Human Factors in Traffic Engineering

BY K. W. OGDEN

The road traffic system may be considered as comprising three elements: the human, the vehicle, and the road. This system is inherently unstable and is maintained in equilibrium only by the frequent intervention of the human (usually as a driver of a vehicle, but also as a pedestrian or cyclist).

Knowledge of human performance, capabilities, and behavioral characteristics is thus a vital input to much of the traffic engineer's task. Traffic 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 of themselves are useless if drivers do not see, interpret, respond to, and obey them. A knowledge of human performance (especially driver behavior) is therefore fundamental to the successful development of such aspects as signing, signals, lighting, delineation, and much of geometric design as well.

In this paper, some of the important aspects of human performance of relevance to the traffic engineer are reviewed. These aspects include information processing, visual characteristics, and information needs.

Conversion Factors

To convert from	to	multiply by
km/h	mi/h	0.62
m	ft	3.3
cd/m²	lambert	0.00031
mm/s	in/s	0.04

The paper includes practical guidelines on how these considerations might influence traffic design and control. For a more extensive review of these issues, refer to Cumming,[1] Forbes,[2] and Shinar.[3]

Information Processing

The Driving Task

Driving can be considered as comprising three essential tasks: navigation, guidance, and control. These tasks require the driver to receive inputs (most of which are visual), process them, make predictions about alternative actions and decide which is the most appropriate, execute the actions, and observe their effects through the reception and processing of new information.[4]

There are numerous problems inherent in this sequence of tasks, arising from both the capabilities of the human driver and the interfaces between the human and the other components of the road traffic system (the road and the vehicle). Among these problems are the following:[4]

- Inadequate or insufficient input available for the task at hand (e.g., nighttime driving, poor sight distance, or complex intersection layouts),
- Driver difficulty in handling extreme inputs or uncommon events,
- Driver may sample inappropriate inputs or process inputs too slowly,
- Overload is dealt with by simply shedding part of the input demand in order to deal with that judged to be more important,
- Errors and misjudgments in decisions related to driver stress, arousal, conditioning, experience, motivation, and type of input, and
- Driver may make serious errors.

A Model of the Driving Task

Provided that the driver is not called upon to receive and process information at too rapid a rate, the driver can remain in control of the vehicle, and hence ensure equilibrium in the road traffic system. However, if the rate exceeds the driver's capability, the resulting stress could cause an error that may in turn lead to a faulty navigation, guidance, or control action; a further consequence may be the occurrence of a crash.

A simple, although very useful, model of information processing is presented in Figure 1.[1,5] This plots the rate at which tasks are presented to the driver (i.e., the rate of input demand) against the rate at which decisions are transmitted (i.e., the output performance).

It can be seen that when demand is low, output 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 still further, output also continues to increase for a time, but at a lesser rate than demand—i.e., there is a gap between input and output. The driver's output continues to increase until 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* in Figure 1.

The gap between input and output (i.e., between line *AD* and line *ABC*) may be indicated by the following:

- An error,
- Input information that is not detected, or
- Information that is selectively and deliberately shed.

Ideally, the road traffic system should encourage and permit the driver to shed information that is not immediately relevant to the driving task. In other words, if part of the demand at point *A* is optional (e.g., listening to the radio or engaging in conversation), then ideally this part of the task should be discarded if a new task is interposed, so that overall demand does not increase beyond *A*.

In performing a skilled task, such as driving, the rate of output may be set by the person (self-paced) or by external factors (externally paced). With self-paced tasks, people set a pace for themselves at or slightly beyond the rate at which they can perform without error, i.e., near point *A* in Figure 1. Thus, a driver in a traffic situation where the external pacing is at a low level (e.g., a lightly trafficked, rural road) will seek to impose a self-paced load by such means as increasing the driving task (e.g., increasing speed, tailgating, precision steering on the center line, etc.) or by attending to extraneous matters (e.g., listening to the radio, engaging in conversation, looking at the scenery, or thinking about matters unconnected to the driving task).

It is therefore important that the road traffic system allows and assists drivers to adjust their pace downwards, by shedding extraneous tasks. The traffic engineer can assist the driver to do this in several ways:

- Provide trend information where possible,
- Avoid the sudden imposition of demand, or the introduction of extraneous demand, when loads on the driver are already high,
- Require a series of simple decisions rather than a single complex decision, and
- Control the rate at which drivers are required to make decisions.

Expectancy

The importance of experience in relation to the driving task was mentioned earlier. Prior experience is critical in reducing reaction times and enabling drivers to adjust their pace downwards when a new driving task is imposed. These experiences develop, over time, into a set of workable expectancies, which allow for anticipation and forward planning. If these expectancies are violated, problems are likely to occur, either as a result of a wrong decision or of an inordinately long reaction time.[3]

There are three types of driver expectancy:[6]

- Continuation expectancy—the events of the immediate past will continue. (This results, for example, in small headways because drivers expect that the preceding vehicle will not suddenly change speed.)
- Event expectancy—events that have not happened will not happen. (This results, for example, in disregard for level crossings, and perhaps for minor intersections as well, because drivers expect that no hazard will present itself where none has been seen before.)
- Temporal expectancy—where events are cyclic (e.g., traffic signals), the longer a given state occurs, the greater the likelihood that change will occur. (This results, for example, in drivers accelerating towards a green signal, because it is increasingly likely that it will change. Of course, others may decelerate for the same reason!)

If the driver receives information in the expected form and events occur in accordance with that information, then the driver's performance is very likely to be error free. When the information does not match the driver's expectations, system failures in the form of crashes and incidents are much more likely to occur.

It is very important for the traffic engineer to realize that driver behavior is largely governed by habit, experience, and expectation, and that any design or operation that violates these considerations is likely to be unsatisfactory and possibly unsafe. The traffic engineer should attempt to ensure that drivers' expectations are recognized and that un-

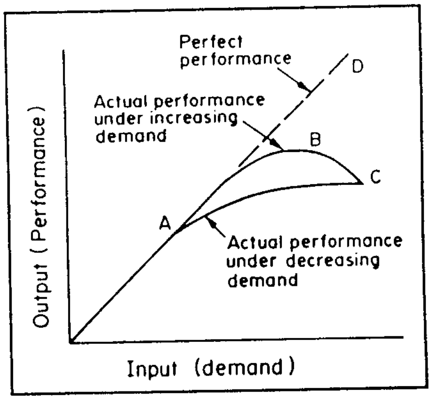

Figure 1: Information processing model (Source: cited reference 1).

expected design or operational situations are avoided or minimized, that predictable behavior is encouraged through familiarity and habit, and that information provided decreases the driver's uncertainty.

Reaction Time

The term "reaction time" is used to describe the period between the occurrence or appearance of a "signal" (usually a visual stimulus) and the driver's physical reaction to it.

Expectancies, as described earlier, reduce reaction times because drivers respond through familiarity and habit. However, different drivers will have different reaction times, because reaction time is affected by a wide range of individual characteristics, such as experience, skill, degree of alertness, motivation, risk-taking behavior, and blood alcohol level. These factors are not under the control of the traffic engineer, but the engineer must recognize that these variations exist and must design the traffic system for as wide a range of driver abilities as possible.

Studies of driver reaction to stimuli have shown, in many situations, an average reaction time of around 1.5–2.5 seconds is typical, but that the variance of the distribution of reaction times is very high.[7,8] Thus, traffic design and operations should aim to reduce both average reaction times and (perhaps more important) the variance of reaction times, especially inordinately long reaction times.

There are several ways in which these objectives may be pursued.[1]

Encourage familiarity. This relates to the discussion on expectancies. Drivers will react much more quickly to a familiar stimulus. Therefore, unfamiliar situations (e.g., unusual intersection layouts or other traffic management treatments) or unexpected responses (e.g., "Keep Left" in countries where vehicles are driven on the right hand side of the road, or "Keep Right" where vehicles are driven on the left) should be avoided.

Minimize the number of alternatives. The reaction time increases with the number of alternative courses of action available, because the driver has to process more information. Therefore, the number of alternatives should be limited. Preferably, there should be only two options, e.g., to maintain the status quo or to be presented with a single alternative to it.

Provide positive information. Ideally, the driver should receive positive information, i.e., be told what to do, not what not to do. This minimizes the time taken to search for alternatives. This is not always possible or sensible, but is revealed in the use, for example, of "Wrong Way Go Back" rather than "Do Not Enter" signs.

Provide prior warning. The reaction time can be reduced if the driver is prompted to expect the event to which the reaction is required. However, a prior warning without a context is likely to be ignored, so the warning should either call for a response (e.g., change lanes) or alert the driver to a situation that is already visible (e.g., a roadworks warning sign should be located where the roadworks are visible).

Short-Term Memory

The human memory may be considered as having two stages: a short-term memory and a long-term memory. The short term memory has a very limited capacity, and material fades after about 30 seconds unless reinforced by repetition or by use in some other activity.[4] Information cannot be recalled once it has faded, unlike the long-term memory, where information can be recalled after the event.

Most of the driving task is performed by processing information that never leaves the short-term memory. That is, details of most of the signs, signals, pavement markings, other vehicles, pedestrians, etc., that a driver encounters on a trip are merely "noted," and after use (if any) is made of the information, it fades from memory, without entering the long-term memory.

Information in the short-term memory fades (or is replaced) if another task is interposed. Thus, there is an interaction between perception and short-term memory, with the result that if a driver is trying to recall something in the short-term memory, the driver's perceptual ability is lowered, and a signal may be missed. Alternatively, if the driver attends to the signal, the information in the short-term memory may be lost.[1]

This factor also has implications for traffic design. The following are some examples:

- Warnings should require an immediate response,
- Drivers should be frequently reminded of control information, which varies along the road (e.g., speed limits), and
- The rate of information gathering that is required should be limited to ensure that the driver has time to respond to one stimulus before the next one is imposed.

Hysteresis Effects

In the model of the driving task described earlier (Figure 1), it was shown that there is a hysteresis effect as demand is taken off an overloaded driver, such that the driver's output is less than it was for the same level of demand as the task was increasing. This is shown in curve *CA* in Figure 1.

There are some implications of this observation for traffic engineering:[5]

- The ability to process information may be lower on the departure side of an intersection than the approach side, perhaps explaining higher pedestrian accident rates on the downstream side of intersections,
- Use of before-and-after methods of assessing traffic design features may be affected because "an accident due to poor performance following overload will not necessarily occur at the feature giving rise to the overload,"[1] and

- Pedestrian crossings, bus stops, etc., should not be placed immediately downstream of an uncontrolled intersection.

Visual Characteristics

As noted earlier, the driving task is information-driven and requires the driver to select and sample signals or inputs from the road traffic system. About 90 percent of the information used by the driver is visual;[4] the remainder is audible and tactile. Because vision is so important to the driving task and is indeed the only way that information provided by the traffic engineer by way of traffic signs, signals, pavement markings, and delineation devices actually gets to the driver, it is necessary for the traffic engineer to have some awareness of the visual characteristics of the human. This paper briefly reviews some of the key aspects—for a more extensive treatment, refer to work by Cole[9] and Lay.[4]

Visual Field

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 degrees to 10 degrees. However, objects outside this field can be detected in peripheral vision: 90 degrees left and right, 60 degrees above the line of sight, and 70 degrees below the line of sight.

These values are for a stationary observer. At speed, the visual field narrows. For example, at 30 kilometers per hour (km/h) the lateral (left-right) angle of the visual field decreases to about 100 degrees, and at 100 km/h it reduces to about 40 degrees (compared to 180 degrees at rest).[9]

Traffic engineers must ensure that traffic signs and traffic signals are within the driver's field of view. Standard references, such as Chapter 23 of the *ITE Transportation and Traffic Engineering Handbook*,[10] describe the procedure for locating signs and for determining their size based upon visual principles.

Eye and Head Movement

The main constraint on the rate of information gathering is the rate at which the eye can move from one object to another and refocus.

Filmed records of eye movements indicate a maximum possible rate of about four fixations per second.[11] However, this rate cannot be sustained for a long period, and perhaps two fixations per second would be the usual maximum rate for an alerted, busy driver. For normal driving, in which the driver is attending to other tasks as well, a rate of 1.0–1.5 fixations per second would be reasonable.

Thus, for traffic design, it is necessary for signals to be separated in time. If the vehicle is in motion, it is also necessary that they be separated in space. For example, at a vehicle speed of 100 km/h, a driver would be able to view a signal only once in every, say, 20–28 meters (m), at a rate of information gathering of about 1.0–1.5 fixations per second. If the signals (i.e., traffic signs, traffic signals, information signs, etc.) are closer than this, some will be missed because the driver is physically incapable of sighting them.

Moreover, drivers tend not to look very far ahead of the vehicle to seek signals that affect the driving task; for example, traffic signs beyond 100 m are rarely noticed.[11]

Although eye movements can be made over a field of about 50 degrees, it is rare for that full range to be used. Rather, the driver will move his or her head to focus on a new object, such that eye movements are limited to about 15 degrees left or right.[4]

Illumination

The human visual system is capable of operating over an enormous range of illumination, from 0.75×10^{-6} candelas per square meter (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}.

While most of this range is the result of long-term (30-minute) regeneration of receptor cells in the retina,[9] the traffic engineer is more interested in transient changes in illumination caused by exposure to relative light and dark as the vehicle progresses along the road, rather than long-term changes in the ambient light level.

On exposure to glare after dark, the pupil diameter contracts at a rate of about 3 millimeters per second (mm/s), whereas on exposure to dark after glare, it is much less responsive, dilating at about 0.5 mm/s.[9] In other words, the eye can adjust to sudden glare more rapidly than sudden dark.

Thus, for example, in tunnels or long underpasses, artificial illumination should be provided at a higher level at the tunnel entrance. The lighting level can be reduced within the tunnel as the eye adjusts to the lower level of illumination, and there is no need for a higher level of illumination at the tunnel exit as the eye can adapt rapidly to the glare of the daylight.

Visual Handicaps

About 2.5 percent of the adult male population has color defective vision, such that they cannot discriminate red, yellow, and green (as in traffic signals), or indeed any three-color combination.[4, 12]

Further, about 2.5 percent of the adult male population has a reduced sensitivity to red—they need about four times the intensity required by unaffected observers.[13] Also, some people experience blurred vision such that their legibility distance is reduced.[12] About 5 percent of the population is visually deficient with respect to detecting low luminance contrasts; visual sensitivity declines with age and the detection threshold of elderly drivers is about double that of younger drivers.[4]

These findings have important relevance to traffic design, especially for traffic signals. The following are some examples:

- Signal faces should be located in a standard fashion, with red on top, yellow in the middle, and green at the bottom; this applies also to colored arrows.
- The intensity of traffic signals and the actual colors used need to be closely specified.
- These considerations also affect the size of traffic signs and the letters on them.

It is important to note that visual capabilities tend to decline with age, so that older drivers are less capable visually.[14]

Finally, it is of interest to note that no correlation has been found between poor visual performance and driver safety. This suggests that drivers with visual abnormalities compensate in their driving behavior or in other ways.[9]

Information Needs of Road Users

The success of many traffic engineering measures and the safety and efficiency of the road traffic system depend to a large extent on successfully conveying information to drivers to aid them in their navigation, guidance, and control tasks. The key needs of road users in relation to traffic control information are as follows:[4]

- Conspicuity (the signal must be seen),
- Legibility (the message must be readable),
- Comprehensibility (the message must be understood),
- Credibility (the message must be perceived to be true), and
- Delineation (to enable the driver to keep the vehicle on track).

Conspicuity

The detection of a signal involves recognizing it against its background. Conspicuity is affected by several factors, including the following:[11]

- Size (large signs are more conspicuous),
- Brightness (bright signs are more conspicuous),
- Boldness (large letters are more conspicuous),
- Edge sharpness (a line around the edge of a sign makes it more conspicuous),
- Contrast (high contrast, especially in brightness, between the signal and its background aids conspicuity),
- Visual simplicity (a signal is more easily detected against a simple background), and
- Eccentricity (a signal is unlikely to be detected if it is more than 6 degrees to 7 degrees from the line of sight).

A number of direct implications of these principles affect various aspects of traffic engineering practice:

- Influence on the size, color, layout, and location of traffic signs,
- Legislation for control of roadside advertising,
- Reflectorization of signs, pavement markings, etc.,
- Illumination of signs (especially directional signs),
- Promotion of safety yellow raincoats for pedestrians and brightly colored vests for road maintenance crews, and
- Roadwork signing and work site protection.

Legibility

A signal is legible if enough detail within it is sufficiently visible to allow its message to be interpreted. Increasing the size of a sign will increase legibility distance and give a driver more opportunity to observe and read the sign. Thus, signs that need to contain a lot of information need to be larger (e.g., directional signs).

Comprehensibility

The driver must perceive the importance of a signal; if the driver does not do so, the signal will be ignored. The vast majority of the roadside visual signals that confront a driver on a trip are simply ignored because the signals are not perceived as being relevant or important to the driver. Therefore, those signals that are important (including those provided by the traffic engineer) must be presented in such a way that the driver appreciates their relevance. Of prime importance is that the driver perceives that the signal affects his or her own well-being.

It is important that traffic engineers realize that much of the information conveyed to the driving public is not well understood. As a result, only standard signs, messages, and formats should be used. Unconventional treatments, using "homemade" signs and formats, are likely to be incomprehensible to a majority of drivers and should be avoided.

Credibility

Credibility refers to the extent to which drivers believe that a signal both is true and refers to them.[12] Credibility is affected by the context of the signal, how it is used in other contexts, and how it is used in relation to other traffic control devices.

The traffic engineer can aid credibility and can also contribute to the overall credibility of the traffic system by ensuring that the use and application of traffic control devices (especially, but not only, traffic signs) is in accordance with current practice as set out in relevant standards and codes.

This would include the following, for example:[12]

- Ensure that sign selection, color, and shape conform with the relevant standards and codes,
- Avoid the unnecessary use of signs and other traffic control devices,
- Avoid unnecessarily restrictive signs; the overuse of "Stop" signs, in particular, detracts from their credibility at sites where it really is important that vehicles come to a standstill, and thus many "Stop" signs should be replaced by "Yield" or "Give Way" signs,
- Display important messages adequately (e.g., speed limit repeater signs should be widely used, advance direction signing should be consistent and prominent),
- Display realistic and consistent speeds on advisory signs, and
- Assist the driver to distinguish between important and relatively unimportant information by consistent use and avoidance of poor practice, the latter may involve removal or replacement of signs or devices currently in place.

Delineation

Delineation of the road alignment immediately ahead is vital information that enables the driver to locate the vehicle on the roadway and make navigation, guidance, and control decisions. Adequate delineation enables the driver to do the following:[4]

- Keep the vehicle within the traffic lane (short-range delineation), and
- Plan the immediate forward route driving task (long-range delineation).

Delineation has always been important, but it is likely that it may become even more critical in the years ahead as the driving population ages. Older drivers have a reduced visual capability and hence rely to a greater extent on correct delineation of the road ahead.[13]

Long-range delineation enables the driver to plan the forward route, and thus it needs to be consistent and continuous. It is not restricted to situations where forward visibility is particularly restrictive or critical, such as horizontal curves over a crest. It is particularly necessary on approaches to curves. Curve direction and curvature may need to be assessed up to 9 seconds ahead, and even detailed tracking for actual curve negotiation (short-range delineation) may be required 3 seconds ahead of the curve.[4]

Short-range delineation provides information to enable the driver to keep the vehicle on the road. There is substantial evidence that it provides important guidance information, especially when visibility decreases due to adverse weather or during nighttime driving.[15]

A range of delineation devices are available:

- Guide posts and post-mounted delineators,
- Center lines,
- Lane lines,
- Edge lines,
- Raised pavement markers (including reflective and nonreflective markers),
- Chevrons, and
- Bridge width markers.

It should also be noted that the road environment may provide informal delineation information to the driver. Such features as fence lines, a row of trees or poles, or general topography can provide visual cues to the driver, especially for long-range delineation. In some cases, this information may be incorrect, as for example where a row of poles continues in a straight line but the road enters a bend. In these cases, very strong formal delineation (signs, chevrons, pavement markings, etc.) may be necessary to overcome the influence of the informal delineation.

Delineation can be an important component of a roadside hazard treatment program, either for an extended length of road or for individual sites, such as bridges.

Delineation is an area of traffic engineering practice that has tended to be handled poorly and inconsistently in the past and has probably not attracted the degree of professional attention that it deserves. It is likely, however, to be an area of increased activity in the future. A range of delineation devices are available, together with guidelines for their use, and traffic engineers are likely to have to use these more widely and carefully to ensure that delineation information is adequately and effectively presented to the road user.

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