PERCEPTION MODEL FOR DESCRIBING AND DEALING WITH DRIVER INVOLVEMENT IN HIGHWAY ACCIDENTS

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•THIS paper explores a theory or model that relates driver perception and action to hazards on the road and discusses what research and countermeasures are suggested by the model.

One useful overview of highway safety is the 9-cell matrix that was developed by Haddon and Brenner several years ago (1) and that is being used today by the National Highway Traffic Safety Administration's multidisciplinary accident teams in characterizing accidents or crashes (2). The matrix is shown in Figure 1. It has been often stated that, in order to describe the operation of highway transportation, we must consider that all 3 factors on the left side simultaneously operate as a total system. All of the interactions of the system must be taken into account. However, in carrying out research aimed at trying to find out how the system works, we usually single out just one component or a subcomponent for attention. It is much too complex to try to deal with the system as a whole. From the results of research on just one part of the system, ways to improve the entire system including accident countermeasures are suggested and, in certain cases, implemented.

Traditionally, the factor getting most of the attention on the highway system is the human. He is regarded as being the chief instigator of highway accidents, as being his own worst enemy. However, a long history of scolding, pleading, cajoling, fining, jailing, and generally trying to influence and modify man's driving behavior does not appear to produce any conclusive, clear-cut results toward greater safety. Consequently, safety men in the past few years have more and more centered their attention on the other 2 factors of the highway system—the vehicle and the environment, the latter including the roadway.

Another reason why attention seems to have switched to these latter 2 elements is that they are inanimate. Thus, they are easier to research. The physical sciences can be employed. Actual crash tests where energy levels comparable to actual highway crashes can be designed. The human, on the other hand, is much harder to research scientifically. It is certainly inhumane and out of the question to subject humans to actual, dangerous road conditions to determine just what psychological and physiological factors lead to crashes. Yet, this is precisely what is needed in order to obtain the scientific background leading to solutions of the problem.

The human part of the puzzle is hard to understand. Normal human behavior is to drive safely and to avoid accidents. In highway accidents, we are dealing with relatively rare events that are not normal and that require an untangling of the roles that man plays. This is no easy thing to do by research or by other means. Certainly controlled laboratory experiments and realistic driving simulators, to name 2 tools used for understanding the human factor, are effective to a degree, but they always leave some measure of doubt as to their relationship with actual conditions. From a research standpoint, it would be nice to eliminate man completely as a control element from the highway system. Then all problems become inanimate ones and, thus, much easier to research and much easier to change and control. However, the fully automated system with man removed completely from control is years away from adoption on primary roads, and probably will never be universally adopted on all roadways. It

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appears that man with all of his capriciousness, complexity, and cussedness will remain one of the 3 factors in the highway system for some time to come.

How about the top of the matrix? We believe that most drivers would prefer to have accident countermeasures begin with the precrash. If given a choice between (a) driving into a barrier at high speed a test vehicle completely equipped with cushioning and restraining devices that had been proved to be 100 percent effective or (b) driving a vehicle and stopping short or steering around that barrier, we believe that it would not take a driver long to make up his mind that he would much rather avoid the barrier completely.

	PRE CRASH	CRASH	POST CRASH
Human	1	2	3
Vehicle	4	5	6
Environment	7	8	9
Results	Accidents	Trauma Injury	Mortality Morbidity

Figure 1. Highway system crash matrix.

However, again from the research standpoint leading to countermeasures to be employed, it is easier to deal with the specifics of the crash and the post-crash. The sequence of events preceding the crash become more and more complicated the farther back in time one goes, and they become lost in haze of uncertainty not very many minutes back. The many factors having cause-and-effect relationships produce an extraordinarily complex picture as one investigates the precrash phase. Then, too, the interplay of the matrix starts to interpose, and there is a suspicion, intuitive and otherwise, that man plays a dominant role in the precrash phase. Because of this, it appears more attractive and effective to research the crash phase and the post-crash phase.

This brings us back to the complete matrix. Are all cells equal to each other? Based on the foregoing discussion, it would appear that it is easier to obtain scientific facts, and hence develop effective countermeasures, by concentrating on (a) the inanimate part of the matrix and (b) on the crash and post-crash phases. The cell that does not fit either definition is the first one, the human-precrash cell. This would appear to be the hardest part of the matrix to research successfully and to develop scientific facts about leading to effective countermeasures.

Are human-precrash factors important, or is this importance just a holdover myth from an earlier, less scientific day? The preliminary findings of an in-depth accident investigation team of the National Highway Traffic Safety Administration show that human-precrash factors are the most frequently cited factors contributing to a crash (2). In 271 accidents investigated, cell 1 contained 444 contributing factors. The next cell was cell 5 with 190 contributing factors. Significantly, the drunken driver represents a human-precrash factor. Even the seat belt, present in the vehicle but not used, is in reality a human-precrash factor.

Perception, too, is a human-precrash factor. Because it involves man and because it is entwined in the complex factors preceding a crash, it is hard to uncover scientific facts concerning it and its role in highway safety. As an alternative to direct research in this area, a theory or model can be formulated that deals with perception. The theory, of course, must fit observable facts as they are known, be able to predict certain other events that would be subject to verification by research, and be able to suggest useful countermeasures. Theories are not only useful but indispensable. Theories are needed especially when research is hard to perform or there are too many variations to explore.

Nearly everyone who approaches the problem of structuring the driving task, in fact, develops his own individualistic theory or model. These models can vary from relatively simple, broad, overview types of models to those that attempt to define everything a driver may do. Many good models have been described but, in the absence of a standard or accepted model, we developed the following in order to help us understand the driving task and accident avoidance.

The driving task is basically getting from the start of the trip to the finish and avoiding hazards along the way. Getting from start to finish involves trip planning, direc-

tional information, maps, and area and route designation, but these will not be discussed at this time. We will concern ourselves only with avoiding hazards along the way.

Figure 2 shows a drawing of the perception model. What appears to be a crude musical instrument or weapon on the left is in reality a vehicle moving down a roadway with a zone of committed motion projected ahead (3, 4). This zone is composed of 4 segments or bands. Band 1 represents distance traveled during minimum perception time; band 2, distance traveled during minimum decision time; band 3, distance traveled during minimum reaction time; and band 4, the minimum committed motion area of the vehicle after activation has been made to turn or stop. Zone 4 out to arc S represents the minimum stopping distance for the vehicle based on vehicle speed and weight, brake efficiency, coefficient of friction between tire and road should the driver choose to brake, and other factors. All of the bands go into making up the minimum zone of committed motion extending in front of the car to arc S. It could be larger, of course, due to any perception, decision, or reaction delay.

On the right, box X indicates a hazard of some sort. This could be many things—a stalled vehicle, a pedestrian, debris on the road, or an oncoming car. As a special case, it can also be considered a potential hazard such as an intersection, a curve, a car ahead just starting to slow down, a railroad crossing, or even the edge of the road.

Point T is the true point, the last point at which action can be initiated to avoid the hazard. It is a point of no return and is determined by the zone of committed motion and the laws of physics. Action initiated after point T may help for injury reduction but will not be effective in avoiding the accident completely. Point M is the mental point and is the driver's perception of the true point T. It is where the driver believes the point of no return is. Point A is the action point or where the driver decides he actually will take action. The action involves slowing, stopping, steering, or accelerating. Points M and A are shown as points on the roadway for the sake of simplicity; they are probably perceived by the driver more as areas. Also, the model represents just one moment in time; in the dynamic situation, the various points, the committed zone of motion, and the driver's perception of the relationships are changing from second to second.

Before going further, we should define perception. The unabridged dictionary gives many choices, but perhaps one that applies here might be "awareness of the elements of the environment through physical sensation" and another version "physical sensation as interpreted in the light of experience." At least 2 elements are involved in perception: (a) a physical sensation such as vision, hearing, or touch and (b) an awareness or recognition of what that physical sensation means compared with other physical sensations received by the driver. In the case of vision, it is not just an image on the retina but a recognition and interpretation of that image that go to make up perception.

In driving, the chief physical sensation received by the driver is a visual one. Other senses play minor roles although, in some cases, important ones. In the case of the model presented here, we will consider that the driver gets his information and perceives the hazard and the various points ahead visually. He perceives his speed in relationship to other objects visually by the changing roadway perspective and visually by referring to his speedometer. From the perception of speed and based on "experience," he has some perception of his committed zone of motion. He makes judgments of the speed and distance of other objects visually. From these visual judgments, he he sets up points A and M continually ahead as he drives. The process is a perceptual one. Sometimes the driver is highly conscious of his search for perceptual cues; at other times, awareness is almost at the subconscious level.

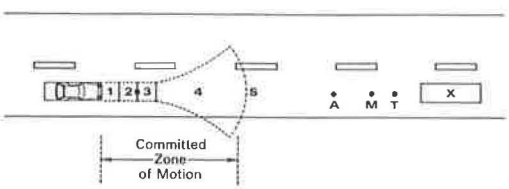

Figure 2. Perception model.

The distance between points T and M is termed perceptual error (Fig. 3). The driver's mental point M can be ahead or behind the true point T and, if no perceptual error is involved, it coincides with

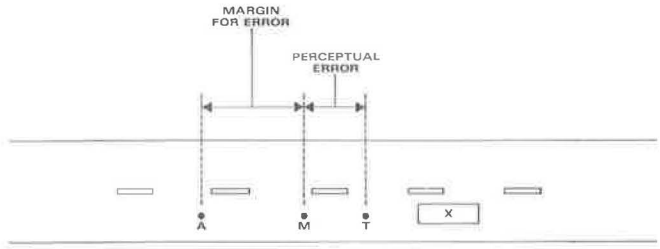

Figure 3. Margin for error and perceptual error.

point T and the distance between points T and M is zero. But generally, this distance is a plus or minus quantity; point M can be on either side of point T.

The distance between points M and A, or the difference between the mental point M and the action point A, is the driver's margin for error (Fig. 3). This quantity is usually plus from point M to point A, if the direction from the hazard back to the driver is taken as the positive direction. It is only minus when a driver deliberately tries to ram into something. A driver consciously trying to commit suicide would have a negative quantity. For most drivers, however, the distance is positive. In other words, the driver places his action point A ahead of his mental point M, the point of no return. He allows some margin for error.

The interaction between points T and M, perceptual error, and points M and A, margin for error, determines whether an accident results. It determines whether point A is toward the driver from point T where no accident results or whether point A is on the other side of point T away from the driver in which case an accident does occur.

Figure 4 shows, in the upper left, that both points T and M, perceptual error, and points M and A, margin for error, are positive producing a safe situation. In the upper right, a larger margin for error (points M and A) compensates for a negative perceptual error (points T and M) producing a safe situation where point A comes before point T. The unsafe situations are shown in the middle of the figure. In the middle left, the margin for error (points M and A) does not compensate for a larger perceptual error (points T and M), and an accident results. (An accident can be defined as an unwanted event and need not always result in a collision. Driving off the roadway, for example, results from perceptual error, but a collision may or may not occur depending on the nature of the adjacent environment.)

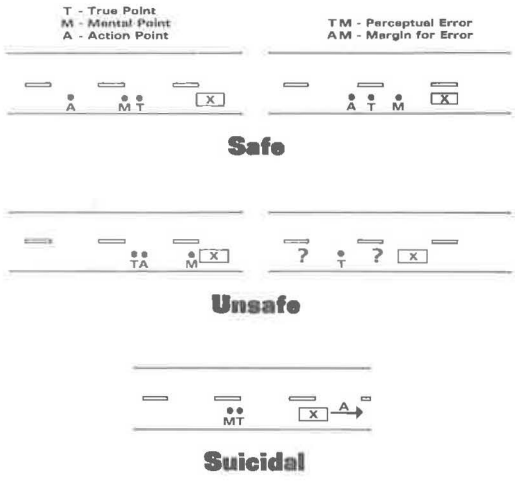

Figure 4. Safe, unsafe, or suicidal situations.

There are many special cases for the unsafe condition. The middle right part of Figure 4 shows failure to set up points M and A entirely, or until after point T is reached and a perceptual error occurs. Failure to treat potential hazards as real hazards, resulting in failure to set up potential points A and M, is a perceptual error that results in an accident that may be benign only if the driver is fortunate. Speeding through an intersection or passing on a curve or hill is indeed an accident waiting to turn into a collision. Figure 4 also shows the deliberate or suicidal situation where point M is established but no action to avoid the hazard is taken. Here the distance between points M and A is negative.

Many conditions and factors contribute to producing this perceptual error. Alcohol has been identified as a significant human-precrash factor and affects the magnitude of perceptual error by degrading vision and producing lack of attention. This produces a potentially greater perceptual error. It also degrades defensive factors such as margin for error and adequate reaction time. Figure 5 shows that the intoxicated driver has a larger zone of committed motion for any given speed because of increased reaction time that alters the true point T, moving it farther back from the hazard. This is not usually perceived adequately by the intoxicated driver, and he continues to set his mental point M as if he were sober. This is coupled with a reduced distance between points M and A (or margin for error) as the intoxicated driver takes greater risks. Figure 5 shows the intoxicated driver setting up the unsafe situation with point A on the wrong side of point T. Similar analysis could be made for other factors such as fatigue and inattention. All lead to that point in time where the driver sets up points A and M and either avoids the hazard or has an accident.

The professional race-car driver and the skilled, youthful driver probably have certain things in common. Both have good perception, fast reactions, and low margins for error. As shown in the bottom of Figure 5, the distances between the perceived points are small, and there is very little leeway for any departure from perfection. The effect of just a small amount of alcohol would be and is disastrous in this latter situation. The professional racer certainly does not drink a six-pack just before driving, but what about the young male driver?

What does this exercise in modeling the driver's action suggest? I believe the following points can be made:

1. Perceptual error is the proximate cause for most preventable accidents. It is the factor common to most accidents out of the myriad of factors possible in the chain of cause and effect. It is a human-precrash factor. On the other hand, margin for error is not an accident cause but a defensive, ameliorating action that does prevent many accidents. There are, of course, sudden cataclysmic failures, such as a heart attack or a blowout, that cause loss of control. Perception, as we are considering it, does not play a major role there. For the great preponderance of accidents, however, perceptual error is the proximate cause and the common factor present.

2. The perception model presented here indicates that accidents can be prevented by increasing the margin for error, making the perceptual error always positive, and making the perceptual error as small as possible. Increasing the margin for error is the predominant method that has been tried in the past. Admonitions to "drive safely" and "slow down—speed kills" and numerous safety articles have emphasized that drivers should develop larger margins for error. In our model, this means increasing the distance between the mental point M and the action point A. Although this is well-meaning and would be effective if drivers really could be influenced to increase this margin for error, actual experience indicates that this approach has not been too effective. It is too restrictive for many to drive ultra-cautiously all the time. Each driver has a built-in risk level that is part of his personality. Remote admonitions that seem unreal have little effect to change it. One good method of producing an increased margin for error would be to arrange for a hair-raising close call for everyone, but this is obviously not practical. Increasing the margin for error of a large number of drivers does not appear promising. It theoretically might be possible to make the perceptual error (points T and M) positive by optical illusions, road

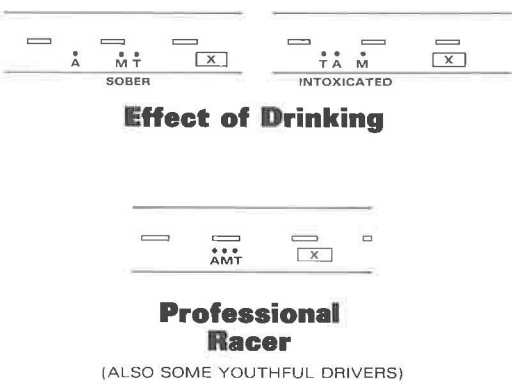

Figure 5. Perceptual errors of drinking drivers and professional racers.

propaganda, and the like. However, experience indicates the driver soon adjusts and compensates for situations that appear unrealistic. For example, an advisory speed sign reading 15 mph on a curve that appears can be driven at 40 mph is usually disregarded. This does not appear to be a promising approach. Making the perceptual error as small as possible perhaps offers the best chance for preventing accidents. To explore this fully would be much too time-consuming here.

1. INANIMATE

A. Generation of the visual signal
B. Transmission of the visual signal

2. ANIMATE

A. Reception of the visual signal
B. Perception of the visual signal

Figure 6. Countermeasures to perceptual error.

The following areas for further research leading to countermeasures will be discussed briefly. The list of countermeasures to perceptual error, by no means meant to be all-inclusive, is shown in Figure 6.

1. Generation of the visual signal relates to the highway environment, to vehicles, and to available illumination and contrast. In daylight, illumination levels are high, and a large variety of natural, visual information exists. Nevertheless, perceptual error can be introduced wherever there is lack of contrast, glare, and visual clutter. At night when this natural information becomes much less visible, the accident rate increases. The essential details visible in the day should be preserved for night driving. Illumination is one answer for selected portions of the roadway if this illumination is bright and does not introduce glare. A more universal solution, applicable to all roadways, is to develop much more efficient headlights and vehicle rear lights. Motor Vehicle Safety Standard 108 is concerned with this area. For many reasons, progress in adopting better headlight systems and more efficient vehicle rear signal systems is slow. Perhaps the reasons are well founded, but, if reducing perceptual error is basic to preventing accidents, the research and its implementation should be accelerated. In general, greater use of distinctive colors and patterns on vehicles, on the roadway surface, and on warning devices and signs should be a considerable aid to hazard recognition either day or night and should lead to the reduction of perceptual error.

2. Transmission of the visual signal relates to the highway environment—fog, rain, snow, and obstructions—and also to the vehicle. At present, little can be done to alter inclement weather. On the other hand, who has owned a vehicle and has not had difficulties in keeping the windows clear of fog, frost, or rain streaks even when the system is operating at peak capacity? Have we done all we can do in this area? Motor Vehicle Safety Standards 103 (windshield defrosting) and 104 (windshield wiping) pertain to this area. Much work has been done on the front windshield in regard to controlled breakage with dramatic reduction of injury. Because of road geometry and vehicle vectors, much of the perceptual information enters through the front windshield. Manufacturers should design the front windshield with minimum optical distortion and obstruction and with maximum transmission. Where tinted windshields are desired, why not use one that fades at night to produce a higher transmission coefficient? Development of this technology should be accelerated. Considering angles to the side and rear, why cannot a truly effective rear mirror system be incorporated rapidly? It is hoped that the safety car research programs and Motor Vehicle Safety Standard 111 will accelerate this.

3. Reception of the visual signal relates to the human—his acuity, his field of vision, and the way his eye gathers the light and brings it into focus on the retina. It might be overly optimistic to hope for large gains in improving the vision of drivers. There should be control, of course, to prevent those with gross visual deficiencies from endangering their lives and others. Most drivers with vision corrected to at least 20/40 and experienced in compensating for other vision problems are probably fairly well equipped to deal with road hazards provided that other visual countermeasures are employed. Problems in vision can be partially overcome by making the light signals reaching the eye larger, brighter, more colorful, and higher in contrast and distinctive pattern.

4. Perception of the visual signal is the final link in the perceptual chain where recognition takes place. Perception, as we noted earlier, is not only the physical sensation, or the image on the retina, but it is an interpretation of that image in the light of experience. It has been demonstrated by Brody (5), Smith (6), and others that man can be taught to perceive better. Good results have been obtained in small groups. However, to our knowledge, improvement of perception has not been attempted on a large scale. In contrast to increased margin for error, which involves fear, restriction, and discipline, improvement of perception decreases fear and increases freedom—and, like the acqusition of any skill, it can be fun.

Reduction of perceptual error lies in being able to perceive the committed zone of motion of the vehicle in relation to perceived hazards or potential hazards on the roadway and to make point M coincide with point T as much as possible. Judgment of distance and velocity, attention to subtle environmental cues, compensation for vision deficiencies, and ability to see many items at a glance, recognize hazards, and distinguish patterns are all involved.

Perhaps, driver-education courses in the high schools can be adapted to emphasize visual and perceptual skills more than they do today (7). High school driver education reaches only a small portion of drivers (albeit when they need it most), and its effect might be transitory. To reach all drivers, a course in perception might be made mandatory before a driver's license is renewed. The course could be in a programmed self-instructional format and be aimed primarily at imparting information and improving skills, not at penalizing at the outset with loss of license. The motivation to complete the course to obtain a license and keep driving would compel most drivers to devote considerable interest to the material. This could be done every 4 years under Highway Safety Standard 4.

In the meantime, could not greater use of the mass media be made to refresh perceptual skills of the public from time to time? Most of the mass media suffer from being remote from the driving scene, but communications can be employed directly on the roadway. Ideally, some form of periodic education and reminder as to perceptual skills should be brought right to the roadway itself where relevancy, reinforcement, and realism are high. Very little attempt has been made to teach safety measures to the public on the roadway itself, although there is powerful logic in favor of it.

In summary, the human in the road equation is truly complex, hard to research, and hard to understand. Nevertheless, we cannot refrain from attempting countermeasures aimed at human-precrash factors on the excuse that the task is difficult.

Perhaps the proximate cause of preventable traffic accidents, which we hypothesize is perceptual error, can be best attacked by concentrating on inanimate countermeasures that have a history of producing quicker and more positive results than animate countermeasures. There is a possibility, however, to try once again to reach the drivers not by using emotionalism and psychological pronouncements but by using a different tactic—teaching them the skill of perception. Mass instruction could be implemented at the time of the driver-licensing procedure. It would not work with everyone, but nowhere in traffic safety can one deal with absolutes. A substantial percentage of lives saved and injuries prevented would make it all worthwhile.

In the conducting of research and in the development of countermeasures, there is a danger that resources may be spread to thinly. There is a need to isolate a few meaningful factors that have a major effect on safety. We believe perceptual error to be one of these meaningful factors in road safety. We need to attack this problem of the precrash phase by making the visual environment as hospitable as possible for good human perception and by training and conditioning man's perceptual process.

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