuity; and the point of best acuity--foveal vision--is relatively inefficient in visual search or in the detection of low level signals, 3 to 8 degrees off center being much better. These and other factors make conspicuity difficult to predict. The only true measure of conspicuity is subjective: whatever observers agree upon is the most conspicuous under a given set of conditions is--unequivocally--the most conspicuous.

In the literature, conspicuity is discussed in terms of target qualities for search by pilots (Williams, 1966) or in other laboratory studies of "complex" displays. Clark (1968) discussed the search value of hue, chroma, value, and brightness contrast, the latter being the most important. He also evaluated target shape using the time to locate a search target as his measure of relative conspicuity. From colored targets, an equivalent achromatic contrast value was computed. Conspicuity was then read from curves and equated to that contrast which yielded the same visual effectiveness. The translation of these results and those from other laboratory study for use in the field is not a simple process. Blackwell (e.g., 1946) has done much of the related fundamental laboratory work, and Odescalchi (1960) compared colors for relative conspicuity in rural surroundings, determining areal equivalence for signs of five colors compared to a white sign as a standard. Connors (1975a, 1975b) also compared colors of light for conspicuity, but in laboratory studies related more to control panel design than to guidance in a complex environment. Gordon and Schwab (1979) defined conspicuity as "the attention-getting quality of a sign." Though there are many studies that use the word, there is little available to define conspicuity operationally for the highway designer.

Conspicuity could be defined in terms of target value, attention value, priority value, contrast, brightness, relative contrast, response latency, search time, response probability, preference, demand, and similar qualities or behavior-related criteria. None is completely acceptable or without problems, and in any setting conspicuity can change, often unpredictably, with the season or time of day as the surroundings or lighting conditions change.

Schreuder (1978) also discusses the concept of "conspicuity level" rather than visibility in referring to that aspect of visibility "really relevant for road traffic." His definition is not stated explicitly. He does discuss a task hierarchy with an implied conspicuity for each level, such that the required conspicuity can be compared with the supplied conspicuity. According to Schreuder, supplied conspicuity "can be derived from the installation parameters by means of well-established methods" (which are not clearly described) while demand conspicuity "requires further research." Gallagher (1978) also discussed supplied and demanded conspicuity, though contrast ratio would seem to fill the driver's requirements more fully. Conspicuity continues to be a difficult concept to pin down. It is intuitively attractive, but more concrete definitions or concepts are needed for applied purposes.

If we continue to use the term conspicuity, its definition will hinge on the conditions in a specific environment and, perhaps, on definitions of visual complexity and driver expectancy. There are some rules of thumb for conspicuity that can be stated, however. These might include:

a. A bright object, observed in a context of one or more distinctly less bright objects of about the same dimensions, will be more conspicuous than those other objects.

b. Any familiar observable object which is well above the observer's visual threshold will be conspicuous if the observer is motivated to detect that object in an otherwise dark or very dim environment.

c. A flashing light source will be more conspicuous than a steady source, even if the total energy radiated from the flashing source is somewhat less. However, when two or more independent light sources are flashing, conspicuous is less predictable (Crawford, 1963) unless the relative brightness, energy, or flash rate of one is much greater.

d. A visible source of information that is required or desired by an observer will be more conspicuous than irrelevant visual sources with similar physical attributes.

e. Behavior is not necessarily controlled by relative conspicuity. For example, the color, and sometimes the shape or context of a visible object may, through well learned coding or expectancies, elicit behavior while a more conspicuous object (according to other criteria) does not.

By using these and similar guidelines, a conspicuity checklist or decision tree could be devised. In any setting, the user of these aids would have to answer a series of questions, and the structure of the form would determine the most conspicuous item(s). Whether this is any more useful than a purely subjective judgment for existing situations is not clear, but a fixed procedure might be useful for predicting whether a given design or improvement alternative would be conspicuous in a current or anticipated setting. It would probably reduce the range of ratings among judges as well.

The conspicuity or detectability of hazards is a different kind of a problem in that the probability of a hazard is low and the location and characteristics of possible hazards can be quite diverse. Pavements, especially fine textured ones, become more mirror-like (specular) and less diffuse in reflecting light when they are wet (CIE, 1978). Hazards, which can range from potholes to a cyclist to an elk, do not conform to any standard set of specifications. Research studies reflect this lack of standardization and have used detection targets which range widely. Hukulak (1978 a,b) used square targets about seven inches on a side as the smallest target that is likely to pose a threat to a driver. He concluded that dark targets are generally more detectable than light ones since headlights from both directions of traffic make the pavement quite bright. He and Pinkney, et al., (1976) also point out the dynamic character of hazard detection. Shadows, particularly moving shadows, are important to detection. The dynamic variations taking place in the eye approaching an object cannot be adequately reproduced in a single photograph. Pinkney, et al. (1976) show instances of null contrast in which static targets appear to blend into the road depending on the particular combination of target reflectivity, road reflectivity, distance, and kinds of light sources. Most types of targets will reach a null contrast condition in the right set of conditions. It is possible to reduce pedestrian visibility, for example, by adding fixed lighting which illuminates the person and reduces the contrast with the pavement surface. P. Gordon (1977) points out that the most visible clothing for a pedestrian is usually a flat-white coat down to about knee level (for high contrast with the non-reflecting horizon) worn above flat-black pants (for high contrast with the headlighted pavement from the driver's viewpoint).

The value of shadows as cues in low contrast hazard detection is partially countered by the problem of miscues from shadows of objects that are not on the road. This usually results from the lights of other vehicles casting shadows which move across a driver's path. Posts or signs in the median are especially likely to produce this effect because they are relatively isolated. In wet weather such shadows may be almost indistinguishable from a pedestrian or animal dashing across the roadway. The value of signs such as "keep right" on a traversible median should be weighed against this potential miscue possibility.

5. Glare Sources and Effects

Glare has been the subject of many studies over the last half century, in industrial and architectural settings as well as on the road. Allen (1968, 1970) and ITTE (1968) gathered and reviewed most of the older literature. Glare for highway purposes is usually classified as either discomfort glare or disabling glare (Guth, 1963; Adrian, 1968), the latter of less practical concern since it is largely predictable and preventable. DeBoer (1973) devised a discomfort index, W, from lab studies and scaled discomfort from 1 (unbearable) to 9 (just noticeable). Bhise et al., (1977) compared the scale values to the frequency of headlight dimming requests on various roadway types. The requests corresponded well to the DeBoer scale values: 50 percent have requested dimming by the time the level reached "3," about 80 percent at "2," but only 10 percent or fewer at "4." At about 250 ft (76m), current U.S. low beams begin to exceed "4" and may be "disturbing" or almost "unbearable" for a short distance, but this is considered tolerable by most drivers since it is seen as unavoidable in a meeting situation.

The DeBoer (1973) index is calculated from

$$W = 2 \log (1 + 269.0966 L_a) - \log \left(\sum \frac{E_i}{\Theta_i^{0.46}} \right) - 2.1097,$$

where L_a is the adaptation luminance (ftL), E_i is the illuminance from the <u>ith</u> source of glare (fc), and Θ_i is the glare angle from the <u>ith</u> source to observer. Huculak (1978a, 1978b) also found that field and lab visibility in glare data are consistent if sufficient precision is obtainable in the description of the prevailing field conditions, and if the glare sensitivity of the individual observer is known. Huculak (1978a) discounted glare from illumination of the dry foreground (the pavement) during driving as a significant factor in reducing visibility, except with unusual geometrics or for individuals with extreme glare sensitivity.

The effect of glare from high volumes of opposing headlights has been shown to be related to accidents. Musick (1970) found reduced night accidents of specific types and overall after the installation of median screens, and Ricker (1979) has produced guidelines for their installation.

In a report by Stoudt et al. (1970), glare was defined in terms of reflection from the vehicle itself during daylight. A review of some of the causes and effects of glare, the effects of age of the observer and techniques for measuring these effects also was included. One unique finding was that the falloff in visibility of objects under glare seemed to be much more pronounced in the visual periphery. In view of the suspected value of conscious and unconscious peripheral cues in night driving discussed elsewhere in this paper, and because glare is a scattering of light within the eye, glare from peripheral angles may be more important than previous considered.

The effects on a driver's behavior in cases of sudden glare depend on the driver's susceptibility (probably the most significant and variable aspect), the driver's familiarity with the road (the accuracy of a road concept), and the geometry of the roadway (e.g., encountering headlights in a left curve on a crest can be quite serious). Weather and vehicle design (angle, surface condition, cleanliness, and transmittance of glazing) are other variables involved but of less direct concern in this discussion.

The wet road surface presents one of the most difficult and most prevalent types of glare. Fixed lighting often increases the glare and distraction to the driver by mirroring each light source one or more times. Although it is possible to design a lighting system specifically for a wet roadway, variables such as surface texture, traffic volume, and degree of wetness are not controllable (CIE, 1978). The lighting and road surface designs seldom seem to be coordinated, and compromises of various types are made, usually because of costs, but also because decisionmakers do not always consider such coordination necessary. This often means that the road will be more specular than desirable during some portion of wet weather. CIE Committee TC-4.6 (CIE, 1978) reports that Denmark is the only country that routinely plots specularity against percent of dark hours (cumulatively) so that, for example, a given roadway is known to be as wet or wetter than the "standard wet condition" 8 percent of the dark hours.

Glare is predictable to the extent that detailed data on conditions and the observer are available. As with conspicuity and some other factors in visual perception, the variability introduced by the qualities of the observer are paramount. The complex calculations that are possible become meaningless without specification of the observer. A design driver or set of design drivers for visual studies seems imperative. A small number of design drivers, and the specification of a small number of road types and operational conditions would make the calculation of guidelines or reference points feasible. Without these the prediction of glare effects will remain complex and impractical or purely subjective and probably insensitive to the needs of many older drivers.

6. Complexity of the Driver's Visual Environment

The range of visual environments which has to be covered in a comprehensive technique for quantifying the driver's night seeing tasks is a fundamental concern. Even the presence of fixed lighting is not straightforward. Highway lighting may be intermittant by design (intersections, interchanges, special hazards) or continuous, or it may be incidental in that it is furnished by business or other private properties adjacent to the roadway. While highway illumination is generally felt to benefit road users, the transitions from lighted to unlighted sections and between levels or even types of lighting (illumination color mix, height, and spacing of luminaries, etc.) can cause transient problems that are hard to specify. Glare from designed or incidental illumination sources will be difficult to separate from useful illumination in any assessment using the usual photometric instruments. The degree and process of subjective or judgmental inputs as they are combined with photometric inputs in arriving at a metric for visual quality is critical in producing useful as well as practical and reliable quality measures.

In the daytime driving environment, with reasonably good atmospheric visibility at least, there presumably is no problem for the driver in obtaining cues enough for confident guidance and hazard avoidance. The seriously impaired driver, obviously, is not always able to use the cues available, but there is little that can be done to improve on the visibility of guidance cues provided by clear overhead sunlight. Discussions of positive guidance (Alexander and Lunenfeld, 1975) point out that miscues are sometimes a problem even in daylight. It also is true that navigation cues might not be sufficient in daylight conditions for the unfamiliar but "normal" driver, but that concern is beyond the scope of this discussion.

Given good weather daylight as the ideal visual environment, the question becomes one of describing the artifically lighted or marked roadway environment in terms of degree of daylight equivalence. An opposing approach of describing the minimal adequate visual environment, and comparing the lighted roadway or reflectorized markings to that, seems much less promising in view of the rich visual environment overhead lighting and some natural settings produce.

On the other hand, a roadway with no active light sources and no artificial aids except vehicle lighting of the natural environment and road surface can provide such an improverished visual environment, compared to daylight, that the first impression is that it could not possibly be acceptable for driving. The fact that this kind of road environment has been the rule and usable even in bad weather does not make it acceptable for modern traffic (and the current legal mileau), but it does illustrate the extremely low information rate which permits drivers to operate.

There seem to be two relatively distinct descriptive approaches, even though the visibility quality is distributed on a continuous dimension from impossible to ideal in terms of guidance performance. This might better be described as a continuum from rich to poor visual quality, with the clear weather, daylight open roadway at one extreme, and an isolated, wooded, unmarked roadway in wet fog at night with no moonlight at the other. For sake of argument we will consider these two conditions as the end points on a linear scale from 100 to 00 in terms of guidance adequacy. For further discussion this will be termed the Visibility Quality Index (VQI).

If the best natural lighting yields a VQI of 100, the best artifical roadway lighting might approach 90 with high-mounted overhead blue-white illumination over a wide area. While some information is lost with reduced level or areal coverage, the performance of the guidance task probably continues near optimum with even very low levels of fixed illumination. Low-mounted street lighting with noticeable intensity variations might not reduce VQI below 80, and even a roadway with only intersections or hazards lighted, discontinuously, might be rated around 75 overall. The imposition on the driver caused by the transitions from lighted to unlighted might cause brief drops in rating to say, 65, even if the unlighted but well delineated section were rated 70 and the adjacent lighted sections were at 80. Thus where artificial, fixed lighting is provided, even intermittantly (and wisely), the VQI ratings would tend to be grouped between 70 and 100.

Unlighted roadways, i.e., these with no fixed lighting by design or from incidental sources related to adjacent land uses, would probably cover a wide VQI range: 00 to 70, perhaps. The 00 roadway situation first described above is still found, but it is not necessarily safe for the expected range of driver abilities. A roadway that is well designed and well maintained for nighttime visibility may begin to approach ideal (70 or more) under certain conditions because the guidance cues are so strong and unambiguous, and they have no competition. However, the monotony or fascination effect ("highway hypnosis") of this situation can be disasterous, at least in terms of driver opinion. Whether this should reduce the VQI rating or not is hard to decide and even harder to quantify rationally.

The addition of traffic in the same and opposite directions adds the first complicating factors. Traffic provides both cues to guidance, in terms of preview, and distractions in terms of the need to react to car following, passing, lane control, and following traffic, as well as the veiling, discomfort, and disabling glare from headlights directly through the windows and from mirrors, the road surface, chrome, and other vehicle surfaces.

Incidental light sources from adjacent land use provide the second physical complicating factor (weather being a third). The fundamental question is whether we describe the visibility quality of roadway in its static condition or consider average traffic levels and some range of expected weather or atmospheric conditions. Can we devise a "worst case" or "near worst case" and if we do, does this result in a large unrealistic demand for improvements? We all have driven in situations where we either are thankful for that other car that helped us see the road, or curse the roadway that would be visually acceptable if it were not for the other traffic. Some level of non-traffic, normal visibility quality probably must be set, but a description of the same roadway with the traffic, weather, and other less desirable conditions which are predictable for it must also be provided. Two ratings seem awkward but two also seem necessary. A roadway could then be described as having 20/50 visibility quality: 20 for a single car in "poor weather," and 50 for "average late night traffic" in "good weather." The problem of definitions is obvious.

After some of these concerns are resolved, the possibilities for a visibility quality metric must be examined. Work done by Merritt, et al. (1978) of Human Factors Research, Inc. (HFR), under NHTSA contract on a Visibility Quality Meter (VQM) mentioned earlier, seems to provide much potential. The original concern was the development of a device which could be used to rate the quality of the image provided to drivers via glazing and mirrors in conditions including ice, snow, rain, fog, haze, use of windshield wipers, vibration, windshield coatings and dirt, and combinations of these. HFR has devised a simple device which provides a measure of visibility quality available after degradation by some material or transmitting system. This measure, when compared to the judgments of human subjects, agrees very well: r=0.97.

As envisioned for its use by NHTSA the VQM essentially compares the contrasts provided by a standard target without and with the system or material to be evalauted being interposed. By establishing a standard set of visibility thresholds (already available) and standard viewing conditions (of windshields, glare, dirt, and atmospheric transmissivity), natural guidance cues or those provided by highway agencies could be evaluated as to adequacy. A scan of the driver's visual field (probably 20 degrees wide and 10 degrees high or less, including the roadway only to about 200 ft ahead) could provide a count of visible cues for guidance. These might still have to be classified as relevant, irrelevant, and misleading, but the first quantification step would have been achieved. HFR also designed a counting scanner of the type which probably would be most useful for this application. However, it has not been developed beyond the prototype stage in view of the NHTSA requirements which were met better by the VQM design chosen.

Another promising, and more general, approach to be explored in the development of a visibility metric is the modulation transfer function (MTF). Visual patterns are perceived by the changes of certain qualities over two or three dimensions or over time. For night vision, the qualities of color, texture, etc., can be ignored (as an approximation) and only changes in the luminous intensity are considered. The patterns of changes in intensity, or the spatial modulation, can be described in terms of frequency and amplitude (see Cornsweet, 1979, pp 311-353 for an excellent introduction to this concept). As discussed earlier, acuity is now a standard requirement for a driving license but good central acuity is not really necessary for satisfactory performance of driving tasks except navigation and certain unusual hazard avoidance tasks. The MTF concept bypasses acuity as the only criterion, and it provides a versatile tool for describing the visual environment. For example, a new, four-inch solid edge line, which drivers seem to make use of only to about 100 to 200 ft ahead (Rockwell, et al., 1970), can theoretically be detected from a distance of 20 mi (30 km) under the best conditions. While edge lines are not likely to be painted at the minimal width theoretically required to be visible at 200 ft (60 m) which is .004 in (0.1 mm), there is little reason to discuss 20/20 (4/4) acuity in relation to guidance cues or hazard detection. In practice, the four-inch solid white line usually is clearly recognizable at over 1,000 ft (4/40) by those with 20/20 (4/4) acuity; still acuity could be about 20/200 (legally blind) and the line still would be usable to over 100 ft, which is sufficient for normal tracking performance. The point is that a bright line is perceived as a line whether it is a narrow line or a wide one, provided the eye senses a transition from dark to lighter to darker again in a small angular scan. A bright narrow line is seen as a bright, fuzzy, wider line by those whose eyes do not focus precisely. The modulation (sensitivity or detection ability) is unchanged, though the high-frequency components are lost. Resolution of details is reduced but not really required, while the guidance value is maintained. Description of guidance cues in terms of spatial modulation frequencies and minimizing the use of cues with high spatial frequencies are goals that are immediately practical. This approach will not cause drastic changes in practice but it opens a new, more versatile way of thinking about an old problem.

E. MODELS AND MODELING

1. Partial Models Related to Night Driving

Models and predictive procedures have been discussed, devised, and revised in several aspects of visibility concerning highways, but they have usually been concerned with either the driver or delineation or headlighting or fixed lighting. The ultimate procedure must include all of these aspects simultaneously since they obviously interact. Assumptions about all other aspects have been (and must be) made when any one aspect is being studied or "optimized." Not only are many assumptions "simplifying assumptions" (i.e., known to be wrong or unrepresentative, especially as to the range of a variable), but each aspect itself is characterized by a range of values which may change gradually or abruptly when another aspect's value changes.

The danger in developing models specific to one aspect of the visibility field is that simplifying assumptions about other aspects are easily overlooked, and the models often are based on unverified "logical" judgments about several or many variables or boundaries. These models are later verified or "calibrated" by means of field studies which often bring about correction factors ("field factors," "empirical constants," or, more frankly, "fudge factors") which are needed to make the results from the model agree with field findings. Whenever more than about four variables are contained in a mathematical expression, especially a non-linear expression, it is possible to fit a wide variety of results with a multiplier or other approximations without ever finding out which of the variables are irrelevant, highly sensitive, intercorrelated, or just plain wrong. A "useful" model can cloud the progress of research because it cannot be proven wrong (or proven correct), and unnecessarily vague assumptions may never be tested and may not even be discovered.

One of the greatest sources of frustration in model building is the fact that many of the components of visual perception are not additive or disjunctive. The concept of conspicuity is one example: conspicuous compared to what or in what setting. Brightness is another: what is bright for one level of adaptation of the eye is not bright or is intolerably bright for another level of the same eye. Even more distressing is the fact that the retina of an eyeball can be light-adapted to bright oncoming headlights where they have impinged, while most of the rest of the retina is at some lower level of adaptation. There is some general effect, no doubt, of the bright lights on the sensitivity of the untouched portion of the retina, but little is known about these partial or transient adaptation levels and their effects on other visual capabilities.

Traditionally, the driver has been required to demonstrate some minimal level of central acuity, usually 20/40 (4/8). An implicit model has existed in this area for decades: one must see to drive; one must have good central acuity to read; central acuity tests are easy and quick to give; therefore, all drivers must pass tests of central acuity. Literacy is not required for operation of a vehicle, but acuity levels needed almost exclusively for reading are required for obtaining a license. Recent data have demonstrated that not only is central acuity not critical to many of the driver's tasks, but, because of night myopia, acuity measured in most tests is largely uncorrelated with acuity in common night driving situations for a considerable portion of drivers.

Rather than attempt models of visual perception as a process, it seems more realistic to model the end products of perception. By this I do not mean behavior, necessarily, though that will undoubtedly remain the foremost practical indicator of perception for some time. Perhaps some signal related to completion of an intermediate process such as perception, attention, or decisionmaking will be obtainable from cortical potentials (EEG). This would begin to reduce the variances which plague current modeling efforts. This will be discussed in a later section.

2. An Outline of a New Model

In negotiating a roadway at night the driver has or may have a variety of cues available for supplying the information needed for guidance. In this discussion, guidance includes maintenance of reasonable path and speed along a roadway and avoidance of fixed and certain (as yet unspecified) moving hazards including other traffic. No navigation tasks are implied, except rudimentary lane keeping, though the driver must be aware of curves, turns, and crossroads, obviously.

Driving is not simply a tracking task. Under certain conditions such as fog or heavy rain, driving might deteriorate into requiring short periods of point-to-point tracking performance, but this is not desirable and certainly not acceptable for the variety of currently licensed drivers.

The driver formulates some concept of the roadway being transversed. How accurate or complete this concept is depends on the driver's degree of familiarity and the amount and type of information assimilated. This information may be provided at various levels during previous passages and during this particular passage over the roadway. The road concept also depends on the experience, skill, motivation, aptitude, and attitudes of the driver and, to some extent, on the vehicle. For sake of simplification we will consider an "average" driver in a "typical" U.S.-made sedan, driving along on an unfamiliar road. We will assume the driver is alert, unimpaired, and experienced with a variety of roadways. In any model each of these assumptions must be tested for sensitivity and specifications must be set to represent the real world.

The following discussion is made without reference to other formulations on cue structure and information levels in order to keep it as coherent and general as possible. This does not deny the value of the efforts of others, such as those reported by Alexander and Lunenfeld (1975), Allen and McRuer (1977), and Allen and O'Hanlon (1979), but seeks to provide a broader conceptual framework for eventual quantification efforts.

The information levels used in developing the driver's concepts of the environment could be considered to start from simple ones and proceed to more complex levels. On the simplest level, the driver is aware of the vehicle's heading only: this is essentially "straight ahead" and provides no guidance information except that, if the heading concept and perceived direction of motion do not appear to be closely correlated, a skid may be sensed and panic probably results.

Guidance information begins to exist only when the vehicle heading (motion) information is coupled with some other point in space related to the desired path. The here-to-there, point-to-point information level provides essentially a monitoring task with minor corrections in heading and simple maintenance of speed.

The information furnished by a simple next point in space is followed by information on a level of direction: the road is not a connect-the-dots game but a series of general directions (consecutive headings) and transitions between them. The point information level is thus followed by a direction level which begins to approach a concept. This is manifest as a series of observed or conceptualized points, at least three in number: here, there, and then.

The next more complex development is the path concept. A roadway is not a series of segments but a continuous course leading from place to place via the terrain. It has continuity and it exists in three, not two, dimensions. On this level the driver is aware of only the surface on which the vehicle is traveling and its next immediate direction or course.

The road information level broadens from that of a course to one with width, including opposing traffic, multiple lanes, median, and shoulders, as appropriate. It should be pointed out that any of the driver's concepts may be in error in various degrees and fashions, but not all errors are necessarily dangerous in routine driving. Errors, such as the false perception that the available shoulder area is firm and smooth, can become critical in the event of a gross tracking error or the reaction to severe glare, for example.

The map information level then follows, broadening the road level of information to formulate or modify a route concept including landmarks, settlements, driveways, crosswalks, and perhaps railroad crossings and bridges, etc. These features are part of the roadway, or immediately adjacent to it. They reflect tasks or possible tasks related to driving, such as slowing for narrow bridges and being alert to crossroads, other vehicles, pedestrians, domestic animals, fire hydrants, curbs, etc.

Beyond the map information level are the vicinity (area) level and the regional level of information. While these ordinarily are less directly involved in the mechanics of driving, the environmental concept which a driver holds can be influential in generating expectancies or risks estimations. The vicinity information level has to do with the urban or rural nature, kinds of activities and vehicles or obstacles to be expected, and the risk of encountering various moving hazards or glare, fog, and slippery or broken road surfaces. Terrain in the vicinity may be described as rolling, mountainous, flat, etc., and the roads may be good, narrow, winding hill-and-dale type, etc.

The region information level is the broadest and includes the variety of terrain, road types and conditions, and hazard types that can be expected over a longer run in any environment. A consistently bad roadway may be less of a problem to drivers than one that is better but presents a few sudden transitions from good to bad. Unusual hazards, specific to localized areas such as slow moving farm equipment, cattle crossings, bicycles, golf carts, and equestrians tend to be regional and of special importance to the unfamiliar driver.

In order to establish a frame of reference for these information levels and concepts, some arbitrary spatial characteristics for them are listed at this point. A summary of the characteristics is found in table 1.

Table 1. Characteristics of levels in driving information and concepts.

Conceptual Level	Information Level	Dimensionality
Heading Concept	0 Heading (aim)	Instantaneous, "now" time only.
	I Point	Information is provided at a single point (one dimension) 30 to 90 ft ahead; 0 degrees to 5 degrees from heading.
	II Direction	An implied course, of essentially two-dimensional information from two or more external cues, allows prediction up to 2 seconds; the cues lie 30 to 200 ft ahead with an implied relationship (e.g., as shoulder or centerline) to surface.
Path Concept	III Course	The vehicle is seen to be on a three-dimensional, continuous surface with at least 2 ft of leeway left and right for travel; preview is over 2 seconds but less than 10 seconds.
	IV Road	The traveled section is perceived as having all the features of a roadway such as width, shoulders, median, multiple lanes, and crossroads. Width is seen to be between 18 ft and 50 ft (or more for divided roadways) and length is about 1 mile.
Route Concept	V Map	The road traveled is seen as one of several serving as a network and providing alternatives in moving from one place to another, with landmarks and other known features. The area covered is about 1 mile wide by 3 miles long.
	VI Vicinity	The area surrounding the road consists of more than roads and landmarks to include activities and character such as residential, school, business, industrial, farming, shopping, urban, suburban, or rural, and flat or hilly. About 5 miles square of area is involved in this concept.

Table 1. Characteristics of levels in driving information and concepts (continued).

Conceptual Level	Information Level	Dimensionality
Environment Concept	VII Region	Cultural or local nature and the activities or objects associated with them are known. This may include knowledge of objects seen on or near the roadway as well as driving habits and patterns to be expected here. A region is generally more than 5 miles square and may extend across several States.

From the driver's standpoint, information at level 0 is necessary but not sufficient for more than a simple reaction: wait, stop, or panic. It is possible that, in heavy fog or a downpour, the driver would proceed for one or two seconds on the faith that the road continued in the same direction and something would be visible immediately ahead. However, to function at all, the driver soon needs at least a point in space to confirm that this heading is acceptable. If this point is provided only by the taillight of a vehicle whose driver is also on only heading level information, the situation could be disastrous. The point level of information, level I, is occasionally encountered in actual driving but it is not acceptable to most drivers for more than a few seconds or minutes. Information on level II, direction, begins to provide the driver with information for staying on the road, but level III information on the course is needed before an acceptable concept of path can be shaped, and before reasonable confidence and speed control will be achieved. The amount that is unknown about hazards, choice points, and other vehicles makes this level acceptable only for a short time and for drivers familiar with the roadway. A stranger, who does not have accurate region, vicinity, map, and road information, will have a very short tolerance for remaining with a current version of only the path concept and will seek higher levels of information. The driver will form some kind of a path concept based on the inputs at lower levels of information. Accurate region, vicinity, map, and road information will be helpful, but without an accurate path concept the driver may fail at the fundamental guidance or control level. This is manifested in slow or unsteady driving and inappropriate actions such as entering a curve at the wrong speed, overlooking a stop sign, or choosing an improper lane.

It may be appropriate to aim for providing cues only to the road information level (IV) for unfamiliar drivers, though accurate road, map, vicinity, and region concepts are desirable. The familiar driver, with highly developed route and environment concepts, will probably continue to drive faster, more confidently, and with more appropriate lane choice and signaling behavior than the stranger, with only limited information on the map level above what can be provided by official signs and markings. Certain vicinity information, such as school zones or railroad crossings, will be provided, as will unusual regional information specific to that area such as the presence of Amish buggies or other slow moving vehicles, but it is not realistic to expect all strangers to absorb this information or to appreciate the implications on the same level local residents do. Consequently, certain conflicts between local and unfamiliar drivers are to be expected. Some of these may be predictable enough to justify providing specific vehicular control information on them by special signing.

Somewhere between road and map levels of information, a usable route concept becomes formed. This is not a navigational concept, but a guidance concept which considers turns and choice points and all the information associated with them.

Region and vicinity information may be obtained at a distance through discussion, travelogs, books, and reputation, but these may not be accurate or useful for making driving more efficient. The point to bear in mind, however, is that each driver has some information on each level and holds a path concept, a route concept, and an environment concept of some type at all times. The traffic engineering concern is that the concepts be complete and accurate enough for the decision and tracking requirements of each piece of roadway. In addition, the stranger should be encouraged, as much as possible, to react so that all actions are compatible with those of local drivers. For example, a stranger encountering a railroad crossing or a yield sign (and in many places, a stop sign) is more likely than a local driver to stop. There may be little that can be done to make the stranger more predictable in such situations, but the fact that such differences exist should be made clear and considered where possible.

For the immediate concern--that of providing a model of the adequacy of night driving visibility--we will return to the information and concept levels and the cues that are used to formulate or modify them. The preceding discussion is intended to demonstrate the complexity of driver expectancies and how they must be shaped or allowed for in providing guidance and hazard avoidance aids.

Heading information from the past few seconds of experience provides a concept of heading which may be modified by signals from the driver's semicircular canals and other proprioceptors. It is supplemented, perhaps, by a feeling of compass direction (for some people). The information on heading is provided, in part, by streaming patterns sensed through peripheral vision. New work in this area suggests that extremely subtle cues (near visual threshold and with very low spatial modulations, i.e., extremely poor definition or resolution) are sufficient for providing a sense of motion or turning, perhaps on a level below the driver's conscious awareness. These cues may be invisible or meaningless to central (focal) vision. Leibowitz and Dichgans have related this (see Ophtalmie Reports, 1977) to accidents in poor visibility: the subtle and non-conscious cues from the transient (peripheral) visual system are strong enough to give the driver confidence in lane keeping and speed control, while visibility in central vision under these conditions is more seriously degraded. The driver drives as fast as usual but objects like pedestrians are much less visible than usual.

By providing lights or reflectors (retroreflectors, or etymologically more accurately, "retroflectors"), the highway agency can provide at least point-to-point tracking information (level I or II) in almost any condition. The driver must detect the bright spot with focal vision and determine only that it is associated with the roadway, not a beer can in the bushes or the floodlight in a farmer's yard.

More points or visible edges (guardrails, telephone cables along the right of way, trees, grass, embankments or road cuts, etc.) add information about direction, path, and road and enrich the concepts of path and route. A given set of visible objects can, with rain, snow, or fog, be reduced to providing lower levels of information, but the path concept should be accurate with at least mild reductions in visibility before delineation can be judged adequate. While some cues are lost in certain conditions, others may be retained and enhanced as a substitue. For example, light snow can cover edge lines but reflectors added to overhead utility cables could replace that lost information. Glare from fixed or vehicular sources must be considered as a possible counter force in achieving this minimal level of tracking information, with short-term reductions to lower levels being tolerable, though undesirable.

The more desirable, route concept is made useful by modifying some generalized concept the driver holds. This is done through use of new information obtained from the passage of other traffic, the sweeping motion of headlights, the experiencing of intersections, and other visible, audible, tactile, and proprioceptive cues. Finally, with the addition of information on vicinity and regional levels, an environment concept is molded from some habitual or general concept of driving duties and tasks to one that is appropriate for the road section actually being traversed.

It must be stressed that all drivers have path, route, and environment concepts when they arrive at any section of roadway. The traffic engineer's task is to insure, by means of a practical number and variety of devices and techniques, that for the drivers who will travel over that roadway, the concepts they have are not seriously in error. Modifying some "average" concept, carried by unfamiliar drivers, to one appropriate for the specific driving challenges of each road segment is done by supplying various types of cues or insuring that the cues present are sufficient, unambiguous, and not misleading.

3. Quantifying Driver Expectancies

It would be convenient if there were some way to convert driver's expectancies to quantifiable measures. Expectancies seem to be essentially subjective probability functions for various kinds of events. First the range of possible events must be established, then probabilities can be assigned to each. It may not be possible to list all possible events a driver could encounter, but it seems likely that more than overt driver behaviors must be covered. The driver can do little other than change direction, slow, speed up, or stop, either voluntarily or after the vehicle has contacted some other object or left the roadway. Models of control motions or human transfer functions have not been very useful because so much of the driver's subjective life has been bypassed. For example, a car slows and stops some distance ahead of another vehicle; the second driver does not slow down. There are several plausible reasons why the driver might act this way:

1. The driver has not seen the first car.

2. The driver intends to go around the stopped car using the shoulder or other lane.

3. The driver thinks the car is already off the roadway.

4. The driver expects the first car to move out of the way in time.

5. The driver intends to almost hit the car to teach that driver a lesson about stopping in traffic.

6. The driver has frozen in panic.

7. The driver intends to hit the car at full speed.

Each of these reasons has some significant probability of being the case. For the first three possibilities the highway or traffic engineer can do little except insure adequate signt distance (preview of stopped traffic), provide a clear area for recovery should the driver have to leave the road, and more delineation of the road, lanes, shoulder, and median as clear and predictable as possible. The plausibility of reason four depends on the conditions and the judgment of both drivers. In many cases drivers make risky predictions of what others will do in order to keep traffic flowing. Drivers with inaccurate concepts of the route will be more likely to have trouble. For example, if there is a curb preventing passage around the first car when the driver did not expect one, or if the surface provides less friction than the driver plans on for the guide stop, an accident is more likely. No one who has driven in urban commuter traffic will doubt that reason five is plausible, and drivers do occasionally panic, either from inexperience or for transient reasons such as momentary inattention which consumes the time needed for taking a preventive action. Reason seven is not to be ruled out either, since suicide by auto crash may be much more common than records imply, and homicides or thrill-seeking behaviors (such as in pushing a stranger off a subway platform in front of a train) are being acknowledged in some parts of our society.

The point of this discussion is that there is a tendency to think in narrow terms of "official contributing factors," rather than in the more complete context of what actually goes on. While the seven reasons listed above are not claimed to be equally likely, the chance of drivers admitting some of them to an investigating office is nil. The almost universal "reason" is "I didn't see him" or the "cause" was "following too closely." For preventive actions, the conclusions are more useful if they are stated as "I didn't expect the car to wait there" or "I thought I could either get around him or I could stop in time," though drivers seldom accept blame by making such statements. Clearer expectancies (more accurate concepts) and more accurate appreciation for risks, options, and current conditions are needed. Some of this can be achieved by signing and marking.

The choice, logically, when the hazard is a squirrel or a woodchuck on the road rather than a stopped car or a larger animal, is to sacrifice the animal rather than risk a much greater loss. The reasons for not slowing may be much the same as the seven listed above, but the decision to hit the animal may be necessary in view of the much greater potential loss in attempting to avoid it in heavy traffic. Not all drivers can take the "logical" action, however, because of startle reactions or concern for the animal. If the driver is prepared to expect such hazards, the choices and their consequences are more likely to be handled without loss of control.

Drivers have feelings of probabilities of the various events they might face. The likelihood of a curve or intersection varies with the road type. Drivers build up a concept of the likelihood of a road's transition from a straight section to an intersection or a curve. These "transitional probabilities" depend only on the physical facts of the roadway, but the driver's subjective transitional probability estimate varies with experience and familiarity with the road. Hazards, such as stopped vehicles and animals on the road, or fog, also have probabilities that vary with time and place. Geometric surprises can be reduced either by signs and markings or by the consistency of their occurrence. The driver's estimate of the probability of each transition is being manipulated in either case. Further effort to quantify the decision and judgment tasks imposed on the driver by a road section will probably be more fruitful if this kind of approach is used rather than one which attacks some "problem site" directly.

4. Development of Knowledge of Safe Visual Environments

Some of the more important factors involving operators and their success in driving are listed in table 2. The listing is in order of the writer's opinion as to criticality or importance in further research efforts for safe driving on "typical" roadways now in use. Each is rated on the state of knowledge in its measurement with reliable instruments, the existence of acknowledged criterion values for these measures, its controllability or correctability through practical means, and its criticality or power to determine success or failure in safe driving. All these ratings and the list itself have been prepared without benefit of specific data. Columns 3, 4, and 5 call for more research and development where ratings are low; column 6 sets relative priorities, with higher rating indicating higher priorities. Further discussion of many of these factors will be found in the preceding pages.

Table 2. Operator factors in safe driving at night.

1 No.	2 Factor	3 Measurement*	4 Criterion	5 Control	6 Criticality
1	Expectancy (concepts of path, route, and environment)	2	1	2	4
2	Alertness level	3	2	2	4
3	Risk assessment and acceptance level	2	1	0	3
4	Drug or alcohol status	2	2	1	3
5	Resting visual accommodation distance	4	4	3	3
6	Adaptation level (static and transient)	2	2	1	2
7	Visual sensitivity (thresholds)	4	3	1	2
8	Glare susceptability and recovery rate	3	3	1	2
9	Visual scan patterns, including rate	2	2	1	2
10	Accommodative power and rate	3	3	3	2
11	Central visual acuity (as driver drives)**	3	3	3	2
12	Training and intellect	2	2	2	2

* Means of measuring (3), criterion development (4), and controlability or correctability (5) are rated on a scale of 0 (no knowledge or development) to 4 (highly developed and practical knowledge). For the last column, relative criticality (6), 0 indicates not important, 4 indicates critical to safe driving.

** Many drivers have uncorrected vision because they have not obtained professional help or they choose not to wear corrective lenses; some have correctable (but uncorrected) night myopia. A considerable number of drivers still do not have driver licenses. A very small proportion have uncorrectable acuity defects.

F. ACQUISITION OF EXPERIMENTAL AND FIELD DATA

1. Current and Developing Techniques

Driver opinion surveys will probably continue to supplement more formalized efforts to provide adequate visual environments. The emphasis in the following discussion is on the techniques that might lead to what are usually felt to be more objective measures, and those that are more convenient and less expensive to collect.

In field data collection the use of manual counts and observations continues, but the kinds of effects being sought as evidence of satisfactory conditions has become more and more subtle. This requires large sample sizes or accuracy that can be obtained only with more sophisticated equipment. The Traffic Evaluator System (TES) developed by FHWA has been used successfully in many studies. It involves the use of one or several types of surface-mounted sensors to register the time and position of vehicle passes. Although it is not generally agreed whether the presence of tubes or tape switches as sensors across the road surface does or does not change driver behavior significantly, the problems of interruptions or lost data from sensor problems can be important. The tape switches cannot be applied to a wet surface and water often disables a sensor after it sustains minor damage. The portability of installed sensors is very limited so that sampling of a variety of sections becomes expensive. The installation, expecially on high volume roadways, usually involves disrupting traffic and always entails some risk to field personnel.

A more portable TES probably could be devised by the substitution of photo-detectors and invisible light or laser sources for the road surface sensors. Photodetectors have been tried in the past (e.g., Hemion, 1968) but the TES is more versatile than most previous systems, and new light sources have greater range, less dispersion, and are more reliable and inexpensive than previous types. It seems likely that the existing TES could be used with minor modifications if the sensors alone were replaced. For multilane roadways, corner-cube reflectors may be needed at each lane boundary. These are easier to install and more reliable than surface units. The prospect of installing a TES-like system simply by dropping off roadside units and cabling is inviting. Probably the cables could be eliminated also through the use of recent developments in telemetering. With as little equipment as one or two black boxes and three reflectors, a trap measuring vehicle counts, speed, length, and placement could be set up in a matter of minutes. The need for greater precision in field measurements, for such things as routine assessment of the adequacy of signing and markings, make a system that is easier to use in bad weather and at night very attractive. Areas suspected of having visibility problems, for example, could be surveyed more quickly and data would allow comparison to other areas to aid in selecting countermeasures and cost-effective treatments.

Vehicle trajectories and speed patterns are the observable end results of traffic engineering efforts. However, the behavior, reactions, and opinions of drivers lie closer to "causal" factors that must be understood before specific traffic behaviors can be predicted or changed. The possiblity of field measurements of electroencephalograms (EEG) is now real, and practical objective measures of perception, recognition, decision time, and other illusive data are now becoming available. It is no longer necessary to wait for a driver's action to discover whether and when a decision to act (or not to act) has been made or whether an object has been seen and recognized.

As early as 1964 investigators (e.g., Proctor and Adey, 1965; Hanley, Walter, Rhoades, and Adey, 1968; LeCret and Pottier, 1969; and Williams, Morlock, Morlock, and Lubin, 1964) were able to distinguish, from EEG records, levels of attention, phases of sleep, correctness of decisions, moment of decisionmaking, level of dark adaptation, eye closure, and similar things of interest to those involved in driver research. Computer and equipment improvements since that time have raised the probability of obtaining useful cortical signals from the scalps of human operators to reduce the extraneous delays and the variability inherent in verbal or behavioral responses. The problems and applications of visually evoked potentials (VEP) were reviewed by Kinney (1977). Among other things, the degree of blur of an image can be measured, and fixation can be assured for vision tests that require it; even blood alcohol may be measurable via VEP.

This direct cortical signaling method opens many possibilities for improved experimental work. For example, in visibility studies it is common for a subject to be instructed to "push button A when you see something ahead, and push button B, C, or D when you can tell what kind of object it is." From signal detection theory (see Green, 1960) we know that sensitivities and response criteria both vary and vary largely independently. A physiological signal indicating detection may allow discrimination between detection and decision to act that go into determining response time. The button-pushing responses are not necessarily compatible with the overlearned responses in actual driving and thus may introduce errors or delays not pertinent in the perceptual event, especially since the instructions are often interpreted in widely disparite ways by different subjects. An additional signal of value, probably obtainable from current EEG data, is related to the confidence with which a decision or response is made. Confidence is often inferred from variance or delays which become "noise" in most data. Behavioral (response) wavering could thus be separated from indecisiveness for clarity in interpretation. The effects of alcohol (Allen, Schwartz, Hoggs, and Stein, 1978) and similar driver-related conditions could be mapped much more precisely.

Czigler (1977) has suggested that the reaction times (RT) and the VEP due to contrast ratios follow the same non-linear function except that VEP responses are much quicker (55 ms) than the RT (200 ms). In the same VEP there was a second component that varied linearly with contrast.

In similar studies, Osaka and Yamamoto (1978) found that VEP latencies increased as the target was moved from 0 degrees to 40 degrees nasally, while Adachi-Usami (1978) found no VEP amplitude change beyond 5 to 10 degrees off axis for green light, depending on the individual tested. He did find that ring stimuli instead of spots elicited VEP responses which peaked at about 18 degrees from the axis. Interestingly enough the peaking for sensory reports by the subjects peaked at 15 degrees, suggesting that the 15 to 18 degree region is important in distinguishing between the focal and transient (peripheral) visual systems discussed in section C2. The slopes of threshold-area functions apparently tied to the two systems were sharply different as well, further suggesting that the mechanisms differ.

Rice (1979) reported confidence that evoked potentials and other physiological measures, currently being studied at the Brain Research Laboratories of New York University Medical Center under Dr. E. Roy Johns, will soon be used routinely in assessing individual intelligence and visual or intellectual processing abilities or developmental status. Kinney (1977) states that VEP has become a useful tool in determining the optical correction an individual needs. For children and non-verbal or difficult subjects including animals, VEP opens many new possibilities. Expectancy, task relevance, uncertainity resolution, and similar subjective qualities seem to be signaled by VEP. "One has the feeling that this area may prove to be the most exciting yet in evoked-potential studies." (Kinney, 1977, p. 1471). Much of this work is being done in Japan, Germany, France, and Britain. There may be pressures in this country (other than funding) that have discouraged this kind of research because it smacks of "mind control" or other such social concerns. It should be obvious from even this brief review that the scientific and practical potential is great, but the potential for abuse is very limited and, with current controls, hardly a matter for concern to public funding agencies.

2. Further Development in Measurement

Ever keeping in mind the need for techniques simple enough to be used in routine field applications, there are tools that might be developed to aid in the progress toward true quantification of visual environments and driver requirements. One of these tools would be used to assess the presence and contrasts of visible objects by scanning the view of the road ahead. The other technique to be discussed here is a simple (and therefore limited) photographic procedure that is immediately applicable if it is found to be worthwhile.

A hypothetical scanning instrument, dubbed the VQA or Visual Quality Assessor and similar to the HFR's Visual Quality Meter (VQM) mentioned earlier, could be used for obtaining the transitional probabilities, P_t (e.g., see Brown, 1976), of the visual field relevant for driving. Information or complexity of a visual scene can be expressed as the probability that, in moving from one spatial cell to the next across the entire field, the luminance will change by some specified increment or more. The solid state photoscanner, which is a square array of equal 256 spots in the VQM, could be modified to cover a perspective view of the roadway and surroundings. By aiming the device at the vanishing point of the road section, a scan of the field available through the windshield could be obtained. The scan weighting would be predetermined by the physical construction of the photo sensors. This is based on the importance of cues and glare sources in various parts of the scene.

Figure 1 is an illustration of the kind of assignment that might be made. The perspective represents a straight roadway. In use, the device would be aligned with the lane width or delineation. For curved or hilly roads the apex of the pattern will not coincide with the vanishing point or horizon. This may not be important, or if it is, the weighting could be changed or the area near the apex, which is most affected, could be switched off. For each area or cell a single integrated luminance value is determined. A scanning program then samples each value and determines the contrasts between various cells. Where a specific luminance value is very high a glare source is suspected; where most luminances are low, a low adaptation level (average, excluding specific glare sources) can be calculated and the remaining contrasts can be scaled (see Graham, 1965; Allen et al., 1977) for the background luminance. The number of contrasts remaining above threshold but below disability glare levels (e.g., see Stoudt et al. 1970; ITTE, 1968; DeBoer, 1973; Huculak, 1978b) indicate the quantity of the available visual information. The quality is next assessed by a cummulative count of elements along specific radials from the apex for which the luminance is above the average for the entire scene, less the glare sources. Radials corresponding to centerline, lane line, or edge line delineation areas are given highest priority; those between the delineation areas and the horizon are next, along with those near the vanishing point; and those from overhead and pavement areas are lowest. Glare sources (sources with intensities much greater than the rest of the scene) are programmed to cancel any signals from adjacent sensors, the number depending upon the intensity of the glare compared to average luminance.

While the engineering of such a portable computer is not trivial, it seems to be within the current technology. The setting of area sizes and priorities is also feasible, if tedious. Rough plastic lenses or some similar method can be devised for integrating the light energy over the irregular areas for assessment by sensors of a single size. Thus the tiny area near the vanishing point is equally as important as each large area above the horizon, but a glare source, which may have small dimensions anywhere within one of the upper cells, must be registered accurately. The computations and interarea comparisons may require sophisticated design or an auxiliary computer. The design of the areas for appropriate relative sizes will be a combination of logic and heuristics, verified by field tests.

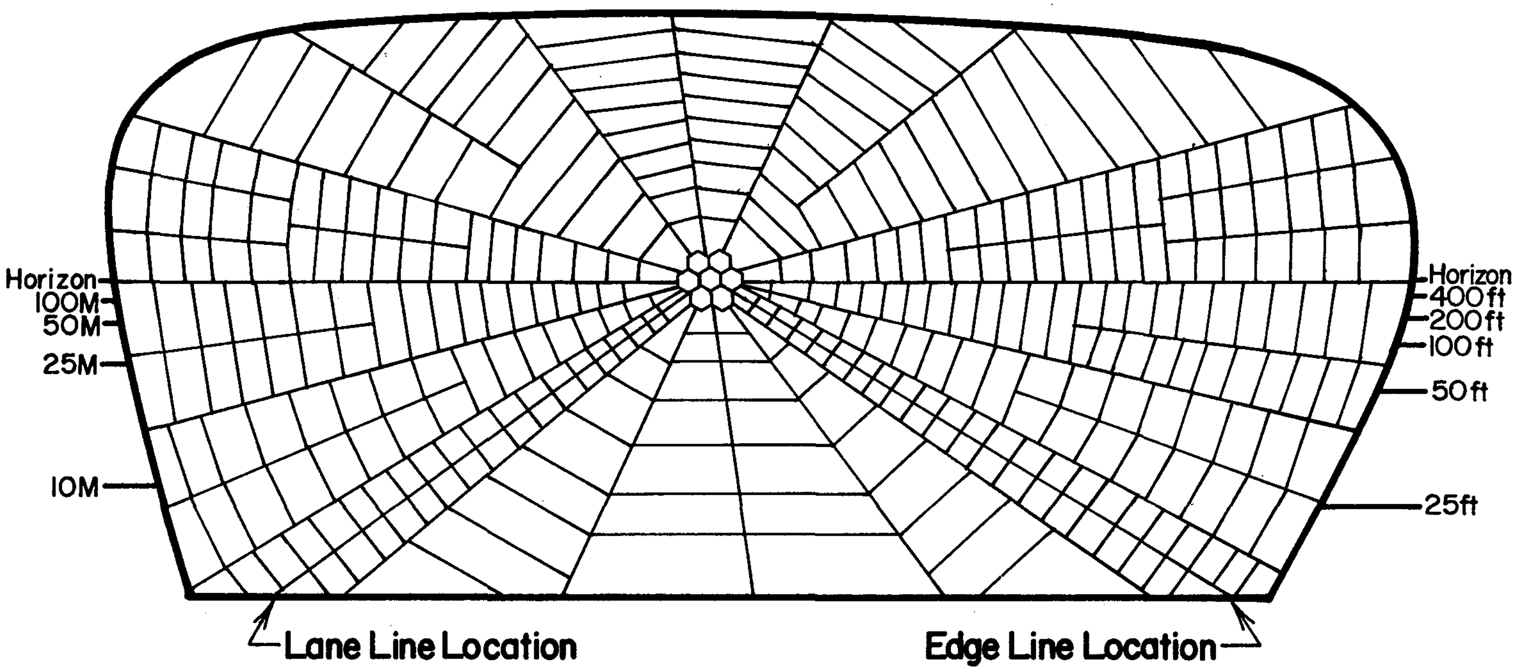

Figure 1. Photocell areas to simulate potential night information source weightings of perspective view of a straight level roadway.

The foregoing VQA instrument is obviously based on a conceptual model of visual search and perception for guidance performance. This model has not been developed formally, but is based on eye movement data such as that gathered by D. A. Gordon (1966a), Mourant, Rockwell, and Rackoff (1963, 1969), and Williams (1966). This explicitly excludes inputs from peripheral vision, which may have to be added from some other type of assessment. The development of the instrument can be done along with or after the development of the conceptual framework, since it should be a useful tool in quantifying at least one aspect of it.

As a possible alternative to an instrument for assessing the visibility in a scene, one must also consider film or video recording. Film techniques have been used, with varying degrees of success, for describing a visual environment or (see Pinkney et al., 1976) for quantifying contrasts in experimental work. Ordinary photos may contain too much detail for analysis by convenient information measuring procedures. More likely in the case of night visual environments, ordinary photos will show too little of what is expected. Time exposures as used by Pinkney et al. (1976) require equipment that is inconvenient and locations that are either dangerous or not representative (off the road) of the driver's viewpoint. While very fast film is available, it may exaggerate problems of product and process variability. Moreover, a "picture" of the scene at night is not necessarily desirable; some more dynamic assessment of the visible environment is the objective.

In a crude attempt to evaluate a simple photographic method, a series of exposures were taken with common (Kodak Plus-X and Ilford FP4) black and white film and a standard 35mm single-lens reflex camera using exposures suitable for hand-held photography from a moving vehicle. The results--contrary to what most photographers might guess--were encouraging. The developed negative film was mounted in 2x2 inch slide mounts and projected on a screen. The negative form seemed to make the assessment more objective--counting black spots or lines seems easier than counting "bright things." The underexposure filtered low contrasts out of the view, simulating some level of defocusing, disfusion, and absorbtion which may be realistic for some observers and some atmospheric conditions. What remains is an impression of visual complexity (number of visible objects) and visibility adequacy (the clarity of the direction of the roadway). Some lines and retroflective signs were visible over a range of exposures (f1.5, 1/15s to f5.6, 1/25s for a 55mm lens). Other center, lane, or edge lines disappeared with similar exposures. A visible portion of any line as illuminated by low-beam headlights seemed to give a good cue to the immediate course of the road. Commercial developments presented patterns or groups of light sources which sometimes obscured the road direction, sometimes enhanced it. Subtle cues in dim environments also could be seen: the sky may be visible through the trees on a rural road, but this "sky line" does not always provide accurate (or any) information on the future course of the road. Shoulders, curbs, foliage--even mowed grass--were visible as cues for guidance, and the headlight aim gave some indication as to surface texture by its sheen in the center (low beam) or right side (high beam) of the lane. Power or telephone lines and poles are definite contributions to a good preview of the road (provided, of course, they remain parallel to it).

A series of exposures was taken of a night target (silver, high intensity 3M signing material) to show the effects of defocusing. The object, a 16 in (40 cm) square, mounted diagonally, was clearly visible as an irregular diamond shape with the camera focused at the proper distance (55 ft), but the pattern (a 2 in (5 cm) purple outline of a 12 in (30 cm) square) disappeared when a much shorter (8 ft) setting was used. The sign lost its shape gradually and became larger and almost circular at a setting of 1.75 ft, but it was no less visible. Clearly acuity is not the issue for detection of this bright object. Defocusing this camera lens from 55 ft to 11 ft simulates about 20/40 (4/8) acuity. The normal 20/20 (4/4) acuity in terms of spatial frequency is 30 cycles per degree (CPD) or a change from dark to light or vice versa every minute of arc; acuity of 20/40 (4/8) would allow perception of only 15 CPD or a transition every two minutes of arc. Photos of edge- or centerlines lose little of their path preview quality with moderate defocusing, further increasing the practicality of this approach as a routine field treatment.

Much remains to be done before a film or contrast approach can be shown to be useful, but it appears that, with standardization of films, exposures, and counting or scoring techniques, this could be a very usable way to determine whether delineation has deteriorated or path markings could be considered confusing. As discussed earlier, glare is not well represented by this technique. A negative shows oncoming headlights as two fuzzy dark dots and a dark area just ahead of the vehicle. In fact, the glare can be painful and almost blinding for some people, though the right edge line, if it is of sufficient contrast, is clearly visible and is information enough for use by the actual driver. This approach to assessment or quantification of the night visual environment seems worthy of further consideration and exploration. Many variations in technique are possible, such as field data gathering by film or video tape and laboratory evaluation of this record, as well as use of a VQM either alone or in conjunction with recorded data. The criteria for "sufficient" delineation hinge on definitions of users and, perhaps, criteria derived from EEG signals. In any case, the use of modulation functions rather than acuity measures for lane-tracking information and hazard detection assessments seems a necessary and feasible change in approach.

3. The Vehicle and Field Data Acquisition

The driver cannot use cues that fail to enter the eye for one reason or another. This implies that vehicle design may still be improved upon for increasing the driver's ability to use the cues that exist. There are compromises between wind resistance and visibility in the angles and shapes of glazed surfaces. Other compromises are made in size of glass areas which limits a driver's ability to see the environment or cues through a car ahead, in the color or transmittance of the glass, and the size, location, and function of mirrors, side windows, and lights. Care should be taken to insure that these subtle visibility factors are not traded away in design for less necessary requirements. Because of the large variability in design features, the specific conditions under which data are gathered must be considered. Some design vehicle values will have to be accounted for in specifying the acceptable cue visibility levels.

G. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH AND DEVELOPMENT

1. The numbers of variables and their ranges in the broad study of nighttime driving visibility are such that it is necessary to restrict them to a more practical extent for most applications. This can be done by establishing a set of specifications for the design driver for which visibility is being provided. The set must include a large proportion of drivers without requiring overly conservative conclusions which would result in unrealistic costs. One or more design driver specifications would allow quantification of the night driving visual environment in terms of acceptability, such as a figure of merit or index. From this, the special needs of other driver populations could be provided for in many cases.

2. Visual capability can be described in terms of visual acuity or in terms of modulation transfer functions and spatial frequencies. The latter is more general and more directly related to the guidance and hazard detection performance of drivers. This approach should be developed into an operational concept so that all designers and traffic and maintenance personnel can be made familiar with it and its applications. This can be made as a first step in the provision of more quantifiable visual environments.

3. The visual environment can be described only in terms of the capabilities and limitation of the users. Some of these capabilities are not being applied; some are not yet understood. Specifically, the lack of distance cues at night induces a night myopia which can be predicted and corrected for individuals but is now being largely ignored; and the non-conscious inputs from the transient visual system (peripheral vision) are probably exploitable but are only now being described in scientific studies. These and other visual functions must be explored before design driver specifications can be established fully and in their most general forms. Interim specifications can be set for current uses.

4. An added reason for pursuing the correction for night myopia is for increasing the applicability of the findings of research. The variability in data from testing programs which results from the introduction of a strong random effect (like resting accommodation distance) largely destroys the hope of finding significant effects. Hills and Burg (1978) and many others refer to inconclusive results which may, in part, be related to the "anomalous myopias" of night vision and instrument myopia, which is similar (Leibowitz and Owens, 1975) and degrades an affected person's (Leibowitz and Owens, 1975) performance on devices like many vision testers. An alternate term--anomalous presbyopia--is informative because it correctly implies that the range of accommodation, rather than only the specific point of focus, is affected by the reduction in cues to distance found in night vision and related situations.

5. Glare is a combination of excessive light intensity or contrast and observer visual characteristics. A practical field test for glare source evaluation should be established, based on specific glare susceptibilities and glare recovery values for one or more design drivers.

6. A survey instrument, probably a solid-state optical scanner, should be developed for the measurement of a visual scene in terms of the numbers of contrasts of various levels that are present, as well as some average value of luminance. Probability of contrast in some incremental visual search would be the measure of visual complexity needed for the first part of a description of the night visual environment. Weighting of these values by the importance of various parts of the visual scene would be a next step. A visual criticality (probability-importance product) might be useful for the overall evalution.

7. Visual search; driver expectancy; the driver's concepts of the path, route, environment and hazards which might be encountered; visual complexity; and conspicuity are some of the ingredients of the ultimate model of driver performance in a night visual environment. There is a responsibility to insure that markings and delineation provide clear indications of the driver's paths and choices without encouraging speed excessive for surface condition or hazard detection. In this regard, public opinion may not be conservative enough for acceptable safety in night driving. Surveys of public opinion and checklists for evaluating conspicuity or adequacy of cues for night driving should be compared for problem and non-problem sites where visibility and speed may interact to increase accident potential.

8. A field assessment of night visual environments utilizing simple photographic techniques seems to offer promise for making decisions on delineation adequacy. This should be explored further, both as an independent approach and as part of the more formal photoscanning approach to quantification of the night visual environment. It may also be fruitful to investigate the use of non-linear intensity representations and other capabilities of video tape systems in this regard, especially in view of the difficulties in representing glare sources on film.

9. Visual complexity has many components, only some of which are now recognized as relevant to driving. Subtle cues should be recognized in sparse visual environments (as driver's do) and exploited through novel techniques such as visually enhancing overhead telephone cables that parallel rural roads and the installation of reflectors above the roadway to indicate oncoming traffic is approaching. Visual quality and complexity are related, and both depend on weather and operating conditions. An index of quality must be expressed in terms of complexity, and more than one index value may be needed to cover good and poor conditions due to weather and traffic variables.

10. New techniques are available which will allow reduction in the variability of data that plagues traffic researchers and operating agencies. Field measures can now be made on visually evoked cortical potentials from scalp-mounted electrodes. Such measures are less dependent on subjective values, memory, or the individual's interpretations of instructions and duties. They should be investigated and used where appropriate in defining adequacy of visual treatments and devising improved visual environments, either in terms of effectiveness for special problems or in terms of cost effectiveness of competing treatments.

11. Efforts to improve the visual environment in a general sense should be continued. This includes further study of the design of lighting, signaling, and glazing aspects of vehicles to enhance road transportation as a system. The road design and the visual environment as influenced by private land uses or advertizing are other parts of that system which can be optimized to varying degrees. The users, with greater knowledge of their visual limitations or aids to vision each might require, can also affect the efficiency of the total system. Quantification of each aspect of the system is necessary before quantification of the total system can be assessed.

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