3. Turning Movements at Intersections. The execution of a turning movement at an intersection can be a complex and taxing maneuver for many drivers, particularly older drivers. Several aspects of executing turning movements deserve attention. At multilane signalized intersections where turning movements are protected by the signal phase, the proper selection of the lane to turn into is a problem for many drivers. This problem is compounded at intersections with dual left-turns. Older drivers seem to have difficulty executing a turning maneuver alongside another vehicle. Drivers of all ages exhibit difficulty with maintaining the proper lane upon completing the turn. At intersections unprotected by signals, drivers misjudge the speed of oncoming vehicles when executing their turns. How can turning movements at intersections be made safer?
4. Car-Following Behavior. The traffic operator seeks smoothness of flow in the traffic stream. Reliance is placed on drivers to adjust their speed and following distance to suit prevailing conditions and situations. How can drivers better learn and be motivated to execute safe following distances and speeds?
5. The Impacts of IVHS Technologies on Highway Users. Almost every conceived technique requires interface with the users. Many systems are designed to reduce the information load on the driver. Other systems may result in overloading or distracting the driver with information. Traffic control systems external to the vehicle must be understood by users so that they can make decisions that will enhance the operation of the total system. How can human factors involvement in the design and operation of IVHS systems alleviate these problems?

SUMMARY

Traffic operations, highway design, traffic control devices, safety and human factors are intricately linked. The safe and efficient operation of our highway systems requires that these components be fully integrated and mutually supportive. We must seek ways to build our systems so that they take advantage of the collective mental power of the systems users and serve the mobility needs of our society.

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Traffic Control Devices, Highway Safety, and Human Factors

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INTRODUCTION

The control of roadway traffic is essential to the safe and efficient movement of vehicles and pedestrians. It traditionally has been the domain of the traffic engineer, but human factors has come to play an increasing part in the design and use of traffic control devices (TCDs) over the past three decades. The need to know about drivers' limitations in information processing and behavior as these relate to traffic control will be examined, a brief review of some relevant literature presented, and future research needs identified.

The driving task can be broken down into three main components: control (driver interaction with the vehicle in terms of speed and direction), guidance (maintenance of a safe speed and path by keeping the vehicle in the proper place in the lane), and navigation (executing a trip from one location to another). Much of the driver information necessary for the last two of these comes from TCDs. This way of looking at the driving task is the basis for the positive guidance approach (Alexander and Lunenfeld 1975).

Several criteria must be met for a TCD to be effective. Initially, it must command attention or be easily detected by the person who needs the information. It must be legible at the appropriate distance (in time to take the necessary action) and must often be legible when seen for a very brief time - glance legibility. At busy urban locations, TCDs can easily be hidden by large vehicles and seen only briefly. The device should also be quickly understood, as drivers often have only a second or two to interpret and respond to the message.

The relative importance of these various design criteria has never been established. They are not all of equal importance and can be in conflict. In an attempt to determine the relative weighting that ought to be attributed to the main criteria for traffic sign symbols Dewar (1988) solicited the views of sign experts in four countries (Australia, Canada, New Zealand, and the United States). There was widespread agreement that comprehension was most important, followed by conspicuity, reaction time, and legibility distance (the last two being similar in importance).

Evidence that decisions about TCDs in the U.S. Manual on Uniform Traffic Control Devices have typically been based largely on subjective judgment has been presented by Shapiro et al. (1987). They examined the research basis for standards in the manual. In all, 90 standards (including 44 for signs) were examined, using 3288 "potentially useful" references. They found little objective support for most of the TCDs in the MUTCD.

DRIVER CHARACTERISTICS

A great many human characteristics and individual differences influence the ability of drivers to obtain information from TCDs. In order to appreciate these, the concept of the "design driver" needs to be introduced. The question is, How will those who design and implement signs take into account driver abilities and limitations? Human factors knowledge about driver abilities is essential to decisions about issues such as color and shape codes, size and style of alphanumeric characters, understanding of symbols, legibility of signs, conspicuity of all TCDs, speed of response to TCDs, effects of environmental conditions such as darkness, individual differences (e.g., age), and information overload. These issues are the domain of the human factors psychologist or engineer. In spite of the considerable amount of research that has been done on these topics, some of which is outlined in the Driver Performance Data Book (Henderson 1987), little of it has been successfully applied to the design and use of TCDs. More detailed accounts are available elsewhere of human factors research on driver characteristics (Dewar 1992; Evans 1991) and traffic signs (Dewar 1989). A good summary of traffic engineering practice related to TCDs in general can be found in the latest edition of the Traffic Engineering Handbook (Pline, 1992).

The problems faced by older drivers as related to TCDs have been outlined by Staplin, et al. (1989) in a review of older drivers' capacities and their implications for TCD design and use. These could serve as a starting point in defining the design driver mentioned earlier.

In designing any aspect of the transportation system, it is essential to cater to the needs and limitations of the older drivers, as they have disproportionate difficulty driving at night due to a number of factors - reduced acuity; poor contrast sensitivity; lower amount of light getting into the eye of older persons; higher degree of glare sensitivity and slower recovery from glare due to headlights, advertising signs, and street lights; poorer perception of color. In addition, elderly drivers often experience more stress than do others, thus reducing the amount of attention they can devote to detecting, reading, and responding to TCDs. Speed of eye movement and visual scanning behavior also deteriorate with age. The best source of information on older drivers is TRB Special Report 218 (1988).

DRIVER INFORMATION PROCESSING AND OVERLOAD

The importance of attention in driving has been documented by in-depth accident analyses showing that difficulties with perception, attention, distraction, etc. are major human causes in over 40% of traffic accidents (Treat et al 1977). Laboratory research suggests that drivers with low mental capacity are more likely to have accidents.

A driver characteristic influencing the ability to pay attention to the driving task while extracting traffic sign information from complex visual scenes is the perceptual style referred to as "field dependence." People who are field dependent have difficulty selecting relevant from irrelevant visual information and appear to be more readily distracted than those who are field-independent. The literature on this matter is divided on the relationship between field dependence and traffic accidents. There does appear, however, to be evidence that field-dependent drivers are poorer at detecting signs embedded in visual scenes (Loo 1978).

For a number of years there has been a concern about the potential for driver distraction and overload because of excess signage or signage unrelated to the driving task. It is known that drivers can only take in and process a certain amount of information without sacrificing other elements of the task required for safe and efficient driving. For this reason there are standards in the MUTCD dictating the maximum number of destinations, motorist services, etc. on a sign panel, and regulations about the proximity of advertising signs near rural freeways.

The effects of overloading drivers with too much sign information at one location may seem obvious, but the extent of the effect was not well understood until Gordon (1981) examined it in a series of experiments.

Subjects were required, in a laboratory experiment, to select the appropriate lane to be in to get to a specified destination when presented with a number of overhead freeway guide signs. Gordon showed that the presence of non-guidance information (e.g., bus lane, exit only) did not increase reaction time to obtain relevant destination information.

Gordon varied the number of guide signs (3, 5, and 8) presented and found that mean response times increased about 35% for place name destinations and 57% for route numbers as number of messages increased from 3 to 8. However, even the worst subjects (95th percentile reaction times) got the information in less than 5 seconds. A more realistic test of sign information processing involved the necessity for subjects to study a map containing information about their position and then, after being told their destination, to indicate the appropriate lane to be in, as in the previous experiments. This is more typical of the way drivers actually navigate, as they had to determine what information on the signs was relevant to their needs. Reaction times were somewhat longer under conditions where subjects had to read and understand the sign content rather than simply scan the content of the signs. Large numbers of errors were also found for some of the destinations. It is evident that overload involves more than simply the number of signs to be processed, but depends on what the driver must do with the information displayed. This study clearly illustrates the need to avoid driver overload and points out the need for drivers to make intelligent trip plans.

In addition to the issue of driver information load due to excessive traffic sign information, there is the possibility of distraction by advertising signs near roadways. There appears to have been relatively little research on this topic. However, it was examined in a series of five experiments by Johnston and Cole (1976), who used a variety of billboard advertising messages (nearly all with pictures and words) in an effort to distract driver attention in laboratory experiments that simulated some of the demands of the driving task. The distractors were color photos, several containing nudes. Small but statistically significant effects due to distraction were found for the measures of tracking and detection response time. The authors state that the driver has the capacity to shed irrelevant information and that "the general effect of distraction is not of great magnitude." They concluded that novel, sensuous, or moving displays are more likely to distract attention; that distractions should be minimal where the driver's load is high; and that glare from advertising signs should be controlled.

More recently, Andreasson (1985) summarized the literature on traffic accidents and advertising signs. In the three valid studies he found on advertising signs and accidents, either no relationships were found or any relationships that were claimed could not be attributed to these signs. No before-and-after studies have been done to provide conclusive data on this issue. The author concludes that "there is no current evidence to say that advertising signs, in general, are causing traffic accidents" (p. 105).

SIGNS

One of the most widely used and efficient ways of communicating information to drivers is with the use of traffic signs. This type of TCD has received more attention than have the others. For detailed review of the literature, see Dewar (1989). The work on this has included letter fonts and size, color combinations, retroreflectivity, amount of information, conspicuity, understandability of symbols, etc. One of the topics receiving considerable attention has been symbols. There are a number of advantages of symbols over word messages. They can be classified (e.g., as regulatory or warning) and identified at a greater distance and more rapidly and can be identified more accurately when seen at a glance (Ells and Dewar 1974); they are seen better under adverse viewing conditions (Ells and Dewar 1979); they can be understood by people who do not read the language of the country in which they are used. One of the main difficulties is that their meanings are not always obvious to the user. Although many are relatively easy to understand (e.g., NO LEFT TURN, CURVE), others present problems even for experienced drivers. Research by Hulbert and his colleagues (1979) and Pietrucha et al. (1985) has revealed relatively poor understanding of many symbols, in part because they are introduced into the system without drivers being properly educated about their meanings. Much of the work has also involved inadequate measures of comprehension.

One of the more extensive studies on TCD understanding was done by the American Automobile Association (AAA) by Hulbert et al. (1979). They examined comprehension of several traffic sign symbols, traffic signals and pavement markings with a large sample (over 3100) of drivers from across the United States. In a follow-up study conducted for the AAA a year later, Hulbert and Fowler (1980) used the same procedure but tested a different set of traffic control devices, including five traffic sign symbols. Comprehension levels were generally poor, with the percentage of correct responses to signs, signals, and pavement markings being 74, 68, and 45 in the first study. The corresponding figures for the second study were 59, 66, and 62 percent correct. Older drivers had more problems than did others.

A study of drivers' understanding of traffic sign symbols was undertaken for the FHWA by Knoblauch and Pietrucha (1986), who examined potential deficiencies in approximately 30 U.S. symbols and made recommendations for their improvement. Certain "families" of signs were found to be quite confusing (e.g., curves vs. turns; pedestrian vs. school signs). Many symbols were poorly understood.

Assuming that an adequate measure of comprehension has been obtained, there is still the issue of just what proportion of road users must understand a symbol in order for it to be safely used. Criterion levels of 65% have been used in some countries, but there is generally no clear statement of what is an acceptable level of understanding.

In many situations the information that would be most useful to the driver changes from moment to moment. To accommodate this need, engineers have developed "real time motorist information displays." These involve changeable message signs (CMS) to manage traffic under the following conditions: recurring problems (e.g., congestion); nonrecurring problems (e.g., accidents, construction); environmental problems (e.g., fog, ice); special operational problems (e.g., tunnels, drawbridges, contraflow lanes). As these systems developed, a number of ergonomics questions arose. What type of information do drivers need? Where should the information be located? What are the best ways to present the information? A large research effort in the United States addressed these issues and produced a "design guide" for real-time motorist information displays (see Dudek et al. 1978 for a review and Dudek 1990 for application guidelines).

SIGNALS

Traffic signals have more impact on travel behavior than any other TCD. Computers have enabled the use of signals which are very flexible - fixed or pretimed, traffic actuated, etc. However, they can be poorly designed, improperly placed and operated, and not properly maintained. They do not always increase safety and reduce delays.

One feature that gives drivers difficulty is the use of left-turn phasing. The three main types are:

- unprotected left turns (no exclusive phasing for left turns)
- protected-only left turns (a separate interval for left turns; they are prohibited at other times)
- protected/permissive left turns (protected phase during one interval - left turn arrow - and allows unprotected left turns on circular green).

Another factor is lead/lag phasing where protected left turns are either at beginning (lead) of the green phase or at the end (lag).

Difficulties with the understanding of traffic sign symbols has been fairly well documented, but relatively little research has addressed the understanding of traffic signals. With the great variety of signal phasing systems (including the various sign messages that accompany the signals) in operation in urban areas, the driver can easily become confused. For example, there is a surprising lack of understanding of left-turn signals. Hummer et al. (1990) examined driver understanding and preferences for a variety of left turn signals and different accompanying sign messages among 402 drivers in Indiana. Subjects were asked to choose one of four possible actions in response to the displays. Responses were scored as correct, close (conservative error), or gross error (actions with probable catastrophic consequences). Pairs of signal alternatives were also shown in order to determine preferences. Only 10.7% of the participants got all 9 comprehension questions correct, while 23% had more than half wrong (close or gross error).

The protected/permissive (p/p) displays gave drivers particular difficulties, with 23% making gross errors when the green ball only was displayed, and 14% when the green ball for through and green arrow for left turns were displayed. The presence of a sign with the signal display reduced gross errors in two of the three signal display configurations, suggesting that appropriate signing may reduce some of the difficulties in understanding signals. The authors conclude that protected signals are best understood and that p/p signals are least understood. The data indicate that most of the variables examined were unrelated to preference, but younger drivers did prefer a p/p signal, while those who drive less and those from rural areas preferred a lagging to a leading protected sequence for left turns.

Statistics indicate that a large proportion of accidents occur at signalized intersections. The effectiveness of installing signals at intersections has not been clearly demonstrated. However, research has shown rear-end collisions to be more common at these intersections. Mahalel and Prashker (1987) have analyzed the decisions faced by drivers approaching traffic signals as they turn from green to yellow. There is a zone during which the driver must decide whether to stop or continue through the intersection. This "indecision zone" has been defined as that range of distances from the vehicle to the intersection stop line which constitute the 10th to 90th percentiles of stopping probabilities. If the distance from the intersection is great enough essentially all drivers will stop, and if short enough none will stop. The area where a choice must be made has been broken down into the "dilemma zone," in which one can neither stop safely before the stop line nor cross the line before the red light, and the "option zone," in which the light turns yellow and one can either stop or cross the line before the red light. If a lead driver decides to stop, and the one following him/her decides to proceed through, there is a good probability of a rear-end collision. The point where the probability of stopping is .5 has the most potential for rear-end collisions. The use of a flashing green light to indicate that the end of the green phase is near has been found to increase rear-end collisions, as this increases the option zone. Further understanding of driver decision making and behavior at signalized intersections could enhance traffic safety.

Persaud (1988) has reviewed the literature on traffic signals and reports that, of the 14 before-and-after studies examined, 6 showed an increase in total accidents after signal installation, while 8 showed a decrease. He concludes that most research has shortcomings. The two common pitfalls he illustrates are regression to the mean and incorrect inferences from cross-section studies.

PAVEMENT MARKINGS

Paint markings on the road surface are an important source of information for drivers. They include all lines, words, and symbols on the pavement. Their function is to guide traffic into the correct position on the roadway and often to supplement signs and signals.

Words and symbols on the pavement must be elongated in order to present the appropriate visual image to the driver's eye. The order of the text is such that the message will read up with the first word nearest the driver. On the basis of studies by Gordon (1976) as well as by Hulbert et al. (1977) and Hulbert and Fowler (1980), it appears that markings are not well understood.

NAVIGATION

A good deal of work has been done on TCDs as they relate to the guidance task. However, the navigation component of the task has been somewhat neglected by human factors researchers. King and Mast (1987) have summarized the work on excess travel, defined as the difference between total actual highway use excluding destination-free "pleasure" driving and the travel required had the optimal route been used. They determined that excess travel is due to suboptimal navigation strategies, route selection, and route planning and to problems in the highway information system. This is a concern for reasons of both safety and economy. After synthesizing the available data from various parts of the world, the authors conclude that excess travel constitutes 4% of all vehicle miles travelled and 7% of all travel time for work-related trips. The corresponding figures for non-work-related trips are 20 and 40%, respectively. They estimate the total annual cost in the U. S. to be more than $45 billion.

Evidence of the problems which drivers have with navigation are illustrated by two studies by King (1987a; 1987b). In one study (King 1987a) subjects were required to drive a 50- or a 15-mile route, going to a number of specific destinations along the way, under three conditions of navigational information. Significant excess travel was found.

In another study, King (1987b) surveyed 125 drivers about their navigational and trip planning abilities. They also rated the effectiveness of various remedial measures that would help navigation on the road. The three most highly rated measures all involved improving directional and information signing. The provision of automatic in-vehicle navigation systems that show the vehicle location or the best route was rated very low. This has interesting implications for the acceptance and use of high-technology systems intended for navigation.

One of the most important developments in traffic control and navigation in the past decade is the rapid growth of Intelligent Vehicle/Highway Systems (IVHS), which can provide the driver with detailed information about his/her location in the street or highway network, as well as when to make a turn, optimal routes to follow in the event of accidents or congestion, distance and time to destination, and information about vehicle status. In future the driver may well get less traffic control information from TCDs and more from inside the vehicle. However, a good deal of research is needed on driver acceptance and the safety implications of such high technology in vehicles (Wierwille et al. 1988)

It is evident from the work on driver navigation ability that an effort should be made to develop and apply the very successful system called "positive guidance." This is particularly the case in view of the increasing numbers of older drivers, who are more readily confused and distracted in busy traffic environments.

ACCIDENTS AND TCDs

The relationship between accidents and traffic control devices has been an elusive topic, except possibly in the case of signals installed at intersections. Police reports may indicate that the "cause" of a collision was failure to obey a sign or signal, but this may be only one among a number of contributing factors.

The safety effects of signals have been examined more than have those of other TCDs. For example, Datta and Dutta (1990) reviewed the literature on installation of signals at intersections and report that most studies find a decrease in right-angle accidents, but an increase in rear-end and left-turn accidents. In their own work Datta and Dutta studied 102 intersections before and after signals were installed. They found patterns similar to those found by others. Rear-end collisions were 53% higher and head-on, left-turn accidents, 50% higher, while right-angle accidents 57% lower after installation. These findings raise the question of driver behavior during the approach to signalized intersections as the light changes.

OTHER TYPES OF TCDs

The TCDs discussed above are the most widely used; however, there are others used for specialized purposes. Object markers indicate obstacles that are in or near the roadway. Delineators (reflectors on posts or on the pavement) are used for vehicle guidance, especially around curves at night. Flashing beacons are used to warn motorists of especially hazardous situations where a sign is not enough. Raised pavement markers, small discs, or humps a few inches in diameter on the road surface are used to improve visibility at night and in wet weather. Traffic cones and barricades are used to route traffic and warn drivers in work zones. Rumble strips are used to alert drivers about a changed condition (e.g., reduced speed, end of a freeway). Unfortunately, relatively little human factors research has been done on these TCDs.

TRAFFIC CONTROL IN CONSTRUCTION ZONES

One location which appears to present a challenge for safe traffic control is the construction zone. This problem has received a good deal of attention over the past two decades (e.g., a special issue on the topic in the ITE Journal, April, 1979); nevertheless, there continues to be concern for the safety of drivers and workers in construction and maintenance zones.

The need to warn drivers well in advance of hazards under such conditions is obvious. It has been suggested that drivers may require 10.2 to 11.7 sec. to detect, recognize, make a decision, and execute a proper maneuver for a lane change in a construction zone (Warren and Robertson, 1979). On the basis of a review of relevant research, it has been suggested that "approximately 2/3 of work zone safety problems could be ameliorated if current standards and knowledge were properly applied" (p. 32). It appears that a major source of the problem is proper implementation of existing regulations and TCDs, rather than design of the TCDs themselves.

Odgen et al. (1990) examined understanding of traffic signs in urban work zones by interviewing 205 drivers. They were asked about signing and viewed specific signs presented in a pamphlet of photographs. The word message CONSTRUCTION 500 FEET was correctly identified by only 2/3 of the subjects - 25% thought it meant construction would continue for 500 feet. The low shoulder symbol was very poorly understood - 84% thought it meant uneven pavement. The work message NO CENTER LANE was understood by fewer than half the subjects. The appropriate maneuver for the CROSSOVER word message with an arrow (seen in context with the sign mounted on a delineation barrel) was at a low level, with 55% saying they could turn before the barrel, while 38% thought turns were not permitted before the barrel. This is an example of where drivers may know what a sign means, but not where to make the appropriate maneuver.

COMPLIANCE WITH TCDs

An important consideration in determining whether a TCD is effective is whether drivers act upon the information they convey. In the case of regulatory messages this is the issue of compliance. It is quite likely that many accidents which involve failure to comply with TCDs are not identified as such.

A "violation" could occur for a number of reasons:

- the driver deliberately violates the TCD,
- the TCD is difficult to detect due to poor placement or visual overload in the roadway environment,
- the device is not legible or understandable because of poor design features or poor maintenance, or
- the violation is of a traffic law rather than a TCD.

Pietrucha et al. (1989) measured the actual compliance with specific TCDs at 906 selected locations. Of the 79,055 drivers observed at traffic lights, 3.5% entered on a yellow signal and about 1% entered on the red. Of the more than 31,000 drivers observed when turning right at a red signal, 61.3% did not stop properly, but only 1.4% were involved in conflicts as a result of this. Approximately 2/3 of the drivers observed failed to come to a full stop at STOP signs, and 1.3% of these cases resulted in a traffic conflict. Illegal left turns were made at NO LEFT TURN signs by 1.6% of the 53,165 drivers observed.

METHODOLOGY

A great variety of methods have been employed for the evaluation of traffic signs (see Dewar and Ells 1984 for a review). Methods can be divided into field (on-the-road) and laboratory procedures. Engineering evaluations often come in the form of complaints from drivers or a series of accidents at an intersection. Assessment based on "expert" opinion is also a common approach to both the evaluation of existing signs and the development of new ones.

The ultimate index of the adequacy of a traffic sign is how quickly and clearly the message is understood by drivers on the road. However, it is too costly to conduct field evaluations of all signs. A more efficient and much less expensive approach is to evaluate them in the laboratory. Psychological and psychophysical measurements such as reaction time, glance legibility, legibility distance, comprehension, preference ratings, and signal detection have been successfully employed to gauge the effectiveness of both existing and new signs. Laboratory techniques have the advantage of economy of time and money. However, it is essential to ensure that these methods are properly validated against on-the-road measures. Unfortunately, there has been a tendency to accept these methods without properly validating them against measures taken in the driving environment.

One of the few studies to use and combine a number of measures was that of Roberts et al. (1977), who compared the symbolic and text versions of 19 traffic sign messages. Most messages had one text and four symbolic versions. Five measures were used: understanding time (the time required to indicate a sign's meaning), comprehension, certainty (how confident the subject was of his/her understanding of the sign's meaning), preference (rank ordering of the symbols used to convey a specific message), and identification time (minimum exposure time at which subjects could accurately identify all elements of the symbol). The authors derived an "efficiency index" for each symbolic version of each message - what they called the "relative 'goodness' of performance" of that symbol.

A method that has shown success in designing more effective symbolic signs is the low-pass optical technique of Kline et al. (1990), who were able to increase the legibility distances of symbolic highway signs for young, middle-aged, and elderly drivers. To identify and thus avoid the problems of contour legibility and interaction between adjacent contours in regulation symbolic highway signs, the experimenters viewed versions of them blurred by strong positive sphere lenses. The visibility distances and comprehension of standard text, standard symbolic and the "improved" symbolic highway signs which resulted were then compared among young, middle-aged, and elderly observers. The average distance at which standard symbolic signs could be identified was about two times that of standard text signs. The visibility distances of their improved symbolic signs, however, were about three times those of standard text signs and 50% greater than those of standard symbolic signs, demonstrating that their optical approach can be used to enhance the visibility of symbolic highway signs for drivers of any age.

ISSUES FOR FURTHER RESEARCH

- Scientific methods for TCD design and use.
- Human factors basis for current design and use.
- Perception and comprehension of traffic signals and pavement markings by elderly road users.
- Effectiveness of TCDs in work zones.
- Education of drivers about new TCD's.
- Development of a "positive navigation" philosophy and methods to complement the "positive guidance" approach.
- Implementation of current standards.
- Relation of TCD adequacy to traffic safety.

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Highway Design, Highway Safety, and Human Factors

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INTRODUCTION

The goals of the highway design engineer include providing roadway facilities which can be safely negotiated by various road users, even under less-than-ideal weather and environmental conditions. To help accomplish this goal, a basic understanding of human characteristics and behaviors as they relate to roadway design features is needed. Road users of interest include not only passenger car drivers, but also drivers of trucks, motorcycles, bicycles, and other vehicles, as well as pedestrians.

The purpose of this paper is to discuss some of the basic safety concepts which are currently known regarding roadway geometric features. Also, gaps in human factors knowledge are identified for which additional research is needed. Roadway features covered include cross-sectional elements (including roadside features), horizontal and vertical alignment, pedestrian and bicycle facilities (including transition curves), intersections, and interchanges. Traffic control devices such as signs, signals, and markings are not covered in this paper.

In discussing each of these topics, it is important not only to concentrate on the "average" driver, but also to point out situations where data exists for certain vehicle types (e.g., heavy trucks) or certain driver populations (e.g., older drivers) which indicate a heightened risk of crash. A major problem here is in defining this heightened risk, due largely to the lack of good exposure data for specific vehicle or driver subgroups. For example, we do not know whether elderly drivers have more problems on horizontal curves than other drivers because of the lack of exposure information on drivers by age in the exposed population. Also, very little exposure data are available on large trucks (by truck size) or pedestrian and bicycle volumes for use in determining the types of roadway features and facilities which affect their safety. Given these problems, the following discussion will explore what is known and what human factors questions remain unanswered.

CROSS-SECTIONAL DESIGN ELEMENTS

Cross-sectional roadway elements are features which are part of a cut-away view of the roadway and include the number of lanes, lane width, shoulder width and type, median width, and roadside design (e.g., roadside slope, placement of roadside obstacles). Elements of a rural two-lane cross-section are shown in Figure 1. From a human factors standpoint, cross-sectional elements can serve several purposes, such as helping drivers to stay in their proper lane (e.g., wide lanes, turn lanes), allowing drivers a place of escape or refuge in an emergency (e.g., wide shoulders and medians), and helping a driver to safely return to his/her lane after leaving it (e.g., mild roadside slopes, paved shoulders).