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17

Human Factors Aspects of Road Traffic Safety

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EDITOR'S COMMENTARY

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I. WHAT DOES TRAFFIC SAFETY REALLY MEAN?

The question "What does traffic safety really mean?" seems to be one that can be answered quite easily, but the contrary is true. It is by no means clear or even agreed upon what the concept "traffic safety" or safety in general should cover. As we shall see, there are two different approaches to a safety philosophy, each of which implies its own research methodology. Even more important to the central topic of this section, is that each approach results in different aspects of human factors being considered in safety problems

Hauer[1] states, "Safety is the expected number of accidents and severity of accidents occurring on a system per unit of time." This has been a commonly shared notion: *Safety as the absence of accidents.* This concept initiated a century of traffic accident research, beginning shortly after the invention of the automobile.

The history of accident research has produced many useful results that have led to a deeper understanding of accident causes and accident effects. Nevertheless, there are two shortcomings inherent in accident research. The first follows directly from the choice of the accident criterion itself: it is by no means clear how an accident should be defined (see, e.g., the discussion in Taylor[2]). But, independent from these conceptual problems, the accident is a very doubtful safety, or better "unsafety," criterion for methodological reasons, which have been documented widely.[3]

The second aspect has to do with theories of accident causation that followed as a consequence of accident research philosophy. The attempt has often been made to associate an accident with a special accident cause, which in turn, was often found to lie in the persons involved in the accidents. This has led to many misconceptions including the *single cause* accident theory (Plotkin, 1984), the theory of *personal causation* of accidents, and the theory of *accident proneness* as a personality trait. Most conceptual errors have been clarified from a scientific point of view, but such misperceptions will always recur in accident research because they are deceptively simplistic and look so very plausible to laymen. An excellent example is the discussion since 1920, about the existence of "accident proneness," as a rather constant personality factor and which could be stopped by no arguments or evidence to the contrary.

To summarize, it can be said that the definition of safety as the absence of accidents seems to be a doubtful way of arriving at a broader understanding of safe or unsafe behavior. This does not mean, however, that accident research is useless or has to be replaced by other concepts. It can be useful in throwing some light on a very rare event at the extreme of a safety/unsafety continuum, but it has to be complemented by a research strategy concerned with the description and explanation of safe behavior. This line of reasoning will be called "safety research" throughout this section.

Clearly, safety research needs a different definition of safety. Hammer[2] puts it the following way: "Safety: frequently defined as 'freedom from hazards.' However, it is practically impossible to completely eliminate all hazards. Safety is therefore a matter of relative protection from exposure to hazards: the antonym of danger." A hazard is a situation with the potential of causing an accident. A danger—perceived as an exposure to hazards—in a man-machine environment can thus be eliminated by a temporal or spatial segregation of man and hazards. This idea is incorporated in some traffic safety countermeasures, e.g., building pedestrian bridges over busy roads or separation of traffic streams by means of signalization. But generally, of course, only very specific dangers can be eliminated that way. Traffic systems without any hazards are not realistic possibilities. More interesting, therefore, is the observation of people acting in an environment containing some hazards, i.e., normal behavior in risky situations. Analyses of "normal" behavior will also supply information about conflicts, near accidents, and other critical events. Compared to accident data, these events have more desirable qualities from a psychometric point of view: they occur more frequently; they can be observed in their actual development; questions of guilt do not distort the data collection; the reliability of observation methods can be controlled for and improved, etc. The best established method using critical incidents as a safety index is the Traffic Conflicts Technique (TCT).[5,6]

Developed in the United States in 1968, TCT has become a research tool for traffic engineers and psychologists in most Western countries. The main ideas have been to use the TCT as an accident surrogate, to quickly evaluate traffic safety countermeasures, and to localize hazardous maneuvers, especially in intersections. Recent approaches try to apply traffic conflicts in residential areas with low traffic density, on pedestrian crossings and bicycle lanes. The use of conflicts, however, gives rise to a number of problems including the validity of near misses with respect to accident data, selection and training of conflict observers, and the reliability of conflict occurrence.

Because the TCT is still in a developmental stage, its utility in future applications on a broader scale can only be estimated. Most empirical studies of accident-conflict relationship show positive correlation coefficients, which are otherwise not high enough to allow for sufficiently precise accident predictions. But, as it seems to be beyond reasonable doubt, that accidents and conflicts have many more common features than could be expected by chance, the application of the TCT as an additional (not surrogate!) measure of traffic safety and level of service of a traffic facility can be strongly recommended.

To summarize the second attempt to resolve the safety problem: safe and unsafe behavioral acts in situations involving exposure to hazards are analyzed. Contrary to accident research, the safety-oriented approach investigates the normal course of action in a man-machine system rather than the exception to the normal course of action.

It may be useful to point out the two different types of accident prevention methods derived from accident versus safety research. Accident analysis can help find accident causes and accident circumstances. This is an adequate strategy for increasing safety by trying to eliminate or reduce the influence of these factors. Safety research tries to find components of safety behavior and should, in its applications, try to reinforce positively safe actions.

II. TRAFFIC AS A MAN-MACHINE SYSTEM

On-the-road behavior can only be understood in terms of a system consisting of main road users (drivers, cyclists, pedestrians), the vehicle, the road, and its environment as subsystems. What has often been overlooked is the fact that vehicles and the main parts of the road environment (pavement markings, signs, signals) have been designed and constructed by humans. This should always be kept in mind if we hear of "poor driving," "human failure," and similar concepts. We, therefore, must extend the scope of "the human factor" in transportation to include all these elements of the system and their interrelationships.

The model in Figure 17–1 shows the information flow in the man-machine system. The information flow is acted upon by the system elements: driver, controls, and vehicle. Speed and direction of the vehicle as the system output provide sensory feedback to the

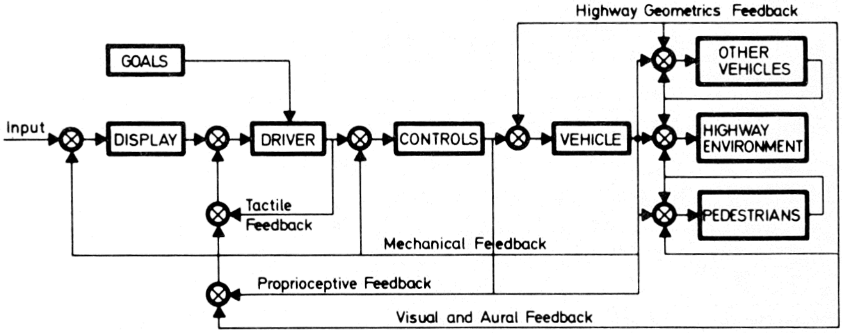

Figure 17–1 Information flow in the man-machine system (from G. E. Briggs, 1968).

driver. Feedback loops contain visual, auditorial, tactile, mechanical, and proprioceptive information.

Johannsen[7] has proposed a hierarchical model of the driving task consisting of a navigation, guidance, and control level. In the navigation level, the driver has to choose his route in the roadway system. Navigation-related activities (reading maps, etc.) are often done before the actual trip begins. The guidance level comprises the perception of the momentary and future course of the forcing function by the forward view of the road and the response to it in an anticipatory open-loop control mode. In the control level, any occurring deviations from the forcing function are compensated for in a closed-loop control mode.

In the following discussion we will focus attention on the guidance and control levels and review the subsystems of the man-machine system beginning with the driver. We will start from a general psychology point of view, including a glimpse of a road-user model as an information processor. Some selected individual and group differences will be noted, followed by remarks on time-dependent human factors relevant to traffic safety.

III. PSYCHOLOGICAL MODELS OF THE DRIVER AS AN INFORMATION PROCESSOR

With the development of cognitive psychology during the last few decades, it has become usual to describe the driving task as an information-processing task. Space limitations do not allow a detailed discussion of all issues and materials that have been brought into the debate. We will restrict ourselves to the presentation of a block diagram showing the most important steps in the information process and its importance in road safety (see Figure 17–2). The model can be useful as a frame of reference for the following reasons. To successfully negotiate a vehicle on the road, the driver has to process continuously new information, anticipate events in the near future, and make appropriate decisions. Hulbert 1984 The majority of the relevant stimuli has to be perceived using the visual channel. The limitations on the human information-processing capacities imply a selection of stimuli, both off the road and on the road. Two strategies of information reduction have been anlayzed in more detail: the distribution of attention and visual search. Several models of attention have been developed in the past. The amount of attention allocated to the driving task varies as a function of the situational demands, the drivers internal state of arousal and motivation. The key role of motivation on the perception of highway signs has been demonstrated in many studies;

for a summary, see Näätänen and Summala.[12] Of similar importance is the distribution of attention over the visual scene. Most investigations use registration of eye movements and look for the visual search strategies of different drivers. Differences between novice and experienced drivers have demonstrated the role of learning and experience in the process of information selection by eye fixations. Alert drivers tend to look toward the end of the road more often. They scan the edges of the road close to the vehicle, using peripheral vision most of the time. Novice drivers, who are more concerned with maintaining their cars on the road, fixate on nearer points and often shift their attention from left to right.[13]

The amount of information needed to feel safe and/or behave safely differs with the difficulty of the traffic situation and personal attributes of the drive. The less attention he has to pay to the driving task, the more spare capacity the driver gains for listening to the radio,

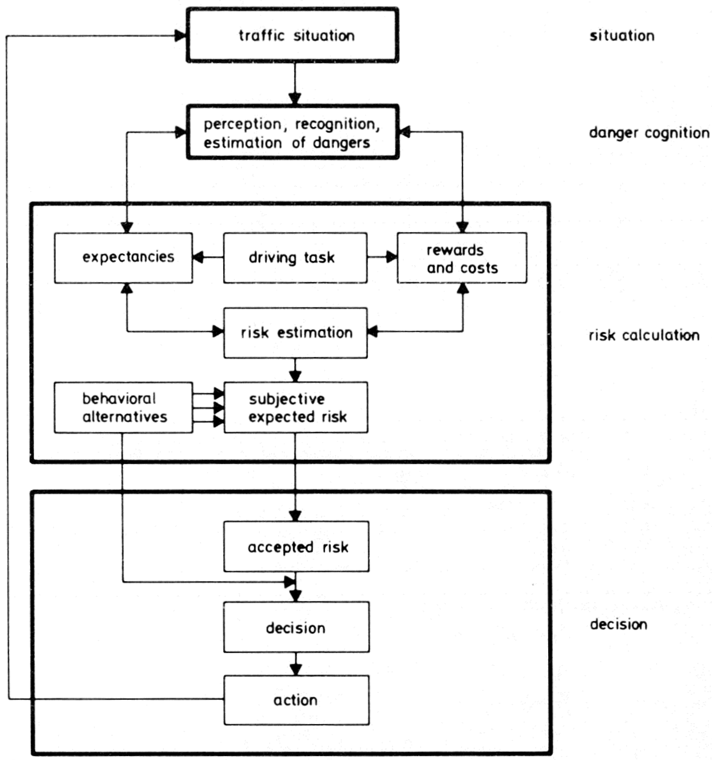

Figure 17–2 A psychological model of the driving task (simplified version from V. Benda, 1977)

talking, smoking, etc. With increasing amounts of information processed, driving becomes safer but more stressful. The quantity of information perceived and processed is, therefore, a function of the traffic participant's estimation of the danger involved in the actual situation. This has been called "dynamic risk"[14] and has been investigated under different methods. The most adequate method of reducing stress is reduction in speed, which decreases the input of information per unit of time.[15]

Once information is selected, it has to be interpreted to arrive at appropriate decisions. With special regard to traffic safety, we shall call this process "risk calculation." Most theoretical approaches state the individual level of risk acceptance as the level against which estimated subjective risks must be compared. The expected risk has to be calculated taking into consideration the rewards and costs of that particular behavior, the anticipated maneuvers of the other road users, and the behavioral alternatives of the driver in question.

A highly interesting model with various conclusions for the effects of different traffic safety countermeasures has been brought into the debate by Wilde[16] and is called *risk homeostasis*. The "risk homeostasis" theory states that road users behave in a manner such that the amount of property damage, personal injuries, and deaths occurring in the use of the roads is directly proportional to the amount of time spent on the roads multiplied by the level of risk accepted in that activity in return for the benefits occurring from behavior in that activity.[17] This theory is still the topic of a very lively debate, see Slovic & Fischhoff (1982), McKenna (1982), Huguenin (1982) for cons and Wilde (1982b, 1984), Wilde & Kunkel (1984) for pros. A recent argument is documented in Wilde et al (1985), a critical review is given by Michon (1985). The highly complex processes associated with risk calculation have yet to be clarified. Hoyos[18] provides a description of theoretical assumptions and empirical findings.

The driver acts on his perceptions and judgments by making decisions. In driving it is important to make the right decisions at the right time and to arrive at these decisions quickly. Therefore, decision time has been investigated in its relation to external and internal factors. Decision times have been shown to be lengthened whenever the driver has to respond to an unexpected traffic situation, has little experience in the particular task, or if the stimulus situation and the appropriate response to it are incompatible.

At the end of the information-processing circle we have the box "action," see Figure 17–2, which is related to the overt behavior of the driver. The loop back to the traffic situation shows that the driver's action creates a new traffic constellation, and the whole process must start all over. Most studies on drivers' overt behavior refer to steering and braking behavior and the relation of speed and accuracy of hand or foot movements.[19]

In addition to the general psychology approach to driver behavior, numerous attempts have been made to link individual and group characteristics to traffic safety. According to Häkkinen,[16] these factors can be classified with respect to their variation in time. To find rather stable personality characteristics closely connected with safe or unsafe traffic behavior would, of course, be of great importance to driver licensing and selection. It also could give valuable hints for driver education and improvement programs. Unfortunately, only very few variables allow for sufficiently valid predictions of future driving behavior or even accident involvement. Only the age and experience of the driver and some biographical data show rather systematic variations. Young novice and old drivers seem to be overrepresented in accident statistics, but even this is not beyond doubt because of different quantitative and qualitative exposures to risky situations. The effects of aging on driver performance are described in Planek.[21] Summarizing discussions of personality factors and traffic safety can be found in Lucas[22] and Hoyos.[23]

Among the various time-dependent human factors having relevance to safety aspects, the effects of alcohol play a predominant role. Numerous investigations have studied the influence of different levels of blood alcohol concentration (BAC) on driver performance and attitude. Overviews are given by Martin[24] and Simpson and Warren.[25] Effects of other drugs on driver behavior are summarized in Buttiglieri, Brunse and Case.[26] Several studies are concerned with fatigue as a consequence of long-distance driving. Results of those studies are described by Hulbert.[27] Combined effects of alcohol and fatigue are discussed by Nelson.[28]

IV. HUMAN FACTORS IN ROADWAY DESIGN

Driver behavior cannot be described or understood without the physical context within which it takes place. The main parameters of this context are the road environment and the individual motor vehicle. An extensive analysis of the highway-traffic environment subsystem is given by Baerwald.[29] Detailed information on both remaining subsystems is also provided by Forbes.[30]

Highway improvements can be an important factor in accident reduction. Design and construction of roadways and their environment, however, have to follow guidelines set by drivers' capacity limits and general perceptual habits. Some significant principles that the human factors approach to roadway design have adopted are outlined below and are illustrated by several examples.

The most important principle to follow probably is that the design of the roadways must fit *driver expectancies.* Shinar[31] lists some common driver expectancies, e.g., "Expressway exits are from the right lane, an exit will have fewer lanes than the continuing expressway . . . ." Whenever one of these expectancies is violated, confusion is likely to occur, decision and reaction times of the driver are prolonged, and typical "driver errors" occur. Automatic and fast responses that have been built up over a long period of time have to be replaced by decisions in a new and surprising driving task. Different types of expectation phenomena such as "continuity expectancy," "event expectancy," and "temporal expectancy" are discussed in Näätänen and Summala.[32] Standardization of roadway design and control devices cannot be overestimated in assisting expectancies to be learned in a consistent manner. In most countries these standards are fixed in handbooks.

With the majority of driving-relevant stimuli being visual, every design consideration has to take into account the limitations and needs of our visual perception. This relates to the design of road signs, roadway illumination, pavement markings, traffic lights, etc. There is a large body of research on visibility and legibility of road signs, varying letter size, brightness contrast, color effects, mounting position, etc. A summary is provided by Forbes.[33] Some new studies are described in Erke and Gottlieb.[34] Rules giving necessary letter sizes for different distances, velocities, and visual angles are at hand. It is important to note that these standards are based on the "normal" or average driver's visual acuity, but they should always be responsive to the limits of most drivers rather than to the average driver. Equally important is the attention value of road signs, a value that is influenced by their location, luminance, design, and contrast against the background.

Nighttime driving must be facilitated by roadway illumination in addition to the small area covered by the vehicle's headlights. Permanent lighting should be installed at high traffic density areas and at those points on the roadway that require maneuvers or decisions on the part of the driver.

Roadway markings and signs help the driver perceive the geometry of the roadway ahead. They can be particularly useful where perception is susceptible to illusions and wrong judgments. A famous study by Shinar[35] has demonstrated the "illusive curve phenomenon." These misperceptions can be restricted by good optical guidance design. Another demonstration of the use of markings is the optic brake: perpendicular stripings with decreasing distance between adjoining stripes are painted on the road to give the driver the illusion of acceleration. This has proven to be a good speed reduction technique, although local drivers become used to it to some extent.

To sum up: good highway design must consider drivers' expectancies, their perceptual limitations and habits, and their decision-making capabilities.

V. HUMAN FACTORS IN VEHICLE DESIGN

Many successful efforts have been made to improve the crashworthiness of vehicles. Here we will provide a short review of precrash vehicle design improvements. For a more detailed discussion, see Forbes.[36]

It is well known that safety features and human design aspects are only two principles guiding vehicle design and advertisement among various others, for example, aesthetics and aerodynamics. Other aspects may even seem to contradict safety requirements in trying to serve what Näätänen and Summala[37] call "extra motives" of the driver besides the mere need of transportation.

Nevertheless, many attempts have been made to improve traffic safety by means of better vehicle design for such items as mirror systems, rear light and headlight constructions, head-up information displays, and various vehicle control systems.

Innovative mirror systems try to enlarge the driver's visual field. Convex and periscope mirrors have been investigated for this purpose. As long as the curvature of convex mirrors is relatively low, they give the driver rather undistorted information. Distortion of the visual field leading to wrong distance and speed judgments is, of course, no problem with the usual plane mirror systems. Combinations of plane and convex mirrors have also been used.

Headlight technology has overcome most visibility difficulties associated with nighttime driving but still suffers from the glare produced by oncoming cars. A solution seems to be the use of polarized light, but this creates organizational problems because all cars on the road would have to be equipped with the same system. A summary of work in this field is given by Shinar.[38]

Rear lights have the important task of communicating the vehicle's position and its driver's behavior to other road users. The deficiency of the present systems—giving information that often is not accurate enough and comes too late—has been addressed by a number of sophisticated approaches.

Most alternatives to the present systems try to give more levels of information by differentiating between coasting with the foot off the accelerator and maintaining speed (or accelerating) with the foot on the accelerator. Examples for innovative systems are the "trilight," the acceleration information display (AID), and variable flashing deceleration lights. The trilight system indicates braking, coasting and foot on the accelerator by red, yellow and green lights, respectively. Acceleration and deceleration are indicated by horizontal rows of green and red lights in the AID-system. Variable flashing deceleration lights are flashing at an increasing rate with greater pressure applied to the brakes.

In-vehicle displays have the task of providing the driver with information that cannot be observed directly. Even today some of the basic ergonomic principles, such as stimulus-response compatibility, are often violated. Recent developments in this area are head-up displays and the master warning light. Most of these approaches, however, are still in their developmental stages.

Much work has been devoted to vehicle control systems over the last few years. Antilock-braking systems are probably the most prominent examples. They attempt to compensate for the driver's difficulties in maximizing the brakes' stopping capabilities.

These technological improvements cannot be described in detail here, but two general principles have to be mentioned in this context. The first applies to the installation of additional information displays, for example, electronic route guidance systems. The processing of additional information has been shown to prolong the driver's decision and reaction time and can interfere with the tracking accuracy. The value of the displayed information thus has always to be checked against the driver's limited mental capacities.

The second principle is more general and refers to all technical improvements designed to increase traffic safety. The objective gain in safety does not automatically lead to safer driver behavior. As many empirical studies suggest, the driver compensates many safety countermeasures effects by adjusting his behavior in a way to keep his individual target level of risk constant; for example, he drives faster if he feels safer with new tires, etc. These findings are in agreement with recently developed theoretical explanations of driver behavior as proposed by Wilde[39] or Klebelsberg.[40] Thus technological improvements should always be accompanied by efforts to influence the level of risk tolerated by the driver.

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[37] See note 12 *supra.*
[38] See note 19 *supra.*
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