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Static and Dynamic Visual Fields in Vehicular Guidance

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•TO UNDERSTAND driving, the visual input must be analyzed. Until the effective stimuli are known, driving cannot be thoroughly understood; when these inputs are identified, driving itself will be described to a considerable extent. It is appropriate that the investigation of visual inputs begin with the study of the positional, velocity and acceleration fields around the moving vehicle. These fields are general and persistent aspects of the visual environment. The velocity and acceleration fields, which present time-varying aspects of the environment, are of particular interest, since they provide information not available in static viewing.

The numerous "cues" available in spatial perception have been discussed previously (4, 20, 22) and the terrain characteristics which may orient the human in his spatial environment have also been described (10). These studies indicate methods which might be employed in vehicular guidance, but we are interested in identifying those which the driver actually uses. Other studies have concerned themselves with human errors in space perception, such as the systematic overestimation of size in distant vision (15) and the hyperbolic metric shown in the judgment of space in certain reduction situations (1). In the present context, the characteristic of the driver's judgment of space of concern is its accuracy rather than incompatibility with physical space.

Two main problems are considered in this paper. The first is concerned with the mathematical description of the moving ground plane from the driver's point of view. The environment seen by the driver involves a perspective transformation of ground position, velocity, and acceleration. The formulas governing these transformations are developed, and the fields themselves are plotted. The positional field, which includes the angular coordinates from eye position of points in the driver's environment, is related to linear perspective. The velocity field includes the vectors of angular motion around the driver's eye as he moves along the road. The acceleration field presents vectors of angular acceleration rather than velocity.

The second problem discussed is the use made by the driver of the positional, velocity, and acceleration fields. To affect driving, these characteristics have to be registered and the driver's sensitivity to them influences their utility. This analysis covers the condition of steady-state driving, where the vehicle moves rectilinearly or curvilinearly with constant velocity. Departures from steady-state driving, in turning, braking, avoidance, and other maneuvers, will be considered in a subsequent paper.

DERIVATION OF EQUATIONS OF POSITION AND MOTION

The coordinate system used is shown in Figure 1. The driver's eye is at the origin and the road is considered to be on an infinite plane at some distance, z, below his eye. Distance ahead of the eye is represented by x and to the side by y. Distance from the eye to any point of the field is represented by ρ, whose projection on the xy plane is r.

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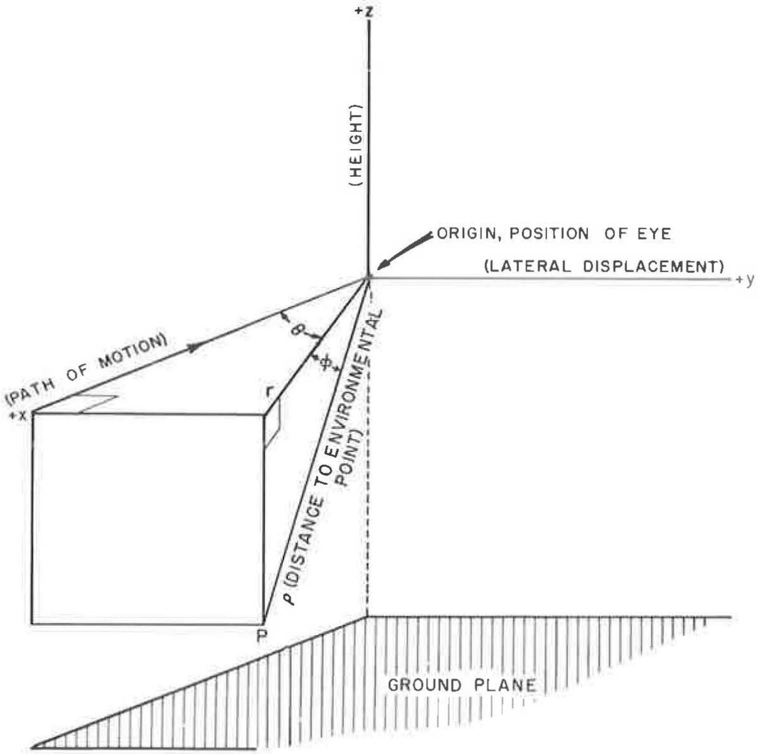

Figure 1. Basic coordinate relationships.

Angular Position

$$\theta = \arctan \frac{y}{x} \tag{1}$$

$$\phi = \arcsin \frac{z}{\rho} \tag{2}$$

$$r = \left(x^2 + y^2\right)^{1/2} \tag{3}$$

$$\rho = \left(x^2 + y^2 + z^2\right)^{1/2} \tag{4}$$

Angular Velocity

$$\frac{d\theta}{dt} = \frac{d}{dt}\left(\arctan \frac{y}{x}\right) = \frac{\partial}{\partial x} \arctan \frac{y}{x} + \frac{\partial}{\partial y} \arctan \frac{y}{x} = -\frac{y}{r^2}\frac{dx}{dt} + \frac{x}{r^2}\frac{dy}{dt} =$$

$$-\frac{y}{r^2}\frac{dx}{dt} + \frac{x}{r^2}\frac{dy}{dt} = \frac{1}{r^2}\left(-y\frac{dx}{dt} + x\frac{dy}{dt}\right) \text{ (rad/sec)} \tag{5}$$

$$\frac{d\phi}{dt} = \frac{d}{dt}\left(\arcsin\frac{z}{\rho}\right) = \frac{\partial}{\partial x}\arcsin\frac{z}{\rho}\frac{dx}{dt} + \frac{\partial}{\partial y}\arcsin\frac{z}{\rho}\frac{dy}{dt} + \frac{\partial}{\partial z}\arcsin\frac{z}{\rho}\frac{dz}{dt} = \frac{1}{r\rho^2}\left(-zx\frac{dx}{dt} - zy\frac{dy}{dt} + r^2\frac{dz}{dt}\right) \text{ (rad/sec)} \qquad (6)$$

The analysis of ground motion into separate azimuth ($d\theta/dt$) and declination ($d\theta/dt$) components seemed more appropriate than the development of a formula for the total angular velocity (14, 21). In some situations, the driver reacts differently to $d\theta/dt$ and $d\phi/dt$ components of motion (28).

Angular Acceleration

$$\begin{aligned}
\frac{d^2\theta}{dt^2} &= \frac{d}{dt}\left(-\frac{y}{r^2}\frac{dx}{dt} + \frac{x}{r^2}\frac{dy}{dt}\right) = \left[\frac{\partial}{\partial x}\left(-\frac{y}{r^2}\right)\left(\frac{dx}{dt}\right) + \frac{\partial}{\partial y}\left(-\frac{y}{r^2}\right)\left(\frac{dy}{dt}\right)\right] \\
&\quad \frac{dx}{dt} - \frac{y}{r^2}\frac{d^2x}{dt^2} + \left[\frac{\partial}{\partial x}\frac{x}{r^2}\left(\frac{dx}{dt}\right) + \frac{\partial}{\partial y}\frac{x}{r^2}\left(\frac{dy}{dt}\right)\right]\frac{dy}{dt} + \frac{x}{r^2}\frac{d^2y}{dt^2} \\
&= \frac{2xy}{r^4}\left(\frac{dx}{dt}\right)^2 + \frac{y^2-x^2}{r^4}\left(\frac{dx}{dt}\frac{dy}{dt}\right) - \frac{y}{r^2}\frac{d^2x}{dt^2} + \frac{y^2-x^2}{r^4}\left(\frac{dx}{dt}\frac{dy}{dt}\right) \\
&\quad - \frac{2xy}{r^4}\left(\frac{dy}{dt}\right)^2 + \frac{x}{r^2}\frac{d^2y}{dt^2} = \frac{2xy}{r^4}\left[\left(\frac{dx}{dt}\right)^2 - \left(\frac{dy}{dt}\right)^2\right] - \\
&\quad \frac{1}{r^2}\left(y\frac{d^2x}{dt^2} - x\frac{d^2y}{dt^2}\right) + 2\left[\frac{y^2-x^2}{r^4}\left(\frac{dx}{dt}\frac{dy}{dt}\right)\right] \text{ (rad/sec/sec)} \qquad (7)
\end{aligned}$$

$$\begin{aligned}
\frac{d^2\phi}{dt^2} &= \frac{d}{dt}\left(-\frac{zx}{r\rho^2}\frac{dx}{dt} - \frac{zy}{r\rho^2}\frac{dy}{dt} + \frac{r}{\rho^2}\frac{dz}{dt}\right) = \left[\frac{\partial}{\partial x}\left(-\frac{zx}{r\rho^2}\right)\left(\frac{dx}{dt}\right) + \right. \\
&\quad \frac{\partial}{\partial y}\left(-\frac{zx}{r\rho^2}\right)\left(\frac{dy}{dt}\right) + \left.\frac{\partial}{\partial z}\left(-\frac{zx}{r\rho^2}\right)\left(\frac{dz}{dt}\right)\right]\frac{dx}{dt} - \frac{zx}{r\rho^2}\frac{d^2x}{dt^2} + \\
&\quad \left[\frac{\partial}{\partial x}\left(\frac{zy}{r\rho^2}\right)\left(\frac{dx}{dt}\right) + \frac{\partial}{\partial y}\left(-\frac{zy}{r\rho^2}\right)\left(\frac{dy}{dt}\right) + \frac{\partial}{\partial z}\left(-\frac{zy}{r\rho^2}\right)\right. \\
&\quad \left.\left(\frac{dz}{dt}\right)\right]\frac{dy}{dt} - \frac{zy}{r\rho^2}\frac{d^2y}{dt^2} + \left[\frac{\partial}{\partial x}\frac{r}{\rho^2}\left(\frac{dx}{dt}\right) + \frac{\partial}{\partial y}\frac{r}{\rho^2}\left(\frac{dy}{dt}\right) + \right. \\
&\quad \left.\frac{\partial}{\partial z}\frac{r}{\rho^2}\left(\frac{dz}{dt}\right)\right]\frac{dz}{dt} + \frac{r}{\rho^2}\frac{d^2z}{dt^2} = \frac{-z}{\rho^4 r^3}\left[\left(\rho^2y^2 - 2r^2x^2\right)\right. \\
&\quad \left.\left(\frac{dx}{dt}\right)^2 + \left(\rho^2x^2 - 2r^2y^2\right)\left(\frac{dy}{dt}\right)^2\right] - \frac{2rz}{\rho^4}\left(\frac{dz}{dt}\right)^2 + \\
&\quad \left(\frac{z^2-r^2}{\rho^4 r}\right)\left(2x\frac{dx}{dt}\frac{dz}{dt} + 2y\frac{dy}{dt}\frac{dz}{dt}\right) + \\
&\quad \frac{2xyz}{\rho^4 r^3}\left(2r^2 + \rho^2\right)\frac{dx}{dt}\frac{dy}{dt} - \\
&\quad \frac{zx}{r\rho^2}\frac{d^2x}{dt^2} - \frac{zy}{r\rho^2}\frac{d^2y}{dt^2} + \frac{r}{\rho^2}\frac{d^2z}{dt^2} \text{ (rad/sec/sec)} \qquad (8)
\end{aligned}$$

Rectilinear Motion

In rectilinear motion, where the eye moves with constant velocity in a straight line, the environment translates in x at a rate of $-\,dx/dt$ (negative of the speed of forward motion). The terms dy/dt and dz/dt equal zero. The equations in spherical coordinates are again Eqs. 1 and 2, as well as:

$$\frac{d\theta}{dt} = -\frac{y}{r^2}\,\frac{dx}{dt} \text{ (rad/sec)} \tag{9}$$

$$\frac{d\phi}{dt} = -\frac{zx}{\rho^2 r}\,\frac{dx}{dt} \text{ (rad/sec)} \tag{10}$$

$$\frac{d^2\theta}{dt^2} = \frac{2xy}{r^4}\left(\frac{dx}{dt}\right)^2 \text{ (rad/sec/sec)} \tag{11}$$

$$\frac{d^2\phi}{dt^2} = -z\left[\frac{\rho^2 y^2 - 2r^2x^2}{\rho^4 r^3}\right]\left(\frac{dx}{dt}\right)^2 \text{ (rad/sec/sec)} \tag{12}$$

These equations are applied in Figures 2, 4, 6 and 9. Modifications of Eqs. 5 and 6 are applied in the illustrations of horizontally curved motion shown in Figures 5 and 7. The equations apply to the induced motion of a flat ground plane, to objects above the ground, other cars, and all other environmental points viewed from a moving vehicle.

POSITIONAL FIELD AND VEHICULAR GUIDANCE

The angular coordinates θ and ϕ of the ground plane from 0 to 50 ft to the left and from 0 to 100 ft in front of the driver are given in Figure 2. The coordinate system

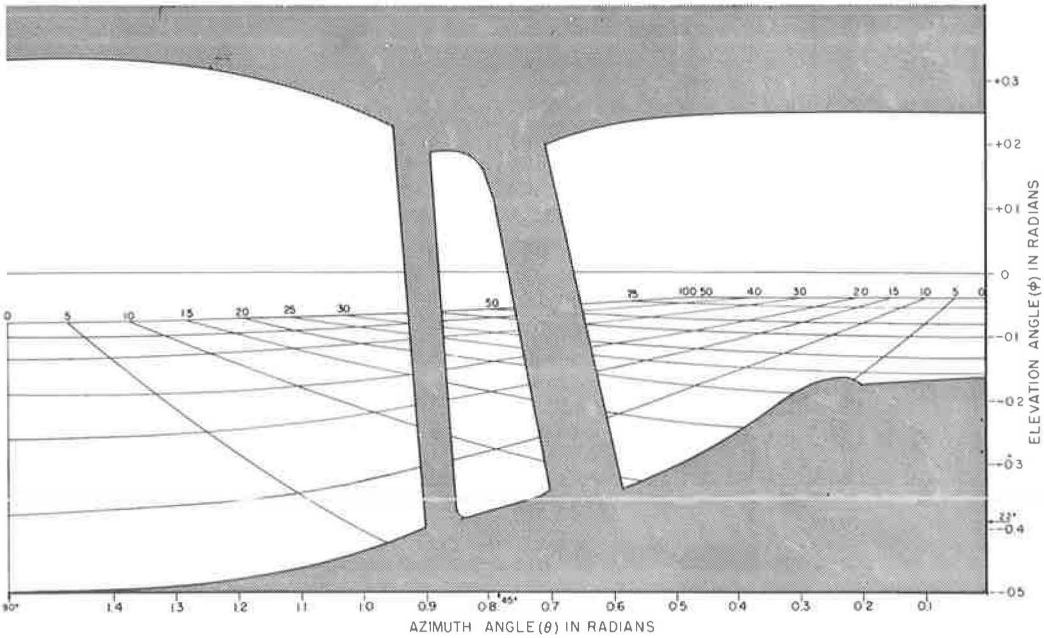

Figure 2. Perspective through windshield and side window.

has been described in Figure 1. Since the driver sits on the left of the vehicle, the window areas and road views are asymmetrical. The left view is described in Figure 2. The flow lines also apply to the right side of the vehicle, if the appropriate window area is superimposed, and to the rear areas if the grid is reflected about the $x = 0$ line. The driver's eye is placed at a representative height of 4 ft above the ground. The empty area at the right of the figure is the automobile cab and hood which partially cut off the view of the road. The blind areas at 0.65 and 0.9 rad are the roof support and window edging.

The equirectangular projection shown in Figure 2 is one of many possible ways of representing a three-dimensional environment on a flat page surface. The figure is distorted because at the zenith and nadir of actual space, 360° of azimuth are reduced to a point; in the figure they would occupy the same extent as on the horizontal meridian. A rectification in the θ dimension may be achieved by curving the page through 90° and viewing from a point close to the center of curvature. The ϕ dimension is not rectified, but in practice need not be, since it covers a limited ½-rad range.

Linear Perspective and Interpretive Scale

Linear perspective, the diminution of angular size with distance, is related to the positional field. The angular scale of the positional field may be expressed in terms such as, $\Delta\theta/\Delta x$, in this case indicating the change in θ angle associated with a small change in x. If Δl is a small change in x, y, and z (i.e., $\sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2}$) and $\Delta\alpha$ is the change in angle associated with Δl, then angular scale is $\Delta\alpha/\Delta l$ in radians per foot or equivalent units. It is seen that angular scale expresses the angular effects underlying perspective and establishes a relationship between linear perspective and the positional field.

Interpretive scale may be defined as the inverse of the angular scaling effects underlying perspective. If angular scale is $\Delta\alpha/\Delta l$, then the corresponding expression of interpretive scale is $\Delta l/\Delta\alpha$ in feet per radian or equivalent units. As applied to a common road map, interpretive scale would represent the miles per inch required to interpret map lengths rather than the inches per mile used to draft the map.

The perception of interpretive scale enables the driver to calibrate visual angle, in terms of length, on the road. Scaling may be explicitly in terms of feet and inches, but more commonly it involves distance implicitly, as exemplifed by the driver's estimation of the space to a road point. The driver's conception of scale may be designated by primes ($\Delta l'/\Delta\alpha'$) to connote that a subjective estimate is implied.

Since scaling involves the inverse of the angular effects underlying linear perspective, it would be expected to play some part in general space perception. It appears as a key factor when the observer takes the attitude of making quantitative judgments of size, distance or motion.

In size perception, the observer estimates scale and then evaluates the visual extent of interest, in this metric. Gibson describes the process as follows:

> ...with fixed monocular stimulation the size of an object is given by the size of the elements of texture or structure in the adjacent optical array....Size is perceived relative to the size scale of the place where the object is seen. (11)

Scaling also applies to distance judgments. Gogel finds that judgments of the relative distance of objects can be explained in terms of the ratio of familiar size to retinal size (17). This ratio is equivalent to what we have called interpretive scale. Gogel states that it underlies the judged distance between objects of similar shape but different size (4, 8, 16), of different shapes (23, 29), and familiar objects of different size and shape (17, 23). If the scale of one object appears smaller than that of another, it will be judged as closer; if it is seen as equal, it will be judged equidistant; and if interpretive scale is seen as larger, it will be judged as farther away. In these experiments, where background cues are minimized, judgments of relative distance are based on relative scale.

Often distance judgments are made between widely separated objects. If distance is large, scale changes along the path and the judgment would be expected to take the following form:

$$\text{Judged distance} = \sum_{1' = 1}^{1_1 = n} \left(\text{scale of } \Delta_{1'}\right) \Delta_{1'} \tag{13}$$

where the Δ_1''s are convenient seen lengths between the objects. It may be predicted that the observer would sum lengths in situations where the scale changes. A similar approach holds for judging distances from the eye, except that scale is learned through experience and does not have to be repeatedly resolved.

It seems reasonable to believe that interpretive scale, once resolved, would be generally applied to size, distance and motion judgments in a situation. Thus, the scale of a familiar-sized object may be applied to distance and speed judgments in the same setting. Speed judgments may depend on interpretive scale; the angular movement of objects seen by a stationary eye is converted to speed by the same rule that governs angle and length. Eqs. 5 and 6 may be expressed in terms of differentials instead of time derivatives; for example, Eq. 9 may be expressed as:

$$\Delta\theta = -\frac{y}{r^2}\,\Delta x \tag{14}$$

It is seen that Δx is converted into $\Delta\theta$ by the same function of y and r^2 as converts dx/dt into $d\theta/dt$. The same approach holds for $\Delta\phi$. Since angular stimulus is the vectorial sum of $\Delta\theta$ and $\Delta\phi$ components, and angular movement stimulus is the sum of $d\theta/dt$ and $d\phi/dt$ components of motion, the communability of angle and angular velocity effects is demonstrated, as is the similarity of interpretive scales required for the correct perception of length and speed.

The relationship between length and distance judgments is discussed in the literature under the "size-distance invariance hypothesis" (2, 9, 30). The hypothesis states: "A visual angle of given size determines a unique ratio of apparent size to apparent distance" (25). Since the hypothesis describes a perceptual relationship, it must be shown valid on the basis of perceptual rather than geometrical evidence. Thus, if size and distance judgments are shown to be based on the same interpretive scale, a rational basis would be provided for an invariance hypothesis. In some circumstances, the scaling underlying size and distance judgments differs. The scale in a film protection may be established by familiar objects included in the scene which would not directly indicate the scale of eye distance. The same principle is true in size judgments of geological specimens. A hammer included in a page illustration may give the size scale, but distance from the eye would not be thereby revealed. The moon illusion is a puzzling example where seen size and distance are paradoxically unrelated (24). The relation of linear and velocity scales has received less research attention. Experiments by J. F. Brown may be interpreted as indicating that linear scale is actually applied in speed judgments (3).

It is tempting to think that slant and shape perception could also be subsumed under the attainment of interpretive scale. Slant could be dealt with as the seen ratio of front-parallel scale to surface scale perpendicular to this line. If the ratio of these scales is $\frac{1}{2}$, the surface lies 60° to the line of sight; i.e., cosine 60° = $\frac{1}{2}$. This explanation of slant perception is objectionable because it seems more complex than the judgment explained. We tend to believe that slant and the perception of shape are basic perceptions which precede, rather than follow, scaling judgments. However, if the observer in a shape constancy experiment makes estimates of the dimensions of simple rectangles or ellipses projected at a slant to the eye, the responses may be considered to involve relative scaling.

The question remains of how scale is obtained. In theory, a decoding could be simply achieved because every x, y point on the ground plane has a unique θ, ϕ representation. A mechanical robot could steer down a level road and avoid obstacles if it could sense θ and ϕ and if obstacles and the road were correctly coded for it. This two-dimensional approach has an appealing simplicity, but introspection compellingly reveals the three-dimensional nature of the visual world.

Scale is most obviously revealed by familiar-sized objects, particularly those with parallel sides. The quantity $\Delta l'$ is then the known length of the familiar object; $\Delta \alpha'$ is its seen angular extent. An example is provided by the space perceptions of a motorist. An obvious key to the terrain configuration is the shape of the road ahead. The roadway is of almost constant width, converges rapidly in perspective, and gives a ready scale for converting visual angle to linear extent which may be applied to other objects (Fig. 3). If the borders of the road are straight, the road itself has no vertical curvature. If the borders are concave, the road surface is concave. If the borders are convex, the road is also. On an uphill, the road may rise above eye height; downhill it will be below eye level and may, in fact, be overlapped and hidden. Light and shadow, texture, ocular adjustments, intersections of surfaces, and overlapping of contours may enhance these perceptions. The roadway is a particularly convenient rule since it is always available, has known characteristics, and provides continual feedback to the driver on the accuracy of his perceptions. However, other familiar objects—vehicles, pedestrians, houses, fence posts, sidewalks and crosswalks--are usually in the field of view and may also serve to calibrate visual angle.

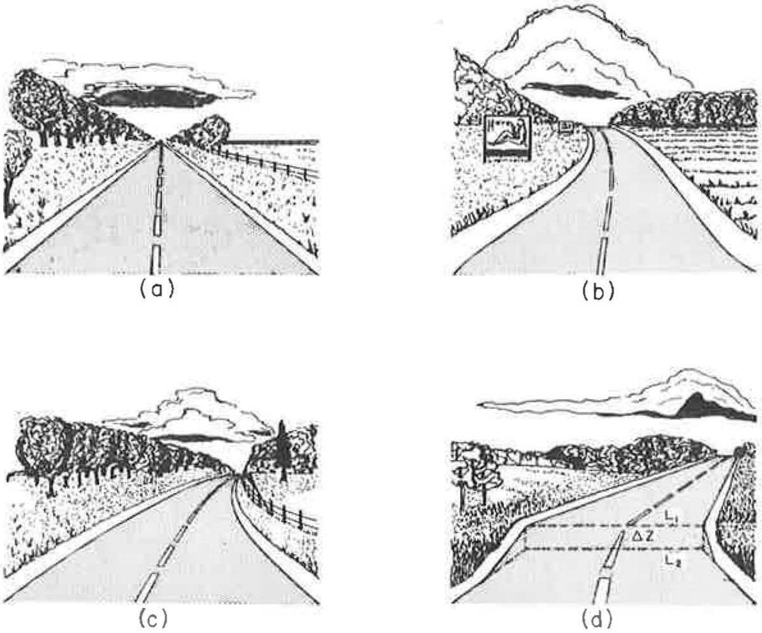

Figure 3. Road configurations: (a) width of road gives the linear scale; (b) and (c) convergence pattern reveals vertical curvature; and (d) pattern of road boundaries shows the vertical rise, ΔZ.

ANGULAR VELOCITY FIELD AND VEHICULAR GUIDANCE

Velocity vectors along the flat ground plane are plotted in Figure 4. The ground area covered is superimposed on Figure 2; the magnitude and direction of the ground flow is shown by the length and direction of the vectors in the figure. The angular velocity field of Figure 4 appears to fit almost exactly over the positional field of Figure 2. The resemblance is due to the approximate equivalence of $d\theta/dx$ and $d\phi/dx$ vectors to $\Delta\theta/\Delta x$ and $\Delta\phi/\Delta x$ angular extents. As the eye moves in x, velocity vectors give the effect of equally sized rods parallel to the x axis. On the ground plane, these vectors fall on perspective lines.

Figure 4 indicates that $d\theta/dx$ is zero along the median plane, approaches zero at $\theta = \pi/2$, and both $d\theta/dx$ and $d\phi/dx$ are zero at the vanishing point at eye level directly ahead. Objects off this path change their $d\phi/dx$ velocity component to predominating $d\theta/dx$ as they are approached.

Applications of Velocity Field

Perception of Motion.—The psychological basis of motion perception is discussed in the literature (20, 22). At slow rates, motion is inferred from a change in position, as in the minute hand of a watch. At more rapid rates, motion is directly perceived, as in the motion of the second hand of a watch, which is actually seen. At still more rapid rates, motion appears as a blur. Similar judgments and perceptions enable the driver to register impressions of motion (not arrows) related to the velocity field around him.

Velocity Field as Basic Reference for Object Motion.—Just as the positional field gives the scale of object size, the velocity field might be expected to provide the background for the seen movement of objects. A difficulty in applying this relationship is that the driver may see the ground as a still reference or, alternately, he may conceive of his vehicle as still and other cars as moving relative to it. For example, the driver reacts promptly when a vehicle approaching his moving car has no apparent sidewise velocity vector. This is visual warning of an impending collision. (This relationship is used by Michaels and Cozan to explain vehicular avoidance reactions (28). The lateral displacement of a moving vehicle to a road obstacle was found to be inversely related to the seen angular velocity of the object.) An analogous situation exists where

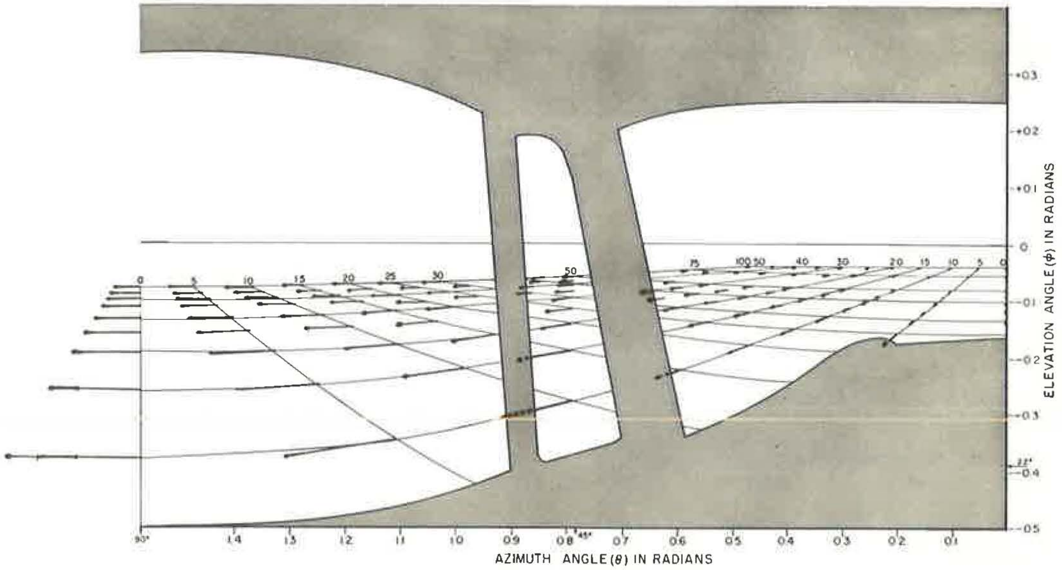

Figure 4. Velocity vectors on basic ground plane.

the resultant vector is directed towards the median plane. The intruding vehicle will cross one's path, and if its course is changed it may collide. The driver takes his own vehicle as reference when he reacts to these situations.

The velocity field also serves as background for the driver's sensitivity to seen motion. As an example, the relatively small angular motions ahead of the vehicle favor the perception of object motion, particularly in the θ dimension. In contrast, the large velocities at $\theta = \pi/2$ inhibit the perception of object motion. If the vehicle is moving very rapidly, the resolution of independent motion is further impaired by blurring of the image. Angular velocities of several hundred degrees per second are generated at the side of a rapidly moving vehicle, and the driver's vision will be severely reduced even if he follows object movement with his head and eyes (5, 26, 27).

Perception of Speed and Direction of Vehicular Motion.--The velocity field indicates the speed and direction of the vehicle's forward motion. Although observed motion is the most direct indicator of vehicular motion, it is only one of its accompaniments. Vehicular speed is also indicated by direct speedometer readings, the pull of the steering wheel, the gear in use, the response to the accelerator, the pitch of the engine and tire squeal, the roughness of the ride, and centrifugal force when a curve is rounded. Apparently the visual appearance of motion cannot be claimed to be the sole, or even the most useful, input for the estimation of speed.

The direction of vehicular motion is indicated by the flow characteristics of the velocity field. There is no $d\theta/dt$ component in the median plane ahead of the driver. This lack of motion may be used by the driver, along with information of posture and the position of objects in the windshield to indicate the direction of the vehicle's motion.

The importance of expansion patterns as an indication of the vehicle's direction of movement has been pointed out by James Gibson (10):

> When an observer approaches a surface instead of moving parallel to it, a modification of its deformation is•introduced in that the focus of expansion is no longer on the horizon of that surface but at a particular spot on it—the point of collision with the surface. The rule is that all deformation in a forward visual field radiates from this point. Crudely speaking, the environmental scene expands as we move into it, and the focus of expansion provides us with a point of aim for our locomotion. An object in our line of travel, regarded as a patch of color, enlarges as we approach. It is not difficult to understand, therefore, why this expansion should be a stimulus for sensed locomotion as well as a stimulus for sensing the lay of the land. The behavior involved in steering an automobile, for instance, has usually been misunderstood. It is less a matter of aligning the car with the road than it is a matter of keeping the focus of expansion in the direction one must go.

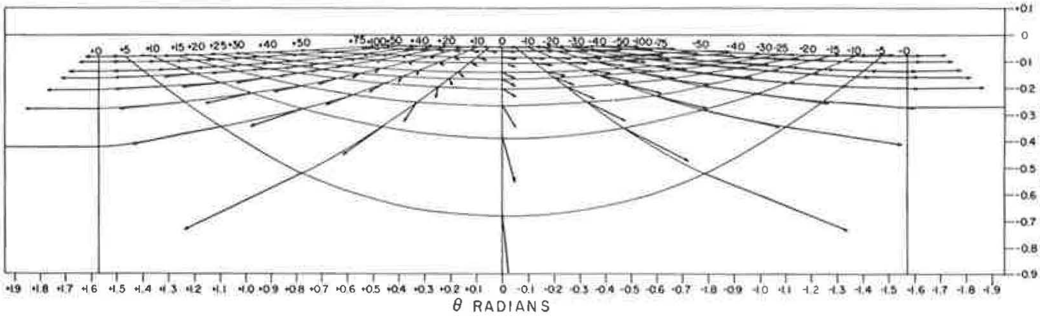

Figure 5. Vector velocity field of horizontal curved motion—Radius of curvature is 100 ft to left of eye (origin). The field is asymmetrical and has null point at center of curvature. It approaches I/R · dx/dt at infinite distance.

Although the direction of vehicular motion is related to the focus of expansion, the focus itself is not the effective cue. The focus of expansion of a flat horizontal plane lies at the vanishing point in the sky, or it will occupy points on trees or buildings if the road is curved. It is generally difficult, if not impossible, for the driver to locate the focus of expansion (Figs. 4 and 5), and contrary to Gibson, the borders and lane markings are used in vehicular guidance. (These results are derived from studies conducted at the U. S. Bureau of Public Roads.) When the vehicle is off course, these lines are at an angle with the y axis and will have a lateral component of movement as the field translates towards the eye.

Motion Parallax, Parallax Curl.—As the eye moves, objects pass on either side; distant things seem to move more slowly than those close by. The relative speed of angular motion (motion parallax) might be expected to provide an indication of distance. Discussions of human depth perception in the psychological literature mention motion parallax as a classical cue to distance, along with perspective, interposition, aerial perspective and shadows (10, 20, 22).

The first thorough discussion of motion parallax as an indicator of distance is given by H. von Helmholtz (22):

> In walking along, the objects that are at rest by the wayside stay behind us; that is, they appear to glide past us in our field of view in the opposite direction to that in which we are advancing. More distant objects do the same way, only more slowly, while very remote bodies like the stars maintain their permanent positions in the field of view, provided the direction of the head and body keep in the same directions. Evidently, under these circumstances, the apparent angular velocities of objects in the field of view will be inversely proportional to their real distances away; and consequently, safe conclusions can be drawn as to the real distance of the body from its apparent angular velocity.

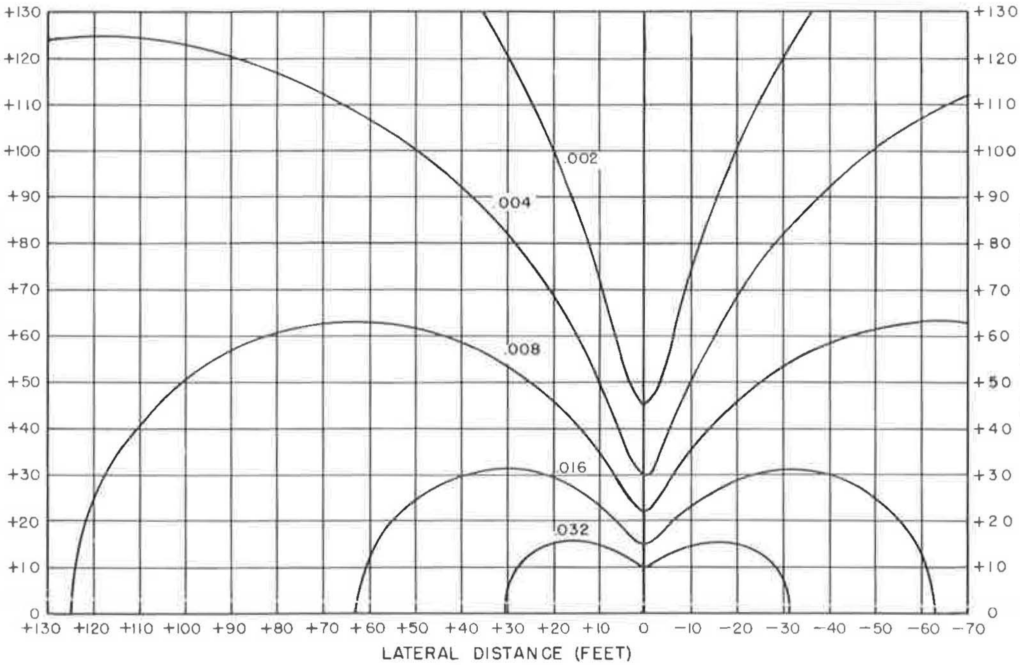

Figure 6. Isoangular-velocity curves under linear motion—Angular velocity in radians per second of each contour can be obtained by multiplying value shown by vehicular speed in feet per second. If speed is increased, angular velocity is increased but pattern remains same.

The position that "... safe conclusions can be drawn as to the real distance of the body from its angular velocity" is subject to modification. When the observer follows a curved path, angular motion of ground points becomes an unreliable indicator of distance. The basic geometry of the situation is altered so that motion of the ground (or other points) does not decrease regularly along a sight line. This fact may be seen from the velocity field of curvilinear motion (Fig. 5) and by a comparison of isoangular-velocity curves of linear and curvilinear observer motions (Figs. 6 and 7).

The vector field of horizontally curved observer motion (Fig. 5) shows a number of features which complicate a motion parallax interpretation. As distance from the eye increases along an azimuth line, the direction and magnitude of ground motion change. Motion on the 0.3-rad azimuth line is to the right at far distances and to the left at close points. The interpretation of distance from these motions alone would be very difficult.

The same conclusion is brought out by the isoangular-velocity plots. These curves show the locus of terrain points of equal angular velocity, regardless of direction of motion. It may be seen that linear isoangular-velocity curves decrease fairly systematically with the reciprocal of distance on each azimuth. The curvilinear isoangular-velocity pattern does not follow the same rule. The functions are asymmetrical and approach a limiting value of 1/R dx/dt, where R is the radius of curvature. Angular movement in Figure 7 is seen to reverse itself on the sight line through the center of rotation at x = 0 and y = 100 ft. An interpretation in line with the motion parallax approach would place the stationary center of rotation at an infinite distance from the eye. Positions beyond the center of rotation on the same azimuth line increase in angular velocity and would be interpreted as decreasing in distance. Evidently, distance is not related to ground motion in the motion parallax manner when the eye is following a curved path.

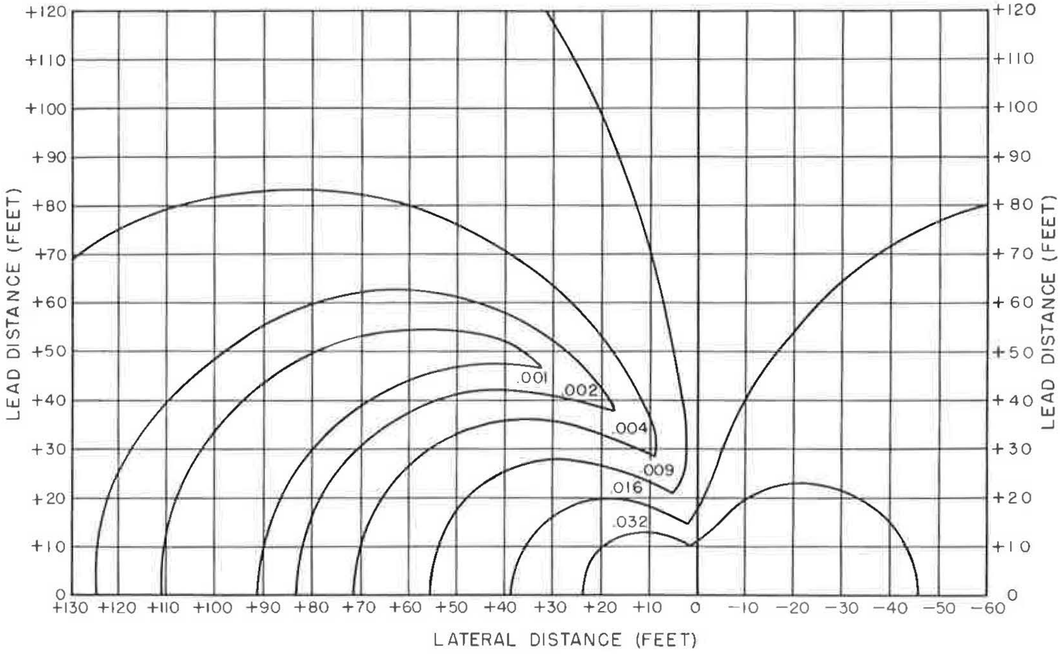

Figure 7. Isoangular-velocity curves under curvilinear motion—Center of curvature is 100 ft to left of origin. Angular velocity in radians per second of each contour can be obtained by multiplying value shown by vehicular speed in feet per second. If speed is increased, angular velocity is increased but pattern remains same.

On a straight trajectory, distances at right angles to the line of movement where angular velocity is high are not noticeably easier to estimate than those ahead where angular velocity is minimal. On the contrary, illusory movements of the terrain, which depend on the observer's visual fixation position, are seen to the side. If the foreground is viewed from an automobile, the background seems to move and rotate forward around it. If the background is fixated, the foreground turns. This illusion of rotation, which may be called motion parallax curl, is based on differences in angular velocity between the foreground and background (Fig. 8). The point of reference of seen movement is ambiguous and is not necessarily the position of the moving eye itself (as a motion parallax formulation would require).

If the velocity field is considered a positional field in motion, the relation of this field to the perception of distance is clarified. Distance enters into the perception of the velocity field, rather than being revealed by it. This approach is supported by the experimental studies of motion parallax, which show that the context of motion must be revealed to an observer if he is to make an accurate estimate of distance. Differential motion simulating the ground projection of the velocity field is not sufficient to permit an accurate judgment of depth to be made (12, 13).

ACCELERATION FIELD

The projection of the acceleration field on the ground plane is shown in Figure 9. The vectors on the field represent the differences in successive velocity vectors, divided by time, as time approaches zero. The cab area of Figure 9 is the same as in Figures 2 and 4, but the vector scale is 10 times as large. As may be seen in Figure

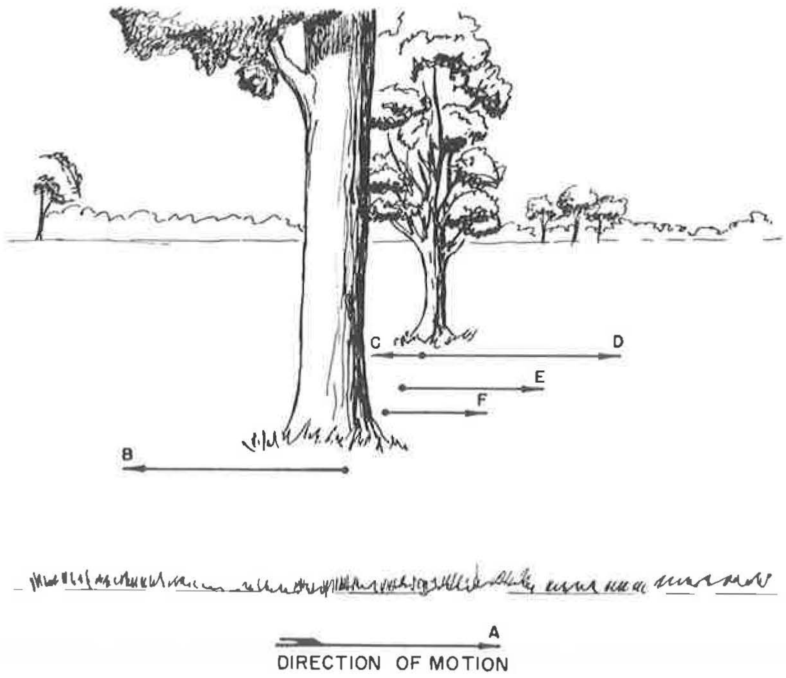

Figure 8. Motion parallax curl—Illusion is shown at right angles to vehicle's line of movement. Vehicle is moving in direction A, inducing vectors B in foreground tree and C in background tree. If foreground tree is fixated, the background moves to right with velocity D (difference between B and C). Ground positions between the trees have linearly decreasing velocity vectors which produce appearance of rotation.

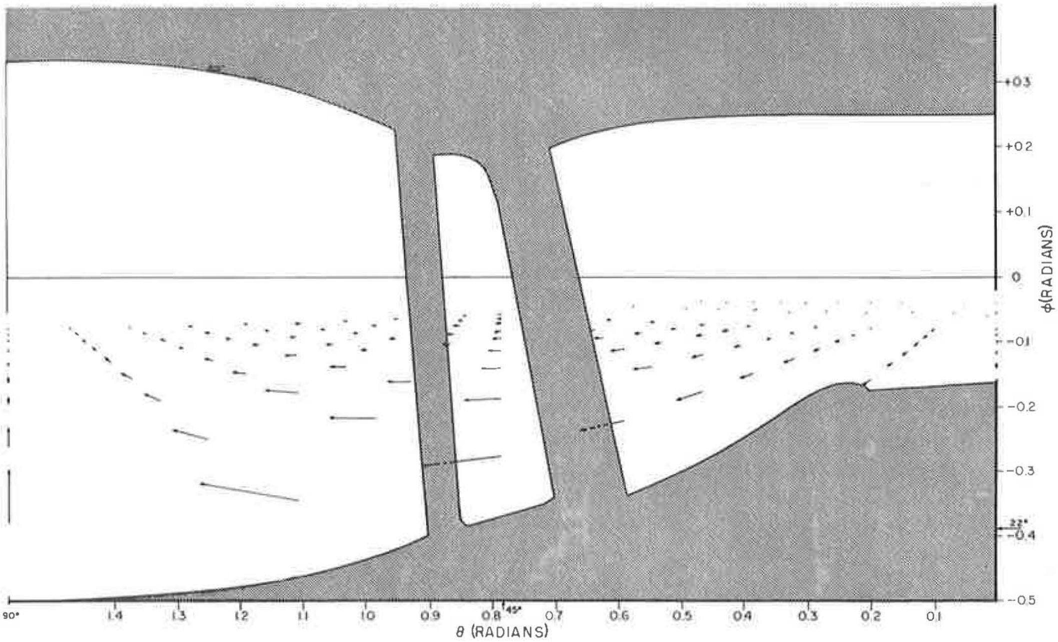

Figure 9. Acceleration vectors on basic ground plane.

9, there is no azimuthal component ahead of the eye under rectilinear motion, and $d^2\phi/dx^2$ is directed towards the eye in those positions. Vectors are directed away from the eye at $\theta = \pi/2$ where $d\theta/dx$ goes through a maximum. At angles between $\theta = 0$ and $\theta = \pi/2$, the vectors shift from an approaching to a receding direction and are generally largest close to the eye.

Perceptual Problems of Acceleration Field

The major perceptual problem of the acceleration input is whether or not it is directly sensed. The human can distinguish accelerations, but it is not certain that they are detected as such. They may possibly be inferred from successive impressions of changing rates. Gottsdanker et al. showed that group performance is more clearly ordered in terms of a threshold based on total change in velocity than in terms of direct sensory impression of acceleration (18, 19).

The vector field shown in Figure 9 furnishes evidence on the sensing of acceleration. The field appears unnatural and no characteristic of experience can be associated with the pattern of vectors shown. This case differs from the psychophysical correspondence between light wavelength and hue, physical energy and brightness, etc. Since the observer does not directly or precisely register accelerations, the acceleration field and the gradients within it cannot be considered as a primary visual input. The same conclusion probably holds, by extension, to higher velocity derivatives. This does not suggest that accelerations may not be perceived as changes in velocity.

Acceleration varies as the square of speed, as may be seen from Eqs. 11 and 12. If speed of the moving eye is doubled, angular acceleration is quadrupled. The same condition holds for the eye on a curved trajectory. This relationship leads to the paradoxical situation that the angular acceleration stimulus is more sensitive to speed than is angular velocity. It would be expected that the appearance of the environment would change markedly as linear speed is increased, and that there would be acceleratory indications of velocity. The visual appearance of increased velocity on a roadway may be a sharp swoop of objects and road features as they change from a ϕ to a θ direction. A jitter due to acceleratory movements may also be seen in the imperfections of lane markers and road edges. However, these acceleratory effects have not been systematically verified.

SUMMARY

Perceptual problems in vehicular guidance are considered here in the context of the positional, velocity and acceleration fields around the moving vehicle. These are very general and persistent aspects of the driver's visual environment. The approach is to examine the equations governing these fields, and the fields themselves, for features and regularities which might serve to explain human spatial perception.

The following findings emerge from the analysis:

1. The interpretive scaling of visual angle, which is the inverse of perspective effects in the positional field, is shown to be a key factor in size, distance and motion perception.
2. Simple and obvious features of the visual environment, often ignored in explanations of space perception, are believed to provide the most important aids for vehicular guidance. The roadway ahead of the vehicle, for example, may be used to obtain the scale of the terrain and objects in it.
3. The velocity field furnishes a reference for the seen movement of objects. However, the driver may see the field, his own vehicle, or part of the field as reference. If the foreground is taken as reference, a curious illusion of motion is seen. The background seems to rotate forward and around the foreground. This velocity parallax curl is based on the difference in velocity vectors in the foreground and background.
4. Some difficulties are pointed out in the motion parallax indication of distance.
5. Roadway boundaries and lane markings are used in aligning the moving vehicle with the road. This conclusion challenges the widely quoted view that the focus of expansion is the cue for the direction of sensed locomotion.
6. The formulas derived indicate that angular acceleration increases as the square of vehicular speed. The consequences of this interesting relationship for the perception of vehicular speed are indicated.
7. Since the pattern of the angular acceleration field does not resemble any familiar pattern of visual experience, evidence is provided that angular acceleration is not directly sensed. By extension, it is doubtful that higher derivatives of motion are seen as such.

The analysis pursued in this paper is concerned with basic aspects of the perception of static and moving visual fields. The great need in future work is to show how the driver responds to these fields in obtaining a correct perception.

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Passing Practices of a Sample of Michigan Drivers

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•ONE OF THE most vexing problems to both the driver and the traffic engineer is the passing maneuver on 2-lane highways. Despite the development of the Interstate Highway System and of complex urban transportation networks, 2-lane highways still provide the largest road mileage and almost all drivers pass other cars at some time on a 2-lane road.

The passing vehicle must travel in the traffic lane normally reserved for opposing traffic, and this is cause for uneasiness and sometimes accidents. Steps have been taken to reduce this type of accident and to relieve the anxiety of the driver by warning him when it is dangerous to make a passing maneuver, but these are aids, not guarantees.

Some time ago we began, as part of graduate study, an informal study of passing practices and no-passing zone marking policies. In the course of this research we found that considerable confusion exists about the intent and the interpretation of no-passing zone markings. Therefore, we decided to find out from the drivers themselves how they understood and acted at no-passing zones on the highways.

The study was initiated as a research program towards a Master's degree (1), without financial support of any kind; therefore, the work must be viewed as a pilot study rather than a rigorous analysis of behavioral patterns. The results are more suggestive than conclusive, even though serious staff effort was utilized in the preparation of the study and in the evaluation of the data.

THE PASSING MANEUVER

A driver preparing to pass another car must estimate the time and distance he will be in the left-hand lane until he has overtaken the other car and can return to his own lane (2). He must ascertain that no vehicle traveling in the opposite direction will interfere with his maneuver. Thus, the driver must estimate if an opposing car is far enough away so that he can complete his maneuver before it arrives. If visibility is limited by alignment of the road, the driver must be assured that the distance he can see ahead is long enough so that he could still complete his maneuver without interference if a car should appear. Usually the driver can see far enough and must judge for himself if the distance he can see is sufficient for him to complete his maneuver safely. But there are cases, such as hidden dips in the road, where the driver can be surprised. Furthermore, there are many drivers who do not know how to judge if the available sight distance before a curve or a hill is sufficient for safe passing. For these cases, the traffic engineers have marked no-passing zones on the roads to inform drivers that insufficient sight distance makes passing hazardous.

The foregoing is a very simplified sketch of the purpose of no-passing zones. The actual reasoning and design is complex (3) and outside the scope of this paper, which deals with the relationship of the driver (not, as always in the past, with that of the engineer) to these zones.

Paper sponsored by Committee on Road User Characteristics.

DATA SOURCE

Once the object of the study was determined, a choice of techniques for obtaining the data had to be made. Measurements on the road similar to those done by Crawford (4) were ruled out because of the difficulty and expense involved. Observations of individual drivers in a test vehicle also was impossible for the same reasons. Of the remaining choices, direct interview and questionnaire, the latter was chosen because the cost of interviews would have been greater in time and money, and because a fairly large number of observations were needed, with relatively few variables considered likely to be important.

The questionnaires were self-administered by drivers applying for renewal of their drivers' licenses at six licensing offices in Michigan. The offices were selected for spread in area of the state and rural-urban residence. Two of the areas where questionnaires were obtained are rural and the others are located in central Michigan urban areas of 100,000 population or larger (excluding Detroit). Of course, this does not provide an appropriately controlled probability sampling for these factors, but our resources did not permit a more sophisticated design.

An additional source of bias was introduced in the actual selection of drivers in the licensing offices. In Michigan, drivers' licenses expire every three years on the birthdate of the driver, so a complete enumeration of all persons applying for license renewal in a brief period will yield a sample with birthdate related bias. However, this does not present any problem in this analysis, since we found no reason to expect a relationship between the other variables and actual birthdate over a short cycle of years. Because office supervisors could not require that all persons fill out a questionnaire, coverage is probably not complete and bias might have been introduced.

Development of Questionnaire

The questionnaire was designed in consultation with a group of staff experts on driver training, statistical analysis, traffic engineering, human factors, etc. Several trial designs were actually used on small groups before the final version of the questionnaire evolved.

The practical guidelines for developing the questionnaire were as follows: (a) one page limit; (b) as self-explanatory as possible; (c) sufficiently explicit for any driver to fill out without help; and (d) answers easily tallied, preferably by machine methods. Figure 1 is a facsimile of the questionnaire, showing the percentage distribution of all answers.

The main question complex was concerned with the way each driver acts at a no-passing zone. Because it was difficult to word questions for this section, sketches were used to illustrate certain passing practices, and the question for each sketch asked only if the driver had ever passed in that manner. This type of diagram is used frequently in driver training and testing, accident reporting, and in press and television (5), so it could be assumed that anyone answering the questionnaire would have seen similar material from other sources. (The number of persons who failed to understand the questions here may be some index of the number who do not understand this type of presentation elsewhere). Check boxes were provided for three possible answers for each sketch: "yes," "no," and "only in rare cases." The latter answer was intended to distinguish between habitual and exceptional execution. At least three situations (sketches) were felt to be necessary to distinguish violations of the no-passing zone. The fourth question was included for logical completeness.

Two additional groups of questions were used, one dealing with the characteristics of the respondent and the other with his evaluation of the existing and proposed no-passing zone marking. Both groups were intended for analysis of patterns shown in the passing practices, as well as for independent analysis. The limitation to one page was a severe handicap.

As indicated, the questionnaire was designed for convenient coding and analysis of the answers. An IBM card was punched for each questionnaire. The card deck was then run for totals and distributions of the answers (Fig. 1). Continuous answers (age and driving experience) were each broken into nine discrete groups. All questions

THIS IS NOT AN EXAMINATION

To the Driver:

These questions are asked as part of a graduate research project at Michigan State University. This study is concerned with the driver's understanding of highway No-passing zones. This questionnaire in no way will affect your license renewal. Please help by answering the following questions as they apply to your normal driving habits.

26.83% 72.22% 0.95% NA

1. Have you ever had a class in driver education? yes ☐ no ☐

2.63% NA

2. Sex 61.55% 35.82% Age * Approximate years you have driven *
male or female years number

84.65% 2.12% 12.57% 0.66% NA

3. Do you like to drive? yes ☐ no ☐ depends on time and place ☐

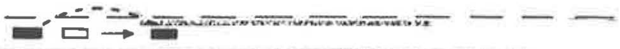
16.45% 92.24% 1.32% NA

4. Do you usually feel uneasy about passing another car? yes ☐ no ☐

5. When approaching a No-passing zone, most drivers know what the yellow line means. We wish to know how the drivers react to this line. In the following sketches, the dotted line shows the path of your car while passing. The solid red line is the yellow line. The dashed line is the centerline. Consider each of the four cases.

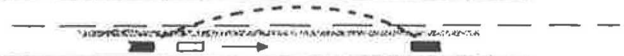
23.61% 34.65% 38.96% 2.78% NA

A. Have you ever passed here? yes ☐ no ☐ only in rare cases ☐



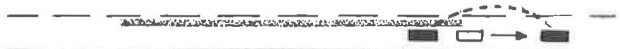
9.14% 81.80% 5.12% 3.95% NA

B. Have you ever passed here? yes no only in rare cases ☐



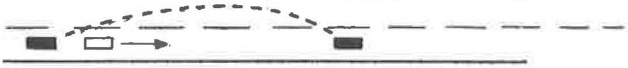
23.03% 52.70% 19.59% 4.68% NA

C. Have you ever passed here? yes ☐ no ☐ only in rare cases ☐



83.04% 8.33% 6.21% 2.41% NA

D. Have you ever passed here? yes no only in rare cases ☐



6. When approaching a No-passing zone, which do you notice first (check one per group)

During the daytime:			During the night:		
a. The yellow line	☐	49.49%	a. The yellow line	☐	36.55%
b. The Do Not Pass sign	☐	45.47%	b. The Do Not Pass sign	☐	54.39%
c. I don't know	☐	5.04%	c. I don't know	☐	8.85%

7. Do you feel that the present system of marking No-passing zones is adequate?
78.00% 19.23% 2.78% NA
yes ☐ no ☐

8. Would a large yellow sign like this one [No Passing] placed on the left hand side of the road, at the start of the yellow line be helpful?
68.86% 28.72% 2.92% NA
yes ☐ no ☐

*Not in suitable form to be placed here.

THANK YOU FOR YOUR TIME

Figure 1. Questionnaire, showing response percentages.

were then compared numerically against all other questions in a bivariate analysis by computer. After these results had been evaluated and discussed, we analyzed certain interesting answer patterns again as to the characteristics of the respondents in the pattern. Passing practice patterns especially were analyzed this way.

Discussion of Sample

A total of 1,368 completed questionnaires were collected. One of the first items to be investigated was the correspondence of the sample to population or to other sampled groups. Inquiries were made of a number of organizations and agencies possessing comparable statistics. It was especially hoped to get national or at least large group averages for age, sex, and driver training.

Age distributions were available from several states (6-10) on samples much larger than the one considered here. Figure 2 shows these age distribution curves plotted year by year. All curves, even those representing large samples, exhibit some irregularities, probably due to local differences and methods of compilation. This might be corrected by a horizontal shift of the curves to adjust for age spread. The sample of Michigan drivers show an irregular curve partially explained by the three-year duration of the driver's license, which brings the drivers back for renewal in multiples of three years from the time of their first drivers' licenses. Since licenses can be obtained at age 16, the peaks at ages 19, 22, 25, 28, etc., were predictable. The dip around age 31 is similarly explicable.

Considering an averaged curve for the Michigan sample, one still finds a tendency for more drivers in the younger than in the older groups. This could be either a characteristic of the respondent population or a bias in the sample, perhaps caused by older drivers being more reluctant to fill out the questionnaire than younger drivers.

Figure 3 shows the age distribution by sex for the national total as assembled by the National Safety Council (10), the Illinois sample (9), and the Michigan sample (5-year plots). It can be seen here more clearly that the Michigan sample contains more drivers in the younger age groups for both sexes. Male drivers show a larger than national average percentage up to the middle thirties, while female drivers predominate only in the teens and lower twenties.

Table 1 indicates that the distribution of all drivers in the sample by sex shows the same breakdown for the Michigan sample as for two other states and the nation as a whole. Only New York has a substantially larger proportion of male drivers than the

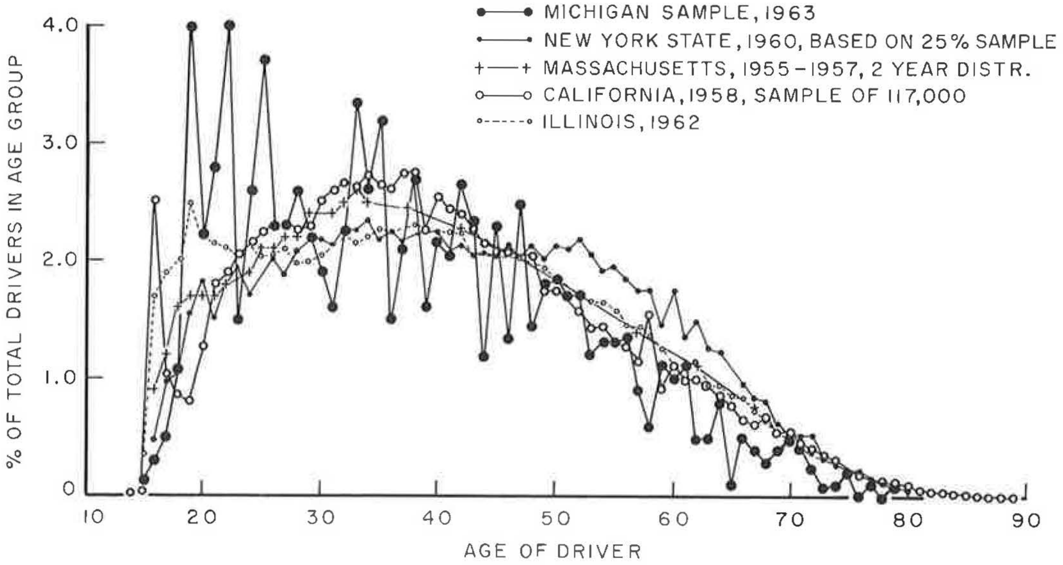


Figure 2. Driver distribution by age.

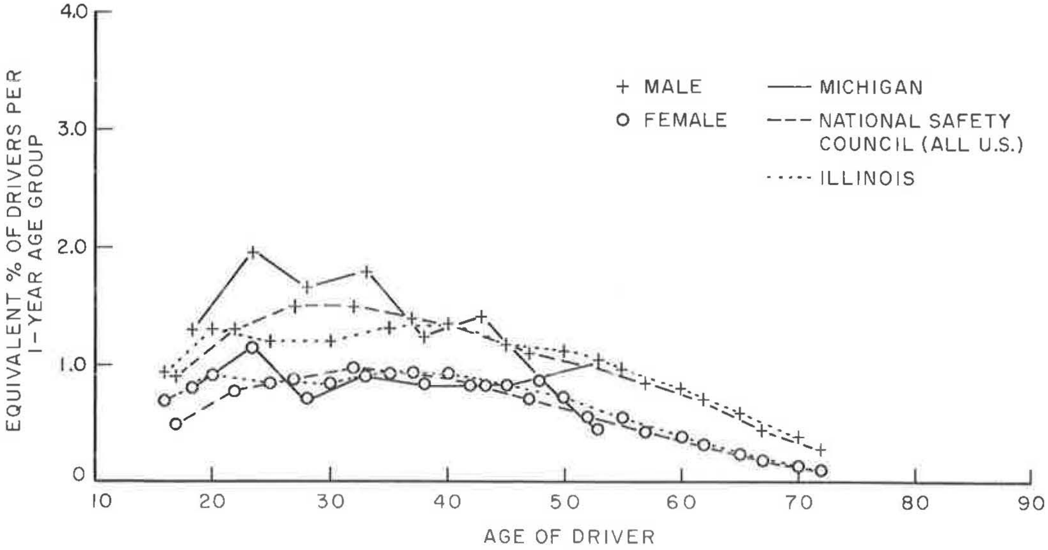


Figure 3. Driver distributions by age and sex.

other samples. The good correlation of the Michigan sample with the national average indicates that if any bias exists in the Michigan sample, it is shown evenly in both sexes.

DRIVER'S CHARACTERISTICS

The first four questions in the questionnaire deal with the general characteristics of the driver: sex, age, and driving background (years of driving experience, driver education, opinion about driving and passing). The locality where he renewed his license was also coded on the form.

One of the most surprising facts is that 85 percent of the respondents in the sample like to drive (Fig. 4). More surprising is that only 2 percent state flatly that they do not like to drive. Even considering the likelihood of improper motivation of the respondents at the time of filling out the questionnaire, the magnitude of the response is overwhelming and suggests that further study of this question is needed. Only nine respondents (less than 1 percent) did not answer this question, making it one of the most complete answers in the form.

The question concerning uneasiness about passing (Fig. 5) also provided a surprising answer, although it was in keeping with the responses given previously. Only 16 percent of the drivers answering the questionnaire feel uneasy about passing, 82 percent do not feel uneasy, and only 1.3 percent did not answer the question at all.

TABLE 1

DISTRIBUTION OF DRIVERS BY SEX

Sample	Year	Total No.	Male		Female	
			%	No.	%	No.
Michigan	1963	1,368	63	842	37	480
California	1958	117,201	61	71,992	39	45,209
Illinois	1962	4,690,467	61	2,848,972	39	1,841,495
New York	1960	7,006,206	68	4,782,072	32	2,224,134
Nat. Safety Council	1962	91,000,000	63	57,000,000	37	34,000,000

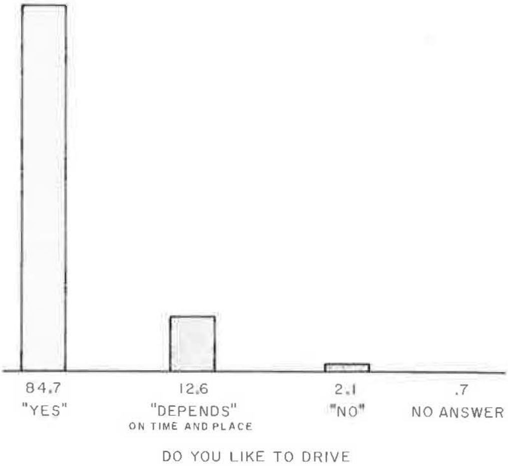


Figure 4. Distribution of response to Question 3.

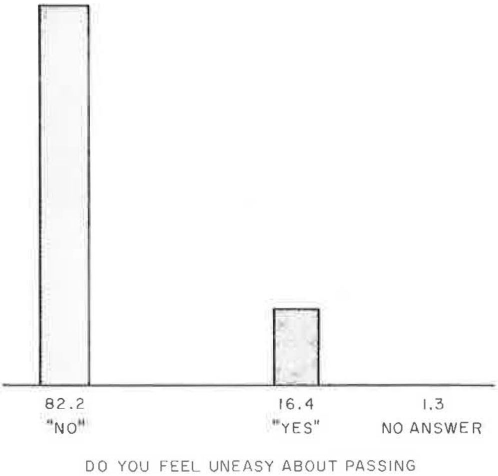


Figure 5. Distribution of response to Question 4.

An analysis of these two characteristics was expected to clarify the relationship between feeling uneasy about passing and not liking to drive. Since the passing maneuver on a 2-lane highway represents one of the most hazardous operations in driving, we expected a close link with dislike of driving. From this point of view, the following results of our questionnaire are especially interesting.

A distribution of the responses into each of the six cells formed by a matrix of the two variables is shown graphically in Figure 6. With the predominance of positive responses, any relationship between uneasiness about passing and not liking to drive is rather unimpressive, even though it can be shown to be statistically significant at levels commonly used in survey analysis. With this limitation in mind, it can be fairly concluded from the combined responses of the two items that there is a strong possibility that uneasiness about passing may contribute to the dislike of driving. One out of every 3 drivers who do not unconditionally like to drive feel uneasy about passing, whereas only 1 out of every 8 who like to drive feels uneasy about passing. It should be emphasized that the data also indicate that other factors contribute more to the dislike of driving. This should be of considerable interest to driving teachers and law enforcement officers.

The same questions about passing and driving were also compared to all other variables analyzed in the questionnaire. Selected values of these analyses are shown in Figures 7 and 8. The values given here include maximum and minimum relations as well as some values where relationships might be considered of interest. It must be noted that in many selected categories, the sample frequency is very small. The numbers of responses on which the distributions are based are given at the top of each column. The reader may judge for himself the significance of each distribution.

The variations in liking to drive are reasonable and predictable. The small proportion of teenage drivers who do not unconditionally like to drive (one-third of the general proportion) could be expected, considering the newness of the experience and the general enthusiasm of that age group—particularly for driving. It might also be important that teenagers generally do not have to drive and those who do not like it may not learn to drive until they need to.

A similar variation exists in the distribution of drivers who feel uneasy about passing in relation to other variables (Fig. 8). The highest increase, almost threefold, is in the group who do not like to drive. This distribution might serve here as a warning about the potential misinterpretation of this type of result. It might be pointed out that more drivers who have had driver education feel uneasy about passing. Of the drivers who do not know which of the no-passing zone markings they see first, almost twice as

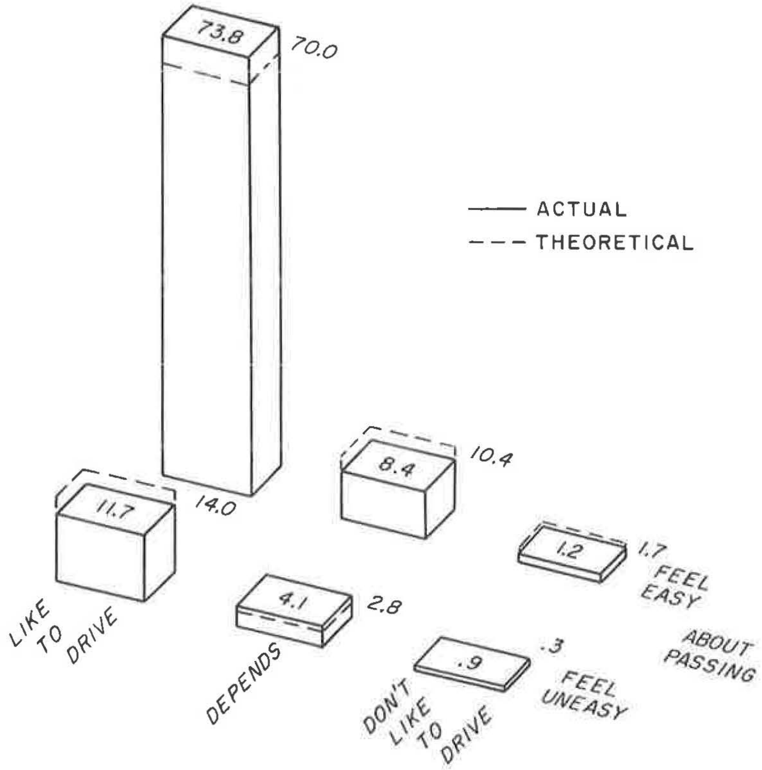


Figure 6. Correlation of opinions about driving and passing.

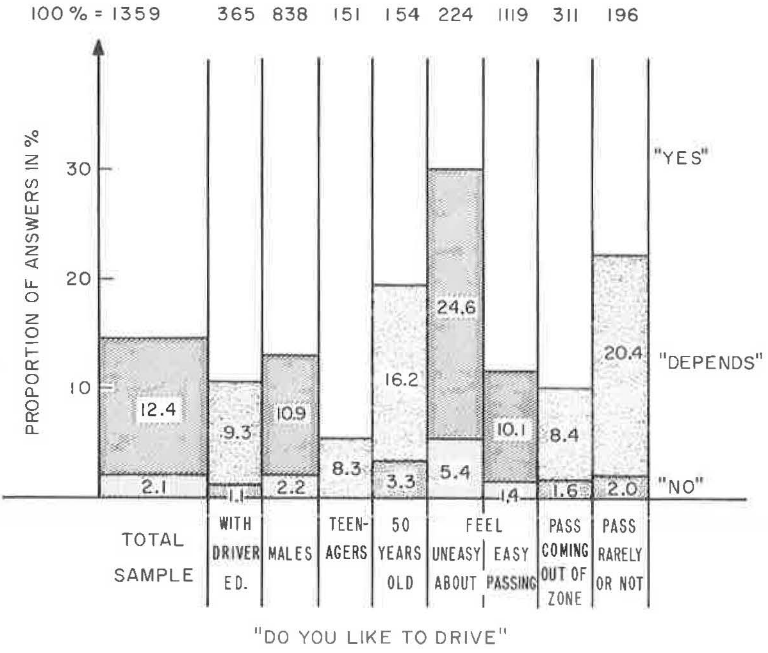


Figure 7. Not "liking to drive" as percentage of selected other distributions.

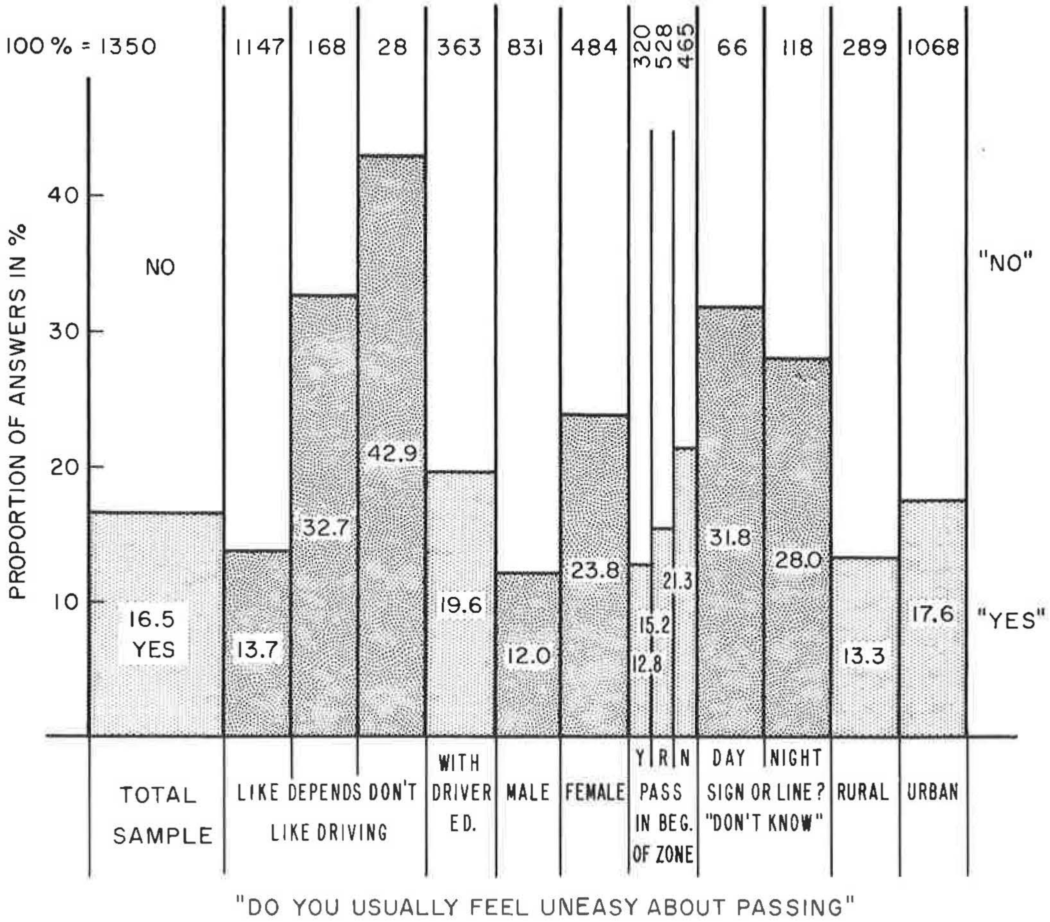


Figure 8. Feeling "uneasy about passing" as percentage of selected other distributions.

many feel uneasy about passing during both day and night. This might be a significant relation, although it might be hard to relate definitively to driver education or to driver personality. It is also reasonable that the proportion of respondents who feel uneasy about passing is much lower for males than for females. In relation to the behavior in no-passing zones, only small indications are found. For instance, of those who pass near the beginning of a no-passing zone and cross the beginning of the yellow line, a smaller percentage feel uneasy than of those who do not pass there. An interesting result is obtained when comparing rural to urban areas. The lower percentage of rural respondents who feel uneasy about passing may be explained by the greater necessity for passing in rural areas. But this conclusion should be accepted with reservation, since there are many other variables which could underlie this relationship; for example, the two rural areas sampled for this study provide fewer young respondents than the other localities.

Another interesting fact in these general driver characteristics is shown in Figures 9 and 10. Figure 10 shows a decided predominance of females with shorter driving experience; males generally learn to drive at an early age and females apparently learn to drive at all ages. This leads to the conclusion that the percentage of female drivers increases over the years, which is supported by Figure 9 showing the decided change in ratio between male and female drivers by driving experience and the essentially constant ratio by age.

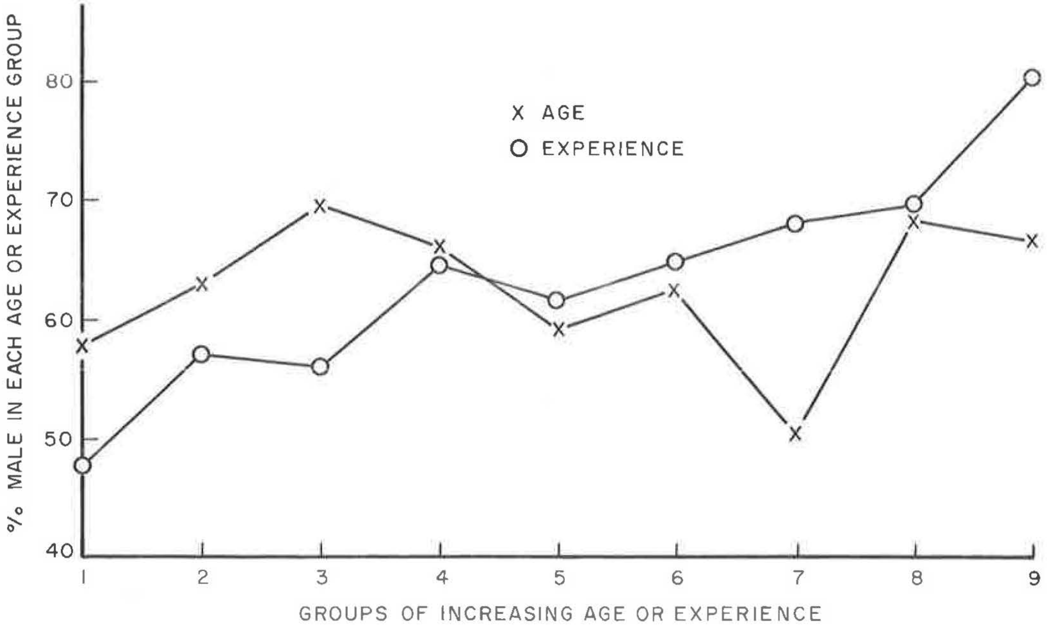


Figure 9. Percentage of male respondents by driving experience and age.

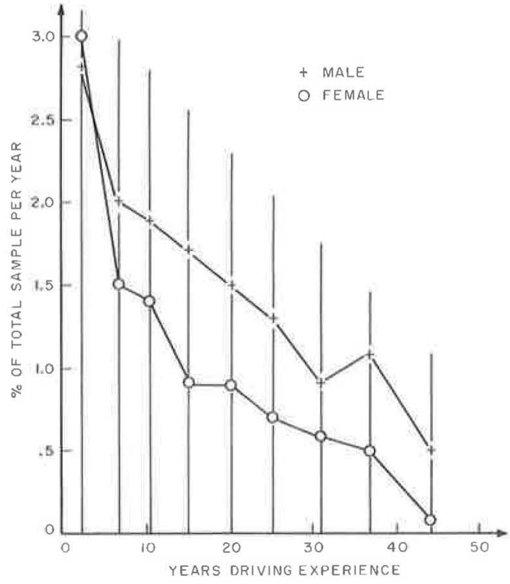


Figure 10. Distribution of male and female drivers by number of years driving experience.

Figure 11 shows the percentage of drivers with driver education by age groups. The strong drop represents the effect of the introduction of compulsory driver education in Michigan schools in 1956.

Reaction to No-Passing Zone Marking

The last three questions in the questionnaire concerned no-passing zone marking practices and their acceptance. Since in Michigan no-passing zones are marked with a yellow line on the pavement, as well as roadside signs both at the beginning and at the end of the zone, we first intended to find out which of the two markings the drivers judged more effective. Surprisingly enough, both types of markings appear to be almost equally noticeable, with the signs having a slight advantage at night. Most surprising was the small response in the uncertain category. Only 5 percent admit they did not know which of the two markings they notice first. The uncertainty rose to 9 percent at night. Approximately one-third of the respondents switch from one type of marking to the other between day and night. Figure 12 illustrates that 23 percent switch from line to sign, only 12 percent switch from sign to line, and the increase in the "don't know" answer comes from both types.

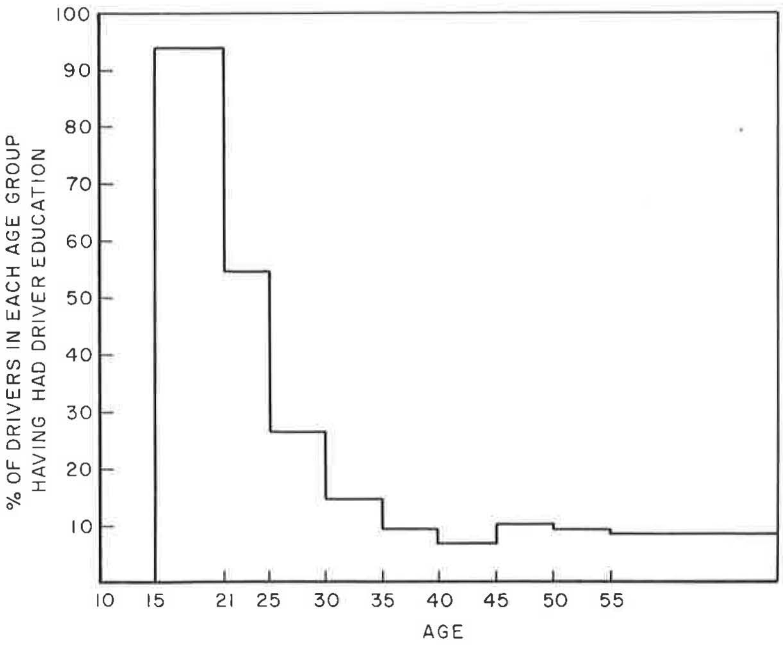


Figure 11. Driver education percentage vs age.

The split of the answers and the low occurrence of indefinite answers is remarkable, but it cannot be concluded that one type is better than the other, nor can it be said that both are needed. The only conclusion is that both markings seem to be almost equally noticeable. It is not surprising, then, that an overwhelming 80 percent of the respondents feel that the marking is adequate. Even 80 percent of those who do not know which they notice first, the sign or the line, feel that the present system is adequate.

The last question in the form, dealing with the large sign introduced by the Iowa State Highway Department, is more informative. Even though 80 percent of the respondents feel that the present marking system is adequate, about 70 percent still feel that the Iowa sign would be helpful. Of those who are dissatisfied with the present marking system, only 87 percent feel that the Iowa sign would help.

The significance of these results lies in the fact that no marking system for no-passing zones seems to be generally preferable. The preference for line and sign is almost evenly divided. The possibility of an Iowa-type sign with its generous size and its conspicuous placement on the left side of the roadway does not appear to generate overall enthusiasm. This result seems to be the more remarkable to the engineer, since each of these marking practices is clear-cut and should be expected to produce a definite preference pattern.

PASSING CHARACTERISTICS

The response patterns given by drivers to the four questions dealing with passing practices are analyzed together, producing various passing patterns of driver behavior. These patterns are considered from two points of view: (a) the engineering or design intention is used as a basis for comparing the patterns, and (b) the patterns themselves are compared to other driver characteristics in an attempt to find possible relationships.

In each of the four questions concerned with passing practices, the drivers in our sample were offered three answers from which to choose: "yes," "only in rare cases," and "no." Another response to each of the four questions could be, and was

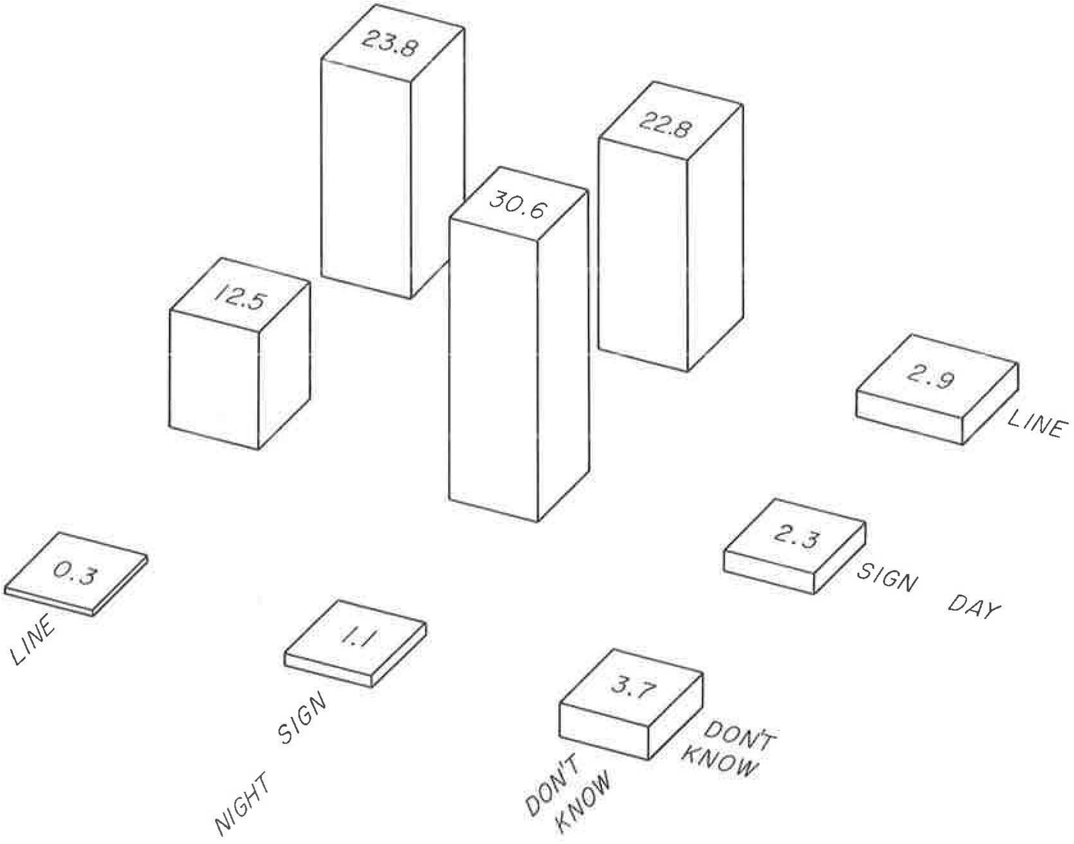


Figure 12. Shift of recognition of sign between day and night.

made, by not checking any of these answers. Of the 1,368 drivers in our sample, 108 (7.9 percent) did not check an answer to one or more of the questions on passing. Failure to answer some passing question(s) was not found to be substantially associated with answers checked on other passing questions; consequently, all 108 were eliminated from further analysis.

For the remaining 1,260 drivers, there were four questions with three possible answers to each, yielding a total of 81 possible (permutations of) response patterns. (Of these possible patterns, 63 actually occurred.) Not all of these would be expected since some order should be anticipated; for example, a driver's answers of "yes" for passing entirely within a zone, and "no" to the other three questions on passing make no sense. Possibly, he may have misunderstood the diagrams used to show the passing situations or the regulations for no-passing zones. However, these drivers were applying for license renewal, and to receive a license, they had to have shown knowledge of no-passing zone regulations. Given the actual wording of the questions, such unexpected (or illogical) response patterns may be correct reports of drivers' behavior, but this possibility does not present a methodological problem of the sort considered here and is generally ignored in the sequel.

Passing Patterns vs Engineering Intentions

A summary illustration of the answers is given in Figure 13. At first glance it appears that there is an overwhelming response of correct answers considering the shaded responses as correct. The answer "only in rare cases" may be considered

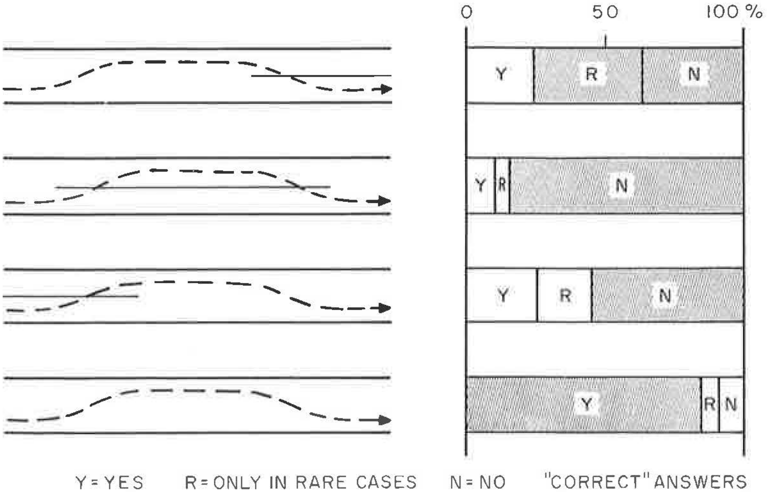


Figure 13. Distribution of responses to passing practice questions.

correct for the driver crossing the yellow line when entering a zore, but it cannot be accepted as readily in the next two questions, where it represents a voluntary action of the driver. It appears from the figure that in all cases the correct answers are more than 50 percent, but this a gravely misleading conclusion, since only the combination of all four correct answers is truly correct driving practice. The view of the frequency of combinations of answers given in Figure 14 indicates that only 424 respondents (30 percent of the sample) give this correct answer. Taken at face value, this is a shockingly low number of drivers who claim to observe no-passing zones according to enforcement intentions.

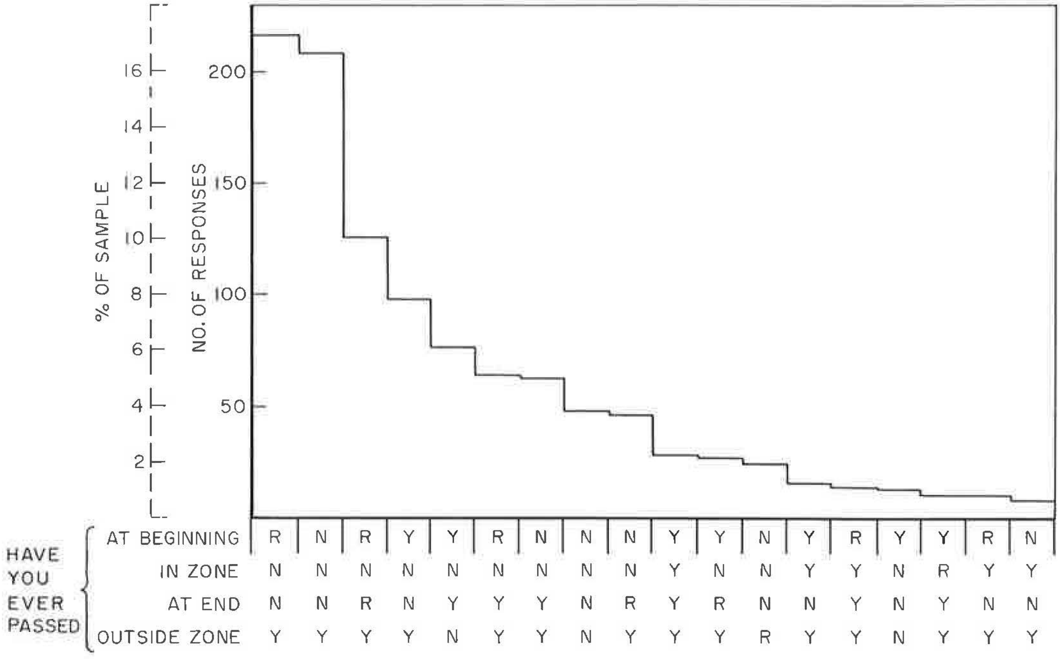


Figure 14. Passing practice response patterns (in descending order of magnitude).

It is surprising, too, to find such wide divergence in the answers and to get so many answers in incorrect answer patterns. As stated above, there are 81 possibilities, of which 63 were given by one or more of 1,260 respondents. This fact in itself is rather disturbing, if one accepts that the questions were answered seriously. It points up the possibility that there is a great variety of misinterpretations (regardless of the number of responses in each pattern) among the driving population represented by this sample. Although this problem is not further explored here, it should be recognized and remembered when analyzing odd driver behavior or a freak accident.

Further analysis of Figure 14 shows some other relatively frequent patterns. Some of these seem to be related and have been grouped as shown in Figure 15. The second of these groupings alone contains 307 responses. This group consists of those people who will violate the end of the yellow line, probably because they believe that they can see far enough ahead. This is a serious misunderstanding since the zone is laid out based on actual visibility, but with a distance shorter than the full passing distance required from the start of the maneuver. Thus, passing is sometimes not even safe at the end of the line, let alone before. But the response is understandable, especially when a driver who has been trailing another vehicle for some time sees another no-passing zone coming up. This pattern with its sizeable representation should be cause for concern for driver educators and highway design engineers.

We included in this grouping all "yes" and "rare" responses to the third question (passing at the end of the zone), and all "no" and "rare" responses to the first question (passing at the beginning). This is based on the reasoning that a rare violation of the beginning of a zone is assumed to be involuntary; i.e., a driver thought he had enough distance to complete his maneuver before the zone but could not. When violating the end of the zone, however, the action is strictly at the driver's discretion and "rare" violations are still voluntary.

The next group comprises those drivers who freely violate both ends of the no-passing zone. This group, containing three patterns with a total of 117 respondents,

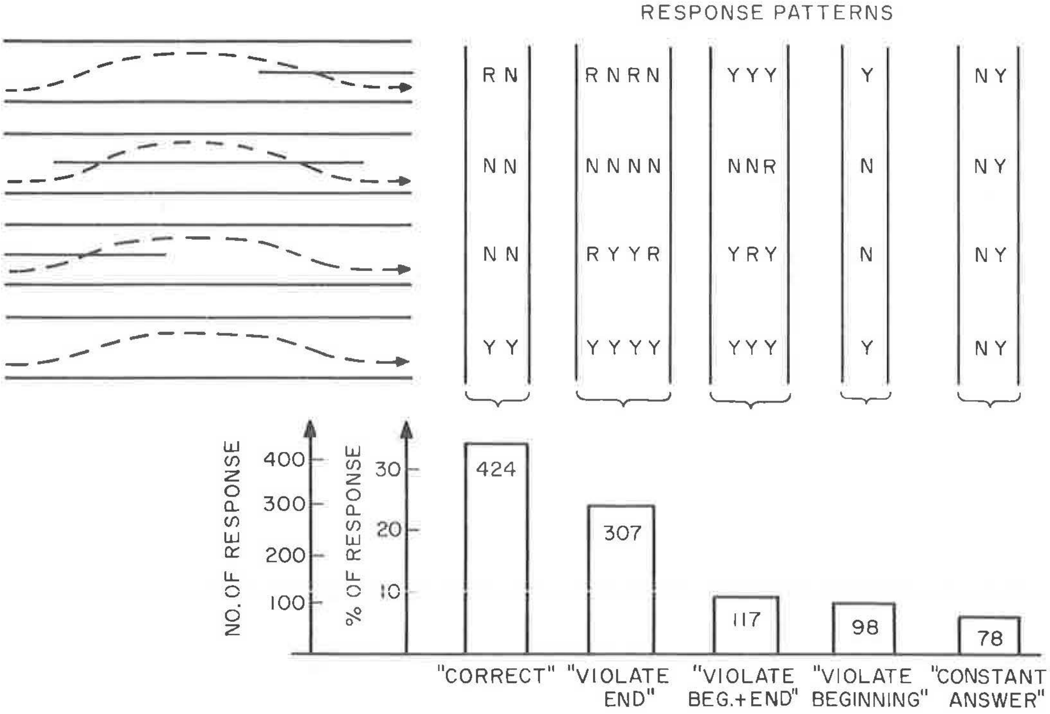


Figure 15. Major passing patterns.

is almost 10 percent of the sample. Another misinterpretation of the zone is made by those drivers who will freely violate the beginning of the zone but will not pass within or at the end of the zone. Only one pattern is included, with 98 respondents who apparently misinterpret the no-passing zone markings to mean that they cannot initiate a passing maneuver but can safely complete it within the zone. It is interesting that the group who never pass or always pass is so large, amounting together to almost 6 percent of the sample.

Passing Patterns as Behavioral Scale

In general, if we assume that the three possible answers are ordered from "yes" through "only in rare cases" to "no," then answers to all passing questions should be at least as positive as the answer to passing entirely within a no-passing zone; none of the other answers should be less positive than the answer to passing within an unzoned area. With this restriction it can be shown that there are only 20 logical combinations of answers to the four questions. In terms of behavioral science conventions, we are arguing that answers to these questions ought, a priori, to form a partial Guttman scale; i.e., the second and fourth items should form the extremes, while the first and third items form the means, but are not necessarily ordered between themselves (11).

In empirical examination of the data, it developed that an even stronger order can be made in which the relation between the first and third items is specified. However, this was not specifically anticipated in the research and constitutes a serendipitous result.

Each of the 20 logical patterns—ranging from "yes" to all four questions to "no" to all four—was actually reported by some drivers, though in greatly varying frequencies. Of the 61 illogical patterns, 43 were actually reported by some drivers. (The most frequently reported illogical pattern was chosen by 16 drivers, or about 1.3 percent of the 1,260 who gave complete answers.) Of the 1,260 drivers involved, 166 (about 13 percent) gave illogical answer patterns.

This substantial proportion of illogical responses raises a problem as to the efficacy of the questionnaire in eliciting true responses from the drivers and again points up the tentative nature of the data we are examining. At the same time, the fact must not be overlooked that nearly 87 percent of those who gave usable answers gave logical responses, and, as will be seen later, substantial proportions of these fall into predictable patterns.

The essential question raised by the illogical patterns is whether the logical patterns are to be regarded as true answers, or whether these could have been obtained by chance. A gross estimate of this possibility can be obtained by calculating the chi-square test of the goodness of fit of the actual frequencies of logical and illogical patterns to the expected frequencies, calculated on the assumption that the answers a driver gave were independent of each other. Without reproducing the calculations here, it may be stated that the null hypothesis, of no relation between the answers to the passing questions, may be safely rejected.

This does not eliminate the possibility that logically correct patterns of answers may have been given by some drivers who did not understand the questions. However, examination of the frequencies of the illogical patterns suggests that drivers who did not understand the questions did not choose any particular patterns. In other words, they misunderstood the questions in different ways and the responses were generally randomized. It seems reasonable to suppose that the same randomizing effect would be observed among the logically correct responses if we were able to interview the drivers involved to obtain corrected data. The general consequence of such randomization would thus be to attenuate any relationships that actually existed between the patterns of answers to the passing questions and the other variables examined. We feel reasonably confident that any bias in the data is actually conservative and probably tends to underestimate real trends.

Therefore, we determined to examine the most frequently reported logically correct patterns of response and their relations to other variables. Of the 20 possible patterns, 7 had low frequencies (the highest was 9) and together accounted for only 43 drivers. These and the logically incorrect patterns were eliminated from subsequent comparisons, leaving 1,051 drivers for analysis. One of the remaining 13 patterns had only 12 responses, and was grouped with a nearly identical pattern. There remained 12 logically correct patterns which are shown in Table 2 with the number of drivers reporting each pattern and other selected statistics. Each pattern has been assigned a type number to facilitate references.

In reading the summary data shown in Table 2 and the discussion, several points should be kept in mind. As noted in the preceding section, there is a wide variation in the number of drivers reporting each pattern; the most frequent pattern (Type 7) is given nearly 10 times as often as the least frequent (Type 11). Smaller samples usually will be less stable as estimators. Also, median values given to show central tendencies of the associated distributions are central values and do not show the spread about the point. (The variances are substantially homogeneous throughout and have not been included here.) Medians have been used rather than means or modes because they are less sensitive to skewness and other irregularities. Percentages are based on the number of drivers in the type less any who did not answer the question. Unless otherwise noted in the discussion, judgments of the strength (or significance) of relations with other variables are based on examination of the chi-square test of independence for bivariate frequency distributions.

The patterns are ordered substantially by decreasingly positive responses to the passing questions. These agree regularly with decrease in the number of males and increase in the median age for drivers reporting each pattern. The ordering was actually determined by examining the relationship between the patterns and other variables to discover what ordering provided the best prediction and retained a manifestly sensible relation among the patterns. As noted previously, the placement of responses to the second and fourth items (positive and negative at beginning and end, respectively) was as constructed, but all expectations about the first and third items were ambiguous. For a given response on the first item, the order of the types is in decreasingly positive response to the third item. The only anomaly in this ordering is Type 2, which might be thought to belong between Types 5 and 6. It has been placed second because of the close agreement with overall ordering of median ages. It is interesting that in Type 2 is the strongest evidence that violation of the end of the zone is regular rather than occasional, based on the fact that all three possible answers to the four passing questions were used.

The patterns show what the drivers report they have done, but two different drivers who have actually passed in the various situations with about the same relative frequency may give slightly different reports, depending on how they answer questions. Some persons, particularly, tend not to use middle alternatives, such as "only in rare cases;" for example, two different drivers might give Types 8 and 9, respectively, but drive in essentially the same manner.

TABLE 2

PASSING PATTERNS AND OTHER CHARACTERISTICS

Type	Begin	In	End	Out	Freq.	Male (%)	Median Age			Driver Educ. (%)	Median Years Driven	Like to Drive, Uncond. (%)	Uneasy Passing (%)	No-Passing Zone Approach (%)				Marking Adequate (%)	Iowa Sign Helpful (%)
							Male	Female	All					Day		Night			
														Line	Sign	Line	Sign		
1	yes	yes	yes	yes	29	83	26	40[a]	28	38	12	86	21	59	38	48	45	69	62
2	rare	no	yes	yes	65	77	30	30	30	31	13	94	15	42	57	23	69	71	66
3	yes	-[b]	yes	yes	89	84	32	32	32	38	15	90	9	56	38	43	51	74	75
4	yes	no	rare	yes	28	68	32	32[c]	32	25	15	96	4	68	29	43	50	67	85
5	yes	no	no	yes	98	76	30	34	31	28	13	87	12	58	38	37	57	72	75
6	rare	no	rare	yes	132	68	34	34	34	29	17	88	21	57	40	40	55	78	79
7	rare	no	no	yes	216	71	33	36	34	26	16	85	11	52	43	40	51	82	66
8	no	no	yes	yes	65	56	39	35	38	19	19	92	18	40	54	17	70	83	72
9	no	no	rare	yes	47	49	41	38	39	23	19	85	19	62	34	45	49	83	77
10	no	no	no	yes	208	52	41	35	38	28	16	84	21	42	51	28	61	87	62
11	no	no	no	rare	25	64	39	44[c]	41	20	12	76	24	28	64	36	56	79	63
12	no	no	no	no	49	38	45	42	43	23	18	80	32	51	45	49	45	83	64
Total					1,051	66	34	36	35	28	16	87	17	51	44	36	56	79	70

[a] Based on frequency of only 5.

[b] Divided between "no" and "rare".

[c] Based on frequencies less than 10.

Passing Patterns vs Age and Sex

The agreement of the ordering of the patterns with age and sex of the drivers is quite striking and is within the range of plausibility based on a priori expectations about driver behavior (given that the reported patterns as such are not really unexpected). A gross measure of the relationship can be obtained from the product-moment coefficient of correlation. The value of the coefficient for the patterns is with age 0.21 and with sex 0.23. The last five types have lower proportions of males and higher median ages than any of the preceding seven types. At the same time it must be repeated that in each pattern there is a spread of ages not included in Table 2. This partially accounts for the low correlation coefficient, but the spread is expectable. On the whole, the relation between the patterns and age is linear. The data seem to confirm what many might suspect; i.e., women are more cautious than men, and people become more cautious as they grow older. This seems most plausible, but it should not be overlooked that differences in driving patterns in relation to age might be due to changes in typical driving habits of new drivers, with fairly constant habit patterns persisting through adulthood. Neither the spread within patterns nor the situation with respect to number of years of driving experience confirm this. It is unlikely that really conclusive evidence can be found without a longitudinal study. The relation of the patterns of sex is not as straightforward as with age, but there is even more gross difference in the numbers of males and females reporting each pattern.

It is worthwhile to speculate on the meaning of the ordering of these patterns, remembering that we have no supporting evidence from direct questions. It is possible that the order reflects decreasing intent to violate the purpose of posted no-passing zones. The relationship of the pattern ordering to age and sex agrees with this, in that we usually expect more conservative and cautious behavior from women and older persons. This interpretation would be supported if drivers on the whole believed that violation of the beginning of a zone is more serious than violation of the end. This is not implausible since those who do not answer "no" to the third passing question include "peekers" (drivers who begin edging out of their lane when approaching the end of a zone in order to see ahead, believing that they will have ample opportunity to return safely, and who do not intend to decide on passing until out of the zone). But they do not cross the line accidentally. On the other hand, at least some of those who report violations at the beginning of the zone have done so unintentionally in their own view. It is possible that there are actually fewer who intentionally cross the beginning of the zone line than there are who intentionally cross the end of the zone. Furthermore, from the viewpoint of driver psychology, it seems quite likely that violation of the beginning when danger is approaching is more serious than violation at the end when danger is receding.

The questions ask what the drivers have done but do not elicit their opinions about this behavior or their reasons for it. This, of course, constitutes an unresolved problem which should be pursued further, since the ordering of seriousness of beginning and end violations of no-passing zones is the reverse of the actual logic (with regard to unimpeded sight distance) on which zone marking is based. If this is true, it is an important area for continuing driver education.

Passing Patterns vs Other Characteristics

Other items on the questionnaire elicited information about the drivers' training, attitudes toward driving, and experience with and opinions about marking of no-passing zones.

The patterns of passing behavior do not appear to be related to the training and experience of these drivers, i.e., there is no strong relationship between these patterns and the question, "Have you ever had a class in driver education?" We do not take this lack of a simple direct relationship as evidence that driver education does not have an effect on passing behavior; it seems more plausible that other factors confound the relationship. There is a relationship between the patterns and the number of years the person has been driving (correlation coefficient = 0.11), but this may be accounted for by the stronger and expected correlation between number of years of driving experience and age. In fact, by controlling for age, the partial correlation coefficient between years of driving experience and the passing patterns is -0.16; i.e., the relationship is inverse. In Table 2, this negative relation is exhibited in decreasing median ages within each subset of patterns with same responses on the first passing question, with the exceptions of Types 1, 2 and 12. This suggests that there may be some tendency for drivers to become less cautious with increased experience.

In regard to the attitudinal question, "Do you like to drive?" there is no evidence of notable relation between the answers and passing behavior. There is evidence of a statistical relationship between uneasiness about passing and patterns of passing behavior, but the general meaningfulness of this is obscure. Those who never violate a zone are more likely to feel uneasy than others. However, in all patterns except Type 12, more than three-fourths answered "no" to the question. This relatively high proportion of uneasiness about passing among those who answer "no" to all passing questions may seem to be in error, but it must be remembered that the questions were only about 2-lane highways.

With respect to zone markings, the passing patterns are more related statistically to experience than to opinions, but again without meaningful detail. There is a tendency for those who do not violate the beginning of the zone to report seeing the "Do Not Pass" sign—during both day and night—more frequently than others. The increase in preference for the sign at night holds for all patterns except Type 11. The opinions about adequacy of marking and use of the Iowa sign are not strongly related to the patterns, but in each case there is a consistent relation. The first types are less likely to consider zone markings adequate, and the extremes less frequently think the Iowa sign would be helpful.

Taken overall, there are clear indications in the data that personal characteristics expressed as demographic factors are significantly related to the patterns of passing behavior analyzed. The present research only permitted inclusion of information about age and sex of the drivers. In future study it would be extremely valuable to gather data about the social and economic status of the drivers, amount of formal education, occupation, and place of residence in rural or urban area. (This last factor was largely excluded from our analysis, because the information was only grossly available in terms of the office where the license was renewed.) Also, additional information should be obtained about the kind and amount of past and current driving experience. It is not to be expected that these factors would completely account for the differences in passing behavior, let alone other driving habits. However, they could provide indications about the kinds of drivers who need education and reeducation in safe driving practices.

Similarly, much more information is needed with respect to the suggestions about drivers' opinions on the relative seriousness of infractions. Such study could provide useful guides to the focus of content in safety propaganda.

CONCLUSIONS AND RECOMMENDATIONS

This pilot study on driver passing behavior on 2-lane highways must be viewed as suggestive rather than conclusive, but many results are obtained which point to the need for further investigation related to both engineering design and driver education.

There is striking evidence of relatively low frequency of what might be called correct driving in no-passing zones; in particular, almost a quarter of the sample appear to violate the beginning, and almost half the sample the end, of the no-passing zone.

Examination of the overall patterns of passing behavior gives evidence of a much wider variety of actual behavior than may be anticipated in design for typical, average, or ideal patterns of practice. The observed relationship between this particular aspect of driver behavior and the demographic information on sex and age suggests the desirability of further study of a wider range of demographic factors, since discovery of substantial relationships could have most useful consequences for efforts to improve driving practice.

Further examination of the patterns themselves leads to the possibility that drivers may make substantially different interpretations of the meaning of zones than do those who design them. The observed—but sometimes anomalous—relations between the patterns of passing and other variables studied provides a challenge for further investigation.

The abundance of interesting and surprising results which come from this small study points out the great need and justification for further, more detailed work in this area, with larger samples and better control. Only then can this pilot effort have served its true purpose.

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A Study of Driver Variability in Car Following and Open Road Driving

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This research investigated the variability of driver velocity control when operating a vehicle under eight different treatment conditions. The following three variables were considered: (a) an instruction for normal or best control, (b) presence or absence of a leading vehicle, and (c) presence or absence of a speedometer.

•DURING THE past few years, many studies have been made of the car following situation. The majority of these have dealt with a situation in which a vehicle is operated in a relatively strange and hostile environment, frequently under traffic density conditions which can hardly be considered typical. Other studies have dealt with normative data consisting of relatively few measures on each of a large number of vehicles. The first type of study does not necessarily produce results applicable to the vast majority of highway driving situations. The second type is viewed as being unable to deal adequately with any time-dependent aspect of car following on other than a macroscopic level.

The intent of this study has been to provide detailed microscopic information on both car following and open road driving for a reasonably large sample of drivers, based on extended periods of driving. Information was sought with regard to the following specific questions:

1. Does a given driver's velocity pattern when engaged in car following differ from that when engaged in open road driving?
2. Is a driver's velocity pattern stable and repeated under similar situations?
3. What is the limit of an individual's ability to control his velocity pattern?
4. Does relative headway affect the velocity pattern of a given driver?
5. To what extent need a driver rely on a speedometer when engaged in car following or open road driving?

EXPERIMENTAL METHOD

Sixteen subjects were employed in this study. Each subject drove the research vehicle for approximately 15 miles of familiarization driving plus eight times over the test highway before participating in the experiment. The test highway, a 14-mile section of I-71 north of Columbus, Ohio, was selected on the basis of geometry to minimize any possible highway effects.

The variables employed in this study were presence or absence of a speedometer, presence or absence of a leading vehicle, and an instruction to drive normally (N) or to drive with best control (B). The eight treatment combinations obtained from these variables, as shown in Table 1, were administered to the subjects randomly. Table 1 also gives the instructions corresponding to each treatment.

The LC+N instruction was intended to produce the type of car following that is frequently observed on the highway where one vehicle will follow another with a headway that apparently is great enough to minimize the influence of the leading vehicle on the

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TABLE 1

TREATMENTS AND CORRESPONDING INSTRUCTIONS EMPLOYED

Instruction Type	Lead Vehicle Present (LC)		Lead Vehicle Absent	
	Speedometer		Speedometer	
	Present (Sp)	Absent	Present (Sp)	Absent
Normal (N)	Sp+LC+N "Follow the lead car as you normally would if it just happened to be in front and you did not want to pass. You will have your speedometer."	LC+N "Follow the lead car as you normally would if it just happened to be in front and you did not want to pass. You will not have your speedometer."	Sp+N "On this run, I want you to drive as you normally would on the open highway. You will have your speedometer. Try to hold your speed down to 65mph."	N "On this run, I want you to drive as you normally would on the open highway. You will not have your speedometer. Try to hold your speed down to 65mph."
Best (B)	Sp+LC+B "Follow the lead car as if he were leading you somewhere and you did not want to get lost. You will have your speedometer."	LC+B "Follow the lead car as if he were leading you somewhere and you did not want to get lost. You will not have your speedometer."	Sp+B "On this run, I want you to drive maintaining a constant velocity of 65mph as best you can. You will have your speedometer."	B "On this run, I want you to drive maintaining a constant velocity of 65 mph as best you can. You will not have your speedometer."

following vehicle. The LC+B instruction was intended to produce a somewhat shorter headway than the LC+N condition without producing the obvious bias that would result if the subject were instructed to follow at a specific distance. It was hoped that these instructions, through their open-ended phrasing, would produce reasonably typical driving behavior.

The N and B instructions for open road driving were intended to produce results that were analogous to the LC+N and LC+B conditions. It was thought that the N instruction would produce behavior characteristic of normal open road driving and the B instruction would produce results indicative of the maximum velocity control a driver could exhibit without training.

The presence or absence of the vehicle speedometer was crossed with each of the four treatments outlined, to give the eight treatments employed in this study. This variable was included to gain an indication of the normal reliance a driver places on this device as a source of information feedback. Extreme deterioration of a driver's velocity control when operating without the speedometer would imply a reliance on this source of feedback information.

Figure 1. Instrumented and leading vehicles.

Two research vehicles were employed (Fig. 1). The subject drove the rear vehicle during each treatment and the front vehicle was operated as the leading vehicle only during the four treatments requiring it. The leading vehicle was operated at an indicated speed of 65 mph. A prior study has shown that the experimenters were able to control the lead vehicle velocity with a variance of less than 0.9 mph^2.

Although the highway used in this study was open to traffic, other vehicles interacted only rarely with the research vehicles. When an interaction did occur, the run was repeated.

The leading vehicle was equipped with a lapse-time camera (Fig. 2) operating at the rate of one frame every two seconds. Headway was derived geometrically from this film for each run which involved the lead vehicle. The vehicle driven by the subject contained an oscillograph recorder which provided an analog record of the velocities driven.

DATA ANALYSIS

The data for the 16 subjects consisted of oscillograph records for each of the eight treatments with photographic data for four treatments. Both types of records were transposed into numerical form by an oscillograph reader having both printed and punched card output. Each frame of the film data was read to obtain relative headway. The corresponding velocity point was also read. A sampling interval of two seconds was used in the reduction of both sets of data; approximately 350 points were read from each type of data for each treatment.

Figure 3 is a plot of the velocity patterns for a randomly selected subject's (No. 8) runs when no lead vehicle was present. Each trace was constructed by plotting the data points read from the oscillograph record. The increased variability in the two

Figure 2. Lead vehicle with camera.

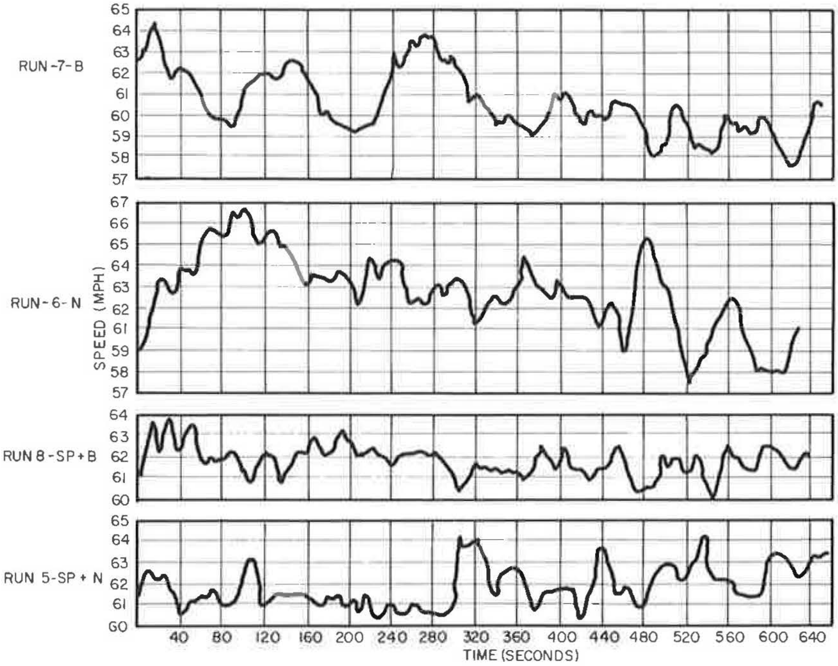
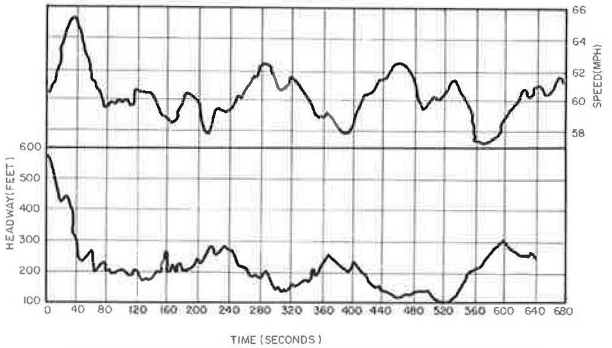
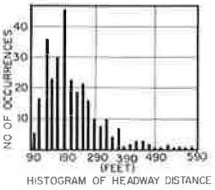
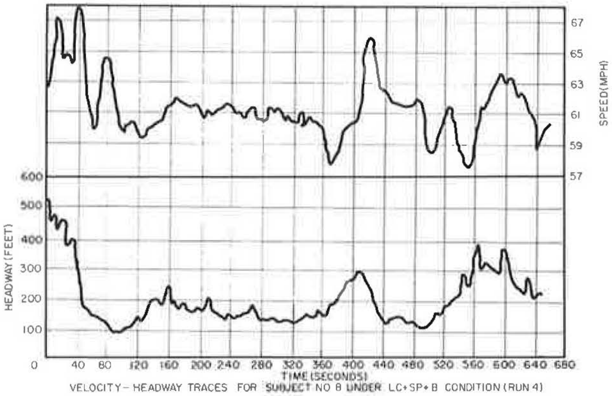


Figure 3. Velocity traces for Subject 8 under no-lead-vehicle condition.



VELOCITY-HEADWAY TRACES FOR SUBJECT NO 8 UNDER LC+SP+N CONDITION (RUN 3)





VELOCITY-HEADWAY TRACES FOR SUBJECT NO 8 UNDER LC+SP+B CONDITION (RUN 4)

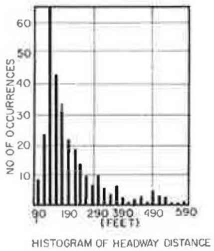
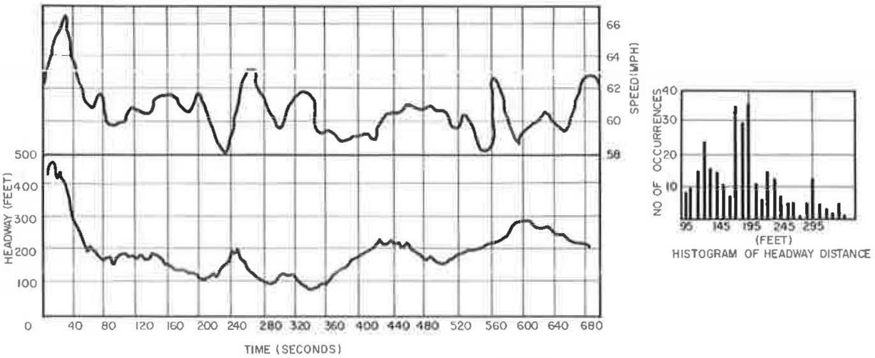
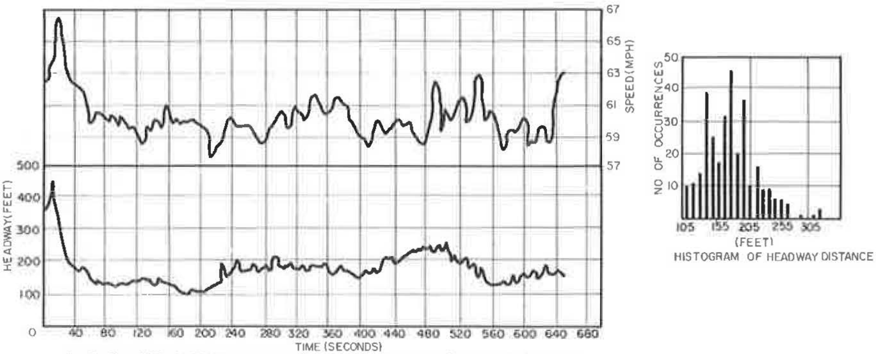


Figure 4.



VELOCITY-HEADWAY TRACES FOR SUBJECT NO8 UNDER LC and N CONDITION (RUN 1)



VELOCITY-HEADWAY TRACES FOR SUBJECT NO 8 UNDER LC and B CONDITION (RUN 2)

Figure 5.

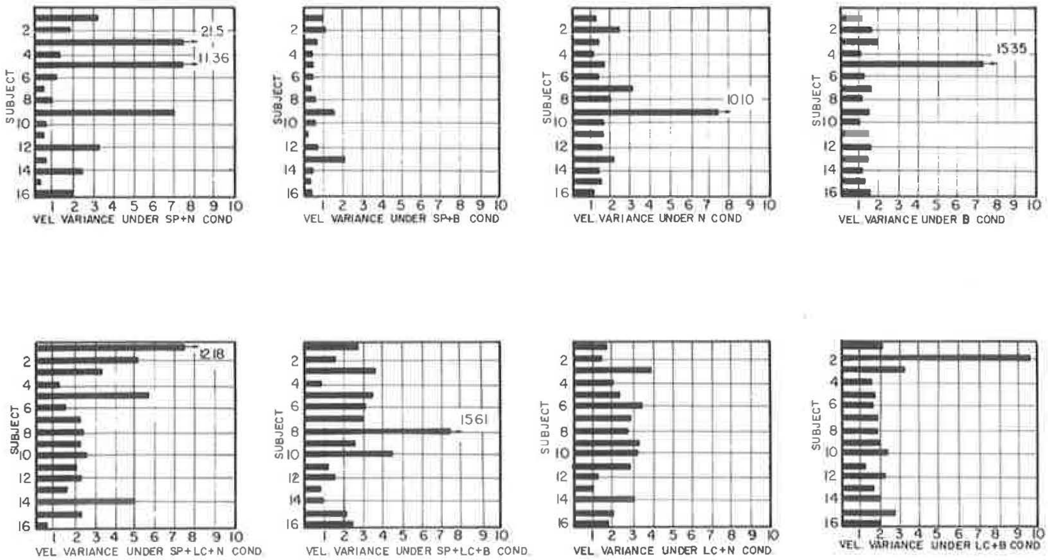


Figure 6. Plot of velocity variance for each condition for all subjects.

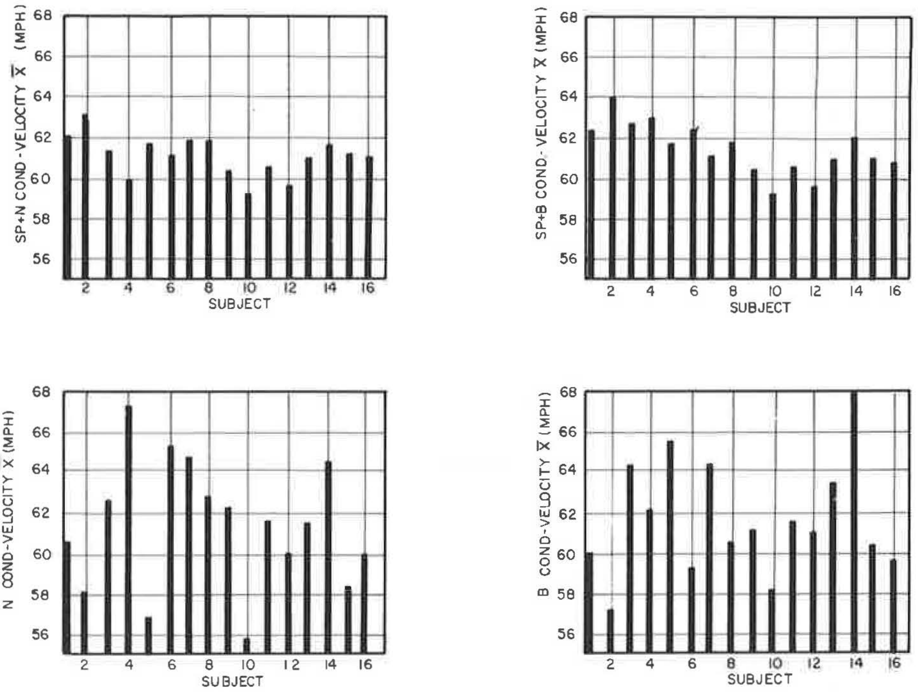


Figure 7. Plot of velocity $\overline{X}$ for each subject for runs without lead vehicle.

runs without speedometer (Runs 6 and 7), compared to those (Runs 5 and 8) with speedometer, is strikingly obvious.

Figures 4 and 5 are graphs of the velocities and headways for Subject 8's four runs with the lead vehicle present. To the right of each graph is a histogram of the headway for that run. In each graph the bottom trace represents headway and the upper trace represents speed. It is apparent from these two graphs that the presence or absence of the speedometer had little effect on this subject's performance when car following.

TABLE 2

ANALYSIS OF VARIANCE

Source	df	Mean Square		F Ratio		Level of Significance (%)	
		$\overline{V}$	6^2_V	$\overline{V}$	6^2_V	$\overline{V}$	6^2_V
Sequences	7	7.55	16.31	1.30	1.44	-	-
Runs	7	6.86	6.19	2.60	0.81	5	-
TREATMENTS:							
SP	1	0.89	1.55	0.338	0.204	-	-
LC	1	56.39	1.44	21.36	0.190	5	-
I	1	0.74	24.81	0.280	3.28	-	10
SP+LC	1	0.11	27.68	0.042	3.66	-	10
SP+I	1	0.05	11.57	-	1.53	-	-
LC+I	1	2.04	24.16	0.771	3.19	-	10
SP+LC+I	1	0.15	10.68	-	1.14	-	-
Residual	42	3.37	10.85	1.27	1.43	-	-
Ss/Seq.	8	5.81	11.28	2.20	1.49	10	-
Ss/Runs/Seq.	56	2.64	7.57	-	-	-	-

Also the difference can be seen between the N and B conditions, with respect to velocity, for the two runs with (Fig. 4) and the two runs without (Fig. 5) the speedometer.

Figure 6 presents the velocity variance of the eight runs of each subject plotted on the basis of instructions. Figure 7 presents the average velocity for runs which did not involve the lead vehicle; runs involving the lead vehicle were not included because their average velocities are effectively the same because of the constant lead vehicle velocity.

Several attempts have been made to analyze the velocity data in terms of repeatable patterns over a period of time. A Fourier analysis was conducted on the data for each run. In each case, the analysis was continued to 40 coefficients with approximately equal values resulting for all coefficients. Attempts have been made, with no positive results, to smooth the data on the basis of fixed-interval averaging.

Table 2 presents the results of an analysis of variance of the mean velocity and velocity variance for each of the 16 subjects' runs. The order in which the subjects performed their eight runs and the presence of the lead car had significant effect on average velocity at the 5 percent level. The treatment instructions and the treatments SP+LC and LC+I significantly affected velocity variance at the 10 percent level. The significance of the run order indicated that some transfer took place when particular treatments occurred before others or that some temporal factor influenced the performance. It would be reasonable to assume that if a subject's first four runs involved a lead vehicle, his velocity maintenance on runs not involving a lead vehicle and speedometer would be better than if runs without the lead vehicle were made first.

On the basis of the initial analysis of this study, two additional studies will be conducted. The first will be designed to investigate further the effect of instructions on the subject's performance. The study will consist of four factors, rather than eight, through the omission of the speedometer variable. The second study will investigate the effects of variable lead vehicle velocity. Further analysis of the data collected in the present study is being continued with particular emphasis on possible time-dependent aspects.

ACKNOWLEDGMENT

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Selection Tests—Dubious Aid in Driver Licensing

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Tests developed for selection or screening of drivers are likely to be inappropriate for public licensing. Whereas selection tests seek to eliminate all but the best in a given applicant pool (a problem of interest to the Army, to commercial transportation concerns, etc.), licensing procedures concentrate on eliminating only the more obvious misfits. Tests that have been successful for Army driver selection include attitudinal, personality and/or adjustment measures developed through thorough empirical tryout, as well as tests of information. Psychophysical measures did not prove to be successful for selection purposes.

If license bureau officials made a decision to deny licenses to applicants scoring low on a typical driver selection battery validated against an accident criterion, it would be necessary to set the cutting score on the battery at a point where approximately 23 million drivers of 100 million, currently estimated to be licensed in the United States, would have to be taken off the road. This would achieve a reduction of fatalities and other accidents from 15 to 10 million per year. If officials arbitrarily removed 10 million drivers from the road on the basis of such a selection battery, only 2 million could be expected to be drivers likely to have accidents.

Limiting licensing in terms of personal limitations of the driver is regarded as a legitimate basic approach to reducing accidents. But a broader approach is needed because accidents occur as a result of multiple, complex causes or because they do not occur with the regularity and consistency needed for research. (An accident criterion could not be used in Army research for the latter reason. A criterion based on the observations and judgments of drivers, supervisors, and associate drivers was used instead.) Real-life simulation facilities are undoubtedly needed for the study of driver accidents as a means of deriving principles of engineering traffic, vehicles and roads and as a means of identifying driver limitations.

•MANY OF us would undoubtedly accept the contention that the driver is the most complex, baffling, and vulnerable of the factors that make up the driving process. This contention has given rise to the repeated query: why are people not given more complete examinations—physical, psychophysical, and psychological—before they are licensed to drive? Hundreds of tests have been developed and used in various settings; many have been used in driver research. Despite this enormous effort, few tests are in operational use, chiefly because of the following difficulties: (a) lack of evidence that many of these tests do an accurate job of screening out those likely to have

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accidents; (b) lack of means of getting undisputed proof in terms of accidents; and (c) administrative and legislative barriers to using such tests for licensing.

Assuming that adequate tests were available for carrying out research, could the needed scientific proof of their effectiveness come from accident records? Turn any eager and inspired researcher loose with accident records and he will feel he should be able to test the worth of any theory for licensing purposes. However, accident records speak loudly but not clearly. So many variables contribute to accidents that no one variable, predominantly responsible though it may be in a specific accident, can measurably account for any significant proportion of the various accidents. The problem is multi-dimensional. Although traffic accidents occur all around us, paradoxically they occur too rarely for research. Research ideally needs replication of identical circumstances if responsible significant variables are to be isolated.

The driver on the road thwarts the advance of science because he can exercise common sense. He is adaptive in ways his vehicle is not. When at the wheel, he typically (though not always) compensates for his deficiencies. If he is color blind, he learns positions and shapes of traffic control signs. If his reflexes are slow, he tends to avoi getting into situations requiring fast stops or turns. He notes an appalling magnitude of accidents and drives defensively. Human factors scientists might well voice their complaint that the traffic accident "is not well enough organized for research."

So far the discussion has been concerned with the difficulties in carrying out research in this area, particularly research which might lead to more stringent testing and tighter licensing regulations. If stringent tests were used in licensing, the screams of rejected driver's license applicants would be heard in every state capitol. But considering the present state of the art, much of the wailing would, in our opinion, be justified.

It is important to make a differentiation at this point between predictive tests used for selection and tests used for licensing. The difference is crucial. In the case of selection and screening, management is interested in eliminating all but the best. In the licensing process, public officials concentrate on eliminating only the more obvious misfits. The Army is concerned with both the selection and the licensing problem, since many Army jobs require driving as an incidental duty. There are also many Army personnel whose primary duty is driving, e.g., Military Police and ammunition truck drivers.

The senior author devoted a number of years to the direction and conduct of researc activities to develop devices for the selection and licensing of Army motor vehicle operators (8). The program has been large in scope but was justified because the U.S. Army is the largest user of motor vehicles in the world.

First, hundreds of existing tests were sifted since the literature appeared to be full of promising leads. Many of these leads were examined to serve as bases for research hypotheses, but most of these hypotheses were ultimately rejected. For many years an assumption existed among driver officials and researchers that visual and psychophysical measures were among the most effective predictors of efficient and safe driving. Close examination of the findings available at the start of the Army research did not bear out this hypothesis (1, 4). Admittedly, in the Army setting this hypothesis had less of a chance of being substantiated since military personnel in the classification stage of Army processing have already met certain minimum physical, visual, and psychophysical requirements for admission to military ranks. Hence such measures as field of vision, eye dominance, visual acuity, reaction time, depth perception, peripheral vision, auditory acuity, resistance to glare, and strength of grip could not be expected to differentiate as significantly among Army driver applicants as they do among civilian applicants. Further, there was little evidence that these measures had significant validity for the civilian population with respect to safe and efficient driving. Therefore, new measures were required to select further from the military manpower pool those Army personnel who would be safe and efficient drivers. Emphasis was placed on development of measures of driving information, emergency driver information, personality characteristics (in the form of likes and dislikes, attitudes, interests, and biographical information), and a variety of specially tailored psychological measures (10).

Almost 2,000 drivers were tested and their driving ability was examined by superiors and training NCO's (5). Six tests from a total of 22 were finally selected as the most predictive and arranged into the following operational selection batteries:

Battery I[1]

Driving Know-How Test—Knowledge of good driving practice.
Attention to Detail Test—A measure of perception requiring the rapid counting of the letter "C" interspersed among large numbers of the letter "O".
Army Self-Description Blank (Transport)[2]—A measure of personality and attitudinal factors such as interest, annoyances, likes, dislikes, preferences, driving and mechanical experience.
Age to 30 years.

Battery II[3]

Emergency Judgment Test—Knowledge of solutions to emergency driving problems.
Visual Judgment Test—Ability to match identical pairs of words as they are presented in progressively smaller type.
Two-Hand Coordination Test—A measure of eye-hand coordination.

It had been recognized at the outset of the research that a simple count of accidents would probably be inappropriate as a criterion of safe and efficient driving for three reasons:

1. During a single enlistment it would not be possible to obtain enough of a sample of the man's driving record to serve as a reliable index.
2. The distribution of accidents would be sharply curtailed in the Army because of the removal from driving duty of any driver who had had a second or third accident.
3. Driving conditions varied widely from motor pool to motor pool (2).

It was decided to employ a carefully constructed criterion based on the observations and judgments of drivers, supervisors, and associate drivers. An instrument was developed, including rating scales and a checklist. Drivers serving as examinees were rated on 11 experimental scales by an average of 4.8 supervisors and 12.5 associates. Of the 11 scales, four were chosen on the basis of (a) reliability coefficients, (b) correlation with an accident-responsibility index, (c) intercorrelation among the scales, and (d) results of a factor analysis of the intercorrelations (12).

[1] Validity coefficients on three samples of 331, 192 and 194 drivers ranged as follows: driving know-how, 0.31 to 0.41; attention to detail, 0.20 to 0.30; Army self-description blank, 0.18 to 0.41; equally weighted composite, 0.39 to 0.51.

[2] The Army Self-Description Blank for Transport may be of unusual interest and promise. The largest Army effort was devoted to the development of this 150-item test. Slightly more than half the items reflect the personality profile of the accident-prone individual. Other items are concerned with personality as demonstrated through attitudes toward the driving habits of others and self-estimates of driving habits and skills. An individual's judgment of another's driving may well reflect his own driving habits; the unsafe driver might check "Most drivers fail to stop completely at STOP signs." In Army research, driver experience such as knowledge of how to "soup-up" a car was found to be not unrelated to driver ability; hence, some "hot-rod" items might be included. For self-estimates of judgment, driving ability and reactions to frustrating situations, such items as "I can handle a car at high speeds" or "I am a careful driver driver" may be useful. Items attempting to measure past history of the driver may be appropriate, including difficulties he may have encountered with credit or disciplinary agencies—indicative of a negative complex in his total attitudinal behavior pattern as opposed to a clean slate indicating a positive complex (9).

[3] Validity coefficients on three samples of 331, 192 and 194 drivers ranged as follows: emergency judgment, 0.20 to 0.33; visual judgment, 0.15 to 0.34; two-hand coordination, 0.09 to 0.23; equally weighted composite, 0.24 to 0.28.

The four scales included in the criterion instrument were:

1. How often does he have near accidents?
2. How well does he react to sudden changes of traffic conditions?
3. How much does "temper" or "nerves" affect his driving?
4. How well does he know his own limitations—poor sight, slowness, lack of skill, etc.—and drive according to what he knows he can do?

The same raters were asked to indicate, for each of 105 descriptions of unsafe driving habits, how ratable (observable) the behavior was and how important it was to safe driving. The 15 statements adjudged most ratable and important were selected for the final checklist. The mean rating on the four scales received double weight and the mean number of checks received had unit weight in the composite criterion score. Sample checklist items included: "shows off when driving," "drives too fast for road conditions," and "follows other vehicles too closely" (11).

The predictive test battery finally developed had a reasonable amount of validity for the purpose of selection—in the range of 0.35 to 0.40 (8). It should be stressed that benefits from this validity can be achieved if the selection ratio is favorable, that is, when many more applicants for driving are presented for assignment than will ultimately be accepted. In the Army, this difficulty is only partially overcome by requiring that all replacement stream enlisted personnel processed through reception stations be administered Motor Vehicle Driver Selection Battery I. However, driving jobs in the Army do not get top priority comparable to combat, electronics and other jobs—perhaps they should not. So even here the selection ratio is not entirely favorable

Enlisted men not previously qualified on Driver Battery I, or officers and warrant officers who are to be considered for standard drivers' licenses, are tested at local installations by Army Motor Vehicle Driver Selection Battery II. A road test is an important part of licensing procedure and consists of a physical evaluation examination (visual acuity, field of vision, foot reaction time, and hearing) and of a driving performance test including manipulation of controls, practice run, depth perception test, check for emergency equipment, before-operation check, and location of instruments.

The three tests of Driver Battery I are scored as number of correct responses and sum obtained. The positive contribution of age to good driving is accounted for by adding to this sum a figure corresponding to two times the applicant's age in years to a maximum age of 30. The final figure is then converted to the Army Standard Score scale with a mean or numerical average of 100 and a standard deviation of 20. When these 20 points are added to and subtracted from the mean of 100, a framework is established into which about 68 percent of scores normally fall. Standard scores, as the name implies, help establish standard interpretations of test performance. At reception stations, a standard score of 90 on Battery I is passing and serves as a screen for further testing (road testing) and licensing for driver vacancies. A standard score of 90 is that score achieved by 65 to 70 percent of all applicants when standardized on a sample which roughly approximates the applicant population.

The scores of Battery II are the number of correct answers converted to Army Standard Score units and averaged. A passing score on Battery II is 80 or may be placed higher for a greater degree of driver judgment or responsibility in selected assignments, as in that of Military Policeman or Investigator.

A score of 70 on the road test is the final requirement for licensing. However, weaknesses revealed on any portion of the physical evaluation or the road test are brought to the attention of the examinee as a basis for further practice or training or for his awareness (so that he can allow for his deficiencies when driving), whether the road test is successful or not. The physical evaluation standards include 20/30 acuity in each eye, a lateral range of 75° on each side of the focus line, foot reaction time to and including 0.60 seconds, and ability to hear the whispered voice at 15 feet. Thus, to obtain an Army Motor Vehicle (Transport) license, a man must pass Driver Battery I at the reception station or Driver Battery II at his local installation, take a physical evaluation test, and pass the road test.

One problem which concerned Army researchers may be of interest. Faced with the requirement of obtaining qualified drivers in foreign countries, the U.S. Army considered appropriate tests for selecting indigenous personnel as drivers, particularly in countries where the motor vehicle is practically a rarity (3). One difficulty is language. Another, perhaps even more serious, is the cross-cultural gap which is not bridged automatically with direct translations—a fact which Army human factors researchers had learned in connection with other research programs. The approach was to construct a battery of tests appropriate for non-English speaking nationals. Several tests were developed with pantomine administration instructions, including types used in the regular Army Driver Battery—attention to detail, two-hand coordination, emergency judgment, and driving know-how. Included were tests of mechanical principles, tool usage, driving concepts, and ability to perceive change in detail of abstract patterns of automotive equipment. A tryout of the regular test battery along with the new tests indicated the feasibility of non-language tests, and such a battery is now available for use when necessary.

In another special study, the U.S. Army Personnel Research Office considered whether differential requirements should be stipulated for drivers of light vs heavy vehicles (6). The tests developed for the selection of Army drivers of wheeled vehicles of any kind did not show practicality for differentiating drivers with good potential for vehicles of differing weights, although one set of tests isolated showed slightly more validity for heavy vehicles.

It seems important to offer some discussion of the significance of selection tests with specified validity coefficients as they relate to possible use in public licensing of drivers. In 1962, there were nearly 100 million persons in the United States licensed to drive vehicles. About 15 percent or 15 million were involved in fatal and other accidents. How many drivers would have to be taken off the road to reduce the total number of accidents to 10 million per year?

We think that a liberal estimate of validity of a good selection battery for drivers is 0.35 for drivers of Army vehicles, using a rating criterion. But because a rating criterion does not necessarily coincide with variance of actual incidence of accidents, we reduced our estimate to a validity coefficient of 0.20. Using this coefficient, public officials would have to take 23 million drivers off the road to reduce the number of accidents to 10 million per year (Fig. 1). Further, the cost to the public would be a loss of 18 million good drivers for the benefit of removing 5 million poor drivers (see Appendix for statistical methods used in estimating these and later figures).

If, through the expenditure of funds for additional research effort, we could raise the validity coefficient to 0.35, public officials could reduce the number taken off the

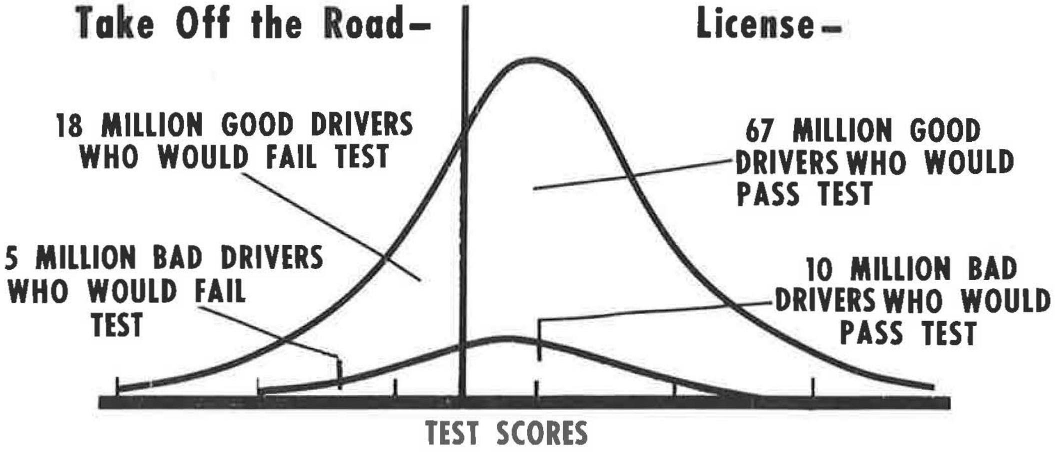

Figure 1. Impact of selection battery for licensing using validity coefficient of 0.20.

road to 18 million to achieve the reduction to 10 million accidents per year (Fig. 2). The loss this time would be 13 million good drivers.

What would be the impact on accident reduction if public officials would be willing to remove 10 million drivers? Using a validity coefficient of 0.20, we might expect only 2 percent of the 10 million to be bad drivers (Fig. 3). With a validity coefficient of 0.35, we might expect 3 percent of the 10 million to be bad drivers (Fig. 4). In eacl case, the increase in validity results in only slight improvement for the research mone invested.

But consider a case of much higher validity. Table 1 provides the answer where 10 percent is retained as the point of cut or disqualification. If a predictive validity coefficient of 0.90 could be achieved, about nine-tenths of the drivers removed would be

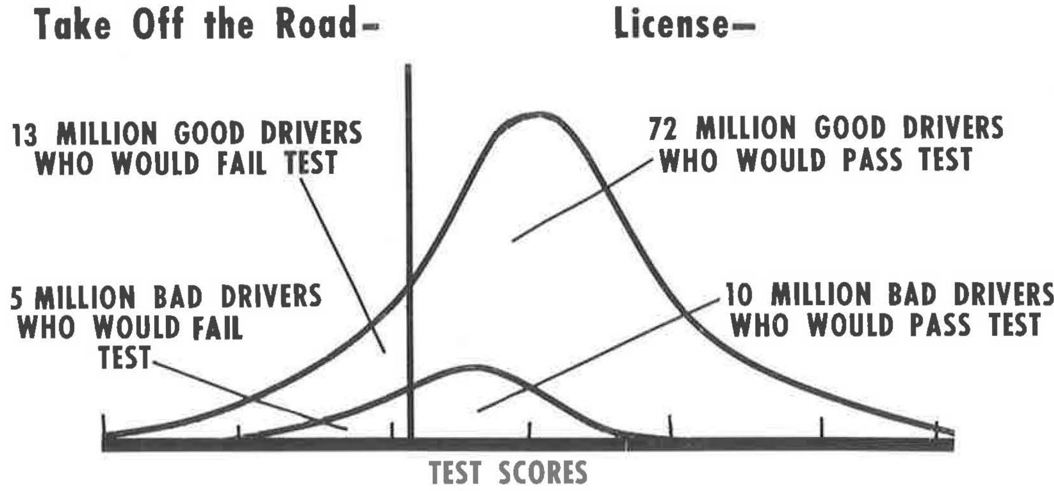

Figure 2. Impact of selection battery for licensing using validity coefficient of 0.35.

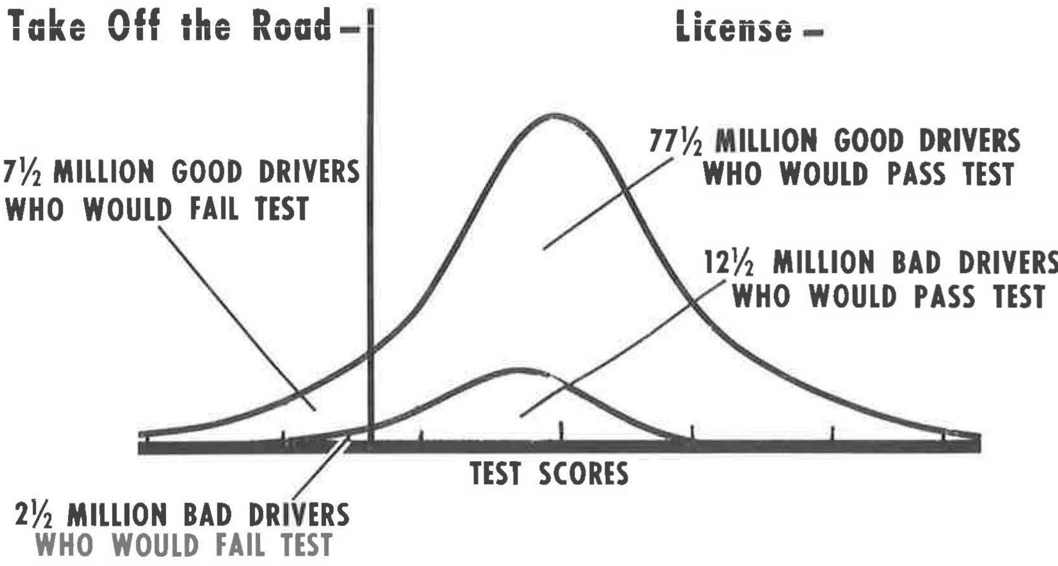

Figure 3. Impact of not licensing lowest 10 percent, with validity coefficient of 0.20.

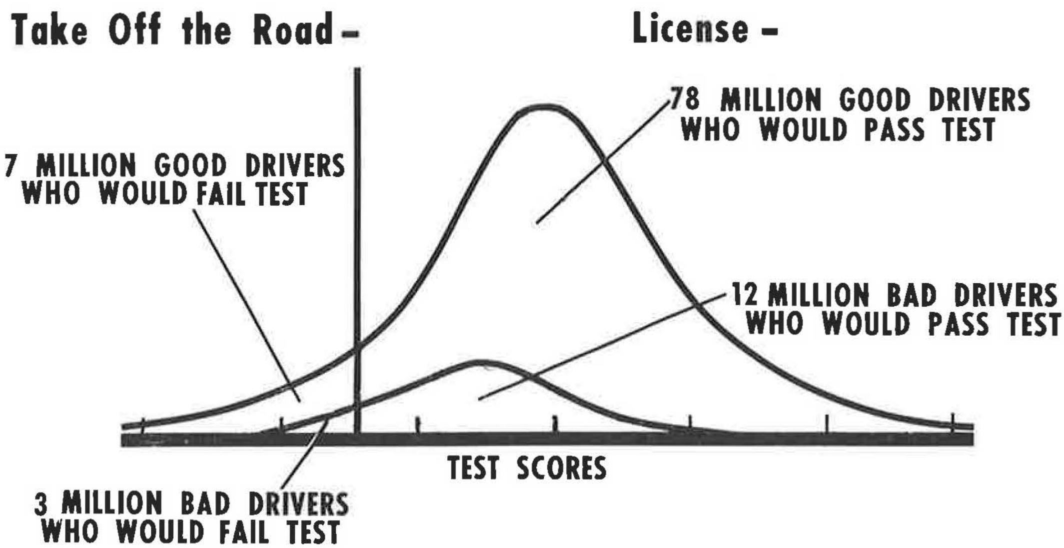

Figure 4. Impact of not licensing lowest 10 percent, with validity coefficient of 0.35.

TABLE 1

EFFECT ON DRIVER ACCIDENT REDUCTION OF REMOVING BOTTOM 10 PERCENT USING SELECTION TESTS FOR LICENSING

Validity Coefficient	Total Removed (millions)		Total Licensed (millions)	
	Bad Drivers	Good Drivers	Bad Drivers	Good Drivers
0.10	1.9	8.1	13.1	76.9
0.20	2.4	7.6	12.6	77.4
0.30	3.0	7.0	12.0	78.0
0.40	3.5	6.5	11.5	78.5
0.50	4.2	5.8	10.8	79.2
0.60	5.0	5.0	10.0	80.0
0.70	5.9	4.1	9.1	80.9
0.80	7.1	2.9	7.9	82.1
0.90	9.1	0.9	5.9	84.1

bad drivers and only one-tenth good drivers, and the bad drivers licensed would be reduced to about 6 percent. Similarly (Table 2) for a validity coefficient of 0.90, with a goal of reduction of the annual accident rate from 15 million to 10 million, virtually all good drivers tested in applying for licenses would receive them. Of course, these examples remain highly theoretical, since no immediate prospects exist for raising validity coefficients beyond present levels.

We may have simplified the picture a bit in that we have not taken into account the supposition that with fewer cars on the road, the progression of reduced accidents would not necessarily be a straight line, but might accelerate in curvilinear fashion. Our main purpose, however, is to illustrate why the present state of the art in driver selection research does not yield a dramatic solution to the problem of reducing our national motor vehicle accident rates when such selection devices are employed in the practical setting of general licensing.

One reason for the ineffectiveness of selection tests applied to a licensing situation is the administrative necessity to leave the point of cut at a low level. Nevertheless, the reader might be interested in learning how selection tests having validity coefficients

TABLE 2

EFFECT ON DRIVER ACCIDENT REDUCTION OF USING SELECTION TESTS FOR LICENSING[a]

(In millions)

Coefficient	Total Removed (millions)		Total Licensed (millions)	
	Bad Drivers	Good Drivers	Bad Drivers	Good Drivers
0.10	5.0	23.0	10.0	62.0
0.20	5.0	18.2	10.0	66.8
0.30	5.0	14.0	10.0	71.0
0.40	5.0	11.4	10.0	73.6
0.50	5.0	7.5	10.0	77.5
0.60	5.0	5.1	10.0	79.9
0.70	5.0	3.2	10.0	81.8
0.80	5.0	1.7	10.0	83.3
0.90	5.0	0.6	10.0	84.4

[a] To reduce accident rate from 15 million to 10 million.

as low as 0.35 or even 0.20 can be of value for selection purposes. Figure 5 and 6 illustrate this phenomenon graphically. As the vertical bar is moved to the right indicating a progressively higher cutting score on the test battery, the 100 million decreases, of course, but the proportion of poor drivers among those selected decreases more rapidly than the proportion of good drivers. Such a procedure requires that the number of applicants far exceed the number to be selected and be practical in only very limited commercial situations. Tables 3 and 4 give the values for 10, 25, 50, 75 and 90 percent points of cut. Maximally effective selection is achieved for a validity coefficient of 0.35 when only the top 10 percent is selected—9.7 percent accident-free drivers vs 0.3 percent accident drivers!

In summary, our research experience in the Army with selection tests and selection batteries is this:

1. Use of selection procedures in public licensing, at least with the types of variables now generally in use, can make only a slight contribution to the accident reduction problem.

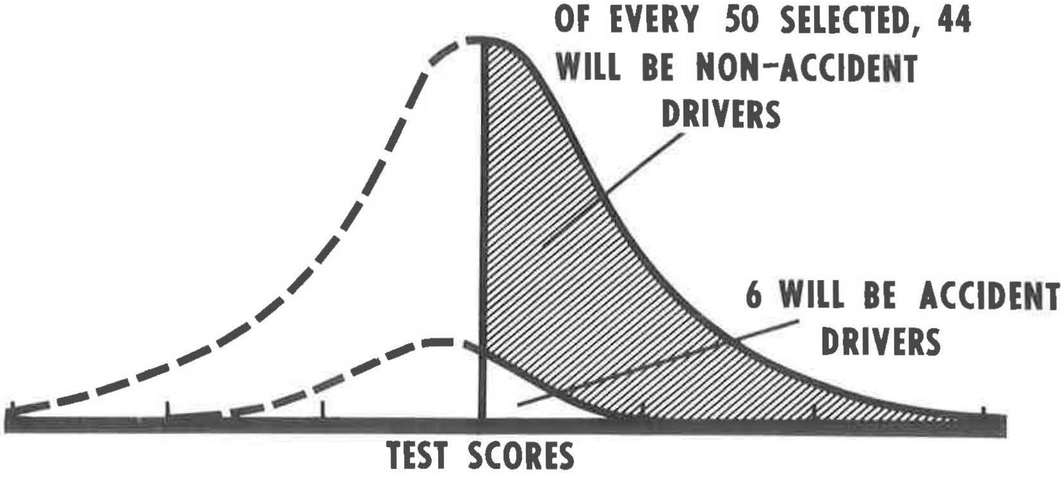

Figure 5. Influence of cutting off bottom 50 percent of selection applicants, given validity coefficient of 0.20.

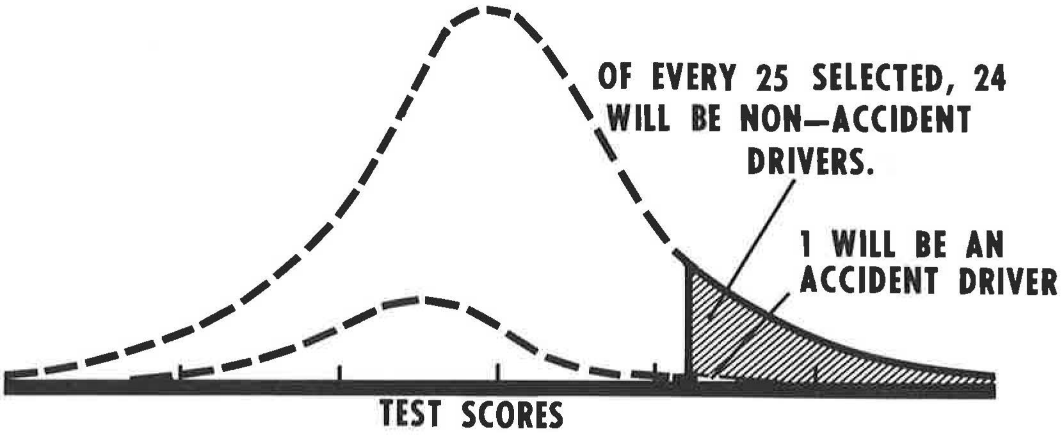

Figure 6. Influence of cutting off bottom 75 percent of selection applicants, given validity coefficient of 0.35.

TABLE 3

IMPACT ON ACCIDENT REDUCTION OF REJECTING VARIOUS PROPORTIONS OF DRIVER APPLICANTS, VALIDITY COEFFICIENT OF 0.20

Selection Ratio[a]	Percent Rejected		Percent Selected	
	Bad Drivers	Good Drivers	Bad Drivers	Good Drivers
10	2.4	7.6	12.6	77.4
25	5.3	19.7	9.7	65.3
50	9.4	40.6	5.6	44.4
75	12.6	62.4	2.4	22.6
90	14.2	75.8	0.8	9.2

[a] Percent to be eliminated.

TABLE 4

IMPACT ON ACCIDENT REDUCTION OF REJECTING VARIOUS PROPORTIONS OF DRIVER APPLICANTS, VALIDITY COEFFICIENT OF 0.35

Selection Ratio[a]	Percent Rejected		Percent Selected	
	Bad Drivers	Good Drivers	Bad Drivers	Good Drivers
10	3.0	7.0	12.0	78.0
25	6.6	18.4	8.4	66.6
50	11.0	39.0	4.0	46.0
75	13.8	61.2	1.2	23.8
90	14.7	75.3	0.3	9.7

[a] Percent to be eliminated.

2. A reasonable amount of success has been possible in the use of selection batteries to assist in selecting only the best drivers in terms of the likelihood of fewer accidents occurring. To generalize to commercial driving, if relatively few are to be selected from among many who apply, selection devices will contribute to more efficient and safe motor vehicle operation.

3. Of selection devices thus far developed and submitted to research evaluation, attitudinal factors, particularly as reflected by personality and adjustment measures reported in this paper, probably can make a significant contribution. But truly effective measuring devices of this nature would have to be developed on the basis of empirical data obtained. (Many of the research studies conducted today in the driver research area reveal background and personality results which are next to uninterpretable because the studies deal with extreme cases only—those with many accidents and those with striking records of absence of accidents—with the bulk of the drivers in the normal range being omitted.)

4. In general, psychophysical measures (visual and auditory skills and capacities, physical coordination and reaction time) make only minor contributions to predicting driver performance. On the other hand, a factor such as age usually is significant in that younger people tend to be more identifiable in the negative complex of driving behavior.

Licensing in terms of the personal limitations of the driver is still a legitimate basic approach to reducing accidents. But a broader approach is obviously needed for the traffic accident usually occurs not as a result of a single variable—inattentiveness because of fatigue or preoccupation, slippery roads, or insufficient light—but as a result of a complex of variables. Indeed, one of the encouraging signs of progress attributable to driving safety researchers is their recent success in reducing the total problem to manageable proportions. Just as the military man and the weapon or machine he serves and the enviroment in which he performs his assigned duties are all viewed as a man-machine or man-weapons system, so should the driving process be considered a system. Viewed this way, malfunction of the driver system can occur because of (a) poorly designed and maintained vehicles, (b) poor roads and poorly controlled traffic patterns, and (c) poor driving.

We believe ultimate reduction of accidents is likely to come about through more effective human engineering of the automobile, the road, and the traffic system, as well as through greater effort in understanding the driver process. Particularly needed is a better understanding of relationships involved in various situational behaviors (psychological functioning in driving both at night and in daylight on turnpikes, in rural areas, and in the city).

The research approach dictates highly sophisticated simulation facilities and should be directed toward the alternate outcomes of educating the potential driver to difficulties inherent in a variety of conditions or limiting the situations in which he may be permitted to drive.

In conclusion, if public officials are inclined to shrink away from action which would eliminate millions of drivers from the road to reduce the national accident rate, then it may be profitable to embark on the so-called systems approach of driving research. This would be essentially a reexamination of the total problem to consider man-vehicle-road-traffic and to derive principles of engineering traffic, vehicles, roads, and identifiable driver limitations.

ACKNOWLEDGMENT

The authors are obligated to John J. Mellinger, U.S. Army Personnel Research Office, who provided consultation on statistical methods presented in the Appendix.

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Appendix

STATISTICAL METHODS FOR ESTIMATING EFFECT OF SELECTION TESTS ON ACCIDENT REDUCTION

Question 1

Assuming a biserial correlation of 0.20 between a driving ability test and a criterion (no accidents vs some accidents), and assuming criterion frequencies of 85 million no-accident drivers and 15 million accident drivers, how many drivers with low test scores should be eliminated in order to reduce the 15 million accident group to 10 million?

Figure 7 conceptualizes the problem in which a continuous varaible x corresponds to scores on the driving ability test, a dichotomous variable y corresponds to criterion

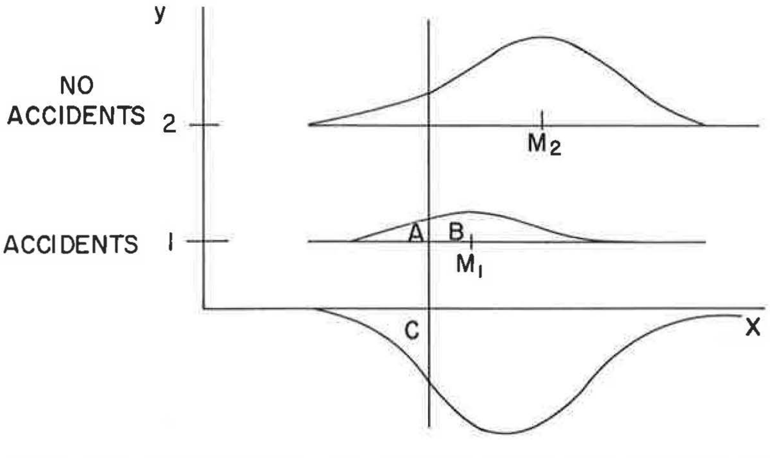

Figure 7. Method for determination of cutting score for accident vs no-accident drivers.

performance, M_2 is the mean x score of the no-accident drivers, and M_1 is the mean x score of the accident drivers. The numbers of people in the criterion groups are 85 million and 15 million, respectively. Scores of 2 and 1 can be arbitrarily assigned to the criterion groups. The vertical cutting line divides the accident group, or No. 1 distribution, into areas A and B, with 5 and 10 million people, respectively. The problem is to determine how many people are contained in area C. The methods described below assume normality of both marginal and conditional x distributions. This assumption is reasonable if the correlation between x and y is low.

Using the biserial correlation formula

$$r_b = \frac{(M_2 - M_1)\,pq}{Z\sigma x} \tag{1}$$

the assumptions provide sufficient information to solve for the difference $M_2 - M_1$. A second equation involving M_2 and M_1 can be written by making use of the fact that their weighted sum is zero. Both equations are expressed in terms of normal deviates of the x distribution. These two equations are $M_2 - M_1 = 0.366$ and $0.85M_2 + 0.15M_1 = 0$. Solving for M_1, we obtain $M_1 = -0.311$. This number describes the extent to which the No. 1 distribution is shifted to the left of the marginal x distribution

The cutting line divides the No. 1 distribution into two parts, A and B. The corresponding normal deviate, in terms of the No. 1 distribution, is -0.43. To express this number in terms of the standard deviation of the x distribution, we must take into account that the No. 1 distribution has a standard deviation slightly smaller than the x distribution. The No. 1 standard deviation is described in the equation

$$\sigma_1 = \sqrt{1 - r^2} = \sqrt{1 - 0.20^2} \tag{2}$$

for which the solution is 0.980. The normal deviate of -0.43 multiplied by the standard deviation of 0.980 gives -0.421, which is expressed in terms of the standard deviation of the x distribution. This number, when added to the mean of the No. 1 distribution ($M_1 = -0.311$), gives a final result of -0.732. This number describes the location of the cutting line in terms of normal deviates of the x distribution. Using tables of the normal curve, we learn that the area below the cutting line (area C) is 0.232, or 23.2 million people.

The conclusion is that roughly 23 million drivers would have to be eliminated to remove 5 million accident drivers. Of these 23 million, 18 million constitute no-accident drivers.

Question 2

Assume a correlation of 0.35 instead of the correlation of 0.20 used previously. Using the same method we get the following results: $M_1 = -0.544$; $\sigma_1 = 0.875$; $-0.43 \times 0.875 = -0.376$; $-0.376 + -0.544 = -0.920$.

The final number, -0.920, describes the location of the cuttling line with respect to the x distribution. The area below this normal deviate is 0.179, or 17.9 million people. Thus, to remove 5 million accident drivers, a total of about 18 million driver would have to be eliminated.

Question 3

Assuming a correlation of 0.20, how many accident drivers are removed by eliminating the 10 million drivers who scored lowest on the driving ability test?

The method of solution here is the reverse of that of Question 1. We are given area C and wish to solve for area A. The normal deviate corresponding to the bottom 10 percent of the x distribution is -1.281. Subtracting the mean of the No. 1 distribution

(-0.311) gives -0.970; when this number is converted to normal deviates of the No. 1 distribution by dividing by 0.980, the resulting normal deviate is -0.990. The area below this normal deviate is 0.161, which in the present case corresponds to 2.42 million people. In other words, removing the 10 million drivers with lowest scores on the driver ability test eliminates about 2.4 million accident drivers. The ratio of total drivers to some-accident drivers, about four, is roughly the same here and in Question 1.

Question 4

Assume a correlation of 0.35, instead of the correlation of 0.20 used in Question 3. From the same initial normal deviate of -1.281, the mean of the No. 1 distribution (-0.544) is subtracted; the result of -0.737 is converted to normal deviates of the No. 1 distribution by dividing by 0.875, giving a final normal deviate of -0.842. The area below this deviate is 0.200, corresponding to 3 million people. Thus, if the bottom 10 percent of all drivers are removed, 3 million accident drivers are eliminated.

Perceptual Analysis of the Driving Task

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This paper attempts to develop a unified and comprehensive model of the driving task having practical and psychological validity. The model specifies the critical tasks of driving, the critical skills to perform these tasks, and some objective measures of these skills.

In the model, the major tasks for the driver are the perceptual organization from moment to moment of a field of safe travel (a region in which the car can move unimpeded), a minimum stopping zone (the smallest region through which the car must move to come to a full stop), and a comparison of these two fields. The driver's organization of these two fields, or the field-zone ratio, is a control stimulus guiding the control actions to the vehicle. That is, the driver varies the speed and direction of movement of the vehicle to maintain a safe field-zone ratio—one in which the field is greater than the zone.

Objective measures of driving skill derived from the model include the "smoothness" of driving, measured by speed and direction changes over time; i.e., the driver who from moment to moment correctly perceives his field of safe travel and minimum stopping zone and maintains the field of safe travel greater than the minimum stopping zone has little occasion for sudden and jerky movements due to contingencies that could have been foreseen.

Experiments are designed to test the predictions derived from the model and to further develop the model.

•MOST STUDIES of human factors related to driving performance attempt to relate some characteristic of the driver, independently measured, to a measure of driver performance. Few studies have been concerned with the behaviors carried out in the process of driving itself (1). According to DeSilva (2), "A really thorough analysis of all the various factors which go to make up driving skill has never been made."

In this paper we begin to develop a model of the driving task which specifies: (a) the critical tasks to be performed and the critical skills required to perform these tasks, and (b) the conditions the driver tries to optimize as he moves along the road. We also describe objective measures of driving that seem useful, as well as a researc program and a pilot study to investigate the relationship of these skills to roadway and driving conditions, driver experience, and physiological and emotional states.

To date several models of the driving process have been presented (5, 6, 7, 8, 9). Of the two general models of the driving task, Michaels' model (5) is concerned broadl with the human functions involved in driving to discover what aspects of the driving tas overload human capabilities and thereby to suggest roadway designs better matched to human capabilities. Task simplification is the major concern. Ross (6) developed two models of driving to explicate the causes of accidents. Thus, he is concerned with factors which cause the breakdown of single driver-vehicle-roadway or multiple driver vehicle-roadway systems.

Paper sponsored by Committee on Road User Characteristics.

The other three attempt to define skillful driving more closely. Interpreting empirical data, Smith and Cummings (7) have singled out certain goals, routines and procedures which distinguish the skillful driver from the accident-producing driver. The critical value for driving effectiveness of the routines and procedures developed by Smith and Cummings has not yet been conclusively demonstrated in an experimental evaluation. The Christner and Ray (8) model of the driving task is based on systems analysis, control and information theory. It is concerned with superhighway driving and framed in terms of engineering requirements rather than behavioral skills. Moreover, it does not yet identify objective indicators of driving skill. Over twenty-five years ago Gibson and Crooks (9) presented a basic framework of critical stimuli guiding driving and critical states the driver tries to maintain. To develop the model further, perceptual skills must be identified and objective measures of the skills developed.

Among the studies which present quantitative methods and measurements which may be used to evaluate driving skill are those of Jones and Potts (10) and Greenshields (11). The former deals with a specific quantity, "acceleration noise," or variability as an overall measure of driving performance. The Greenshields study presents a detailed method of investigating driving skills and several measures aimed at reflecting skillful driving, one of which, total speed change, is closely related to acceleration variability.

THE CURRENT MODEL

Following Gibson (9) our model would view driving as a form of locomotion with a tool, the car. Locomotion is guided by perception, so that paths are found in the visual field leading to a destination without collision with obstacles. Hence, in driving, visual perception is considered more critical than the motor skills of controlling the vehicle. For most driving tasks, the motor responses are relatively simple, easily mastered and relatively invariant, once the driver knows the relationship between his responses to the vehicle and the vehicular output. The visual scene the driver perceives is constantly changing and must be continually organized. On the basis of this organization, the driver is seen as making compensatory motor responses to the vehicle in the form of speed and direction changes.

Critical Tasks of Driving—Assessment of Optimal State

The critical tasks to be performed and the conditions to be optimized are as follows:

1. The perceptual organization from moment to moment of a path or series of paths, the "field of safe travel," where the driver can move without colliding with obstacles or leaving the roadway. This field as perceived by the driver should be in reasonable accord with objective reality.
2. The perceptual organization from moment to moment of the smallest region within which the driver could come to a full stop if necessary, the "minimum stopping zone." This should also be in reasonable accord with reality for the speed at which the car is moving, the condition of the brakes and the roadway surface.
3. The comparison of these two fields to assess the optimal state; i.e., the minimum stopping zone at a given moment is less than the field of safe travel. The driver should maintain a field of safe travel greater than the minimum stopping zone; the ratio of the field to the zone should be greater than unity, for if they are roughly the same, the space needed to stop the car is the only space available in which the driver can move and the driving is dangerous. If the field becomes less than the zone and the driver has to stop suddenly, he will have a collision.
4. The translation of the overall route to the destination into a series of momentary courses to follow, with planning far enough in advance so that at any instant the course lies within the field of safe travel. For example, if a driver wants to make a right turn from a fast moving stream of traffic, he must move into the proper lane well ahead of time, give up his desired course now outside the field of safe travel, or take the risk that might be dangerous.
5. While carrying out the specified tasks, a driver is continually making compensatory changes in the car's direction and speed to achieve an optimal state; namely: (a) the

car should be headed within the field of safe travel, (b) the minimum stopping zone should be less than the field of safe travel, and (c) the car should be moving on a course leading to the ultimate destination.

While organizing the information from the terrain and making control responses to the car, the skilled driver is also organizing the perceptual information he receives from the car itself as it moves along the terrain. These kinesthetic, auditory, tactual and visual cues from the car, in combination with cues from the terrain, form the totality of cues on which driving is based.

Critical Perceptual Skills

According to Gagne (12), the nature of the information-processing skills required to perform the critical tasks of driving are (a) observing, (b) identification, and (c) interpreting skills.

Sensing or Observing.—This involves noting the presence or absence of differences in stimulus information. Since sensory capacity per se has not been correlated with driving performance (4), it is reasonable to assume that the critical factor is the ability of the driver to use his sensory capacities systematically. Under pressures of time, the driver must develop an efficient observational procedure enabling him to sense changes that occur.

Efficient scanning may be accomplished by a sequential scanning routine, as taught by the Smith system (7). Thus, the observing behavior is carried out under a set of instructions by which the individual continues to tell himself where to look (12). Some kind of scanning and search routine, not necessarily intuitively obvious, is evidently a requirement for efficient driving. Gagne reports (12) that scanning and search routines as a prelude to detection have been successfully taught to military personnel who must carry out missions in the dark. An initial sensing of movement puts into operation a systematic routine of observing "out of the corner of the eye" to use the more sensitive foveal receptors. Such routines must be systematically learned because they are counter to daytime seeing habits. Studies are needed to explore the advantage of different scanning and search routines for varying driving conditions, night vs day, for example.

Identification.—This involves classifying the stimuli into meaningful categories on the basis of information stored in memory against which the input can be matched. The meaningful categories are environmental changes which may affect the field of safe travel or the minimum stopping zone. According to Gibson some of these factors are (a) stationary obstacles such as parked cars, walls, curbs, or ditches, which determi the boundaries of the field of safe travel; (b) moving obstacles, e.g., pedestrians, other vehicles, particularly those approaching from the front or side, and vehicles in the rear when the driver slows down or turns; (c) barriers to sight, e.g., darkness, rain, fog, headlight glare, curves in the road, crests of hills, blind corners, or parke cars; (d) legal obstacles such as traffic lights, road markings, and rules of the road, e.g., not passing on the right; and (e) the speed of the driver's own vehicle because increasing speed decreases maneuverability, thus narrowing the field of safe travel.

Interpreting.--This skill involves the development of expectations—translating the present stimulus information into possible future outcomes on the basis of rules or strategies stored in memory. For example, the driver who wishes to pass another driver has to interpret various cues and rules and decide whether or not he will be able to pass the other car. The rules or strategies he uses in interpreting are of three types: (a) rules of the road, e.g., the width and curvature of the roadway and whether the roadway is one-way or is accommodating two streams of traffic; (b) the rules based on nonhuman cues on the part of the other driver such as the way his wheels are turned, or whether his taillights are on indicating that he is slowing down; and (c) rules having to do with human behavior in general, e.g., the age and sex of the other driver, whether the other driver appears fatigued or perhaps intoxicated—all of which yield additional information about the other driver's possible course of action.

Objective Performance Measures of Driving Skill

As the driving scene changes from moment to moment, the driver tries to compensate for or match these changes by his control responses to the vehicle to maintain an optimal state. An optimal state was defined as that in which the field of safe travel is greater than the minimum stopping zone. Therefore, skill in driving is reflected by the accuracy with which the driver perceives the field of safe travel and the minimum stopping zone, and in the ratio of the field to the zone he maintains over time. Driving skill could also be measured by the driver's output to the vehicle which reflects his perception of the two fields and the field-zone ratio.

We have elected the measures derived from the driver's output to the vehicle to measure his performance. Specifically, we have selected "smoothness" of driving as measured by speed changes over time, called acceleration noise by Jones and Potts (10), and direction changes over time as the two main objective performance measures of driving skill. Clearly, the smoothness of a driver's speed-time plot or direction change-time plot will reflect the nature of the roadway and traffic conditions. These plots will also reflect skill in processing and organizing the information of the driving scene. A driver who accurately processes the incoming information has less occasion for abrupt speed and direction changes due to unexpected contingencies. The skillful driver would tend to be a "smooth" driver.

Additional measures of driving skill which can be derived from the model were singled out by Greenshields (11). He found that drivers of different skill levels (as measured by their past histories) varied in the total number of control responses made. Specifically, the more skilled drivers had fewer accelerator actions, brake actions, total speed changes, and steering wheel reversals.

EXPERIMENTS TO TEST MODEL AND DEVELOP PARAMETERS OF DRIVING PERFORMANCE

In the experiments planned and under way, the critical skills and the task conditions are the independent variables; measures derived from the control responses to the vehicle are the dependent variables. The experimental equipment consists of a standard four-door passenger car equipped with a Drivometer and a tachometer. Experiments were divided into four classes, as we attempted the following:

1. Class I—to manipulate variables affecting the field-zone ratio (width and curvature of road, etc.) and to show that changes in these variables are mirrored in changes in driving performance, e.g., smoothness of driving as measured by the plot of speed changes over time (acceleration noise);
2. Class II—to show that the performance measures singled out as critical (the plot of speed changes over time) do, in fact, reflect driving skill by obtaining driving performance measures from drivers of different skill levels as assessed from past driving histories;
3. Class III—to identify and measure the critical driving skills (search, identification, and interpretation) and to show the relationship of these skills to performance measures derived from output responses to the vehicle.
4. Class IV—to single out emotional and/or physiological states which significantly affect the driver's perceptual skills and to evaluate the effect of these physiological and emotional states on the driver performance measures.

PILOT STUDY

To date we have analyzed one pilot study which yields data supporting some of the hypotheses to be tested in Class I and II experiments. The equipment used consists of an experimental car equipped with a Greenshields Drivometer (11) which measures total number of steering wheel reversals, speed changes, accelerator actions, and brake actions per trip, and total trip time, which according to the current model reflect smoothness of driving or driving skill. The vehicle is operated by subjects (Ss) on an experimental track at Bolling Air Force Base made up of unused airstrips and taxiways a little over a mile in length in the shape of a U.

The Ss were twelve AirForce personnel ranging in age from 19 to 24. Each filled out a Driver Inventory form indicating how long he had been driving, how many miles he drove per year, the type of driving he had done (e.g., rural or urban), and his violation and accident history. All Ss were tested in the experimental car along the U-shaped track on two consecutive days. Each day they drove along the track for 16 trials or laps. Each S alternately made four laps of outside turns followed by four laps of inside turns until the 16 laps were completed. On the first day all drivers were asked to drive at 30 mph. On the second day, half of the experienced and half of the inexperienced drivers were asked to drive at 45 mp and the remainder at 30 mph.

The main independent variables in the experiment were the two variables postulated to affect the field of safe travel and the minimum stopping zone: (a) taking turns on the inside vs outside of the track, and (b) going at different speeds along the track. The third variable was driving skill defined in terms of total driving experience. The main dependent variables were the Drivometer measures.

The following experimental questions are to be answered by the study:

1. Are the measures reliable?
2. Do they covary with manipulable roadway conditions, factors which affect the field of safe travel and the minimum stopping zone, of the current model?
3. Do they reflect driving skill?

TABLE 1

DRIVING PERFORMANCE MEASURES OF SIX SUBJECTS ON TWO CONSECUTIVE DAYS[a]

Driving Performance Measures	Mean No. per 16-Mile Trip		
	Day 1	Day 2	t Value[b]
Speed changes	851.0	874.8	1.0
Accelerator actions	72.5	61.5	1.89
Steering wheel reversals	967.8	938.0	0.58
Brake actions	92.8	106.5	1.71
Total time	415.6	410.6	0.78

[a] Conditions were identical for both days.
[b] None of the differences were significant.

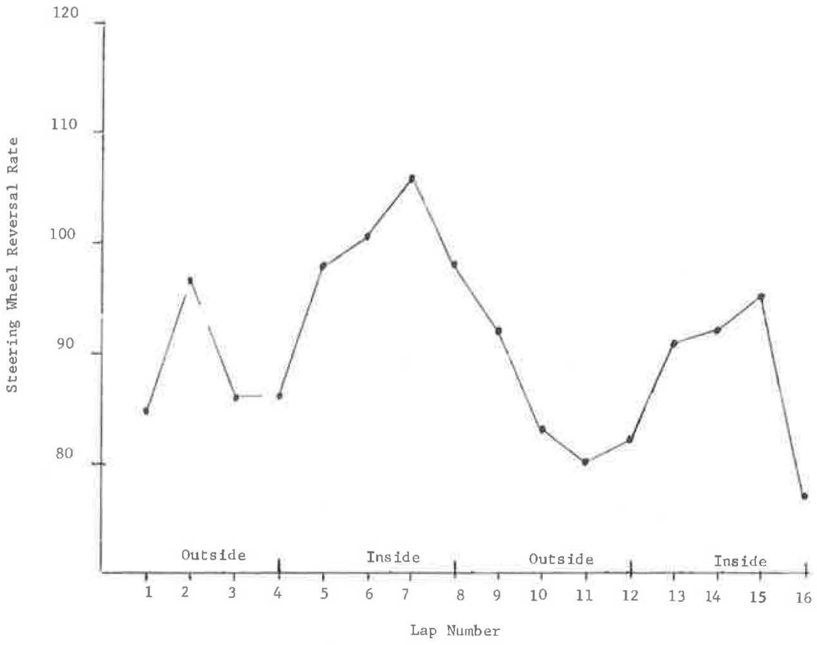

Figure 1. Mean steering wheel reversal rate for six subjects driving on outside (laps 1-4 and 8-12) and inside of track (laps 4-8 and 12-16).

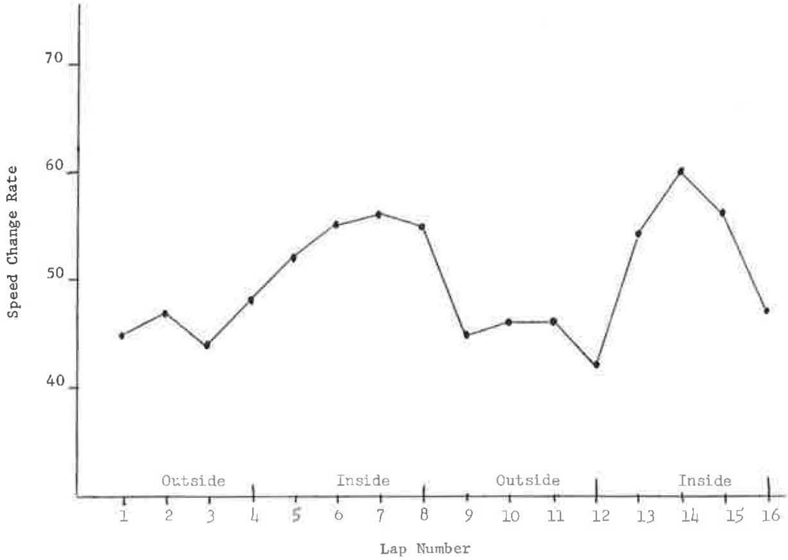

Figure 2. Mean speed change rate for six subjects driving on outside (laps 1-4 and 8-12) and inside of track (laps 4-8 and 12-16).

Results

The results indicate that the measures are reliable in comparing each S's performance across the 16 laps. Using Kendall's Coefficient of Concordance, the correlation across trials was +0.44 (significant at the 0.01 level) for the measure of speed changes and +0.58 (significant at the 0.01 level) for steering wheel reversals. Furthermore, the data of the six Ss who were tested at 30 mph on two different days indicated that their mean performance on all measures was not significantly different on the first and second days (Table 1). In fact, in the case of steering wheel reversals and accelerator actions, the correlations between the first and second days (using Spearman Rho) was +0.95, significant at the 0.01 level.

The measures were found to covary with manipulable roadway conditions which affect the field of safe travel and minimum stopping zone. For example, in comparing the driver's total number of steering wheel reversals and speed changes on the inside of the track with those on the outside (Figs. 1 and 2) and a "t" test, more total steering wheel reversals and speed changes on the inside of the track were observed. The "t" was significant at the 0.01 level for steering wheel reversals and at the 0.001 level for speed changes (Table 2).

TABLE 2

DRIVING PERFORMANCE OF TWELVE SUBJECTS ON INSIDE VS OUTSIDE OF TRACK

Driving Performance Measures	Mean per 8-Mile Trip		
	Inside of Track	Outside of Track	t Value
Speed changes	450.7	391.6	6.29[a]
Steering wheel reversals	537.1	488.3	3.43[b]

[a] $p < 0.001$ [b] $p < 0.01$.

TABLE 3

COMPARISON OF DRIVING PERFORMANCE OF SIX SUBJECTS UNDER TWO EXPERIMENTAL CONDITIONS[a]

Driving Performance Measures	Mean No. per 16-Mile Trip		
	45 mph	30 mph	t Value
Speed changes	980.3	847.8	8.2[b]
Accelerator actions	131.6	84.6	2.9[c]
Brake actions	123.0	78.0	4.05[d]
Steering wheel reversals	950.5	1,148.0	4.12[c]

[a] Condition 1 at 30 mph, Condition 2 at 45 mph; Condition 1 was administered on Day 1; Condition 2 on Day 2.

[b] $p < 0.001$. [c] $p < 0.05$. [d] $p < 0.01$.

As for the effect of higher speed (45 mph vs 30 mph) on these measures (Table 3), it was found, using "t" tests, that there were more total speed changes (significant at the 0.001 level), more brake actions (significant at the 0.01 level), more accelerator actions (significant at the 0.05 level), but fewer steering wheel reversals (significant at the 0.01 level).

None of the measures appeared to differentiate drivers on the basis of amount of driving experience per se, except for total trip time. That is, the more experienced drivers drove around the track faster. Using the Mann Whitney "U" Test, this finding was significant at $p < 0.07$. However, in comparing the highly experienced drivers who had one or more accidents for which they were responsible (N = 3) with those who had none (N = 3), the trend was for the accident drivers to have more total driver actions, e.g., speed changes, accelerator actions, brake actions, and longer total trip times. However, only this last finding was significant at $p < 0.05$. The accident drivers had fewer steering wheel reversals, possibly because they took more time.

Discussion

In general the results of the pilot study support the current model of the driving task. The finding that Ss driving on the inside of the U-shaped track had more steerin wheel reversals and total speed changes could be predicted from the model. In the inside lane, the driver has a more variable and smaller field of safe travel (the field of all possible paths through which he can move unimpeded and without leaving the roadway). Thus, the driver must make more compensatory changes in the field of safe travel and minimum stopping zone to have a safe field-zone ratio.

The finding that at higher speed (45 mph vs 30 mph) the drivers had more speed changes, accelerator and brake actions can also be explained by the model. Higher speed reduces the field of safe travel and increases the minimum stopping zone resulting in a smaller field-zone ratio; thus, the driving is less smooth as evidenced by the greater number of accelerator and brake actions and speed changes. Also, at the higher speed, the driver is covering more area in a unit of time and has fewer possibl paths available to him. He, therefore, does less steering or selecting of the possible paths he can take.

The driving task was evidently too simple to reflect differences in driving experien However, with our very small sample of three accident and three non-accident drivers the general trend was for the measures to reflect driving skill, as was found by Greenshields (11). However, final confirmation of these results must await a larger scale study.

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