PROVIDING FOR VISIBILITY IN NIGHT DRIVING

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

MODELING THE PROBLEM

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

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

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

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

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

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

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

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

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

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

SOME PROMISING CONCEPTS

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

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

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

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

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

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

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

SUMMARY

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

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