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# DYNAMIC FEEDBACK CONCEPTS OF HUMAN VEHICULAR BEHAVIOR AND THE HIGHWAY INFORMATION DISPLAY SYSTEM*

By

Henry S. R. Kao
Highway Safety Research Institute
The University of Michigan

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Henry S. R. Kao

ABSTRACT

This paper proposes a conceptual framework for the understanding of human vehicular behavior and the design of highway information system. Central to this are the fundamental concepts of sensory-motor feedback control in human performance. Human vehicular performance is considered as a closed-loop operator-vehicle-road tracking system with built-in time and space coherence. Essential to efficient motor control of vehicle operation is the multi-dimensional channelling of the motor-sensory information of the vehicle movement through feedback control mechanisms.

Highway information display system is believed to be maximally efficient if multi-channel sensory inputs are utilized in design. Based on the levels of space-time coherence for efficient human vehicular performance, a primary and an auxiliary information system is suggested for highway tracking. The possible utilization of several sensory modes for information display is discussed. Research evidence is cited for the theoretical assumptions.

## 1. INTRODUCTION

This paper is an attempt to place within a conceptual framework the basic elements of a modern highway information display system. So far, there has been little effort toward theoretical formulation of the basic design principles in this area. Research and design have primarily emphasized visual considerations, starting from the dominant guiding principle of the conventional stimulus-response concept of behavior organization and motor learning, and display has generally been designed as part of a one-directional (open-loop) man-machine control system. The limited application of information theory to design has not yet outgrown this conventional framework, even in road signs (Froshung, 1963).

In cybernetic terms, the highway information system is an integral part of a dynamically interacting, feedback-regulated man-machine-roadway control system. On the basis of thirty years' research on human tracking, this is considered basically a closed-loop system with well defined force, spatial and temporal properties. Visual display is considered not as a one-directional source of input to the operator within a vehicle on the road, but as an important element positively interacting with the dynamic performance movements of the whole operator-vehicle-road tracking system. Sensory modes other than vision are equally important as desirable means of information display and must be considered for optimal use of our knowledge of human perception in designing a highway information system.

## 2. BASIC ELEMENTS OF A FEEDBACK CONTROL SYSTEM

In the past thirty years of research on human performance, the most important conceptual development has been the incorporation into behavior theory of the idea of feedback. Although long recognized previously by psychologists involved in tracking research during World War II (Craik, 1947), Wiener (1948) formulated the concepts of feedback control of tracking in a mathematical context, using the term cybernetics to crystalize the concept of living control.

A feedback control system generally consists of three primary functions: it generates movement of the system toward a target or a defined path; it compares the effects of this action with the true path to detect error; and it utilizes error signals to redirect the system. Feedback mechanisms also define the control system as a self-generating, closed-loop process that controls the patterned and organized behavior, in contrast to an open loop process directly governed by environmental stimuli. This closed-loop feedback concept may be applied to instrumental and environmental design for human performance and skill learning, of which human vehicular behavior and the design of the highway information system are practical examples. Since tracking research in the war years was the forerunner of the present cybernetic control concepts some basic properties of closed-loop tracking systems should logically be discussed before making any theoretical application to perceptual information design for highway systems.

## 2.1 Components of Man-Machine Control System

### a. Closed-Loop Vs. Open-Loop

In a continuous control system, display and control are the main components of the entire system. A display subsystem provides information input regarding objects, targets or machine paths in the environment which set the goals for tracking performance. The control subsystem consists of tool-using behavior, with various levels of motor manipulation for precision performance according to the path or target set by the display.

In the open-loop type of human tracking performance, the relation between display and control presupposes a series of discrete motor responses separated by fixed intervals. By contrast, in the closed-loop concept of tracking, performance accuracy as consisted of a highly organized, precisely coordinated motion pattern of at least two component movements: positioning and rate control. Tracking efficiency is space-structured relative to target movements. Performance accuracy depends on continuous or real-time sensory feedback information from the target-cursor display of spatial differences. Any discrepancy between target and cursor, recorded by feedback mechanisms, leads to an immediate motor control adjustment of the tracker toward the target or object course. Because numerous small positioning movements must be integrated with larger rate control movements, precision of tracking performance depends on the continuous regulation of these two kinds of movements by their own sensory feedback mechanisms, and their smooth integration into a well-organized tracking motion (Smith, 1962). In the design of any control system whose central component is the human being the dynamic feedback properties of the perceptual display and motor control movements of the system must be understood and taken into serious consideration for efficient human factors designs. Some of the fundamental elements of a tracking system are presented in the following Section.

b. Temporal Continuity

The basis of human tracking performance lies in the conceptualization of the motor-sensory feedback mechanisms of organized motion. In eye-hand tracking, organized motion is considered as the visually monitored eye and hand motions involved in actual tracking. Tracking is viewed not as composed of sequentially linked perception and response with measurable delays between responses, but as the rate control movements effected by an interrupted linkage of muscular responses which are regulated by a continuous outpour of afferent visual impulses from the target-cursor display. The feedback control mechanisms, sensitive to minute spatial differences between target and cursor display, constantly detect the speed and direction of rate control movements.

In this closed-loop motor tracking system temporal interruption of visual feedback is assumed to be detrimental to performance efficiency. The rate control movements of arm and hand depend upon real-time visual feedback, or the accuracy with which motor activities conform to the target course display or environmental patterns in space. Any temporal delay in the continuity of visual monitoring of the cursor-target difference generated by motor activities will disrupt this normal regulatory mechanism. This real-time property of feedback control in performance has been established through a number of research experimentations (Schul, 1965; Schmidt, 1965; Lincoln and Smith, 1952; Warrick, 1949; Foxboro, 1945; and Conklin, 1957). In this context, it will be noted that delays in feedback are generally characteristic of machine systems that partially automate human tracking and steering performance.

c. Feedback Intermittency and Motor Performance

In addition to the temporal delay effects of feedback on tracking performance, the common phenomenon of temporal intermittency of information feedback constitutes another source of sensory-motor perturbation which is detrimental to the precision control or tracking movements. Although the reaction-time or intermittency hypothesis of tracking performance based on concepts of open-loop systems was proposed some two decades ago, study of this subject in relation to real-time sensory feedback study of this subject is rather recent (Sussman, 1967; Smith and Smith, 1966). The author (1968) reported an experiment on manual tracking with several levels of visual feedback intermittency. Although less detrimental than the delay effects, increases in feedback display intermittency also proportionally increased tracking errors.

Intermittency effects are commonly manifested in situations requiring repetition of information input through sensory channels for motor response. In some tracking situations an operator is required to perform with intermittent feedback display, yet only a minor degree of intermittency is tolerable, beyond which accurate motor performance will be degraded. When the feedback of motor control effects is made intermittent and also subjected to temporal delays, performance accuracy will decrease more than in the presence of either perturbations alone (Kao, 1968).

d. Self-Generation and Self-Regulation of Control Movements

Another basic concept in the feedback regulation of human performance is the dependence of organized control behavior upon the intrinsic generation of body movements by which the organism supplies itself with differential feedback patterns which serve as the basis of subsequent motion control. Thus, such a motor-sensory stimulus and response linkage establishes a closed-loop control system (Smith and Henry, 1967; Riggs, et al. 1953). This concept, in contrast to the traditional interpretation of motion organization as discrete chaining of unitary sensory inputs, emphasizes the stimulus differences generated on the sensory surfaces by the intrinsically produced activities of the response mechanism. The individual is viewed not as passively reacting to external stimulation or emitting random responses, but as generating directionally guided control movements which produce spatial differences in stimulation. These feedback conditions define and control continuing motion reactions.

e. Instrumental Transformation of Motor-Sensory Feedback Control Mechanism

Sensory-motor feedback concepts of the determination of human motor performance also emphasize the principle of systematic transformation of real-time feedback mechanisms. In using a tool or instrument or operating a machine, an individual multiplies various sources from which he can search and receive feedback information about particular responses.

On the basis of sound neurophysiological evidence, three levels of sensory feedback have been suggested in the functional integration of human motor activities in machine and tool operation (Smith and Smith, 1966): reactive feedback, the signals an individual receives from self-generated bodily movements; instrumental feedback, received from the action of the instrument or machine; and operational feedback, received from the dynamic persisting effects of a tool-using operation on objects, materials or environmental situations.

For efficient motor performance, the different aspects of the machine, control, display and operational characteristics must be made coherent with the properties of the individual's motor movements, regulation and sensory information and integrative actions. Therefore, space and time coherence of dynamic feedback from these three variable sources of information are the key factors in human performance and motor learning. Research findings have shown that none of the three sensory feedback types alone affects performance as much as combined instrumental and operational feedback. Operational feedback has been found to be the most important of the three in efficient motor regulation of human performance. An understanding of the interactions of the variable feedback factors is necessary for the design of efficient tools and machines and of environments favorable to perceptual-motor control systems for human skill acquisition.

f. Temporal and Spatial Continuity

In a complete closed-loop, feedback regulated performance system, time and space are inseparable and essential considerations in system functioning. It has been shown in various research studies that a real-time feedback system is a necessity for optimal motor control and performance efficiency. The real-time property implies the importance of an unbreakable link or continuity of interaction between control motion and its sensory information feedback. It has been shown that feedback delay or intermittency degrades motor control. In the field of perceptual feedback display, this suggests the importance of spatial continuity for immediate feedback regulation of subsequent control activities. This is supported by experiments where zero-delay, zero-intermittency conditions resulted in the most efficient performance in tracking. In a recent study comparing continuous and intermittent visual feedback display in a compensatory tracking task (1968), the author also found tracking accuracy under intermittent visual feedback display to be poorer than that obtained under continuous display. Other researchers have previously reported deterioration of tracking efficiency with intermittent visual display generated by occluding a pursuit display (Poulton and Gregory, 1952), by regulating the illuminating target frequency (Battig et al., 1955), and by converting a sinusoidal function into a series of step functions (McConnell and Shelly, 1960; Hunt, 1961).

In feedback terms intermittency itself involves certain levels of temporal feedback delay between intermittent units and is detrimental to motor performance.

The inferiority of intermittent feedback display to continuous display may be analyzed in the blinking of eyes. The longer the period of blinking, the less visual information is transmitted through the optic nerves to the brain.

## 3. HUMAN VEHICULAR BEHAVIOR AS A DYNAMIC CLOSED-LOOP CONTROL SYSTEM

The chief concern in highway safety is an operator's ability to position the vehicle continuously and accurately within the limits or, ideally, in the center of the motorway. Accurate positioning depends in turn upon the information the operator receives from all aspects of the highway environment through most of his sensory channels about his movements, vehicle motion, speed, acceleration and other related variables.

### 3.1 Sensory Channels in Vehicular Operation

The most important sensory input is the visual mechanism as in all types of man-machine control systems. Most of our present-day highway information designs are planned in terms of the maximal message input through vision. But since human behavior is organized through multi-channel sensory feedback mechanisms, driving control should be viewed as regulated by biological feedback factors which also utilize the non-vision sensory channels.

Thus, the proprioceptive and exteroceptive receptors, with special units in the skin, muscles, tendons and joints, supply information on factors such as tension and pressure. Sensory impulses from these structures provide feedback information about bodily movements and positions as well as those of the vehicle. Sensory receptors within the vestibular organ of the labyrinth furnish continuous supplementary information on the postural movement and motion of the operator and vehicle (Henriksson, Nilsson and Andersson, 1965). The auditory system is yet another input channel in operator-vehicle performance, i.e., friction of tire with road surface, and winds in high speed driving. Any design of highway information plans should take into consideration the possible utilization of these sensory modes for effective information display and sensory inputs.

### 3.2 Self-Generation of Vehicle Movements and Motor-Sensory Feedback

As discussed previously, a closed-loop feedback system depends for precision performance on continuous sensory detection of spatial variation from the ideal path or goal in the control environment. The property of motion-generation in vehicular performance is evidenced in continued vehicle movements in deviation from the predefined roadway course. These dynamic variations are critical motor-generated sources of sensory feedback information to the operator for subsequent motion and directional control performance. In the operator-vehicle-road tracking system, dynamic operational feedback information is continuously registered as the spatial difference between the roadway course and the front-end and rear-end edges of the automobile and in terms of positional and directional changes. Figure 1 shows the basic sensory feedback loops involved in dynamic human vehicle operation (Fig. 1 inserted here). A recent study (Kao and Nagamachi, 1969) tested the application of this operational feedback concept in terms of the effects of portrayal or blocking of these portions of a vehicle on accuracy of road tracking performance in actual driving. The results showed definite detrimental effects of such visual deprivation on vehicle tracking accuracy. This supports the concept of driver performance as a closed-loop tracking task wherein the leading edges of the front and back of the car are used as cursors in guiding the vehicle relative to road markings. The data suggest also the necessity of clear roadway markings as a fundamental requirement for the completion of the closed-loop, operator-vehicle-road tracking system.

### 3.3 Continuous and Closed-Loop Nature of Vehicle Highway Control System

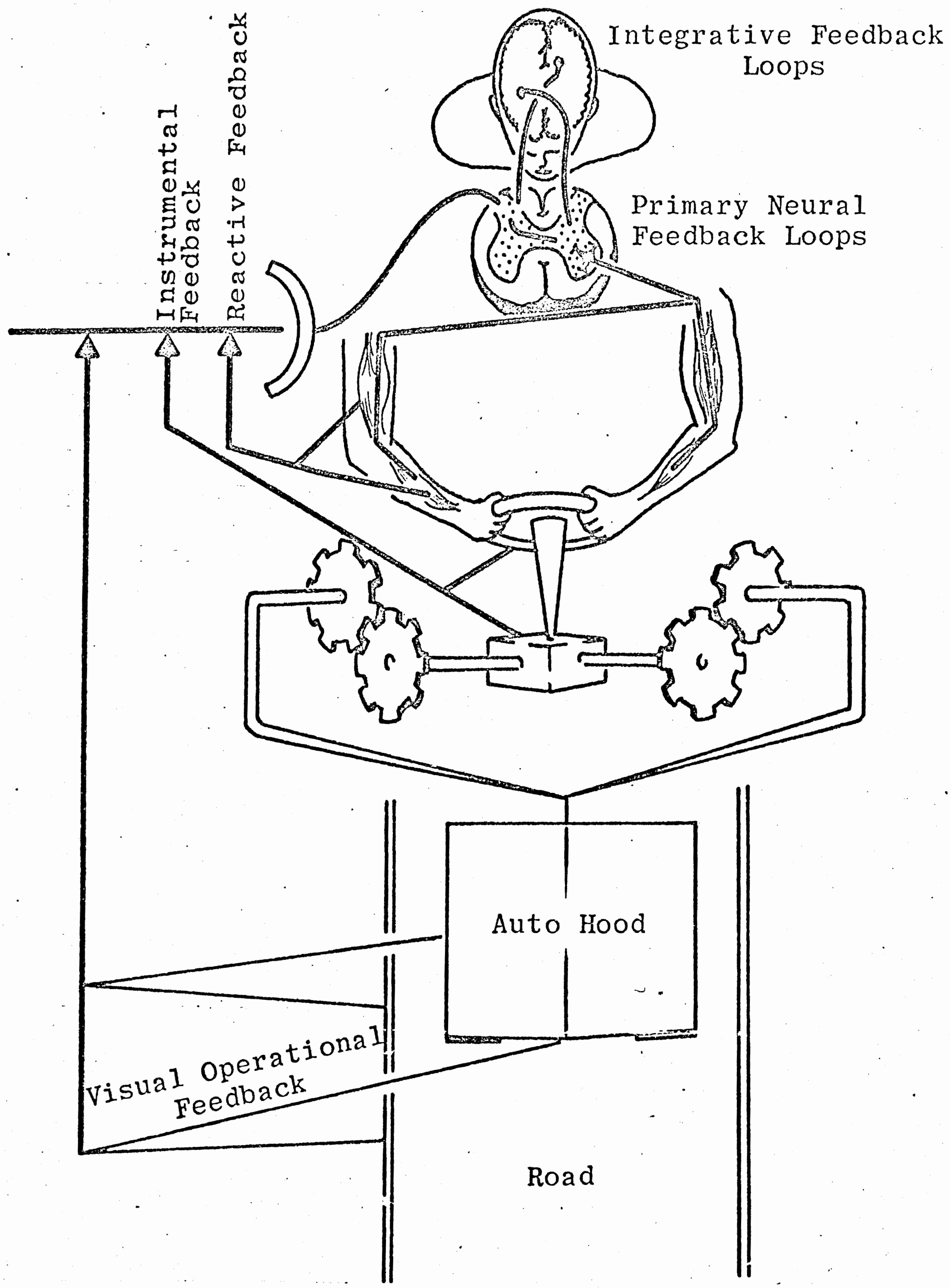


FIG. 1. The differential sources and transformation of sensory feedback information in dynamic human vehicular performance.

The closed-loop property in operator-highway tracking is established by a motor sensory circuit that links highway information indicators with the continuous spatial zeroing tracking function of vehicle movements on the road. During highway driving, the critical nature of this loop increases as a function of increased vehicle velocity because increased velocity of car movement reduces the time constants of closed-loop control in particular instants of tracking. Evidence from tracking studies (Lincoln and Smith, 1952) strongly support the feedback velocity function in driving.

Besides continuous visual display and the visual feedback of positional variations on the road, the manual control movements of the steering wheel also assume a continuous function. Circular arm and hand movements constitute smooth and continuous rate control activities in regulation and guidance of the vehicle changes which are controlled by the unbreakable visual display of the course. The precision of highway driving depends on the temporal and spatial refinement and coordination of such factors as visual displays and motor regulation of vehicular movements; the feedback mechanism as the basis for continued performance.

### 3.4 Sensory-Feedback Delay and Intermittency in Highway Tracking

As is true with all automated man-machine systems, there are certain inherent transmission delays in guidance of vehicle. Such delays have been shown to have variable detrimental effects on motor performance. Vehicle braking is no exception to this finding. Regardless of the type of steering system visual feedback delay at various levels is evident in every automobile. This is especially true of power steering systems, which reduce additional sensory feedback. Variable force feedback of hand and arm movements in steering and operation is absorbed by the automated power system which furnishes only uniform feedback information through the steering wheel. With such a reduction or elimination of tactual and kinesthetic feedback, the operator is correspondingly more dependent on visual and other sensory information for continuous manual control to achieve an equivalent level of steering performance.

The intermittency phenomenon in vehicle tracking may be rather unusual, if not entirely absent. High frequency vertical vibration on poorly constructed road surface is one example of sensory intermittency; dashed lane marking may be another. Though less severe than delayed feedback conditions, intermittent perceptual display does have certain perturbing effects on motor performance.

In normal highway driving situations, the effects of either temporal delay or intermittency or a combination of both may not be readily sensed by the operator. But when emergencies require swift execution of such operations as braking, acceleration or deceleration, the detrimental effects of delay, intermittency, and other physical factors are magnified and will definitely contribute to loss of control and eventually to fatal accidents. Sudden and momentary sensory deprivation under both delay and intermittency conditions is an area that demands immediate scientific investigation for a better understanding of human vehicular performance and the problems associated with highway safety.

## 4. VISUAL CONSIDERATIONS APPLICABLE TO HIGHWAY INFORMATION DISPLAYS

In a closed-loop highway performance system, the primary information display has been engineered through visual perception. There are several phenomena upon which an optimal design for a highway information system may be based. Some of these have been used for visual design for road information display. But great amounts of concerted effort can be exerted toward an evaluation of the present display system and possible utilization of many other visual properties for a more effective information system.

4.1 Illumination and Visibility

Illumination is an important consideration in night highway driving. Although complete illumination of high-speed ground transportation does not seem economically feasible, some particularly well traveled and potentially hazardous sections of highway do seem to warrant such measures. Numerous traffic accidents and fatalities before and after changes in street and highway illumination have been reported in favor of such installment (Darell and Dunnette, 1960; Richards, 1952). Aside from the obvious advantage of roadway illumination, certain related problems such as glare, amount of illumination and spectral quality should be given detailed consideration which is beyond the scope of this paper.

4.2 Shape and Form Discrimination

These factors refer to the capacity of an operator to recognize and identify the primitive outline of objects in the visual field from a distance, under adverse weather conditions, and under illuminated or non-illuminated visual conditions. This has been used in highway and street signing systems with fast and effective information processing value.

4.3 Light Contrast

Where lights are colorless, contrast may be manifested in brightness; and its effect lies in increasing the observed difference in brightness. If lights possess hue, color contrast shifts each one in the direction of the other's complement as well as heightening the difference (Geldard, 1953). The application of contrast to the highway information system concerns road surface design with reflectance characteristics, markings, illumination, and surface contrast between roadway and shoulders and lighting geometry. All such elements may be experimentally tested to design better display for road guidance, clear visibility and efficient vehicle control.

4.4 Color Variation

It is generally known that color discrimination is largely dependent upon the cones of the human retina. The 7 million cones clustered in the center section of the retina are highly sensitive to differences in light wavelengths, thus giving rise to the subjective sensation of color. The peripheral retina is said to be relatively colorblind, being less sensitive to light wavelengths. Color variation is good for road surface information design where greatest distinctness of the environmental situations may be discriminated during dynamic vehicular operation. Signing and signalling are the areas where color variation has been used extensively (Neuman and Davis, 1962; Huber, 1961; Birren, 1957; Forbes, et al. 1968).

These fundamental visual considerations may be experimentally evaluated and applied to design aspects of the high-speed highway information system, either as single factors or as combined multivariable modes of information display. Any aspect of such a display system should be based on the premise that operator-vehicle-road tracking is a closed-loop motion-generated control system wherein visual display is an important constituent of the feedback loop and directly influences precision performance by the operator.

## 5. VISUAL-FEEDBACK VEHICULAR CONTROL SYSTEM AND HIGHWAY INFORMATION DESIGN

Human vehicular behavior has been considered fundamentally as a real-time and real-space control system with all the properties of a closed-loop, continuous, sensory feedback regulated tracking system. The specific temporal and spatial characteristics related to human motor performance are all manifested in this operator-vehicle-road tracking system. Information display, constituting the target or path of the tracking task, is an indispensable component of the whole interacting system. Clarity, simplicity and overall uniformity are some of the basic requirements for an effective road information display system.

In the vehicular control system, the design of visual information may be considered in the light of two functional classifications of information display. From a cybernetic viewpoint, the information needed for immediate control and regulation of the vehicle is that providing real-time and dynamic visual feedback on the spatial difference between vehicle and the road. The coherence of time and space dimensions with respect to levels of performance feedback for optimal driving control is best achieved by proper visual design of the immediate road conditions ahead of the moving vehicle. The immediate two-dimensional visual display on the road surface constitutes the primary highway information system. Including the aforementioned visual design variables, primary visual display is concerned with target or road course preview, dynamic operational feedback display, visual design symmetry and spatial continuity for efficient and accurate manual control of motor vehicle on the road. The real-time and real-space nature of display design is the core of the primary visual display system.

The second level of visual display design concerns information inputs or auxiliary channels of sensory input which are supplementary and indirectly related to the dynamic control behavior itself. Signing and signalling systems belong in this latter category.

## 5.1 Primary Visual Display System

The most primitive roadway information display is the construction of a shoulder adjacent to the highway, where contrast between the two becomes the primary information for vehicle guidance and regulation. More advanced forms are the use of edgemarkings, lane markings, curbs, reflective raised markers, and other new electronic devices and delineation systems which have been used only casually without uniformity. From the dynamic tracking point of view, the target display, in the form of roadway edge and lane markings, is the most important of the primary visual information system. An obscured or ill-defined target course leads not only to control confusion but also to deteriorating and dangerous performance. Clear target display may be achieved by lane and edge markings incorporated with other variables. For optimal visual course-setting, roadway path anticipation, and proper utilization of human peripheral vision, the requirements for clear-cut roadway edge and lane division through marking, color discrimination, contrast or other modes, are absolutely necessary. For either shoulder-road contrast or the marking system on the highway, the basic visual variable may very well be in singular or combined form to be applied to the design of road-path clarification and distinction with maximal visual stabilizing effects for driving performance. The sole fact that non-collision, ran-off-the-road accidents accounted for 25.1 percent of all U.S. traffic fatalities in 1967 should call for some concern over visual information in relationship to highway accidents. Most studies comparing the accident rate before and after delineation in some form have shown a substantial decrease in accidents (Mills, 1958; Taylor and Foody, 1966; Willey, 1965; Taylor, 1966; Basile, 1962; and Musick, 1960). The changes reported by these researchers are no surprise because, from the feedback-controlled operator-vehicle-road tracking concepts on human vehicular performance, the conduciveness to accidents of a system lacking clear delineation and a decreased accident rate after correction are generally assumed and predicted on neurophysiological and behavioral evidence. Numerous traffic reports and accident analyses have supported the requirement of roadway edge and lane markings as fundamental visual display for dynamic vehicle operation.

Another type of accident which may be accounted for by roadway marking is that involving collisions of vehicles moving in opposite directions. About 21.0 percent of rural fatal accidents involve this type of collision not at intersections. Accidents caused by vehicles colliding with parked cars on the shoulder (Charlesworth, 1962) represent another area of potential support and effective application of the feedback concept of roadway tracking and the basic marking requirement for visual information display.

The dynamic feedback concept of sensorimotor tracking performance not only calls for suitable roadway delineation in the form of complete edge and lane markings; it also emphasizes the desirability of uniform design of edge markings and lane markings. This emphasizes the basic concept of spatial continuity of road-path display, i.e., continuous markings throughout the roadway for both edge and lane dividers. It suggests continuity and uniformity of visual delineation with proper consideration of the temporal and spatial factors involved for a closed-loop control system. This is supported by a previous study that reports a general tendency for drivers to search and obtain roadway guidance information from both edges of the road as well as the center marker (Rowan, 1963). Gordon (1966) found the markings to be primary sources of visual information for driving under isolated vision. Another important consideration in delineation which is based on the principle of spatial continuity is the undesirability of intermittent delineation markings for immediate roadway course display. Therefore, dashed center lines on many highways are not considered as effective as continuous delineation. Intermittent marking provides the driver both with momentary visual information of the road path as a tracking target and with constant visual input intervals. In a high-precision control system such as visual-manual tracking, numerous reports have established the validity of display intermittency in degrading performance accuracy. In high-speed highway driving the spatial allowance for vehicle positioning is reasonably large, so that the crucial role of intermittent markings is not readily perceived. However, in adverse weather and at night, the importance of continued visual anticipation of the forthcoming road markings in dashed lanes mounts amazingly. This is especially true when edge marking is absent or intermittent. Practically, little is known about the effects of broken or intermittent delineation on driving accuracy, since most surveys or evaluations have concentrated on continuous markings.

Still, from the feedback and perceptual standpoint, continuous visual display of dynamic roadpath information is preferable. Controlled experiments are needed for evaluation.

In addition to the lane and edge delineation requirements for efficient human driving performance, ground signing with unlimited variations is another useful method of immediate visual information display within the framework of closed-loop highway tracking. This will further enhance the effectiveness of dynamic information input to the operator at the point of action, the interaction of cars with the highway course in generating operational feedback for performance accuracy. The ground signing system may take the form of colored pavement, directional indicators, road-shoulder contrast, and so on.

All these basic elements have been suggested for the primary visual information display system within an experimentally tested theoretical framework of human performance and sensory-motor organization. The dynamic nature of operational information feedback is an area definitely related to performance efficiency, motor control coordination, sensory input, and particularly to accident-inducing emergency conditions. Highway accidents ought not always to be blindly attributed to human operators. Improper design features of the roadway and vehicle components of the dynamic highway tracking system also cause many accidents and fatalities. Effective design of primary visual information display provides the most important guidance and channelling effects for human motor vehicle control on the road.

5.2 Auxiliary Visual Information Display System

Besides the primary visual display system for the dynamic closed-loop highway tracking system, which concentrates on the immediate road surface information display, other information elements outside of this loop which also have direct bearings on visual inputs are considered within the framework of the auxiliary display system. On high-speed highways, vertical signing, delineators, overhead signing, luminaires and other discrete visual displays constitute the core of design considerations for this secondary visual information system. They serve primarily as visual aids in providing highway regulation, road conditions, and warning or prohibitory messages at a discrete and non-immediate level. Specific evaluations could be made of the effectiveness of delineators and luminaires relative to the visual variables discussed above. Our attention at present is directed toward basic principles affecting the design of the highway signing system as it involves operator cognitive behavior.

5.3 Development of Human Communicative Behavior

Cybernetic concepts represent the individual as a control system and interpret language development in terms of progressive changes in learning as an elaboration of his ability to exercise symbolic control over himself, other people and environmental events. The changes in non-verbal and verbal communication throughout his life represent systematic expansion of various levels of symbolic control of his physical and social environment: expressive movements, expressive vocalization, graphic symbols, spoken language, writing, quantative and machine communication. By developing and refining these levels in the course of maturation and learning, man has achieved specialized forms of control over different levels of his environmental organization (Smith and Smith, 1966).

Communicative behavior may be generally categorized as verbal or non-verbal. These categories represent graduated levels in the continuum from concreteness, such as expressive body movements or physical objects in the environment, to complete abstractness, represented by words. They also roughly indicate the difference in feedback organization between the two systems. Verbal and non-verbal patterns of information processing represent, respectively, temporal and spatial organization of behavior feedback.

Graphic and pictorial information displays within the framework of non-verbal communication and the verbal communication in the form of written words have been extensively investigated as to their effectiveness in conveying visual information for identification and discrimination. Ivins (1953) reported that purely verbal structures are likely to lose contact with reality of the source of information unless they can be checked and corrected against observable specific events or objects in the environment. Gibson (1954) emphasized the importance of graphic stimuli or displays, saying that the realism of graphic stimuli substitutes for first hand experience and thus teaches concrete information. Smith and Smith (1966) also proposed non-verbal visual design for effective information display in terms of structuring the individual spatial organization of his response in relation to the environmental stimuli at various sensory sources through feedback.

The factors of organization and patterning are known to be so important that the individual usually establishes arbitrary patterns to help organize, learn, retain, and identify visual information. The establishment by individuals of various memory forms to reference new materials in the learning process is a known phenomenon. The belief that such a spatially structured framework facilitates learning and memory, is evidenced in most non-verbal graphic display systems. In written verbal communication, the reader must organize and project himself into the described events and situations by using verbal symbols and referring back to his own experience with the situations. This requires perceptual translation from the indirect verbal meaning of a message to a non-verbal symbol in the memory with previously organized spatial structures. Purely from the information processing standpoint, the time requirements for transmission are greatly prolonged in such translation. In a dynamic control system where secondary information takes the form of discrete verbal messages, the time needed for perceptual interpretation could be crucial for sufficient and effective information processing without losing contents. Despite the desirability of the non-verbal symbolic display in advertising, book design and other information display, an effective information system usually is composed both of non-verbal symbolism in the form of graphic or pictorial designs and of more abstract verbal patterns. There are great practical difficulties in complete utilization of non-verbal symbols because individual ability to interpret symbols varies with culture, age, experience and education (Fonseca and Kearl, 1960). An understanding of the basic principles of information display should provide a perceptual basis for an evaluation of relative effectiveness and for suggestions toward optimal visual design of the highway signing system.

5.4 Perceptual Basis of Highway Signing System

Despite the importance of the previously mentioned visual considerations to an effective signing system, modes of display in highway signing may be divided into relatively verbal-symbolism-inclined and non-verbal-symbolism-inclined display designs, with a great majority of highway signs possessing a combination of the two. Generally, North American and Latin American countries have emphasized the verbal information system more than the non-verbal symbolic display, while England and the Continent have preferred graphic and pictorial display.

From the behavioral viewpoint, highway signs with non-verbal symbolic orientation would be expected to provide faster message transmission, more accurate identification, quicker interpretation of information contents and higher legibility than can be achieved with purely verbal symbolic design. In practice, use of non-verbal symbolism alone in highway signs has been almost impossible because of individual variations in age, education, experience and other factors. Hence we should also expect non-verbal symbols combined with some degree of abstract verbal symbols to be more effective than pure verbal symbolism.

A brief survey of research literature on verbal and non-verbal symbolic systems may provide some insights useful in evaluation of the relative effectiveness of the two systems.

An early study (Lauer, 1932) on symbols showed that a graphic arrow was more effective than the printed words "right" or "left" or their abbreviations. Janda and Volk (1934), studying the sign detection time of drivers on word and arrow displays, found that an arrow alone was the most effective. Words and arrow combined were second, and words alone gave the longest detection time. Levels of information abstractness may be represented by the measurement of simple reaction for concrete graphic or pictoral display, choice reaction as in combined verbal and non-verbal display, and interpretation and perception time as in pure verbal information display. Forbes (1941) showed that simple reaction required 0.5 seconds and a choice reaction time required 0.7-1.0 seconds. The perception-judgment time was reported to be between 2.8-3.2 seconds. A survey (Traffic Engineering and Control, 1960) of the effectiveness of sign reading and interpretation of American and English sign systems with the same number of words showed much lower error scores in interpretation for English signs (more graphic display) than American signs (more verbal). Gray and Russell (1962) conducted a cross-cultural comparison of sign recognition. Easily interpreted symbols used on the Continent were understood by English drivers. However, they had difficulty in correctly interpreting signs with more abstract symbols. Moore and Christie (1963) investigated the long-range sign recognition problem in terms of the recognition of types of signs and legibility among European, American and English signs. The European "map sign was best for both types of recognition, while the U.S. "stack" sign was second and the English "panel" sign third. Representative symbols were found to be more effective than words; purely abstract symbols were least satisfactory.

These findings strongly support the basic perceptual assumptions of the superiority of non-verbal symbolic display design of highway information systems over that based on verbal symbolism. The need for universal signing and non-verbal symbols in the "polyglot and illiterate world" is great. Although adoption of a particular non-verbal symbolic signing system will depend on such factors as cultural tradition, educational level, technology and cost considerations, considerable thinking, planning, and designing with consideration of the human factors in the design of a visual display system still may be initiated and evaluated for better regulation of highway traffic, possible reduction of accidents, and safer driving conditions on the road.

## 6. OTHER SENSORY SYSTEMS AND HIGHWAY COMMUNICATION

Besides the prime importance of visual display to highway information design, other human sensory modes can be utilized very well for information transmission. Two of these are the auditory system and the vestibular system in the form of vibratory sensation. While visual information display may be neglected or resisted intentionally by the operator of a motor vehicle, auditory and vibratory information displays are very difficult to ignore; hence their effectiveness and value in information transmission. Proper utilization of these sensory channels through research experimentation could be very fruitful for highway information designs.

### 6.1 Auditory Display

Proper utilization of audio information display may be effectively approached through remote electronic sensing technology, where transmission and receiving devices are keys to the system. Depending upon the type of information to be displayed, such as sharp curves, stopping signs, warning of the vehicle swerving off the road, and major traffic signs, an unlimited number of display designs is possible. On these lines, some efforts have been made in Japan to use electronically triggered sound signals to warn of hazardous intersections and railway crossings. This is a potentially effective balance to drivers' possible neglect of visual information. Extensive research in this area is recommended to achieve a more effective system of perceptual information display in highway transportation.

6.2 Vibratory Display

The sensation of vertical body vibration is transmitted through neuroreceptors on a real-time basis. No one can possibly avoid such sensory information display. An outstanding example of this type of display in current highway information systems is the surface friction differential between the highway pavement and shoulder. A motorist mistakenly driving his car onto the roadway shoulder detects his performance error almost instantaneously and repositions his car on course immediately through sensory information feedback. A great many possibilities of vibratory information display for effective message transmission and safe vehicle operation might be investigated. In Japan, for example, where sharp curves, hilly slopes and other road conditions might easily induce unsafe human control and vehicle performance, raised markers are placed across the road to generate an uncomfortable sensation in the form of vertical vibration of the automobile. Design is such that motorists must slow down considerably to maintain a tolerable level of vehicle vibration, and no accident-conducive situations are created by the markers. Similar procedures have been adopted in Italy. The same system has also been applied to railway crossings.

In California, the recently adopted state-wide installation of raised pavement markers, used as lane markers, serves as another example of the potential of roadway information display through human vibration. Although designed for the purpose of avoiding undesirable weather conditions when road markings tend to be obscured, these raised markers also provide good vibratory information for safe lane changes and alerting effects in high-speed travelling. Vibratory information display opens up a new area of research in highway information design for safe driving performance, accident prevention, and defensive driving behavior. Concerted efforts toward such objectives are urgently needed among highway engineers, psychologists, and information systems experts.

6.3 Highway Communication System

A recent development in the field of transportation guidance has been the design of vehicle-road and remote station-vehicle communication systems. A number of research centers have been experimenting with and designing such systems to facilitate summoning assistance in emergency conditions on highways, remind drivers of speed limits and road signs, and provide automatic routing information for long trips. Road-vehicle communication includes audio or visual sign reminders, or both. The visual sign reminder and a combination of audio and visual information for attention arousal have been reported in the recent development of highway communication systems (H.R.B. News, 1966; D.O.T. News, 1968; Highway Research Record, 1968). The audio-visual sign reminder, triggered by roadway signals from transmitters, repeats highway sign information on the display panel inside the car through a sound signal. All of these new potential electronic instruments for highway communication are part of the auxiliary information display system, using sophisticated and high speed information technology. They promise to be very effective in providing accurate information display of highway conditions for safe vehicle control. The roadside station-vehicle communication system renders primarily service information for motorists such as routing guide for trips, emergency traffic bulletins, roadside accomodations, and so on. Great possibilities for designing highway information systems can be expected in this area of communication technology, through which most of the auxiliary information systems on the road might be enhanced. In the light of the ever-growing demand in industrialized societies for high-speed, efficient and safe highway transportation, a much greater joint effort is needed to explore the possibilities of highway communication.

## 7. CONCLUSIONS

In this developing age of cybernation, we are approaching a better understanding of human beings: their behavior, their environment, and their man-made instruments for the control of events in the environment. The conventional approach of behavicr investigation to man as a helpless and passive respondent to environmental stimuli has made its contribution in the developmental process of behavior research. In this searching era of specificity, the outside-in approach has proved seriously inadequate in defining the basic mechanisms of behavior organization.

A new approach, based on concepts of internal control mechanisms in artificial and biological systems, has been evolving for many years. This development in many academic fields takes an inside-out view of environmental situations and internal-external relationships with an ever-enlarging level of control loops. Various efforts toward the establishment and refinement of some fundamental concepts are represented in the discipline of cybernetics.

This paper has attempted to introduce some of the basic ideas of cybernetics toward a fresh understanding of some of the organizing elements within the dynamic system of operator-vehicle-highway performance. Human vehicular control behavior has been approached from the basic sensory-motor feedback mechanisms. The principal factors of time and space coherence within the biological system are generally demonstrated in man-machine or operator-vehicle performance systems. Most of the closed-loop feedback properties of biological systems are also manifested in the motor control activities of tracking and steering. These properties include self-generation of movements, temporal and spatial continuity of sensory feedback display, the real-time and real-space nature of motor-sensory feedback control, and others.

Multi-dimensional channeling of sensory information through feedback mechanisms is essential to efficient and optimal motor control. Any detrimental perturbations on the closed-loop system would definitely contribute to performance deterioration. This is applicable to simple tool-using behavior as well as to the complex highway tracking performance.

Highway information display is believed to be maximally efficient if the multi-sensory input channels are fully utilized, on the basis of the notion of feedback multi-dimensionality. Possible means of utilizing various human senses have been suggested for the design of highway information systems. From a dynamic operational standpoint, information display on the highway may be classified as primary and auxiliary information display systems. Primary visual display focuses on the dynamic and continuous information presentation of immediate road situations crucial for real-time vehicular control activities. Auxiliary information displays are those bearing direct yet discrete messages about environmental situations which are outside of the dynamic control loop. Sufficient evidence has been reported for these theoretical assumptions.

Overall efficiency of the operator-vehicle-road control system depends on the optimal coherence of human design, vehicle design, and road design with feedback mechanism as the organizing basis. Uncoordinated investigations on separate systems components have produced no fruitful results toward our understanding of human driving behavior. This paper has suggested some inside-out and human-centered multi-loops as the fundamental framework for our understanding of human vehicular behavior and highway information displays.

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