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VI
DRIVER INFORMATION SYSTEMS

Slade Hulbert

DRIVER INFORMATION NEEDS

Drivers, as a whole, perform their tasks very well considering the difficult nature of the task. The driver must constantly process a stream of information coming to him from the environment, primarily through his visual faculties. Since any vehicle (or object) in motion is committed to occupy a certain amount of space directly in its path within the next instant, the driver must make a continuous series of such spatial commitments. Hulbert and Burg (1970) describe the shape of this spatial commitment for automobile drivers as fan-shaped, extending in front of the vehicle, as shown in Figure 1. The exact configuration of this spatial commitment, of course, varies from vehicle to vehicle and is effected by road surface and highway design features. Generally, however, this fan-shaped area grows in size with increased speed and/or reduction in the pavement friction. As the driver proceeds along, he makes an unalterable commitment to be somewhere in this fan-shaped zone immediately ahead of his vehicle. The portion of this zone that he actually uses is his path. At the same time the immediate path is being chosen, the driver is making provisional commitments extending out beyond the immediate zone (to which he is totally committed).

The various bases upon which these provisional commitments are made is the subject of this chapter and we shall attempt to describe the information processing that underlies these successive spatial commitments that are continually being made and re-made as the driver proceeds along the highway.

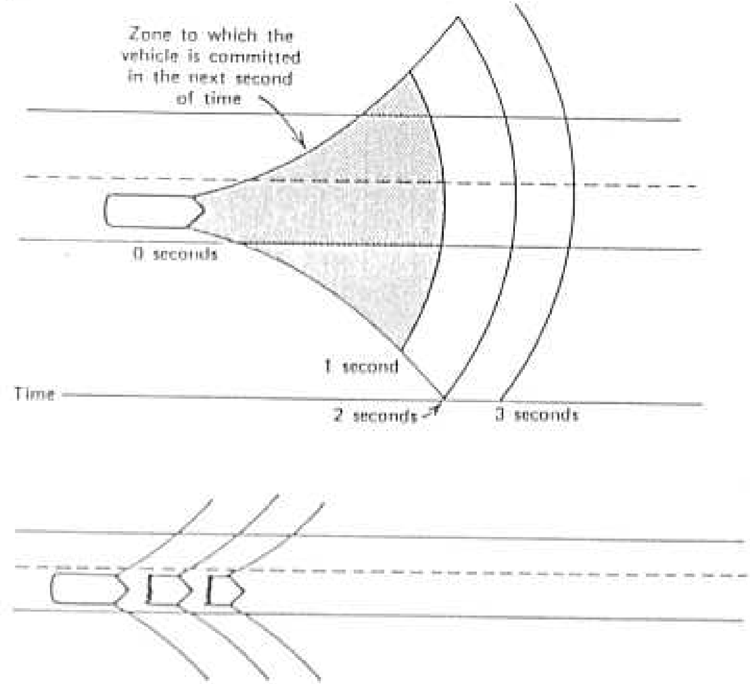

Figure 1. The exact configuration of this fan-shaped zone will depend upon the vehicle speed, turning radius, and stopping distance as they interact with the driver's reaction time. As each driver proceeds, the fan-shaped zone extends in front of his path and changes shape as velocity and pavement conditions vary (Hulbert and Burg, 1970).

INFORMATION PROCESSING BY DRIVERS

In a recent textbook Hulbert and Burg (1970) set forth a generalized framework for considering the role that humans play in transportation systems. This framework is shown in Figure 2 where, for the sake of simplicity, human decision-making is classified into pre-trip decisions about route selection and scheduling (the timing of a trip); decisions about vehicle path, speed, and failure. These types of decision-making create an information need, some of which is met by pre-trip planning and the balance of which is met during the actual act of driving. We will concentrate our attention on the driving and deal with traffic control devices, vehicle control feedback, and traffic situation judgment.

Unfortunately, man, although he may appear otherwise, is essentially a single-channel information processing system. His ability to rapidly

Human Functions Common to All Transportation Systems			Sources of Information	Range of Performance	Selection and Placement	Training of Personnel	Performance Evaluation
MAKING DECISIONS	TRIP PLANNING	Schedule					
		Route					
	VEHICLE OPERATION	Path					
		System Failure					
		Speed					
EXECUTING DECISIONS	(+, 0, −) Acceleration						
	Direction						
MAINT. VEHICLE	En Route						
	At Home						

Figure 2. Generalized framework for considering human factors in transportation systems.

shift his attention from one task to another enables him to carry on more than one simultaneous task. The driving task has two major simultaneous elements—namely, tracking and object avoidance. If man's single central processing channel is occupied with one type of information, it cannot be utilized to process additional information. Therefore, time spent reading a highway sign or looking at a pedestrian is time taken away from the tracking task and vice versa. For this reason designers of roadways and vehicles have striven to make the tracking task easier, and traffic control devices have been designed over many years of trial and error to be relatively unambiguous information generators, demanding a minimum of the driver's attention to comprehend.

DRIVER INFORMATION FROM TRAFFIC CONTROL DEVICES

The role of standardization and uniformity of traffic control devices is obvious in respect to simplifying the driving task. Uniformity is reflected in the *National Manual on Uniform Traffic Control Devices* (U.S. Department of Transportation, 1971) where both shape and color coding are employed, along with standardization of the placement and the size of traffic control devices, in order to avoid confusion among drivers.

Warning signs are yellow in color, diamond in shape, and are placed where the driver needs some advance notice about the nature of the roadway or traffic situations he will soon encounter. Such warnings are necessary because the driver cannot see very far ahead of his vehicle, especially at night or when roadside objects block his view; and yet, as we have shown earlier, he has committed himself to be somewhere in a fan-shaped space extending in front of his vehicle. Wherever a warning sign is placed, it is there because experience has shown that many drivers, at that location, will unknowingly commit themselves (spatially) beyond their limits to respond to the situation.

Pavement markings also play a major role in warning drivers about such situations as "no passing" and "ped Xings" which is a cryptic way of saying "pedestrian crossing." Color is used in pavement markings with yellow standing for "no passing," which is a regulatory traffic control device.

Regulatory signs are rectangular and black and white which distinguishes them as having the force of law. Red and white is used for extremely hazardous situation regulatory signs such as STOP and YIELD and WRONG WAY. For both warning signs and regulatory signs it is important to know more about how signs attract the attention of passing drivers. Recent studies at Michigan State University by Forbes, Snyder, and Pain (1963) have produced formulas that relate such things as the size, the brightness, and the contrast ratio of the sign against the background scenery. In general, the problem facing highway and traffic engineers is to create signs that attract enough attention for the driver to be able to read them before they pass from his view. The legibility or reading distance of each sign, therefore, must enter into the formulas used.

Research beginning as early as 1932 (Lauer, 1932) has resulted in the current format of letter height and width ratios, stroke width, spacing between words and letters and lines of message. Several subtle factors have emerged such as the "irradiation effect" that white letters have against black backgrounds which causes them to have the appearance of larger stroke width letters. Also, interactions have been found between letter contrast and letter and word spacing.

It was in this part of the driver information problem that the first "human factors" contribution was forthcoming when Forbes and Holmes (1939) studied the alphabet for highway signs that had been approved by the U.S. Bureau of Public Roads. This alphabet produced a reading distance of about 50 feet for every inch of letter height in daytime and 33 feet at night. Forbes, in Chapter 5, states:

"Legibility distance of 60 feet per inch, stroke width 20 percent of height, correspond rather well with the usually accepted figure of one minute of arc for normal (20/20) visual discrimination. However, most states only require 20/40 vision for a driver's license."

Green and white signs display guidance information although current practice does permit the use of black and white guide signs on city streets and county roads. This should not prove confusing because directional information obviously does not carry the force of law and guide signs have their own characteristic appearance and location along the roadway.

Freeway Information Requirements

Freeway or expressway driving is creating special demands on drivers to quickly interpret directional signs and there is a continuing effort to improve these signs. In 1968 the House of Representatives Blatnik Committee conducted hearings about safety and freeway signing (U.S. Congress, 1968). Witnesses called attention to a 1960 study by Schoppert et al. where 12,000 motorists were interviewed concerning their experiences with finding their way on the California freeways. These interviews led the researchers to conclude that out of every ten trips in new territory, one trip would involve getting lost due to poor signing. The primary recommendations of these researchers were set forth as the following six basic principles:

"1. *Interpretation.* All possible interpretations and misinterpretations must be considered in phrasing sign messages (words and symbols).

"Messages must be complete and clearly stated. Cryptic messages, which are easily misinterpreted, must be avoided. The difference between two alternatives must be emphasized and, where possible, choices offered must be between things of the same kind, for example, two route numbers. Care must be exercised to avoid giving more information than can be read and comprehended in the time available.

"There are two important general points to be remembered. The first is that a motorist's interpretation of a sign message is based not only on what the message says but also on what it does not say. The second point to be kept in mind is that literal interpretation results in the motorist doing exactly what the sign indicates exactly at the sign location. For example, drivers reported turning into alleys and driveways by mistake because the on-ramp sign appeared to direct them to do so.

"2. *Continuity.* Each sign must be designed in context with those which precede it so that continuity is achieved through relatively long sections of highway.

"The driver should be expected to evaluate not more than one new alternative at any advance sign. At the decision point he should never be given new information about either the through route or the turnoff. For example, sometimes several communities (or streets) are served by one turnoff. The advance sign will say 'Orangevale Exit 2 Miles,' the next sign, 'Orangevale Exit 1 Mile,' and finally, at the exit the sign says 'Orangevale, Jamestown.' The "Jamestown" on the third sign violates the principle of continuity and throws the motorist for a loss. He says to himself, 'I wonder if this is the exit they have been referring to as the one for Orangevale, or is this just an alternate route to Orangevale?' For another example, the advance signs say 'Castro Blvd 1 Mile,' then 'Castro Blvd ½ Mile,' and finally, at the exit, 'Castro Blvd.' Then a few seconds later the driver comes upon a sign like the one shown in Figure 3. He is

Figure 3

totally unprepared for this new information. He has 8 sec to digest it, visualize a map, mentally turn the map upside down if he is southbound, and finally take action.

"3. *Advance Notice.* Signing must prepare the driver ahead of time for each decision he has to make.

The term "advance notice" is frequently used by traffic engineers and motorists, but is practically never analyzed. Essentially, when the motorist is surprised to find that he has to make a decision, he assumes that he was not told about it ahead of time. Very large signs, and signs well in advance of decision points, have been in place on California freeways for many years and still there are many surprised motorists. In almost all of the cases investigated during this study where the motorist said he did not have advance notice such signing did, in fact, exist. This signing, however, did not adequately prepare the driver for his decision.

"The real point is that the motorist does not want to learn suddenly about the decision, regardless of how far ahead he is told or how vividly (that is, how big the letters are). He wants to know where he is located in relation to the point of decision throughout the trip. This is the only advantage that repeat motorists have over unfamiliar motorists.

"A single advance sign can easily be missed, as can one sign of any kind, especially in dense traffic (*cf.* principle 5, below). Two advance signs can also be missed, although the probability is not as great. Of course, the size of the sign and the distance in advance have a bearing on this problem, but more 'advance notice' cannot be achieved merely by increasing the size or distance or both.

"4. *Relatability.* Sign messages should be in the same terms as information available to the driver from other sources, such as touring maps and addresses given in tourist information and advertising.

"To insure this result, maps used by engineers as the basis for sign design should also include some which correspond in scale to touring maps. Outside of large metropolitan areas, signs should relate to a state road map. In a city represented on the map by a small circle or dot, signs preparing the driver for an important junction within the city should take into consideration that there will be many turnoffs from the main route to other streets, while the map may show only the one junction. In metropolitan areas, he must be expected to receive more detailed information than a state map can show.

"5. *Prominence.* The size and position, as well as the number of times a sign or message is repeated, should be related to the competition from other demands on the driver's attention.

"These demands can come from other visual aids, other signs or parts of the message, as well as the task of driving. One huge sign in a group or one huge word in a message tends to attract so much attention that the other signs or the rest of the message may not be comprehended. Thus, it often happens that the sign designer defeats his very purpose.

"When the road is very wide, the traffic very dense, and there are numerous competing 'spectacular' commercial signs or buildings (as is typical of a downtown urban freeway), the directional signs must be very large, well-illuminated and well-placed, even if this means costly overhead installations. There is no certainty that a motorist will, in the face of such competition (particularly dense traffic on curves) see a given sign no matter how large it is. Repetition suggests itself, not only for 'advance notice,' but for initial notice. On the other hand, the use of a gigantic sign in a sparsely settled rural area where there is no visual competition will serve to lessen the impact of using extra large signs where they are really necessary.

"On city streets, where proper signing is just as important to the motorist as is signing on a freeway, the signs do not have to be as large, but the competition is much greater. Trees, poles, parked cars, signs on buildings, and traffic regulation signs all make it difficult to find the essential sign saying how to get to the freeway. Although standardization of color, shape, and style (uniformity) is one way to make the essential sign distinctive, it should not be relied on too heavily. Location, size, and contrast with surroundings are more important factors.

"6. *Unusual Maneuvers.* Signing must be specially designed at points where the driver has to make a movement which is unexpected or unnatural.

"The driver's natural inclination to turn a certain way frequently will lead him to do the wrong thing. Clarity in signing wins the driver's confidence and helps him avoid mistakes resulting from instinctive movements. Although cloverleaf interchanges are becoming more prevalent, the unfamiliar driver never knows whether or not the next interchange is a cloverleaf, and if it is, whether or not it has a collector-distributor road. Standard directional arrows used for near-side turnoffs cannot be used successfully to prepare a first-time user for the series of decisions he must make within a short time interval if his proper course of action is to take the far-side turnoff."

Unfortunately, over ten years later, these principles still are not being followed in many areas of the United States with resultant driver confusion and highway accidents (U.S. Congress, 1968), as was documented in a 1966 report (Schoppert, 1966), of observations of hundreds of confused motorists on the Beltway that encircles Washington, D.C. These data clearly show that the more of the six basic principles that are violated, the more drivers are confused. This study reached the conclusions that 0.2 of 1% of the traffic volume is a "normal" proportion of confused drivers to be found at choice points in the highway.

Currently, studies are underway (Eberhard and Berger, 1970) to develop some form of graphic symbols that will more clearly inform the motorist about the geometry of the off-ramps he is approaching. Several types of ramps have been selected for study, among which are the following:

1. Those where you must take a right-side off-ramp in order to go left, or vice versa (Figure 4).
2. Where a major fork occurs and therefore both choices appear equally important (Figure 5).
3. A cloverleaf (Figure 6).
4. Those interchanges where a through lane is discontinued at the turnoff (Figure 7).
5. Where two right turns (or left) are required in quick succession (Figure 8).
6. Where there are sequential choice points after a main exit (Figure 9).

The superhighways also have made the availability of motorist services less obvious than when the roadway actually led through the city. A study by Foody and Taylor (1969) indicates that special signing to indicate the availability of services does increase the motorist's awareness of these services and in some cases changes the use patterns.

Another, more serious, problem created by superhighways is wrong-way driving. Several years of research effort in California and other states

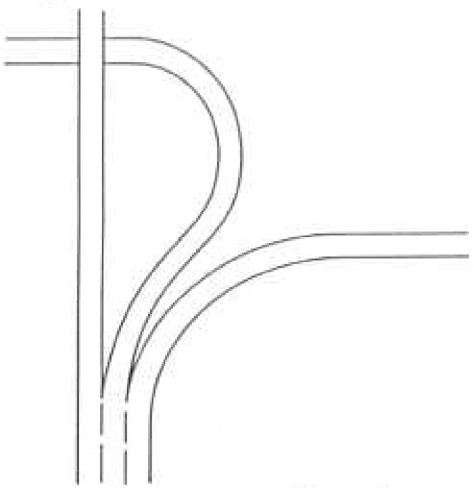

Figure 4

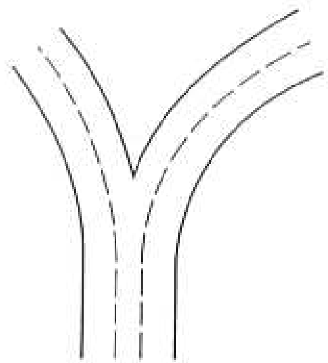

Figure 5

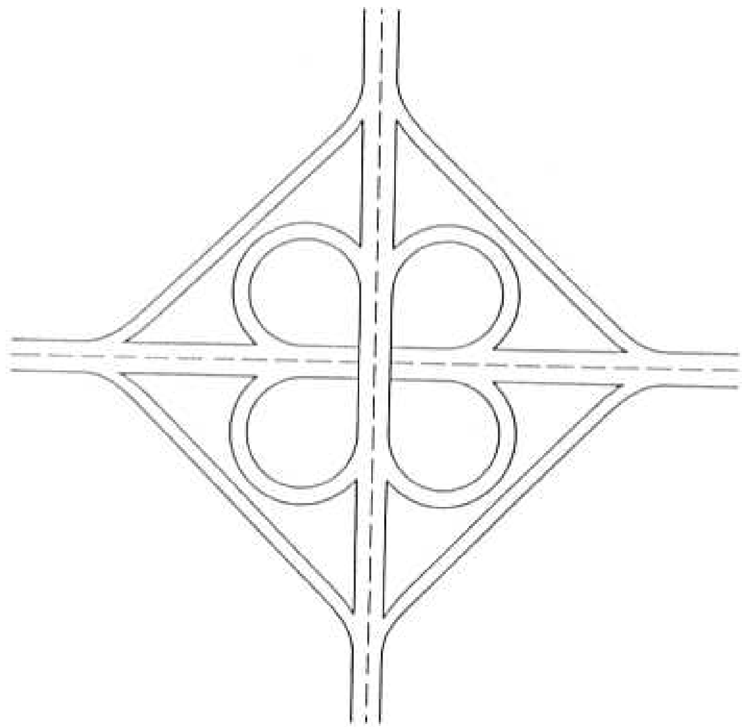

Figure 6

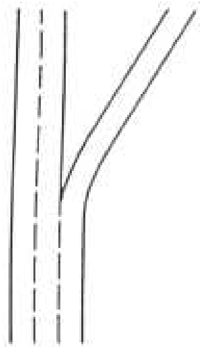

Figure 7

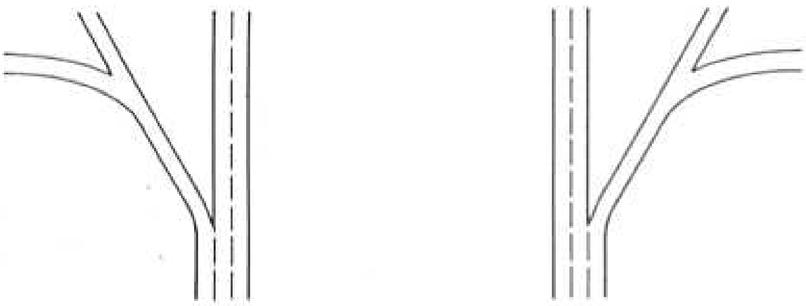

Figure 8

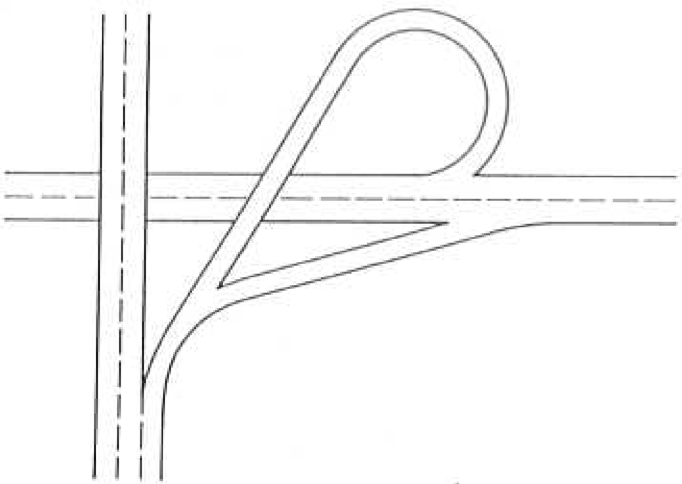

Figure 9

have resulted in special traffic control devices to warn motorists of this hazard. There is a definite interaction between the geometry of off-ramps and the alignment of adjacent roadways that causes more confusion at certain types of ramps. Research in the field and in the UCLA Driving Simulation Laboratory (Hulbert and Beers, 1966, see Chapter 3) resulted in design of special green-colored "Freeway Entrance" signs and red "WRONG WAY" signs and large white pavement arrows. Accident records (Tamburri, 1969) clearly show that these devices are effective in reducing wrong-way accidents by as much as two-thirds. The effect of red-colored raised pavement markers is still being evaluated.

Advance Information at Railroad-Highway Crossings

Traffic control devices at railroad-highway grade crossings were among the earliest of roadway hazards marked by signs, but they have not been improved greatly for at least 30 years. This unfortunate condition was documented in a 1968 study by Schoppert and Hoyt (1968) in which a human factors analysis is made of the special problems these crossings pose for motorists. The report recommends that a clear difference be established between those crossings that are "protected" by signal devices and those where the driver must actually detect the approaching train without any assistance from traffic control devices. As it is now, there is *no difference* in the advance warning signs.

This study also considered rumble strips as an alerting device to help notify the driver he is approaching a crossing. These devices have been used in Texas rather widely since 1956, and New Jersey as early as 1947 reported experimental use at approaches to tollgate plazas.

Bellis (1969) describes two basic types: one composed of actual strips of material placed at intervals across the highway to cause intermittent jolts and bumping vibration, and the other made of a rough surfacing material to create a "rumble area" of perhaps 25 feet in length or longer. Results indicate the rumble *strips* to be more effective than the rumble *area* tested. Several important considerations are raised in this report, namely,

"1. Serious consideration should be given to the question 'Does the motorist require advance notice of the oncoming rumble strip.' And if so, how should it be given?' This seems nonsensical in a way because the rumble strip in itself is to warn, alert, wake up, the motorist. However, quite a few alert drivers, given no advance notice of the experience, and apparently not acquainted with such experience, pull off to the side and examine their car for mechanical trouble. This type of reaction slows down traffic and is hazardous to the motorist.

"2. Consideration should be given as to whether or not a series of strip patterns, rather than only one, would better suit the purpose.

"3. That when the decision is reached to use rumble strips, consideration be given to whether they should be installed on more than one of the roads which form the dangerous intersection.

"4. Consideration should be given to the possible necessity of developing ways and means for preventing the local motorist, familiar with the installation, from deliberately driving around it. This 'driving around' practice is not only very hazardous in itself, but it becomes much more so when non-local motorists unwittingly follow the local driver in this dangerous manner.

"5. Every consideration be given to establishing the proper distance between the warning device and the critical area. If the distance is too great, acceleration rather than deceleration can be effected by the determined aggressive motorist; if too short, the alert motorist, who however, is exceeding the speed limit, is in trouble."

The railway crossing report (Schoppert and Hoyt, 1968) suggested the possible use of "quiet strips" which more rightly should be called "quiet areas" to create an unusually smooth surface immediately preceding a rumble strip.

A rumble strip installation was reported by Bellis (1969) to be successful in creating a 20 percent reduction in accidents during a two year before-and-after tabulation of collisions at a traffic circle. Injuries were reduced 40 percent during the same period.

Symbols or Pictographs

In the United States, traffic signs contain fewer symbols than the Canadian or Mexican system and far fewer symbols than are generally used in Europe. As more and more drivers have the opportunity to drive in foreign countries, the need for universal traffic signs is increasing (Elliott, 1960). In general, there are two types of symbol signs. The abstract symbols bear no obvious relation to the traffic situation and their meaning must be learned by the motorist. Graphic symbols, on the other hand, are pictographs that attempt to depict the highway situation and thereby create an immediate awareness without any prior learning. If a pictograph is completely successful, it will require *no* uniformity because it requires no language or prior learning. Therefore, the problem lies with those many traffic situations for which no clearly understandable graphic has been devised. Examples are "slow," "no parking," "do not enter," "resume speed," and many others.

One solution for these situations is to adopt a universal symbol and have all drivers learn its meaning; the other solution is to adopt a single language for a certain sign. The United Nations has attempted these solutions and before them the League of Nations. Several European countries have announced they are going to adopt the American stop sign and the U.S. Committee on Uniform Traffic Control Devices is recommending many symbol signs for the *National Manual*.

Information from Traffic Signals

The red, yellow, green signal light at intersections has become so well known that it is hard to imagine how traffic could move without it. Various styles of mounting and types of lenses are continually being developed but several factors generally are found in all signals. They all take into account the fact that upwards of 8 percent of drivers (mostly males) are color weak in the red-green area. Therefore, there is considerable blue in the green lens and yellow in the red lens (Hoxie, 1961).

In addition, for the placement of lens, there is a position code of red over green that generally is followed and is relied upon by color-weak drivers. In order to be more effective in attracting drivers' attention, there is increasing use of 12-inch diameter lens (particularly for red) to replace or augment the standard 8-inch lens. For the same reason, redundancy of signal is created by multiple signal heads that reduce the unfortunate consequences of lightbulb failures. Complex control of traffic has brought about the use of arrow symbols in traffic lights and uniformity of usage is slowly coming about, but drivers can still expect to see yellow, red, and green arrows at various locations and unfortunately carrying different meanings.

The time it takes for pedestrian movement across intersections is the most limiting time factor that traffic engineers have to cope with in attempting to set the signals for "green wave" movement. In order to increase pedestrian safety and better control the time cycle problem, special pedestrian signals are being added to many urban traffic signals. Soon these "walk—don't walk" type of signals will be standardized as to color and message, but at present, as with all new traffic control devices, there are several variations of these signals. One unexpected and not generally recognized consequence of pedestrian signals is their use by drivers as a pre-amber indication which can be a safety improvement.* To the extent that pedestrian signals are uniform in their use, drivers will learn to pace their approach speed so as to avoid emergency braking

* Some before-and-after evidence has been found that installation of pedestrian signals reduced not only pedestrian accidents, but also vehicle accidents, in comparison with a parallel and similar boulevard where the pedestrian signals were not installed (Los Angeles City Traffic Department, 1969).

or even running the signal when they are caught in the so-called "dilemma zone."

The major difference between signals and other traffic control devices is that the message changes. This, of course, produces a group of problems having to do with the timing of these changes and the way that drivers can or cannot be expected to react. Traffic engineers try to time signals so as to create a "green wave" of signals at the speed they wish traffic to flow. When they can do this, motorists (particularly commuters) learn to pace their speed so as to move along without encountering a red signal. The yellow (or amber) signal timing creates a so-called "dilemma zone" for vehicles traveling at certain speeds approaching a signal that goes to yellow for too short a time period for the car to clear the red and not soon enough for them to be able to stop. This problem is far from simple and the latest study by Jenkins (1969) lists the following driver tasks that are involved:

1. Detect presence of signal.
2. Detect color of signal.
*3. Estimate time of change to yellow.
*4. Estimate time remaining on yellow.
*5. Estimate braking distance at driven speed.
*6. Estimate time to clear intersection far enough so starting or moving vehicle on other legs will not contact.
7. Estimate discomfort if stop is made.
8. Estimate effects of action on others.
*9. Decide on action.
10. Take action.
11. Reappraise all factors.

Factors influencing errors in connection with "items most likely to be in error by driver" listed above are:

Item 3. Estimate time of change to yellow.
- a. Short- or long-term conditioning of driver to nonexpressway driving and signal operation.
- b. Driver familiarity with the specific location.
- c. Visibility distance of signal.

Item 4. Estimate time remaining on yellow.
- a. Conditioning—same as (3a).
- b. Familiarity—same as (3b).
- c. When yellow was detected or how long since previous scrutiny of the signal.

Item 5. Estimate braking distance at driven speed.

* Items most likely to be in error by driver.

- a. Conditioning—same as (3a).
- b. Familiarity—same as (3b).
- c. Type and condition of surface.
- d. Knowledge of vehicle characteristics.
- e. Human capability for distance estimating.
- f. Availability of estimating aids and cues.

Item 6. Estimate time to clear intersection.
- a. Conditioning—same as (3a).
- b. Familiarity—same as (3b).
- c. Initial velocity.
- d. Knowledge of vehicle accelerating ability.
- e. Actions of or presence of inhibiting traffic.

Jenkins concludes that further research is needed before an optimum yellow interval can be determined or a national standard recommended.

This same type of problem plagues the engineers who are planning for the use of changeable message highway signs. A few such signs, remotely controlled, are already in use for limited situations such as when mountain roads are blocked with snow requiring use of tire chains or when desert roads are flooded. But more extensive use on heavily traveled streets and freeways will require far more complex signs and messages. The changeover time and methods are causing engineers to have to consider such things as the creation of a dilemma zone and the effect of partial messages. This type of freeway sign is being considered for a 17-mile section of a Los Angeles freeway where a vastly improved new system is being tested for continuously monitoring traffic movement and adjusting sign messages and radio messages to cope with accidents and other types of congestion. These messages would give drivers advance warning of slowdowns ahead and also divert them to alternate routes if that becomes necessary.

Another special message traffic signal is the red X symbol for controlling the direction of traffic in certain lanes where at times, it is necessary to reverse the flow of traffic. These situations occur on bridges, in tunnels, and major arterials, and on expressways where, due to heavy in-bound or out-bound traffic demand in peak hours, it is efficient to use several more lanes in the direction of heavy demand than in the direction of lesser demand. The research work that led to the development of the red X symbol for this special purpose is described in Forbes et al. (1960).

Detours and Construction Zone Warning Principles

A general principle of handling construction zone traffic is stated in a 1967 publication of the California Division of Highways (Obermuller, 1967) as follows:

"The safest and most convenient construction trafficway is one that has been designed to provide a facility which is geometrically equal to or better than the approach roadway in order to present the motorist with a condition of sufficient continuity of function and appearance that he will react properly, naturally and without confusion.

"If the above objectives can be attained, the construction trafficway can be treated as a continuation of the approach roadway using standard signing, delineation, etc., and it need not be designated as a 'Detour.'"

To the extent that this principle is followed, the trafficway through construction would not be noticeably different from the approach roadway and the motorist would not be aware that he is moving along a temporary path. However, for many reasons, this ideal trafficway, in most instances, cannot be created and it is necessary to warn the motorist that he is in a construction area. For this reason the *National Manual* calls for the use of orange instead of yellow warning signs in construction zones so that even if standard warning signs are used, and this certainly is desirable, they will offer a color cue that will notify the driver when he enters and when he leaves a construction zone.

Special problems of roadway delineation arise in construction and a variety of portable and temporary products are marketed to help guide the motorist. One such device, the battery-operated flashing light, has been found excellent for attracting the nighttime motorist's attention to obstacles, but very confusing as to showing their location. Thus the California report strongly recommends that only reflectors or steadily burning lights be used to mark the roadway. Oddly enough, the old flame pot that was used in the past has two desirable human factors characteristics. The flame is a constant light, and yet, it does move and thus attracts attention. The flame pots have other features that are undesirable and the modern devices are superior when they are properly used. A special circuit can be purchased to sequentially operate flashing lights in order to produce a strobe effect similar to those used in some airport runway approach lighting systems. The strobe effect is attention-getting but of questionable value for delineating the roadway.

Color and texture of roadway surfaces are often likely to present misdirection cues to the motorist in construction areas where the temporary pathway joins or departs from the approach roadway. Special attention must be given to these false cues so that they either are concealed (by covering) or are overwhelmed by lane markers, painted arrows, traffic cones, or other devices available to the traffic engineer. Devices that reveal a continuous connection with the road surface (e.g., cones) are more easily comprehended than reflectors on stands or paddles that at night appear to float or be suspended somewhere over the roadway. For this reason, raised pavement markers (containing reflectors) that are fastened to the road surface are excellent delineators not only for construction, but for all roadways where they can be kept free of snow or mud.

Information Functions of Highway Markings

Yellow stripes designate the center line separating opposing traffic. Other lane markings are white. No-passing zones are designated by double, solid yellow stripes that are a clearly visible cue but that unfortunately have two different meanings depending on the state law. In some states the no-passing stripes mean that the motorist may never legally drive to the left of the double yellow marking. In other states, however, the law states that motorists may not *begin* a passing maneuver that would cause them to cross the double yellow lines, but they are permitted to complete a pass as soon as possible if they began the pass before reaching the double yellow stripes. This unfortunate ambiguity has not been resolved and the law enforcement policy (as well as the distance preceding the curve), of course, agrees with the law in each state. Therefore, it constitutes a safety hazard for those out-of-state drivers who expect to be able to safely complete a pass before encountering head-on traffic, because the beginning of the double stripe is placed closer to the curve in those states where driving to the left of the stripes is not permitted.

Raised, reflectorized markers are available in colors that can be used to carry through the color coding for pavement markings. They are particularly effective in fog and when there is water on the road surface because the markers stick up through the glare surface and are thus clearly visible day or night. Steel snowplow blades tend to scrape off the raised markers, which makes them more difficult to use in snow country. A side benefit of tire rumble noise when crossing these markers may be helping to "wake up" tired or drunken drivers as they drift out of the lane. Some observers believe that motorists tend to make more abrupt lane changes in order to receive a minimum duration of rumble noise and vibration. If true, this is not necessarily unsafe.

Another aspect of raised markers is that the other side can be made as a red reflector to warn wrong-way drivers. A recent study using specially created animated films in the UCLA Driving Simulator has concluded that some irregular pattern of red-sided markers will be more attention-getting than having every marker red (Case, Hulbert, and Beers, 1970).

Ten years of trial installation evaluation preceded the adoption by the State of California (1968) of raised markers. Texas Highway Department (1969) thoroughly documents their positive evaluation of these extremely effective devices for clearly showing motorists lane lines and freeway ramps in foggy and inclement weather as well as in normal day- and nighttime driving conditions. Yu (1970) included raised markers in his study of delineation in which he reports cost and maintenance factors for various types of devices. He finds, for example, the effectiveness and maintenance costs of providing edge striping to delineate the outer, right-hand edge of the pavement, are significantly greater than the costs of providing median delineation.

In urban areas where there are many midblock opportunities for left turns, pavement markings are now authorized to create a two-way left-turn area in the center of the roadway. Into this lane, created by two pairs of dashed double yellow stripes, drivers may enter from either direction in order to make their left turn. This clears the through traffic lanes from being obstructed by left turners waiting for a gap in opposing traffic. This two-way left-turn area also creates a wide "buffer zone" separating opposing traffic.

Left-turn pockets at intersections require special pavement markings and many intersections are now marked for two pocket lanes that must turn and one optional turn or straight-through lane. Drivers are able to cope successfully with these complex situations probably because they are placed at locations where multilane turns are demanded by the predominant flow of traffic and these moves are "protected" by green arrow traffic signals and are depicted both by large symbol signs overhead as well as pavement arrows and legends.

Changeable Message Signs

As highway systems become more complex and carry greater volumes, the need for better communication with motorists has led to the development and trial use of several traffic surveillance systems. These systems use airborne observers patrolling overhead, vehicle detecting devices, or remote-control television installations to monitor traffic flow. This flow information is then either directly relayed to motorists via their car radios or, in the case of Chicago and Detroit, relayed indirectly through remote activation of lane control and ramp control signal systems.

These signal and radio message systems are proving only partially satisfactory (Highway Research Board, 1968), therefore, a system now under design for a portion of the Los Angeles freeway network is planned to include changeable message signs in addition to car radio messages.

Several types of changeable message signs are available ranging

from those that can display any message (such as news signs or scoreboard signs) by illuminating appropriate bulbs in a matrix, to simpler mechanical type signs that can show only a limited number of predetermined messages in a predetermined sequence. At this time it is not known how many messages are needed for any given roadway nor what driving safety hazards may be created by various rates of change and partially visible messages. Neither the importance of random access to messages nor the relative desirability of using a novel color are known. Research will soon be started on these important questions.

Radio Messages to Drivers

Two basic types of radio systems are available. The general commercial broadcast bands are in use in at least 20 major United States cities (Highway Research Board, 1968) and many have several stations that devote some time during rush-hour morning and evening traffic to provide a wide range of traffic flow information. These systems originated in Los Angeles and have spread widely due to the large radio audience that they attract. This is evidenced by the fact that commercial time is far more expensive during traffic broadcasts than at other times of the broadcast day.

Unfortunately, no standardization of terminology has been developed or required of these many different broadcasts. Therefore, there are many different styles of messages as well as different input sources. The results are systems whose usefulness to the motorist are of unknown value. Even a casual acquaintance with these systems reveals many inadequacies and much room for improvement and standardization.

Roadside, limited range, radio systems have been developed for highway use (Covault and Bower, 1964). They make use of induction type radio transmission that can be initiated either from fixed location or portable transmitters that are activated either remotely or on-site for live broadcast or taped messages. Some systems automatically turn on the specially adopted radio receiver in the passing vehicle, other systems are less fully automatic and require a signal system to alert the driver to turn on his receiver. Messages from these transmitters can be very specific to the area, perhaps 80 to 100 feet along the roadway, or longer as may be required.

A two-way communication system has been thoroughly planned (Bauer, Malo, and Quinn, 1969) using citizen band radios for use in emergencies. This system has been in experimental use since 1966 by the City of Detroit, Department of Streets and Traffic not only for emergency reporting but also for traffic flow and other related information. Informal use of these two-way radios is reported in the Washington, D.C. area and most likely is occurring in other locations. These calls for assistance are placed on the emergency channel 9 that often is monitored in relays around the clock by volunteer members of the local citizens' band radio group. Well over 100 traffic related calls per month are reported and in Washington, D.C. over 50 calls per month are reported from lost or confused motorists asking for directions.

ROADWAY ESTHETICS

An intangible communication from the roadway is associated with the general aspect it presents the motorist. Of late there is increasing attention to the humane considerations involved in highway placement and in landscaping. Also there is pressure to consider not only "cleaning up the roadside," but to include artistic concepts in the original engineering. Bridges have long been evaluated not only functionally but also artistically; but consideration of highways as things of beauty is a more recent concept. Snowden (1966) has dealt with this difficult topic of describing the relation between engineering design of highways and the artistic aspects of their dynamic appearance. He touches upon, but does not unravel, the complex interactions that may subtly, yet profoundly, influence motorists as they move along any given section of roadway. It will remain for future research, perhaps utilizing ultra-sophisticated brain wave analyses to eventually describe these important effects.

HOLOGRAPHIC IMAGES

In ever so many instances, traffic engineers would like to be able to place a sign message exactly in front of the driver and thereby eliminate ambiguity and related confusion due to parallax. The phenomenon of holography has been extended so that is now possible to project visual images in space so that they appear as solid tangible material. These techniques have been demonstrated and soon may actually be used in highway situations. Harry Forster describes these possibilities in an article (Forster, 1968) in which he states, "holography is a technique for storing information about the phase and amplitude of light waves so that the original light waves coming from the object holographed can be reconstructed."

Wrong-way driving situations seem to be an ideal application for these images because they characteristically are visible only from a limited cone of viewing angle and therefore can be so placed that they would be invisible to right-way drivers and yet squarely in the path of

the wrong-way driver. Imaginative traffic engineers, in contemplation of this possibility, already have suggested a wide variety of images other than signs that might be effective in reaching the befuddled or rum-soaked mind of the wrong-way drivers (Tamburri, 1969).

GENERAL SUMMARY

An all-embracing description of driving has been set forth and related to current and near future systems for communicating to the driver the information he needs using methods and traffic control devices that are based on awareness of man's limited ability to process information. Improvements have been frustratingly slow, but there has been progress and there is great hope for accelerated progress in the future if public funds are directed to meet the challenge that booming traffic volumes, highway speeds, and age range of drivers is certain to provide.

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VII

SKILLS, JUDGMENT AND INFORMATION ACQUISITION IN DRIVING

Thomas Rockwell

Dr. Thomas H. Rockwell*, Professor in Ohio State University's Department of Industrial Engineering, has been a faculty member since 1955. He also serves as director of the Driving Research Laboratory and as Principal Investigator of the Systems Research Group of the Engineering Experiment Station.

Born in Loma Linda, California, he received the Bachelor of Science degree in Chemical Engineering from Stanford University in 1951. From Ohio State he was awarded the Master of Science degree in 1953 and Ph.D. degree in 1957, both in Industrial Engineering.

Dr. Rockwell is currently carrying on research projects in such areas as risk acceptance in man-machine systems, driver education curriculum evaluation, driver eye movements, effects of alcohol and carbon monoxide on driving, measurement of driver performance, evaluation of highway signing, the use of electronic guidance devices for traffic safety and flow, systems performance in light aircraft control, and simulation of insurance operations. His research program currently receives support from the U.S. Public Health Service, Ohio Department of Highways, National Highway Traffic Safety Administration, Federal Highway Administration, Society of Automotive Engineers, Ohio Department of Education, and from local industry.

Active in professional affairs, he holds memberships in many professional societies and is a fellow of the American Association for the Advancement of Science and the Human Factors Society. In 1969 he received the A. R. Lauer award from the Human Factors Society. Dr. Rockwell also serves on two committees of the Highway Research Board.

* This resumé appears also in *Who's Who in Engineering*, 8th ed., 1959, and *American Men of Science*, 1965 Edition, published 1967.

In 1966 he received a five-year grant from the U.S. Public Health Service for the training of graduate students in transportation accident research.

Skill and judgment in driving form the heart of the driving task. Lack of skill and poor judgment undoubtedly are factors in a majority of accidents and materially affect the flow conditions on our high-density highways. The two concepts, skill and judgment, cannot be separated since judgment can often be offset by driving skill and vice versa. In the context of this discussion, skill is not the mere manipulation of controls but rather the safe, smooth processing of information in the driving environment. Despite the efforts of many researchers, an accepted task analysis of driving has defied description, suggesting that driving consists of more than simple control manipulation and obstacle avoidance. Although the automobile is a forgiving system permitting operators of a wide skill range to use our highways successfully, the driving task also demands a great deal of attention since a lapse of a few seconds in information sampling can lead to catastrophic results.

In order to assess the dimensions of driving skills, it is first necessary to structure a few of the basic driving control subprocesses, such as information acquisition, decision-making, and control in the context of three major control tasks:

1. longitudinal control with and without traffic (this might also be described as open-road driving, car following, and the transition states between these states);
2. lateral control of the car in the roadway including curve negotiation, lane changing, cornering, and so forth; and
3. situational demands for specialized skills that are demonstrated in passing, parking, backing, and merging maneuvers.

A PROPOSED CONCEPTUALIZATION OF THE DRIVING TASK

A basic conceptualization (see Figure 1) helps to put these tasks into a framework for analysis.* Driving may be viewed as a negative feedback control system wherein the driver samples the lateral and longitudinal status of the vehicle and compares this to a target or reference input and acts on any observed deviation between the two. This con-

* "Proceedings, Conference on Mathematical Models and Simulation of Automobile Driving," Massachusetts Institute of Technology, September 28, 29, 1967, Appendix II, p. 179.

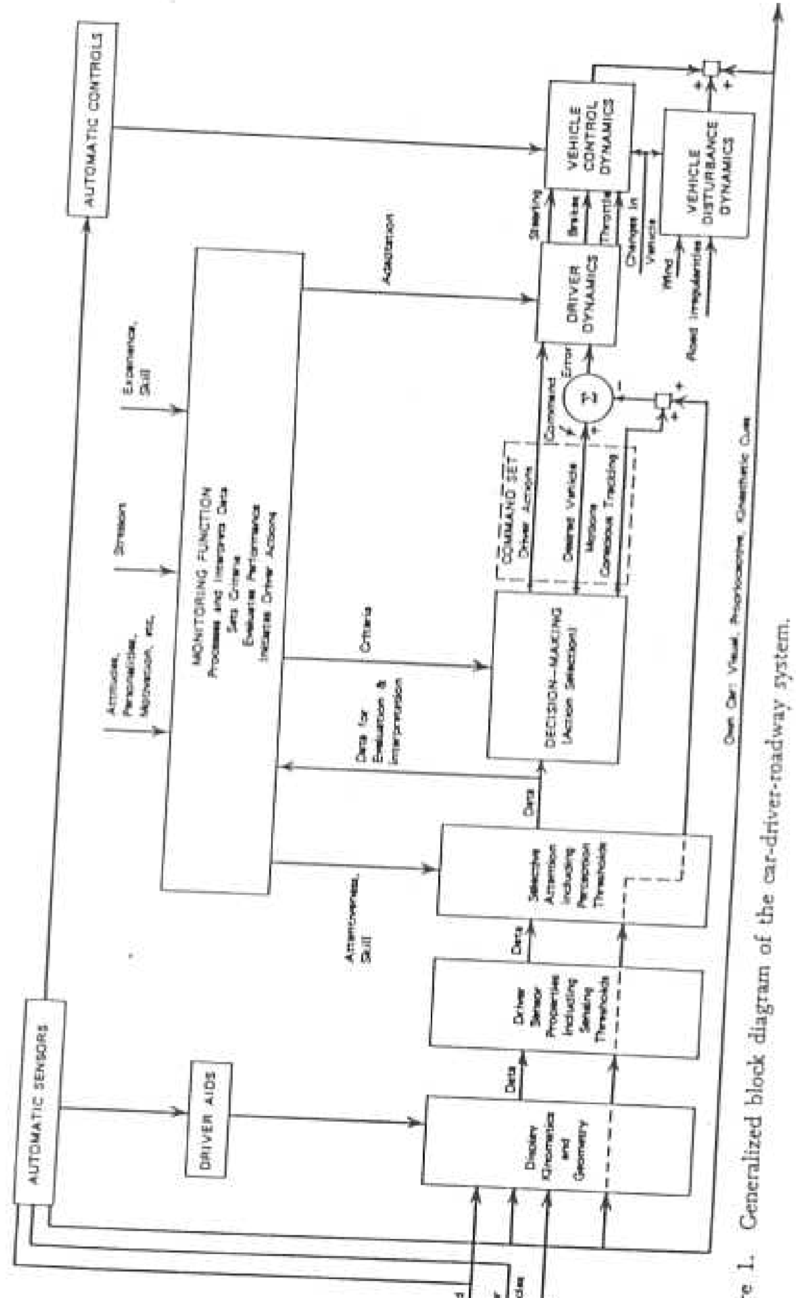

Figure 1. Generalized block diagram of the car-driver-roadway system.

..ion relates the sensory aspects of driving to decision-making control. The entire process is embedded in various environments forced by the demands of the traffic and roadway conditions involved and is sensitive to vehicle dynamics. Using this qualitative model, we can readily note how failure in various components can lead to accidents or flow disturbances. Failure on the input side is immediately apparent. The driver may sample the wrong information, the right information too late for processing, or fail to sample at all. Clearly the information acquisition aspect of the driving task is subject to degradation from the following factors:

1. within the individual, such as emotion, alcohol, or fatigue;
2. from vehicle design and corresponding eye height (that is, can the driver see the necessary cues for driving); and
3. from the environment, for example, traffic, glare, rain, fog, or lack of illumination.

The system can also fail in the information processing or decision-making stage. In this case, information may be used incorrectly, such as, risk-taking in passing operations. Finally, errors in control selection and usage can also cause system failure.

There are also situations in which traffic conditions develop so fast that the driver cannot effectively convert information into control behavior in sufficient time. The classic example of this is found in multiple rear-end collisions in high-density traffic where drivers are forced into very small time spacing between cars. An initial flow perturbation results in accumulated response time, that is, a standing shock wave results in which virtually no hope for accident avoidance exists for the drivers who by chance or by choice operate with such short time headways.

A further advantage of this conceptualization is that we can readily see the role of aiding in driving control, for example, sensory supplementation using electronic sensors that enable the driver to get information sooner and more accurately than he can visually, and decision aids that assist in passing. Providing time headway* information in car-following is another aiding possibility. Obviously, aiding in control manipulation exists today with power steering and power brakes. These have been extended to anti-skid devices to compensate for driver overbraking.

Thus, this conceptualization is useful in examining the driving task, particularly those elements of skill and judgment that make up this complex man-machine system.

* Headway—the interval, time or distance, between a lead car and the following car.

The above discussion has viewed the several modes of driving in a qualitative context. In the literature (Weir and McRuer, 1967; Crossman, 1967; Sheridan, 1962) there are mathematical models of various restricted uses of the servo model, for example, transfer functions that predict drivers' lateral control in curve negotiation.

Rockwell, Ernst, and Hanken (1968) have studied regression type models that predict driver acceleration or deceleration as a function of the changing intervehicular dynamics in car-following. To date, models of "driver transfer functions" have been limited to very specific driving situations. Our ability to predict driving performance is largely limited by the difficulty in understanding driver reference input signals, that is, what the driver desires to do in any given situation. In addition, the nonlinear, intermittent, adaptive nature of drivers makes application of classic feedback models difficult. Nonetheless, these mathematical models are powerful tools in analyzing the driving task and perhaps represent the best approach to predicting driving control that exists today.

In studying driving skill, it is necessary to first define (a) the input measures to the driver, (b) his output relative to vehicular control action, and (c) the output of his vehicle. In the case of open-road driving, this implies that the driver must be able to sense velocity and change of velocity. In car-following, he must sense acceleration, headway, and relative velocity related to his car and the vehicle ahead. Driver outputs are gas pedal, brake, and steering wheel inputs to his vehicle while vehicular outputs consist of speed changes, lane position, relative velocity status, headway status, and lateral and longitudinal acceleration. In the main most human factors researchers have elected to view the driver vehicle system as one unit, concentrating on predicting vehicle acceleration as a function of changes in intervehicular spacing, relative velocity, and velocity. Mean and variances of speed and lateral placement are reasonably good measures for open-road performance. In car-following, headway mean and variance, time headway, relative velocity variance, and the variance transmission ratio (defined as the ratio of the lead car velocity variance divided by the following car velocity variance) have all been used to measure car-following performance of the driver. In the discussion to follow, these measures of performance will be developed more extensively.

THE DRIVER AS SENSOR

Before describing actual open-road and car-following performance of drivers, it is first important to establish the sensory capabilities of man for these tasks. The conceptualization above indicated that the driver must sense changes in spacing and/or relative velocity and/or relative acceleration as a basic input(s) to his control response. The question of how well the driver can make such judgments is an important concept in understanding the longitudinal control task. Research has indicated that man is a fairly accurate sensor of his own car's dynamics (Rockwell and Snider, 1969). In general, drivers can sense ± .01 g in the form of vehicle acceleration. They are capable of producing or estimating velocities very well—overestimating speeds at higher velocities and underestimating at lower velocities—acting much in the same way as the speedometer. Their capability for estimating changes of velocity range in the neighborhood of 4 to 5 mph.

This capability to estimate velocity is degraded, however, when we begin to study the two-car case where the driver must act upon intervehicular spacing and rates of change in order to make proper decisions in car-following. Research by Mortimer (1969) and Ernst and Rockwell (1966) have indicated the change necessary for detection in headways obeys Weber's law with ΔH (headway change) $\sim KH_i$ (initial headway) where $0.1 < K < 0.2$, that is, at 100 feet it would take the driver 10 to 20 feet to detect a change in spacing. Headway estimation or production is woefully poor in most driving situations with errors ranging anywhere from 20 to 100 percent for various drivers. Novice drivers overestimate headways by as much as 300 percent early in their training. To date, it is not known why drivers are such poor sensors of spacing. Relative velocity change detection is somewhat more accurate. Whether relative acceleration is indeed capable of being sensed by man is a moot point at this stage of our knowledge of intervehicular sensing. Tables 1 and 2 summarize data on perceptual sensing capabilities of acceleration, velocity change (no speedometer), speed estimation, production, headway change detections and headway estimation.

Sparse data exist for intervehicular sensing between cars traveling in opposite directions. Silver and Farber (1969) suggest that the driver has little skill in determining velocity of oncoming cars and in quantifying relative speed in such situations. However, their data have indicated that subjects could reasonably predict the time of arrival of oncoming cars, especially in the 10- to 12-second range. In terms of protensity (time sensing) measurement, drivers tend to overestimate elapsed time particularly as speed increases.

The data in Table 1 illustrate typical perceptual skills of normal alert test drivers. Under stress or with low motivation, perceptual errors would likely increase. These studies do not tell us how the driver arrives at these skills. Research by Gordon (1966) and Gordon and Michals (1965) and others has begun to suggest the cues (e.g., rate of change of visual angle) the driver uses to make psychophysical judgments. Mourant and Rockwell (1970b) have studied driver search and scan patterns to identify perceptual cues for various driving situations. These will be discussed later. Until the sensory decision-making process is developed, it is sufficient to say that the present question is how good is the driver in ascertaining information necessary for proper control.

In general, alert test drivers can maintain constant speeds of plus or minus 3 mph without the use of a speedometer (Rockwell and Ernst, 1965). Decelerations from 50 mph to a specified stopping point revealed consistent deceleration patterns for individual drivers but widely varying patterns between drivers. Deceleration rates in nonpanic stops rarely exceed 5 feet per second² in residential driving. Novice drivers tend to begin with rates of 3 feet per second² but, with training, rapidly approach levels of the experienced driver. As precision in required deceleration is increased, lateral placement accuracy decreases. In a series of nighttime illumination deprivation studies, it was found that lateral and longitudinal accuracy could not both be maximized (Matanzo and Rockwell, 1967). If the subject emphasized precision in either velocity maintenance or lane position, the other performance measure was degraded suggesting a single-channel processing characteristic of man.

Test drivers can generally equal or exceed the precision of automatic velocity control systems in modern cars at least for roads with little or no vertical curvature.

CAR-FOLLOWING SKILLS

Considerable research has been directed to car-following skills. Some of this research began with traffic flow researchers (Herman, et al., 1959) who were interested in the macro-system of platoon* flow and the stability characteristics of vehicles at various traffic speed and density conditions. In this case the acceleration of the following car ($\ddot{x}_2$) was predicted by headway, H, relative velocity, RV, stream speed† conditions, vehicle mass, M, and a constant (λ), depicting driver and vehicle response time as in the general equation below (when τ = time lag).

$$\ddot{x}_2(t) = f\left[\lambda \frac{RV\ (t - \tau_1}{H\ (t - \tau_2}\right]$$

* Platoon—a group of n cars with $n - 1$ engaged in car following.

† Stream speed—the average vehicle speed for a given section of highway at a defined time. For a platoon, may be $(v_1 + v_2)/2$.

Table 1 Driver Sensing Capabilities[a,b]

Single-Car Case without Knowledge of Results

Task	Number of Subjects	Number of Observations per Subject	Dependent Variables	Initial Velocity − = deceleration + = acceleration		Results				
Acceleration sensing	27	20	g's	v_i = in mph		−35	+35	−50	+50	
				Average acceleration threshold		0.0117 g	0.012 g	0.035 g	0.0115 g	
				95% C.I.	Upper	0.0123 g	0.0129 g	0.0145 g	0.0125 g	
					Lower	0.0105 g	0.0111 g	0.0124 g	0.0108 g	
Velocity change detection	10	18	mph	v_i in mph		−35	+35	−65	+65	
				Average velocity threshold		3.5 mph	5.9	5.0	4.2	
				95% C.I.	Upper	4.1 mph	7.0	6.4	5.3	
					Lower	2.9 mph	5.0	4.0	3.3	
Velocity estimation	12	48	mph	Actual v in mph		20 mph	30	50	70	80
				Average estimated velocity		15 mph	27	50	75	88
				95% C.I.	Upper	29 mph	38	62	82	92
					Lower	3 mph	15	38	60	75
Velocity production	12	48	mph	Requested v in mph		20 mph	30	50	70	80
				Average produced v in mph		22 mph	31	45	62	68
				95% C.I.	Upper	32 mph	40	56	73	80
					Lower	12 mph	18	45	50	59

C.I. = Confidence Level

Table 1 (Continued)

Two-Car Case without Knowledge of Results

Task	Number of Subjects	Number of Observations per Subject	Dependent Variables	Velocity		50 mph			70 mph		
Headway estimation (H) in feet	12	140	feet	Actual headway (ft)		100	300	500	100	300	500
				Estimated headway (ft)		70	180	280	50	130	210
				95% C.I.	Upper (ft)	180	300	400	130	220	300
					Lower (ft)	—	40	160	—	50	120
Headway production (H) in feet	12	140	feet	Specified headway (ft)		100	300	500	100	300	500
				Produced headway (ft)		90	180	240	60	130	180
				95% C.I.	Upper (ft)	250	350	450	140	210	250
					Lower (ft)	—	50	120	—	50	90

Task	Number of Subjects	Number of Observations per Subject	Dependent Variables	Polarity		Results: Positive Acceleration		
Headway change detection (positive polarity)	6	80	feet	Original headway (ft)		50	100	200
				Threshold (subject) (ft)		3	8	10
				95% C.I.	Upper (ft)	10	13	20
					Lower (ft)	—	—	5

Task	Number of Subjects	Number of Observations per Subject	Dependent Variables	Polarity		Negative Acceleration		
Headway change detection (negative polarity)	6	80	feet	Original headway (ft)		50	100	200
				Threshold (subject) (ft)		4	10	15
				95% C.I.	Upper (ft)	12	18	23
					Lower (ft)	—	—	8

[a] From Ernst and Rockwell (1966).
[b] From Rockwell and Snider (1967).

expect headway variances to be 50 to 300 percent of the mean headway obtained with ≈ 200 percent being the median figure.

Again we must be careful in using any of the above measures in describing skill since drivers will often relax such measures if the situation does not demand it. In effect, drivers appear to apply skill in driving situations only to the extent to which such skill is necessary.

DRIVER JUDGMENT

The measurement of judgment in driving is a difficult task because decisions cannot be adequately evaluated without knowing the alternative courses of action open to the driver and his motivation behind a given decision. Field observation of elected spacing, passing, and so on, suffer from this problem. Experimental studies provide better control of contributing variables but can produce bias.

Judgments must be classified into the three following categories:

1. emergency decisions—one-time situations requiring unique, often rapid decision-making and response, such as to an object on roadway. Simulation of these events lack the realism of real-world threat and after the first exposure the situation is no longer unique. Field studies, in addition to being dangerous, again limit unbiased data to one exposure.
2. decisions whether or not to engage in driving. These cover situations where the driver may be tired, drinking, or aware of vehicle defects. Such decisions are also unique and not easily researchable although obviously perhaps the key to good driver judgment.
3. operational decisions, including routine decisions as to headway election,* speed selection, passing decisions, and merging decisions. These decisions are amenable to observation and research and are important because they dictate the level of subsequent skill required of the driver to execute the decision and maintain a given performance. It is apparent then that skill and judgment are highly interrelated.

Two areas of such operational decisions are reported below—car-following strategy and passing decision.

DRIVER JUDGMENT IN CAR-FOLLOWING AS REFLECTED IN HEADWAY ELECTION

Elected headways represent an interesting part of driver judgment. When headways are expressed in time it is found that both large intra-

* Headway election—driver statagem for maintenance of headway.

subject and intersubject variability exists. With aerial photogrammetry Lee (1971) found that on expressways under free flow, the minimum mean time headway was approximately 2 seconds for densities from 35 to 100 vehicles/miles. At higher densities the average time headway actually increases. Greenshields (1935) reported that accidents were related to the mix of speeds and headways in driving. It is easy to visualize this since the interaction of two cars of different speeds encourages decision-making, such as passing, and hence increases the probability of errors. Differences in speed and headway also result in flow perturbations. Intrasubject variability is somewhat easier to explain since it is known that merely changing instructions will produce different headways, for example, normal car-following results in approximately 3 to 4 seconds of time headway. "Following so as not to lose the lead car" might increase this to 4 to 6 seconds. "Following at minimum safe distance" is in the order of 1 to 2 seconds and following with preparation to pass may be down in the region of 0.5 to 1 second. In any event, there is little data to suggest that drivers follow a National Safety Council rule of one car length for each 10 mph, probably because of the perceptual difficulties described earlier and partly because, where they have the option, most drivers refuse to car-follow in low traffic density. Rockwell and Snider (1967) in studying truck drivers were unable to get the drivers to car-follow even when deliberately impeded by [illegible] course. In general, drivers will prefer more than 4 seconds as compared to the National Safety Council rule of approximately 1.5 seconds. On the other hand, in high-density urban expressway traffic, drivers are forced to operate below the National Safety Council rule because of system constraints. In general, drivers do not elect to car-follow and will usually attempt to either pass or fall back beyond a 4-second time headway.

Intrasubject variability in headway election is influenced by several factors. Forbes (1959) found in tunnel operation that right curves, downgrades, and low illumination levels all tended to increase elected headways in the Holland and Lincoln tunnels. Tunnel operation, which reduces the field of vision, typically results in larger headways at equivalent speeds or reduced speeds at equivalent headways.

As indicated earlier, while the headway variance figures might be suggestive that the driver is not precise in car-following, it is well to note that operant skill is a function of the demand placed upon the driver. Large variation in headway in a two-car case might be acceptable if the platoon is two cars. If n cars are involved, the drivers compensate by reduced inter- and intradriver variability. Thus, the interesting feature in car-following is the adaptability of the driver's strategy and corresponding faster response times. This adaptability exceeds any automatic system that could be practically designed today. In effect, the driver makes up for poor highway and vehicle design and crowded traffic conditions. It is only when flow patterns become unstable that the driver falls victim to the system.

As Herman, et al. (1959) demonstrated, with n cars in a chain at conservative initial headways, normal velocities, and attentive short response time drivers, it is possible that a flow disturbance caused by the platoon leader* can cause a chain reaction in which the drivers back in the platoon have little or no hope of accident avoidance. In this instance, no amount of skill can offset system instability. It is in these situations that driver-aided systems might be used to supplement sensory and decision-making abilities.

DRIVING SKILL AND JUDGMENT IN OVERTAKING AND PASSING

In discussing the two-car interface in driving, we can conveniently separate out three phases: overtaking, car-following, and passing. Overtaking covers the transition from open-road to car-following, that is, from large time headways down to the region of 3 to 4 seconds when the following-car driver becomes affected by the perturbations of lead-car velocity. Passing involves elements of car-following in terms of the actual intervehicular dynamics before the decision to pass (called the prepass headway). Passing also includes intervehicular dynamics associated with oncoming cars (in the case of the undivided highway) and associated elements of the pass, such as, speed and safety margin.

For a comprehensive review of two-lane rural overtaking and passing, the reader is referred to *Overtaking and Passing on Two-Lane Rural Highways*, Franklin Institute (1967). For two-lane highways the elements in the overtaking and passing situation include:

1. distance required to pass,
2. the time required to pass,
3. the prepass headway and stream speed,
4. the postpass headway and stream speed,
5. passing reaction time,
6. available time and distance to execute a pass,
7. the safety margin or that interval of time between the time the passing car regains the right-hand lane and the time when the oncoming car arrives,
8. passing threshold—the minimum separation between a lead and oncoming car that a driver will accept for passing.

* Platoon leader—the first car in a platoon.

Several types of passes are also recognized: the flying pass where no deceleration is required of the passing vehicle; and the acceleration pass, that is, a pass which is made from the car-following mode in which the following car must accelerate in order to execute the pass. Passing return may be elected or forced by low safety margins.

Passing times from Matson and Forbes (1938), Prisk (1941), and Crawford (1963) for different overtaking car speeds are summarized in Table 3. As can be noted, passing times increase with stream speeds and are longer for flying passes since prepass headways are longer for the flying pass as opposed to the acceleration pass. These prepass distances reported by Forbes and Matson (1938) are surprisingly small; 40 feet for an acceleration pass and 70 feet for a flying pass. These result in time headway in the neighborhood of 0.5 to 1 second in the prepass condition. As expected, acceleration prepass headways varied with speeds. Longer time headways exist for slow overtaken car speeds, gradually shortening to approximately 1 second as this overtaken car speed increases. That overtaken car speed does not affect the prepass headway for the flying pass suggests that drivers lack sensitivity to closing relative velocities in this situation.

Crawford (1963) found driver response time to be minimum during acceleration passes near the passing threshold (that is, the minimum time to accept the pass) and longer either at more safe or more difficult passes. This is supported by the work of Veliz (1961) who showed that reaction time in simulated industrial tasks is a function of stress; that is, as stress increases, reaction time first decreases and then reaches a point of human disorganization and begins to increase. Psychologists would relate this phenomenon to the arousal hypothesis or the Yerkes-Dodson law.

Forbes and Matson (1939) reported 20 percent of drivers left themselves a safety margin of 1 second or less and 10 percent forced oncoming cars to give way. Safety margins reported by Crawford vary as a function of time available above passing threshold. In general, 10 to 20 percent of passing is executed with safety margins less than 2 seconds suggesting that drivers are poor estimators of closing relative velocities.

It is not known what cues the drivers use in making decisions to pass. Rockwell and Snider (1969) suggest decisions are not based solely on distance and gap size. Drivers make use of visual cues such as vehicle size in the selection of offered gaps. They may well get gross cues regarding closing relative velocity but this has not been clearly demonstrated.

Passing on divided highways represents a less serious problem from a safety point of view and illustrates that the drivers elect different available gaps in lane changing. It has been found that subjects varied con-

Table 3* Passing Times

Type of Pass	Overtaken Car Speed (Medians)[a]		Overtaken Car Speed (Means)[b]					Overtaken Car Speed (Means)[c]			
	30	50	0–19	20–29	30–39	40–49	50–59	25	30	40	50
Accelerative, voluntary	10.0	11.5	8.7	8.8	9.8	10.8	10.5				
Accelerative, forced	8.0	9.5	7.7	8.0	8.8	9.4	8.4	7.8	8.1	8.9	9.6
Flying, voluntary	10.5	12.0	10.0	9.9	11.0	11.9	9.6				
Flying, forced	8.0	10.5	8.1	8.9	9.8	11.8	9.3				

[a] Forbes and Matson (1939); Matson and Forbes (1938).
[b] Prisk (1941).
[c] Crawford (1963).
* From Franklin Institute (1967).

siderably in terms of the gap available in the passing lane but are relatively unaffected by the closing velocities of approaching vehicles. As with any risk study, subjects varied widely. Thresholds varied 70 to 140 feet with test cars speeds at 60 mph and the following approaching car speed at 70 mph.

Perhaps the classic field experiment in overtaking and passing was conducted by Farber (1969). In this case selected vehicle target speeds were first evaluated and these vehicles were subsequently impeded by a test vehicle before a no-passing zone. Upon leaving this zone, the passing behavior—that is, time available, speed, and so forth—of the impeded vehicle was measured. It was found that the probability of a pass increases with distance to the oncoming car and decreases with increasing stream speed. Night passing decisions were more conservative requiring 2800 feet at night compared to 2050 feet in the daytime. If 13 seconds is taken to be a minimum acceptable passing time (8 seconds for passing and 5 seconds safety margin), then on the basis of median speeds encountered, distances are between 1600 and 1800 feet. Forty-two percent of acceptable (safe) night passes were rejected while 25 percent of acceptable nighttime passes were rejected. Mean passing times were of the order of 8 seconds and safety margins varied as a function of passing opportunity distances decreasing to 4 to 5 seconds at distances below 1500 feet. Nighttime visibility conditions did not have a large cautionary effect on passing behavior possibly due to additional cues from headlights in short-sight distance situations.

While more research is needed in the area of passing, evidence to date would suggest that drivers do a remarkably good job in passing decisions especially in view of the fact that their sensory capability in these situations is poor.

SKILL AND JUDGMENT IN NOVICE DRIVERS

Studying the novice driver provides insight into skill and decision-making development. Zell (1969), Harootyan (1969), Vojir (1969), and Mourant and Rockwell (1970a) tested novice high school drivers before, during, and after their driving education program, at 2- to 3-week intervals. It was found that psychophysical performance developed rapidly in training with headway estimation, velocity control, and car-following developing early in training. Typical range tests, for example, rapid deceleration to a fixed point, likewise showed early learning as did cornering and lateral acceleration. Gap acceptance* shows that changes

* Gap acceptance—driver decision making whether to pass on a 2-lane road. The

continue later in training, suggesting that decision-making is later in development. Of particular interest was the fact that eye search and scan patterns continue to develop long after licensing. This will be discussed in more detail below. Much of the skill development depends in large measure upon exposure both as driver and passenger in the family auto environment.

INFORMATION ACQUISITION IN DRIVING AND EYE-MOVEMENT RESEARCH

For years researchers in human factors have attempted to define the driving task and to ascertain the elements of the driving control process in order to develop an understanding of human vehicular control. This understanding is imperative if we hope to design better vehicles and highways around the capabilities and limitations of drivers and to train drivers themselves to effect safer and smoother flow on our highways. The problem has been a difficult one because the input side of the process has been largely unknown. Skill and judgment in driving have been studied without knowing the information acquisition aspects of the task. General conceptualizations, such as information theory and servo theory, have not been altogether convincing because of our lack of knowledge about the information needs and information acquisition characteristics of the driver. Since driving information acquisition is largely a visual process, it was apparent that this sensory mechanism first demanded quantification and analysis. Several years ago the techniques in eye movements began to be applied to the driving task and results, while still exploratory, suggest a new area of research investigation with exciting potential.

The role of vision in driving is believed to constitute over 90 percent of information input to the driver. Regardless of the exact percentage, without a doubt, visual perception is paramount in vehicular control. Unlike motor output, perception is very sensitive to changes in the roadway environment, vehicular design, and particularly to changes in the driver's psychological and physiological state at any given time. Visual processes can be degraded by glare, fog, lack of illumination in the environment, by vehicular design (in terms of tinted glass windshields or "A" pillar location), and by such factors as alcohol, fatigue, and drug usage.

gap is the available interval for passing, that is, the time or distance between successive oncoming cars.

Eye-Movement Technique

Eye-movement technique essentially permits determination of foveal fixations in time and space, recording voluntary and/or involuntary saccades. Drift or tremors of the eye are too small and of too short a duration to be captured with the equipment to be described. Pursuit eye movements, however, can be detected and represent one of the unique characteristics of the fatigued driver. Eye movements can also be characterized by amplitude of movement (angular distance between successive fixations) and fixation duration. Most eye movements in driving are less than 6 degrees travel and most eye fixations are between 100 and 350 milliseconds in duration. In driving we can further determine that some 90 percent of the observed fixations fall in a small region, within ± 4 degrees from the focus of expansion.*

The earliest measurement technique involved direct photographs of the eye, used in aircraft instrument flight operation to record instrument sampling. This method is not too accurate and is not useful if the scene objects change their position in time as with automobile driving. Direct photoelectric methods that measure contrast differences of the sclera and the iris are useful only for static scenes because they suffer in vertical accuracy. Such systems can be used for laboratory confirmation tests of such questions as sign reading time. Mechanical cups or mirrors fastened to the anesthetized eyeball are found in precise laboratory research but not in the harsh realities of the actual driving situation.

One system in use today involves both video and 16-mm motion picture processing and operates on the corneal reflection technique (see Figures 2 and 3). With this method a small collimated beam of light is reflected off the cornea back into a collecting lens and recorded on film or tape. The proper calibration of normal eyes permits accuracies of ± 1 degree vertically and ± 0.5 degree horizontally. Subjects must have reasonably round corneas to get a small eyespot. Range of eye travel for useful calibration is ± 10 degrees from line of sight. Subjects must also not suffer from amblyopic problems.

The key to good and accurate eye-movement research technique is stabilization of the input system relative to the position of the eye. The three-vidicon system has a 54- by 41-degree field of the view and uses only one fiber optic cable to transmit the corneal reflection. The system synchronizes three vidicons—one for the scene, one for recording the corneal reflection, and a third to photograph the eye directly to record

* Focus of expansion—that point in the moving visual field straight ahead of the driver where objects on the roadway appear stationary.

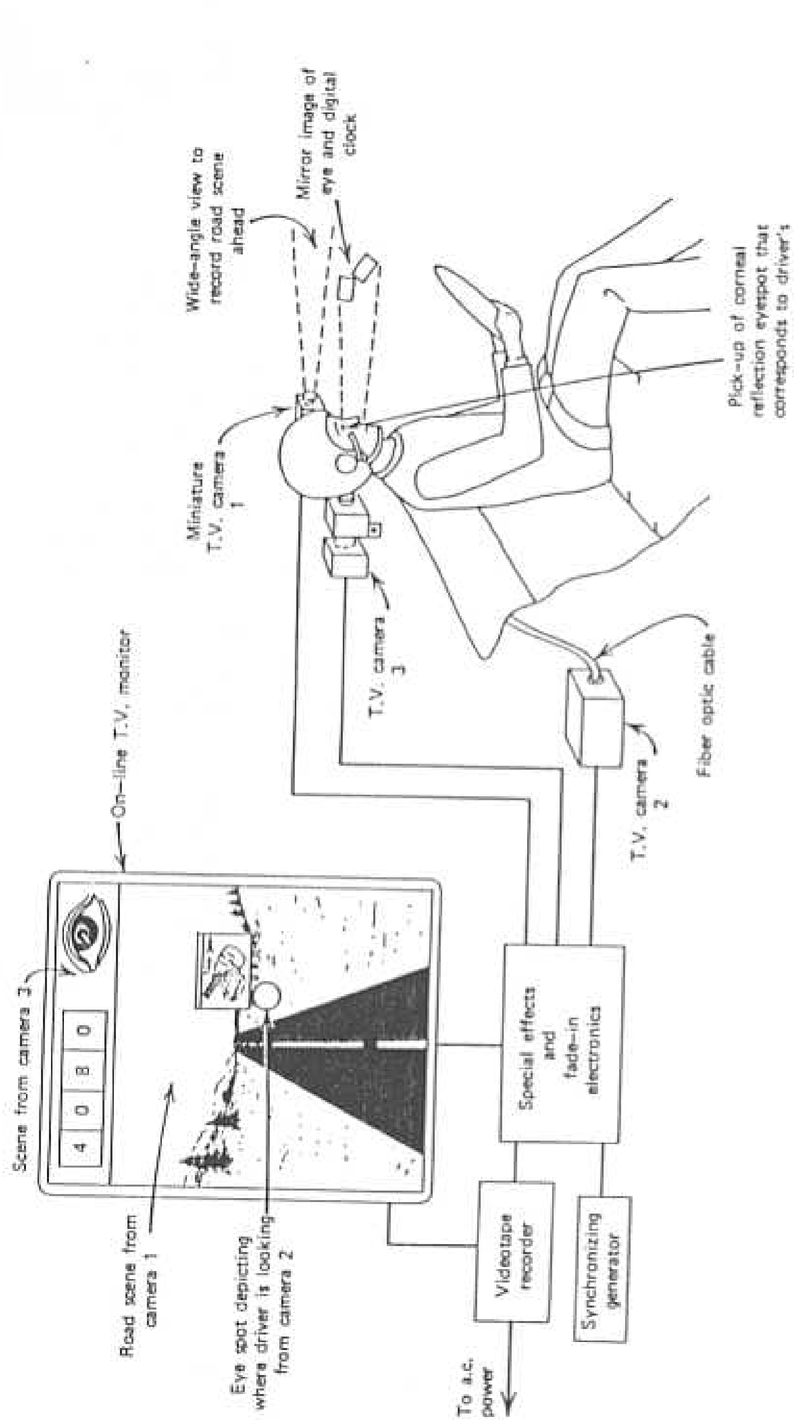

Figure 2. Television eye-movement system for automobile driving.

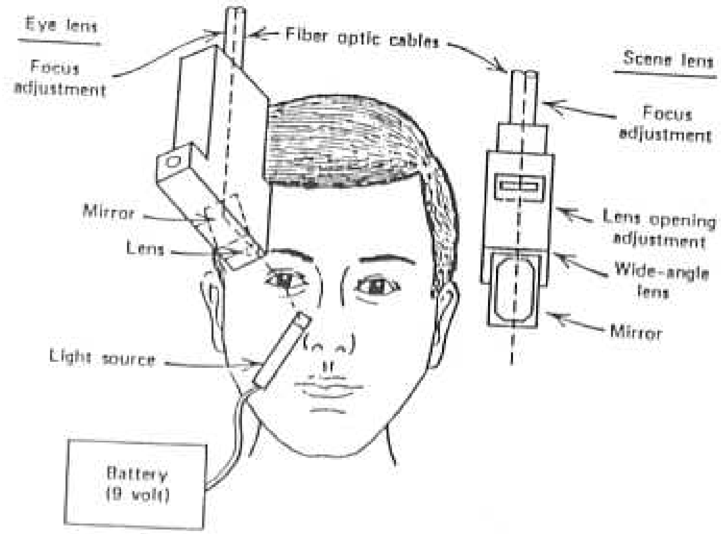

Figure 3*a*. Input system.

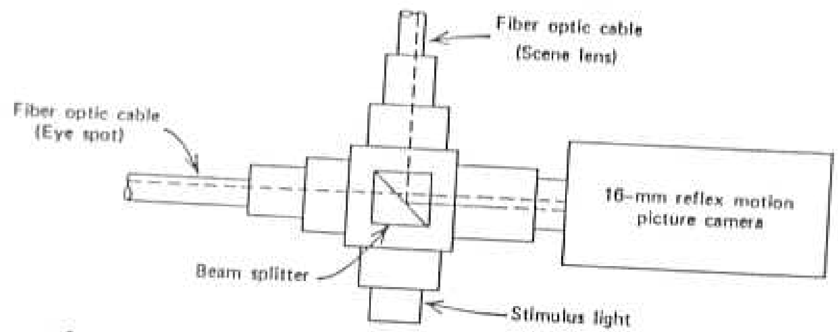

Figure 3*b*. Output system.

mirror and speedometer usage when the eyespot leaves the 35- by 35-degree view forward. Thus we can ascertain the rate the driver is mirror- or instrument-sampling and can also record head movements, blink rates, and time (in 50 millisecond intervals from a digital clock).

Basic analysis formats involve temporal analysis using fixation histograms or fixation aggregation (glimpse) histograms. Eye movements may also be analyzed by spatial density maps, assuming that one understands what a coordinate means in terms of the driving task and environment. Eye movements can be studied as a Markovian process examining transition probabilities, that is, the probability of the eye moving from one spatial segment to another or from one object to another. Eye travel distances can also be used to analyze a particular sample of eye-movement data by recording the distribution of eye travel distances. Object analysis is becoming a common procedure whereby we determine the percent of time that the driver spends on details in the scene such as signs, delineators, or the car ahead. Spatial-temporal analysis, that is, the percent of time the eye spends in a given location, is still probably the basic approach in analysis. In addition, eye-movement results can be identified by the degree and amount of pursuit eye movement in terms of the total visual task.

Eye-Movement Technique Potential

In describing eye-movement research, it is important to point out that use of an eye-marker camera probably has fewer artifacts than any other technique of measurement of driving performance because there are no instructions on how the driver is expected to use his vision. Unlike response time studies, vehicle control studies, or car-following studies, the driver has no indication as to what constitutes "good" performance. Thus the task is essentially instruction free. If we decide to study signs, we never tell the driver that we are interested in sign fixation. It must be admitted, however, that the wearing of this equipment may well influence eye-movement patterns and head movement although recent data have indicated little differences in head movements with and without the head-mounted eye-movement device. The fact that drivers can wear the helmet for 2 and 3 hours and the fact that drivers in fatigue research will actually begin to fall asleep with the device in place would suggest that subjects can adapt reasonably well to the system.

Because the state-of-the-art in eye-movement research is in an embryonic development stage, a few major limitations in interpretation must be faced. First, in most cases the driver has considerable spare visual capacity. Most interstate driving probably requires less than 50 percent of a driver's perceptual capability. Thus, the driver often deliberately samples at repeated intervals completely irrelevant information such as signs which are covered. The second major problem in eye-movement research is the role of peripheral or extra-foveal vision. A fixation may be merely a reference point for organization of peripherally acquired information. Research indicates that extra-foveal vision plays a large part in driving. Indeed it may well be said that driving is largely a dynamic peripheral vision task. Foveal vision is important in terms of its characteristics of finer discrimination (e.g., sign reading) and higher rates of information extraction, such as quick glimpses of oncoming vehicles on undivided highways. It is no surprise that research has found little correlation between visual foveal acuity and accidents because

visual acuity may be less important in driving than the detection of movement by peripheral visual processes. Finally, the driver may be looking at an object but he may or may not be processing the information.

Despite these drawbacks, however, there are some interesting and provocative results derived from eye-movement research to date. Eye-movement studies have been shown to be useful as a means of measuring degradation of driving performance as a result of intrasubject factors, such as experience, alcohol, or fatigue, and environmental factors, illumination, traffic load, and so forth.

As proposed by Mourant and Rockwell (1970b), the visual task in driving may be described as the monitoring of the continuous stream of information through which the vehicles travel. At a given instance the foveal region of the eye examines only about a 2-degree circular (diam.) region of the stream. Much more of the information is available to the extra-foveal portions of the eye. There is some evidence (Mackworth, 1965; Sanders, 1966) that the planning of eye movements is partially controlled by information received through the periphery of the eye. For example, a vehicle traveling in an adjacent lane may first be detected peripherally and confirmed foveally. Because the visual function of information seeking plays a basic role in the driving task (Connolly, 1968), several benefits may be realized from describing the search-and-scan behavior of drivers. For example, Walraven and Lazet (1966) have suggested that a record of drivers' eye movements may provide a better method of assessing driving skill than has been available in the past. This assumes that analysis of eye-movement patterns of well-experienced and accident-free drivers will result in the development of criteria for good search and scan patterns. If such criteria were developed, they could be used to assess drivers' visual performance during licensing examinations by objective quantitative measurement. Eye-movement research may also improve the content of driver education programs. Standard methods may be developed to teach good search and scan patterns to inexperienced drivers. Finally the relationships between perceptual load and driving environment may be explored by studying driver eye movements. The effects of various types of highway geometry, traffic conditions, road signs, visual aids, and vehicle designs could be evaluated by recording and analyzing driver eye movements.

Studies of Eye Movements in Driving Degradation Conditions

While intersubject differences in driving eye movements are difficult to analyze because of the varied idiosyncratic perceptual characteristics of drivers, it is possible to use eye-movement techniques to study intra-subject differences as a function of degradation situations such as alcohol, carbon monoxide, and fatigue. Here eye-movement changes can serve as early detectors of subsequent control process degradation.

Belt (1969) examined eye-movement changes as drivers were studied at blood alcohol levels of 0.04, and 0.08 milligrams of alcohol per cubic centimeter of blood. In these cases, eye-movement patterns were dramatically affected. At the 0.04 level, some concentration of eye-movement pattern was apparent. At 0.08, significant perceptual narrowing or tunnel vision was evident. In this case using a concentration index (defined as the percent of time the fixation occurs in a 3- by 3-degree space near the focus of expansion), it was found that in open-road driving the concentration index went from 25 percent in the control case to 40 percent at the 0.08 blood alcohol level. In car-following, one driver elicited almost a complete lack of search outside of the concentration zone. Passing vehicles were always fixated when the driver was sober. However, at 0.08 level the driver made no fixations on passing cars, suggesting the degradation of peripheral detection. Fixation duration tended to increase with increasing alcohol level. Finally, since lateral control was lost twice in these studies at the 0.08 level, it was decided to investigate what eye-movement patterns preceded these conditions. It was found that before loss of control, the driver reverted to his sober sampling techniques. The implication from this study suggests that perceptual narrowing is an adaptive process that the driver needs in order to maintain any semblance of control. Abandoning this compensatory action leads to loss of necessary control cues. It is believed that eye movements will reflect the effects of alcohol long before overt control or measured driving performance degradation is detected.

Kaluger and Smith (1970) employed eye-movement techniques to study the performance of drivers with and without sleep in the previous 24 hours. In the fatigued state, drivers were observed with a large number of fixations in close and to the right of the highway, which the authors interpreted as a foveal compensation to offset diminished peripheral detection capability. In addition, they observed that while no pursuit eye movements were found in the control conditions, subjects exhibited pursuit eye movements almost 5 percent of the time in the sleep-loss condition. Despite the use of this testing equipment, the fatigued driver would frequently doze or close his eyes for 1 to 3 seconds during the test runs.

LEARNING AND SEARCH AND SCAN PATTERNS

Considerable efforts over the past few years have been directed to visual information seeking of novice drivers. Zell (1969) and Mourant

and Rockwell (1970a) have discovered significant changes in eye-movement patterns with experience. Most of the differences are reflected in spatial rather than temporal changes. During their training, drivers switch from frantic cue searching, large eye-movement travel distances and fixations on nonrelevant cues, such as lamp poles and guardrails, to alternate sampling near and far. The far fixations are thought to be primarily directional cues while the very near samples (usually less than 1 second ahead of the vehicle) suggest foveal determination of lane position. The experienced drivers concentrate fixation near the focus of expansion and are thought to use peripheral or extra-foveal processes for lane positional feedback (see Figure 4).

In the main, students early in their driving experience fail to adjust their preview sampling as a function of their velocity. Experienced

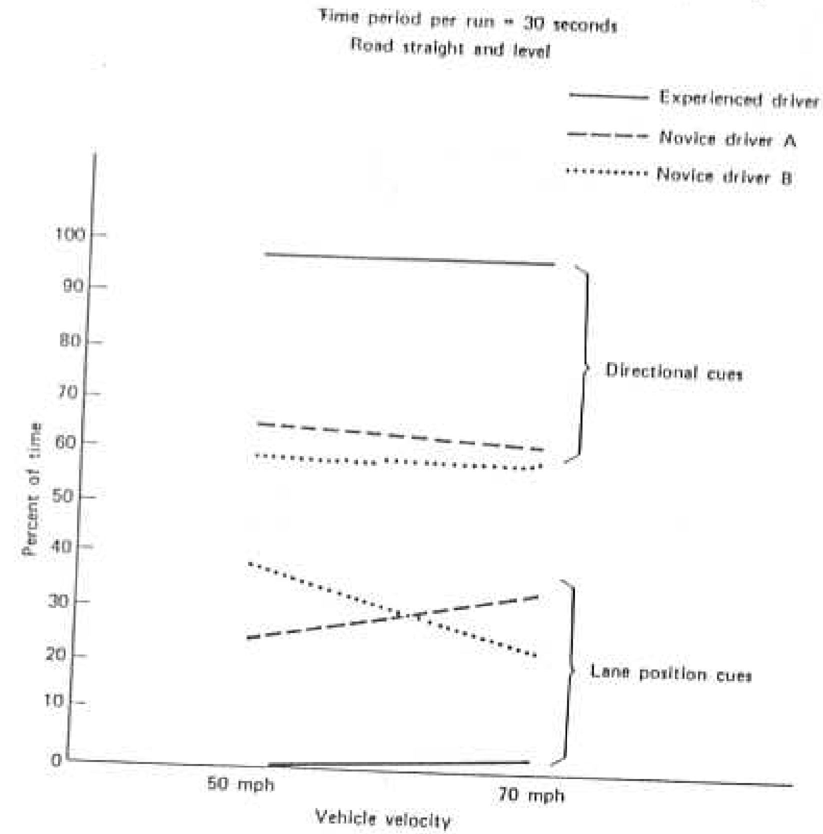

Figure 4. Percent of time sampling for directional and lane position cues as a function of vehicle velocity.

drivers, on the other hand, attempt to maintain a good 2.5 to 3.5 seconds minimum preview time adjusting their forward reference distance with velocity changes. Novice drivers, especially in their early hours of driving, sample close in to the car. This may be due to their inability to make temporal-spatial estimations and good use of peripheral processes.

The potential of eye-movement techniques in understanding the driving phenomena is virtually untapped. Eye-movement research has developed sufficiently over the past four or five years to begin the study of other facets in the driving task. These include the possible effects of carbon monoxide, narcotics, and marihuana on information acquisition, the effect of background and landscaping on curvature search patterning, the effects of driver aided systems (e.g., head-up displays), the effects of glare, rain, and fog on search patterns, and the use of eye-movement patterns for evaluating traffic control devices. While eye-movement research focuses on only one aspect of the total driving task, it is significant that without knowledge of the information-acquisition side of driving, no real development in driving theory such as information processing, anticipation, and learning can be developed. Any generalized predictive model of driving will have to have quantification of the informational inputs to the driver.

DRIVER AIDING

Driver aiding in control functions is well accepted. For example, power steering and power brakes do much to improve driver performance. Velocity control systems, anti-skid devices, and speed limit warning devices are all examples of systems that supplement the driver's sensory, decision-making, and control functions. Because of his inherent limitations in intervehicular sensing, efforts have been made to provide the driver with sensory supplementation. Gantzer and Rockwell (1968) presented the driver with both headway and relative velocity information and established headway and relative velocity bandwidths within which the driver was to operate. If the driver nulled the red and green lights on the dashboard, he was confident that he was in "the safe operating zone." Using target headways of 70 and 170 feet and average stream speeds of 60 mph, Gantzer was able to show that the driver indeed could drive with less headway variance and relative velocity variance under this aided system. The headway variance improvement was in the order of 100 percent at the 170 feet target headways but was substantially less at the 70 feet target headway. It was hypothesized that at short target headways the driver is less interested in using sensory supplementation information and more dependent upon his own perception. Interestingly enough, psychophysically at 70 feet and 70 mph the driver is able to detect very small changes in spacing ($\approx$ 10 ft). While there are some improvements in individual subject performance from aiding studies, the most striking feature of the data is that the intersubject differences become smaller, that is, there is a homogenizing effect with aiding systems that makes the drivers perform more alike. This has obvious implications in terms of improved stability of traffic flow patterns.

There is little question that providing the driver with accurate relative velocity and headway information would improve car-following performance. The basic technological problem is whether we could develop a passive system in automobiles that would sense spacing and relative velocity reliably and economically.

While open-road longitudinal performance can be aided by velocity control systems, and experimental headway and relative velocity aiding can provide improvement in car-following, the ability of aided systems to assist the driver in lateral control remains suspect today. This is because no method for measuring lateral placement along the highways has been reliably demonstrated and, further, the response time characteristics of such a sensing and warning system would be such that by the time the information on lateral deviation from the path is detected by the sensor, it would be of little or no use to the driver. It may well be that systems design must evolve from the current system into a semi-automated lateral control system in which vehicles are controlled down highways following centerline guidewires embedded in the highway pavement.

HEAD-UP DISPLAY AIDING IN DRIVING

Head-up type displays are so named because the operator does not have to lower his head to look at instruments or displays located inside the vehicle. This concept was first applied in aircraft but has recently been adopted for use in automobiles.

In early 1968, the Bureau of Public Roads contracted with the Kollsman Instrument Corporation to conduct a feasibility study and build and test a feasibility model of a Route Guidance Head-Up Display. The Head-up Display (HUD) was to be installed in an automobile for presentation of route guidance directional symbols to the driver as a subsystem of the Bureau's Experimental Route Guidance System (ERGS). This study demonstrated that the HUD concept could be applied to automobiles and that it was both technically and economically feasible to do so (Benzinger and Bell, 1969).

In 1969, Robbins (1969) adopted the HUD principle as a method of aiding the automobile driver in the close-interval car-following situation. In previous experiments conducted by Gantzer and Rockwell (1968) the driver was presented with discrete headway and/or relative velocity information via color coded lights on the instrument panel but the results indicated that the drivers became more reluctant to look down at the display to get the information as the car-following distance decreased. The HUD was considered to be a possible solution to this problem since the same information could be presented to the driver.

Within the context of driver aiding, it becomes evident that any additional information presented to the driver must not act as a distraction to the primary task of longitudinal and lateral control. Since it takes about 0.7 second to get information from instrument panel displays, novel techniques to display information on the windshield have been investigated. These would present information focused at infinity which the driver could look through while he undergoes his normal search and scan patterns. At the same time there would be no need for accommodation.

The results of using the HUD to present the information were very similar to the results of using the dashboard display. The headway variance was significantly reduced and the relative velocity variance increased somewhat, as a result of the drivers making speed changes in response to HUD information that would have gone undetected without the aiding. It was also determined that headway information alone, without relative velocity information, produced the best performance.

Unlike the dash-mounted display, however, the HUD has several other effects on the drivers' performance. First, the drivers appeared to be able to receive and use the information even at very short headways. This was also reflected in the fact that the drivers' estimates of the minimum safe distance were consistently revised toward a shorter distance using the HUD. Secondly, the drivers were more alike in their driving performance, as measured by the variance of headway, when using the display than without it. These two results have significance toward achieving a high speed/density traffic condition without risking a further increase in the number of accidents.

Harrass and Mourant (1970) extended HUD application to close-interval car-following using continuous headway information, via a moving reticle that depicted actual headway and desired target headway, computed from stream speed conditions. The results of this experiment showed again a significant reduction in headway variance and a small increase in relative velocity variance. The reduction in intersubject variability was found again but it was a much more pronounced effect

with the continuous display. This was probably because there was less interpretation to be made by the subjects using the continuous display. When the discrete green light came on, the subject had to decide, using other information, whether to slowly accelerate back to the desired headway or whether to rapidly accelerate because he was rapidly falling behind. With the continuous display, the driver could get all the information that he needed to make the decision right from the display itself. The continuous display not only told the driver that he was off the desired headway but also told him how much he was off and how fast he was getting farther off because the rate of movement of the marker was actually giving him relative velocity information.

Can the Head-up Display be used to give automobile drivers useful information other than route guidance or car-following information? To answer this question, an experiment was designed to test the effects of giving the driver a "preview" of the road geometry ahead under conditions of reduced visibility, when he is unable to get the information without some kind of aiding. Since the easiest condition of reduced visibility to achieve is darkness, the experiment was conducted at night.

The results of the experiment showed that there was a significant shift in the average lateral acceleration on the curves between the day and night, but the HUD preview information did not cause any change in the mean lateral acceleration at night. Also the variance of the gas pedal position was found to be higher at night without HUD aiding, but the difference was only marginally significant ($p < 0.25$). The HUD preview in this case did have the effect of significantly reducing the variance of the gas pedal position over that of the unaided night condition.

While head-up display technology is still developing, it represents a new approach to the information acquisition issue. Whether such a display will *really* improve driving skill is still open to debate.

SUMMARY

Based on the evidence of driver skill, it is apparent that the driver will not easily be replaced by automated systems. Despite his variability in performance, the driver still can perform complex driving tasks with amazing reliability and safety. Considering the opportunities for accidents, the accident record of the average driver is very commendable. If we were to design a system with the specifications of the diverse skills of the human operator, most systems engineers would quickly concede defeat.

Indeed, contrary to the usual platitude about the "nut that holds the wheel," it can be argued that it is the driver who by his adaptability and skill makes what is often a badly designed car and/or highway system, work safely.

This chapter has attempted to show what can be expected of today's driver in terms of his skill and judgment. Serious questions arise concerning the role of the driver in transportation systems of the future, at least in terms of his role as vehicle controller. For example, can drivers be expected to safely operate on highways with 100-mph speed limits? Has the evolution of driving skill reached the limit and, if so, can aiding be developed to assist him particularly in the areas of information acquisition and decision-making where his limitations seem greatest? It can be argued that at the present time the complexity of the driver-vehicle system will demand further studies of perception and skill of drivers.

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VIII

THE DRIVER IN A MILITARY SETTING*

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Since 1961 J. E. Uhlaner has been director of the U.S. Army Behavior and Systems Research Laboratory (formerly the Army Behavioral Science Research Laboratory). After obtaining his degrees in psychology—B.S. from the City College of New York, M.S. from Iowa State University, and Ph.D. from New York University—he started his career of over 20 years as an Army scientist.

Dr. Uhlaner has made major research contributions in the fields of screening, selection, classification, and behavioral evaluation. He devised and directed the development of the Armed Forces Qualification Test (AFQT). In recent years he has concentrated on development of a research program of human factors utilization problems in man-machine systems, integrating personnel measurement and experimental approaches. Specifically in the field of driver research he has advocated the consideration of driving problems within a framework of the traffic-way-driver-vehicle system.

His most recent publication in the field of driver research is on the use of tests in driver selection and licensing.

Dr. Uhlaner is a member of the Road User Characteristics Committees of the Highway Research Board, and the APA Committee on Accident Research. He was the instigator of the Annual Human Factors Workshop now sponsored by the Highway Research Board. Dr. Uhlaner was the 1969–70 president of the Division of Military Psychology of the American Psychological Association. He is a fellow of the APA and five of its divisions, of the Human Factors Society, of the Iowa and the Washington academies of science and a member of the Operations Research Society of America,

* The opinions expressed in this chapter are those of the authors and do not necessarily represent the viewpoint of the Behavior and Systems Research Laboratory or of the Army.