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Human factors for safe and efficient roadway design and operation

Tanweer Hasan

Department of Civil Engineering
Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh

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Abstract

Since the safety and operational efficiency of the highway system depends, to a great extent, on the ability of the system's human element to perform in a proper, error-free manner, an appreciation of human factors is essential to highway design and traffic control. This paper summarizes various characteristics of drivers, pedestrians and bicyclists, which the road safety and traffic engineers should consider while designing transport facilities.

Keywords: Road Accidents, human factors, driver error, traffic safety.

1. Introduction

It is seldom that an accident results from a single cause. There are usually several influences affecting the situation at any given time. These influences can be separated into three groups: the human element (usually as a driver of a vehicle, but also as a pedestrian or cyclist), the vehicle element, and the highway element. Researchers estimate that 85% of all causative factors involve the driver, 10% involve the highway and 5% involve the vehicle (Bryer, 1993).

The road safety engineering is concerned with various aspects of traffic control, but such control is often introduced through, or relies upon, influencing human behavior. For example, traffic signs and signals are useless if drivers, pedestrians or cyclists do not see, interpret, respond to, and obey them. Therefore, knowledge of human performance, capabilities and behavioral characteristics is a vital input to much of the road and traffic engineer's task and a prerequisite to understanding how human behavior may be influenced.

2. Human factors related to the driver

As a principal controlling element, drivers are the primary determining factors in the successful operation of roadway systems. Skillful performance of driving task performance, maintenance of vehicle control, safe and efficient guidance through roads and traffic, and proper navigation using an optimum mix of routes represent ways in which driver performance enhances system operations and safety.

While engineers have considerable knowledge about vehicle characteristics, load factors, environmental effects on pavements, they often have only a rudimentary understanding of the behavior of the motorist (Alexander and Lunenfeld, 1986). They fail to account for driver error, the consequence of designs that are beyond the capabilities of the driver, maneuvers that are unusual and unexpected, decisions that are overly complex, or information displays that are confusing and ambiguous.

Driver error is one of the leading contributors to accidents and inefficient traffic operations, and must be minimized for the highway system to perform its intended function, the safe and efficient movement of people and goods. Driver errors occur for a variety of reasons. Some of the major reasons are: expectancy violations; situations that place too much demand on drivers, causing overload; situations that put too little demand on drivers, causing lack of vigilance; information displays that are deficient, ambiguous, and missing content; misplaced information; blocked or obscured information; information that does not possess sufficient size, contrast, or target value; and fatigue and driving under influence of drugs and alcohol (Alexander and Lunenfeld, 1986).

2.1 The driving task

It is first necessary to understand what drivers do, and how they receive and use information to perform the driving task. The basic driving task consists of three performance levels- control, guidance and navigation with increase in complexity from control through guidance to navigation (AASHTO, 1990). Control refers to a driver's interaction with the vehicle. Usually drivers exercise their control through three or four mechanisms- steering wheel, accelerator, brake, and the gear. Guidance refers to a driver's maintenance of a safe speed and path. This subtask requires decisions involving judgment, estimation, and prediction. Navigation refers to the activities involved in planning and executing a trip from origin to destination.

The three levels- control, guidance, and navigation- form a hierarchy of information handling complexity. At the control level, performance is relatively simple and performed almost by rote. At the guidance and navigation levels, information handling is increasingly complex, and drivers need more processing time to make decisions and respond to information inputs.

The key to successful driving task performance is efficient information handling. However, the total driving task does not consist of independent activities performed independently. At any given point of time, drivers are faced with a multitude of information, transmitted from a variety of sources, and received through a number of sensory channels. They may be required to sift through the information to determine its relative importance. When drivers are required to sift through a mass of information, both relevant and extraneous, under time pressure, they need to assign a relative priority to the competing sources, and therefore require a criterion upon which to base their decisions. Similarly, engineers need a basis for deciding what information to give the driver. The concept of primacy has been developed to deal with this problem.

2.2 Primacy

Primacy refers to the relative importance of each level of the driving task and of the information associated with a particular activity. The major criterion upon which primacy is assessed is the consequence of driver error on system performance. Since control and guidance level errors often result in crashes, these levels assume a higher primacy than do errors at the navigation level, where the consequences of error are likely to be lost and confused drivers.

2.3 Information handling

Drivers use most of their sensory input channels to gather information. Although most senses are used to gather information, drivers receive more than 90 percent of all information visually (Alexander and Lunenfeld, 1986). While driving, drivers do many things either at the same time or very nearly so. They look at traffic, follow the road, read signs, listen to the radio, and steer their vehicles. To accomplish this, they gather information from many diverse information sources, both informal (e.g., the road, its alignment) and formal (e.g., signs, signals, markings); make many decisions (e.g., take a particular exit, brake for a road hazard, speed up to avoid a signal change); and perform continuous control actions (e.g., steering, speed control, gear shifting).

An important consideration in the reception and use of visually displayed information is that drivers can only attend to and process one source of visual information at a time. Drivers are “serial”, rather than “parallel” processors of visual information (Alexander and Lunenfeld, 1986). Drivers integrate various subtasks and maintain an overall appreciation of a dynamic, ever changing environment by sampling information in short glances, and shifting attention from one source to another. They make some decisions and delay others, depending on the primacy of the need. They rely on judgment, estimation, and prediction to fill in gaps. Such task-sharing behavior enables drivers to use their limited attention span and information processing capabilities (Alexander and Lunenfeld, 1986).

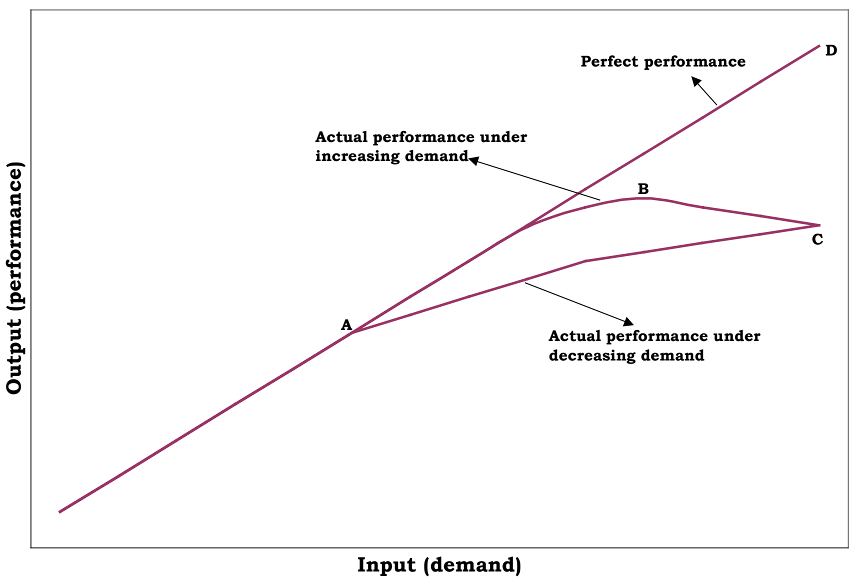

Fig. 1. Driver’s information processing model (reproduced from Ogeden, 1990)

A simple, though very useful, model of information processing is presented in Fig. 1 (Ogden 1990). It can be seen that when demand is low, performance equals demand, i.e., all inputs are processed correctly, and all decisions are appropriate. However, as demand increases, there comes a point (A) at which the rate of output starts to fall below the rate of demand. Beyond A, if demand is increased further, output also continues to increase for a time, but at a lesser rate than demand. The driver's output continues to increase till it reaches a peak (B), after which it actually starts to fall away with the information overload, resulting from a continued increase in demand. For a driver who has been significantly overloaded (C), there is a residual effect on performance even after the demand is reduced. This is shown by the lower curve CA on Fig. 1. The gap between input and output (i.e., between line AD and line ABC) may be indicated by an error, input information that is not detected, or information, which is selectively and deliberately shed. It is interesting to note here that, due to "self-challenge" or "self motivation", most drivers tend to set themselves at or slightly beyond point (A).

Drivers are not identical in their capabilities or habits. Driver behavior seems to vary between individuals according to two factors: ability and motivation (Ogden 1990). Behavior is dependent upon both what the driver is able to do and what the driver chooses to do, and the degree of difficulty depends upon the latter. For example, a driver can choose to drive faster or slower, can choose to overtake or not, can choose long headways or short, and so on. Thus, there is little correlation between driver skill and driver accident experience.

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2.4 Reaction time

Information takes time to process. Drivers' reaction times increase as a function of increased decision complexity and information content (see Fig. 2). The longer the reaction time, the greater the chance for error. Whether or not a decision is expected also affects reaction time (see Fig. 2). Researchers (Alexander and Lunenfeld, 1986) measured brake-reaction time (usually known as "perception-reaction" time) for expected and unexpected signals. When signal was expected, the reaction time was, on average, 2/3 sec (ranging from less than 0.2 sec to greater than 2.0 sec). When the signal was unexpected, reaction time approached 1 second, with some drivers taking over 2.7 sec to respond.

2.5 Expectancy

Expectancy relates to a driver's readiness to respond to situations, events, and information in predictable and successful ways. It influences the speed and accuracy of driver information processing and is one of the most important considerations in the design and operation of highways and the presentation of information. Expectancies operate in all levels of the driving task. Psychologists first identified the concept of expectancy over seventy years ago. It was not until the 1960's, however, that the concept found its way into highway applications (Alexander and Lunenfeld, 1986).

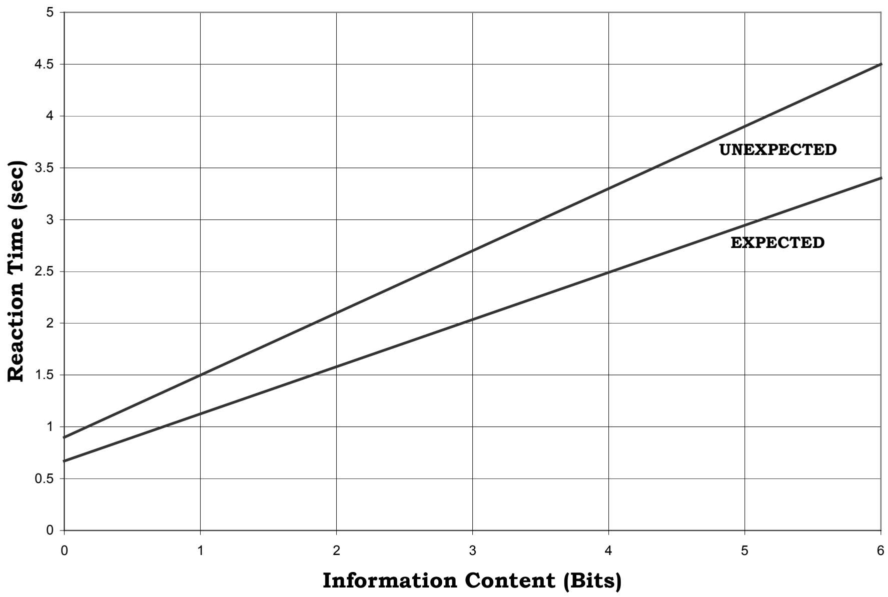

Fig. 2. Driver reaction time (reproduced from Alexander and Lunenfeld, 1986).

There are two types of driver expectancies. The first are long term, a *priori* ones that drivers bring to the task based on past experience, upbringing, culture, and learning. The second are short term, *ad hoc* ones that drivers formulate from site specific practices and situations. Both types affect driving task performance and should be accounted for in highway design and traffic control.

Reinforced expectancies help drivers respond rapidly and correctly. Unusual, unique, or uncommon situations that violate expectancies may cause longer response times, inappropriate responses, or errors (AASHTO, 1990). Most design features are sufficiently similar to create expectancies related to common geometric, operational, and route characteristics. For example, left turns are usually allowed when the signal is in "Red" and the drivers expect turn left on red. Again when the signal is turned red for the main lane traffic, the cross street traffic expects the green. However, a protected right turn on the main lane may violate the expectancies of the cross street traffic. Drivers travelling on high-speed rural highways expect to drive upstream at the same speed. Narrow bridges or lane drops also violates drivers' expectancies.

The production of designs in accordance with prevalent expectancies is one of the most important ways to aid performance. Unusual or nonstandard design should be avoided, and design elements should be applied consistently throughout a highway segment. Care should be taken to maintain consistency from one segment to another. When drivers get the information they expect from the highway and its traffic control devices, their performance tends to be error free. When they do not get what they expect, or get what they do not expect, errors may result.

2.6 Visual characteristics

2.6.1 Visual acuity

Visual acuity is the ability to see fine details of an object. If a visual signal is to be seen, it must be within the driver's visual field. For reading purposes, the visual field is quite narrow- 3° to 10°. However, objects outside this field can be detected. Signs and signals within 10°-12° of the line of sight can be seen and understood, while objects can be detected in peripheral vision to 90° left and right, 60° above of the line of sight, and 70° below the line of sight (Ogden, 1990). However vision beyond the 10°-12° range is usually blurred (Garber and Hoel, 1997). Age also influences peripheral vision. For instance, at age 60, a significant change occurs in a person's peripheral vision. The peripheral vision is affected by the speed of the vehicle. For example, at 30 km/h, the lateral (left-right) angle of the visual field decreases to about 100°, and at 100 km/h, it reduces to about 40° compared to 180° at rest (Ogden 1990).

2.6.2 Color vision

Color vision is the ability to differentiate one color from another, but deficiency in this ability, usually referred to as color blindness, is not of great significance in highway driving because other ways of recognizing traffic information devices can compensate for it. Combinations of black and white and black and yellow have been shown to be those to which the eye is most sensitive (Garber and Hoel, 1997). Increased intensity of colors used in the traffic control devices can also minimize this problem.

2.6.3 Glare vision and recovery

Glare occurs when relatively bright light appears in the individual's field of vision, which causes decrease of visibility and also causes discomfort to the eyes. The time required by a person to recover from the effects of glare after passing the light source is known as glare recovery. Studies have shown that this time is about 3 sec when moving from dark to light and can be 6 sec or more when moving from light to dark. This phenomenon has direct effect on street lighting designs and also on the design of longitudinal median barriers in case of glares caused by headlight beams.

2.6.4 Illumination

The human visual system is capable of operating over an enormous range of illumination, from 0.75×10^{-6} cd/m^2 (a very dark night) to 10^5 cd/m^2 (a beach on a bright day)- a range from the darkest to the brightest varying by a factor of over 10^{11}.

2.6.5 Eye and head movement

Filmed records of eye movements indicate a maximum possible rate of about 4 fixations per second (Ogden 1990). For normal driving, in which the diver is attending to other tasks as well, a rate of 1.0 – 1.5 fixations per second would be reasonable. Thus for traffic design, the signals should be separated in time and space. Although eye movements can be made over a field of about 50°, it is rare for that full range to be used. Rather, the driver will move the head to focus on a new object, such that eye movements are limited to about 15° left to right (Ogden 1990).

2.6.6 Depth perception

Depth perception affects the ability of a person to estimate speed and distance. It is particularly important on two-lane highways during passing maneuvers, when head-on accidents may result from a lack of proper judgment of speed and distance. It should be noted, however, that the human eye is not very good at estimating absolute values of speed, distance, size, and acceleration. This is why traffic control devices are standard in size, shape, and color. Standardization not only aids in distance estimation but also helps the color-blind driver to identify signs (Garber and Hoel, 1997).

2.6.7 Hearing perception

The ear receives sound stimuli, which is important to drivers only when warning sounds, usually given out by emergency vehicles, are to be detected. The drivers also may receive continuos sound stimuli from the horns of other cars in the stream. Loss of some hearing ability is not a serious problem, since it can normally be corrected by a hearing aid.

2.6.8 Dilemma zones

Most probably, every driver has encountered the situation of approaching a signalized intersection just when the traffic signal turned amber (yellow) and has faced the decision of whether to apply the brakes in order to stop for the red signal or to attempt to clear the intersection on yellow. Drivers may also feel that it is impossible to safely execute either maneuver. A properly selected amber duration that incorporates the motion of the vehicle during the driver's perception-reaction time can eliminate this problem, and design equations can be found elsewhere (Papacostas and Prevendouros, 1993).

2.6.9 Lateral displacement

When approaching an object located near their paths, drivers show a tendency to displace laterally away from the object even though it may not be on their direct path. This lateral displacement mainly depends on the speed of the vehicle and the lateral distance of the object from the line of sight of the driver. Different mathematical models are available to deal with this problem (Michaels and Gozan, 1963).

3. Human factors related to the pedestrian

A pedestrian is any person afoot. Involvement of pedestrians in traffic is a major consideration in highway planning and design. Pedestrians are part of every roadway environment, and attention must be paid to their presence in rural as well as urban areas. The urban pedestrians, being far more prevalent, more often influence roadway design features that the rural pedestrians do.

Pedestrian characteristics related to traffic and highway engineering practices include those of the driver, discussed in the preceding section. In addition, other pedestrian characteristics may influence the design and location of pedestrian control devices. Such control devices include special pedestrian signals, islands at intersections, pedestrian underpasses, elevated walkways, and crosswalks. Apart from visual and hearing characteristics, walking characteristics play a major part in the design of some of these controls (Garber and Hoel, 1997). For example, the design of an all-read phase, which permits pedestrians to cross an intersection with heavy traffic, requires knowledge of the walking speeds of pedestrians.

3.1 General characteristics

To effectively plan and design pedestrian facilities, it is necessary to describe the typical pedestrian. The pedestrian will most likely not walk over a mile to work or over 0.5 mile to catch a bus, and about 80 percent of the distances traveled will be less than 3000 ft. The typical pedestrian is a shopper about 50 percent of the time that he or she is a pedestrian. The pedestrian volumes are influenced by weather, or in specific locations, advertised sales (AASHTO, 1990).

Pedestrian actions are less predictable than those of motorists. Many pedestrians consider themselves outside the law in traffic matters, and in many cases pedestrian regulations are not fully enforced. This makes it difficult to design a facility for safe and orderly pedestrian movement.

Pedestrians tend to walk in a path that represents the shortest distance between two points; thus along a streets they often cross at midblock and fail to stay in crosswalks. Pedestrians also have a basic resistance to changes in grade or elevation when crossing roadways and tend to avoid using special underpass or overpass pedestrian facilities. Also, pedestrian underpasses may be potential crime areas.

An important factor in relation to pedestrian accidents is age. Very young pedestrians are often careless in traffic from ignorance and exuberance, whereas the elderly appear inattentive or defiant toward motor vehicles and drivers. Pedestrian accidents can also be related to the lack of adequate sidewalks, which forces pedestrians to share the pavement with motorists.

Designers should also consider the characteristics of handicapped pedestrians while designing traffic facilities. Successful designs of signals, crosswalks, islands, and curbs to accommodate pedestrians with walking, vision, and mental impairment are available and are being used in other countries.

3.2 Physical characteristics

3.2.1 Body area

The physical dimensions of the human body are reflected in the design of pedestrian facilities. For the design of sidewalks, stairs, or transit-loading areas, a knowledge of the width and depth of the body is most useful. Studies have shown that nearly all males have a shoulder width less than 20.7 inches and a depth of less than 13 inches. For design purposes, the area of a body is approximated by an ellipse 24 inches wide and 18 inches deep (Fruin, 1971). These minimum dimensions apply only to situations where individuals are forced into close proximity. If a greater degree of comfort or mobility is required, a larger body area per person must be assumed. As curbs, stairs, or other irregularities on the ground surface are encountered, at least one space or one stair-step separation is required for normal walking (AASHTO, 1990).

3.2.2 Walking speed

There is a broad range of walking speeds among pedestrians. The rates when crossing a street are significant in design. Average walking speeds range from approximately 2.5 to 6.0 ft/sec. The Manual on Uniform Traffic Control Devices (MUTCD, 1988) assumes a normal walking rate of 4.0 ft/sec. Older people will generally be in the slower part of this range.

4. Human factors related to the bicyclist

Usually, a bicyclist either crashes with other vehicles or may loose control due to surface irregularities. Nearly 70% of drivers report that they did not see the bicyclist before the crash (Burden, 1993). This may be true to a large extent, but it does not change the driver's responsibility to look for road users other than autos. Bicyclists have a thin, pencil-like profile in the complex traffic mix. Many drivers do not expect bicyclists to be in the traffic mix at all. This is especially true when the proportion of bicycles in the traffic mix is very low. Past study results have indicated that the drivers do look for bicyclists when the proportion of bicycles in the traffic mix gets increased.

Designers should do all they can to keep bicyclists visible, especially at night. A leading cause of bicycle crashes is riding against the traffic (wrong-way riding). A large proportion of bicyclists is young aged, while the drivers are usually adult males. There are several physiological and psychological differences between children and adults. Designers often fail to realize the abilities of the bicyclists. Most bicyclists have little or no training and inexperienced riders. Bicyclists have longer reaction times for a turn or to begin applying their brakes.

Bicyclists, in general, have a misconception that the traffic rules do not apply to them. They often ride their bicycles on the sidewalks and also through the crosswalks while crossing the roadway. Another special factor contributing the crashes is the wobbling effects of the bicycles. Bicycles are in a constant state of imbalance and wobbles left or right as it goes down the roadway. Sudden wobbling to the right may directly result into crashes with other vehicles. The most worrying factor is that the bicyclists rarely wear helmets. The fatality rate among the bicyclists can be reduced significantly if the bicyclists wear helmets. Research showed that 80% of fatal injuries, and 75% of disabling injuries could be reduced by widespread use of bicycling helmets (Burden, 1993).

5. Conclusions

For safe and efficient traffic operation and safety, an appreciation of human factors related to drivers, pedestrians and cyclists is necessary to highway design and traffic control. Road safety and traffic engineers are major determiners of the success of the highway system. Their productions of designs that match the capabilities of the driver, that take human limitations in account, and that, through the highway information system, convey the operating conditions of the highway and its environment to the driver, enhance the optimum driving task performance. The traffic control devices should convey clear and simple message to the drivers. The conspicuity, legibility, comprehensibility, and credibility of the traffic control devices must be ensured. Care should be exercised so that expectancies of the drivers in relation to highway design and traffic operation are not violated. The drivers should be given positive guidance. The designers should also take into account the visual capabilities of the drivers, and place the traffic control devices within the clear cone of vision. The roadways should be designed in such a way to provide adequate sight distances corresponding to the reaction time of the drivers. Drivers should be aware of the fact that alcohol and drug uses drastically reduce their information handing capabilities and increase the reaction times.

The pedestrians form a major portion of the total road users. Any pedestrian facility design (crosswalks, sidewalks, refuge islands, overpasses and underpasses) should consider or take into account the physical characteristics and walking speed of the pedestrians. The drivers should be aware of the limitations of the pedestrians. Similarly, the pedestrians should also follow the rules and regulations while walking. This also applies to the cyclists. It is worthy to note that bicycle related fatalities can be reduced significantly if the cyclists wear the safety helmets. Driver training and development program and educational programs directed toward pedestrians and cyclists should be formulated to reduce the extent and severity of road accidents.

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